Neuropsychologia 172 (2022) 108274

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Can't stop thinking: The role of cognitive control in suppression-induced forgetting

Suya Chen[a,1], Xinrui Mao[b,1], Yanhong Wu[a,c,*]

[a] School of Psychological and Cognitive Sciences, Peking University, Beijing, 100871, China
[b] Collage of Elementary Education, Capital Normal University, Beijing, 100871, China
[c] Beijing Key Laboratory of Behavior and Mental Health, Key Laboratory of Machine Perception, Ministry of Education, Peking University, Beijing, 100871, China

ARTICLE INFO

Keywords:
Cognitive control
Memory suppression
Think/no-think paradigm
Intrusion
Cognitive control capacity

ABSTRACT

The ability to control unwanted memories is essential for emotional regulation and maintaining mental health. Previous evidence indicates that suppressing retrieval, which recruits executive control mechanisms to prevent unwanted memories entering consciousness, can cause forgetting, termed suppression-induced forgetting (SIF). Since these executive mechanisms involve multiple mental operations, we hypothesize that the efficacy of SIF may be limited by individuals' capacity limitation of cognitive control. Here, we tested this hypothesis. Participants were assigned to two groups based on the median of their cognitive control capacity (CCC, estimated by the backward masking majority function task) and performed the think/no-think task with electrophysiological signals recorded. The results showed that the SIF effect was observed only in the high CCC group but not in the low CCC group. In accordance, repeated suppression attempts also resulted in a steeper reduction in intrusive thoughts in the high CCC group. Furthermore, ERP analysis revealed a decrease in recollection-related late parietal positivity (LPP) under the no-think condition in the high CCC group. A mediation analysis revealed that the reduced intrusive memories mediated the effect of CCC on SIF. These findings suggest that suppressing retrieval could reduce traces of the unwanted memories, making them less intrusive and harder to recall. More importantly, successful SIF is constrained by the capacity of cognitive control which may be used to ensure the coordination of multiple cognitive processes during suppression.

1. Introduction

There are some unpleasant memories that we would prefer to forget. For example, people sometimes suffer from intrusive memories after a traumatic event. To reduce the emotional distress caused by these memories, individuals need to deliberately control their memory. It has previously been proved that people often have control over their memory even when directly confronted with reminders; this is called retrieval suppression (Anderson and Hanslmayr, 2014; Catarino et al., 2015). Suppressing the retrieval of unwanted memories is considered a critical ability for mental health (Costanzi et al., 2021). But not all individuals are equally effective at suppressing retrieval (Levy & Anderson, 2008, 2012) and many studies suggest that deficits in controlling memories and thoughts are the core of some psychological disorders (Goschke, 2014; Hertel, 1997, 1998, 2007; McTeague et al., 2016). Why does the ability to suppress memory retrieval vary among people and what is the key factor determining this variation? Figuring out answers to these questions will contribute to effective management of long-term memory, the maintenance of mental wellbeing, and in particular, better intervention in those psychological disorders characterized by intrusive thoughts and memories.

Retrieval suppression in the laboratory is generally studied using the think/no-think (TNT) task (Anderson and Green, 2001). During this task, participants learn a series of cue-target pairs, such as word pairs. Then they are presented with cues from learned pairs and asked to recall the target word corresponding to the cue (think condition) or avoid recalling the target word (no-think condition). Sufficient evidence has shown that the "no-think" manipulation leads to worse recall of target words compared to the "baseline (natural decay)"; this is termed as "suppression-induced forgetting" (SIF, Anderson and Hanslmayr, 2014; Depue et al., 2007; Noreen et al., 2014; Noreen and Macleod, 2013, 2014). The SIF effect is suggested to arise from inhibitory control process

* Corresponding author. School of Psychological and Cognitive Sciences, Peking University, Beijing, 100871, China.
E-mail addresses: chensuya@pku.edu.cn (S. Chen), maoxinrui.123@163.com (X. Mao), wuyh@pku.edu.cn (Y. Wu).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.neuropsychologia.2022.108274
Received 22 September 2021; Received in revised form 28 April 2022; Accepted 19 May 2022
Available online 24 May 2022

that disrupts the availability of the unwanted memory and later renders it inaccessible (Anderson and Green, 2001; Anderson and Hanslmayr, 2014; Engen and Anderson, 2018; Meyer and Benoit, 2022). Recent neuroimaging studies showed that "no-think" effort engages brain areas related to cognitive control, i.e., the right dorsolateral prefrontal cortex (DLPFC) and the dorsal anterior cingulate cortex (dACC, Anderson et al., 2004). Increased DLPFC activation is correlated with decreased activities in the hippocampal (HC) and sensory processing regions (Anderson et al., 2016; Benoit and Anderson, 2012; Benoit et al., 2015; Depue et al., 2007; Gagnepain et al., 2017; Levy and Anderson, 2012), and this correlation can predict later forgetting (Benoit and Anderson, 2012) and involuntary memory intrusions (Benoit et al., 2015). A recent study found that the dACC dynamically modulates inhibition control according to different cognitive control demands (Anderson and Hulbert, 2021; Braver, 2012; Braver et al., 2009; Crespo García et al., 2021). On the one hand, upon seeing the reminders of unwanted memories, dACC triggers an active control to prevent them from entering the consciousness. On the other hand, dACC is engaged in detecting the emergence of unwanted content, which amplified the top-down inhibitory control through DLPFC-HC pathway, to counteract the intrusions and remove them out of the mind (Crespo García et al., 2021). Therefore, the effective retrieval avoidance and successful intrusion elimination may depend on the integrity of one's cognitive control (Mackie & Fan, 2016, 2017).

Cognitive control refers to the flexible allocation of mental resources in favor of current goals (Badre, 2008). Well-functioning cognitive control enables individuals to coordinate mental operations under conditions of uncertainty, so that important information can be selected and prioritized into consciousness (Fan, 2014; Miller, 2000). Studies have found that cognitive control correlate with many high-level cognitive processes, such as attention (Mackie et al., 2013), thinking (Zabelina and Ganis, 2018), decision making (Waskom et al., 2017), and motor inhibition (Hampshire et al., 2010). However, it is clear that there is a capacity limitation of the mental operations in cognitive control (Fan, 2014). Recently, research has made progress in directly quantifying cognitive control capacity (Fan, 2014; Wu et al., 2016). According to information theory, the capacity of a channel is the maximum transmission rate while guaranteeing accuracy (Fan, 2014). In this frame, the capacity of cognitive control can be estimated based on the relationship between the information rate of cognitive control and response accuracy through a backward masking majority function task (MFT-M) (Chen et al., 2020; Wu et al., 2016, 2019). Cognitive control capacity (CCC, in bits per second, bps) is a direct quantification of individual's cognitive control and it refers to the upper limit that one can reliably make binary decisions at a time (Miller and Cohen, 2001). The CCC of healthy young adults ranges from 1 to 5 bps with a mean level of 3–4 bps (Chen et al., 2020). Theoretically, individuals with high CCC can perform mental operations more accurately and efficiently in a limited time and thus obtain better performance on tasks involving multiple steps of mental operations.

Previous studies have indirectly implied a correlation between cognitive control and SIF. For example, Noreen and de Fockert (2017) examined the impact of manipulating cognitive load on suppression using the TNT task with modified n-back task. They found that participants demonstrated a lower level of SIF at high working memory loads than at low working memory loads (Noreen and de Fockert, 2017). Subsequently, Nareen et al. (2020) revealed that the influence of depression on impaired SIF was partially explained by its effect on working memory function (indexed by the operation span task, Noreen et al., 2020). These findings illustrate the necessity of cognitive control for successful SIF. However, a direct evidence on how individual differences in cognitive control affect SIF is lacking. Prior findings suggest that suppressing the retrieval of unwanted memory is a complex task that requires control and regulating a set of processes, including selective attention of cue information, intrusion detecting, conflict monitoring, overcoming interferences, global inhibition of any thought, and so on (Anderson and Green, 2001; Anderson and Hulbert, 2021). These control processes are expected to be better coordinated for people with high CCC. Therefore, we propose the hypothesis that the efficacy of SIF may be constrained by individual's cognitive control capacity.

To test this hypothesis, we investigated the effect of varied CCC on SIF and used a measure of event-related potential (ERP) to elucidate its temporal impact. Previous ERP studies using the TNT task have identified several ERP components related to suppression. A consistent finding is the reduction of late parietal positivity (LPP) at 400–800 ms window for no-think compared to think trials (Bergström et al., 2007; Cano and Knight, 2016; Chen et al., 2012). The LPP effect is more positive for learned items than new items and is also known as the old/new effect or the retrieval success effect (Friedman and Johnson, 2000; Lopez-Caneda et al., 2019). Therefore, the decreased LPP during the no-think trials implies that recollection could be avoided by suppression retrieval attempts. In addition, a negative deflection of the FN400 component at 300–500 ms window over the fronto-central region for the no-think trials has been found. Dutra et al. (2019) systematically reviewed 12 ERP studies on memory retrieval inhibition and found that larger FN400 deflections during retrieval inhibition predict greater SIF (Dutra et al., 2019) and less distressing intrusive memories (Streb et al., 2016). This effect has been thought to be similar to the N2 reported in motor stopping tasks (Mecklinger et al., 2009) which reflects the engagement of cognitive control (Waldhauser et al., 2012). Besides, a more positive frontal slow wave (FSW) has been shown to be associated with regulating (i.e., reducing) the accessibility of unwanted memories to facilitate intentional recall (Lopez-Caneda et al., 2019; Waldhauser et al., 2012). Finally, a P2 effect that peaks at about 200 ms after the cue onset has been suggested to be associated with retrieval attempts (Hellerstedt et al., 2016; Mecklinger et al., 2009). This effect is larger in the think than no-think condition (Bergström et al., 2007; Mecklinger et al., 2009).

In sum, the goal of the current study was to explore the impacts of cognitive control capacity on suppression-induced forgetting, ERPs related to suppression, and intrusive memories. We first used the MFT-M task to estimate the CCC of participants and then conducted an adapted TNT task with ERP recorded. Following Levy and Anderson (Levy and Anderson, 2012), we asked participants to report whether memories associated with the presented cue had entered consciousness after each trial in the TNT task. The trial that entered consciousness was counted as an "intrusive trial". We expected that participants with higher CCC would show more SIF (Hypothesis 1). Base on Watkins's elaborated control theory (Watkins, 2008), impairments in cognitive control will result in difficulties with regulating current thoughts. Therefore, we expected that higher CCC would predict more decline in verbally reported intrusion (Hypothesis 2). Finally, we predicted that a higher CCC would lead to a greater decline in FN400 and a weaker parietal new-old effect in the no-think trials (Hypothesis 3).

2. Methods

2.1. Participants

Forty-nine participants (23 female, aged 18–28 years, $M = 22.9$, $SD = 2.11$) were recruited from universities in Beijing, China. They were all right-handed, native Chinese speakers, with normal or corrected vision, and no history of mental disorders. At the beginning of the experiment, they signed an informed consent form and were given a fee after the experiment. The data of 7 participants were excluded because of an insufficient number of valid trials (<17). The 42 remaining participants were divided into two groups taking the median of cognitive control capacity as the dividing point (Iacobucci et al., 2015): 21 were in the high cognitive control capacity group (H_CCC, $M_{\text{H\_CCC}} = 4.30$ bit/s, $SD = 0.32$), and 21 were in the low cognitive control capacity group (L_CCC, $M_{\text{L\_CCC}} = 3.52$ bit/s, $SD = 0.32$). No statistical methods were used to predetermine sample size for this experiment, which was similar to those reported elsewhere (e.g., Streb et al., 2016). The independent sample *t*-test for CCC showed that the two groups were significantly different, $t(40) = -7.925$, $p < .001$. Participants were asked not to consume psychostimulants, drugs, or alcohol before the experimental period. This study was approved by the local Research Ethics Committee of the School of Psychological and Cognitive Sciences, Peking University.

2.2. Procedure

2.2.1. Measurement of cognitive control capacity

The CCC of each participant was measured using the MFT-M (Chen et al., 2019). In each trial (Fig. 1), five arrows were presented simultaneously in 8 possible locations after fixation of 0–500 ms. Each arrow extended 0.37° in visual angle and pointed either left or right. Eight positions were arranged in an octagon, approximately 1.5° from the fixation. Then a mask for 500 ms was displayed at each location, followed by fixation of 0–1750 ms (depend on the presentation time of arrows). The response window began with the presentation of these arrows and lasted for a maximum of 2500 ms. Participants were asked to judge the direction of the major arrows as quickly and accurately as possible while trying to ensure accuracy. For example, when three arrows pointed right and two pointed left, the correct answer should be "right". If failing to identify, they were asked to guess within the response window. Following the response was feedback for 750 ms. A fixation was displayed at the end of each trial for a variable period of 1250–1750 ms to ensure that the duration of all trials was 5000 ms in total.

The cognitive load in this task was measured as information rate and was parametrically manipulated by varying the congruency (3 levels) and the exposure time (ET, 4 levels). The ET of these arrows was 250, 500, 1000, or 2000 ms and the congruency referred to the ratio of the arrows pointing in the majority and minority directions (5:0, 4:1, or 3:2). This task consisted of 12 blocks (3 blocks for each ET) in random order. Each block comprised 36 trials with the same ET (12 trials for each congruency level). The orders of these blocks and the trials within each block were both random. A fixation was presented at the start and end for 3000 ms. This task took 40 min with 432 trials in total and was run on a PC using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The CCC of each participant was estimated using model fitting based on the level of cognitive load and response accuracy. Details about these can be found in a previous study (Wu et al., 2016, see https://github.com/TingtingWu222/CCC for the E-prime program of the MFT-M and Matlab scripts for the CCC estimation).

2.2.2. Think/no-think task (TNT)

Following the MFT-M task, participants performed the TNT task. The stimuli consisted of 60 semantically weakly-related two-character Chinese word pairs (e.g., "PORT-SURFACE") and 16 additional two-character words. The selection of words was based on the literature (Zhu et al., 2016). Forty-eight word pairs were randomly assigned into three equal sets for different conditions (think, no-think, and baseline), and 12 word pairs were used as stimuli for practice. The assignment of word sets was counterbalanced across experimental conditions and across participants. Word frequency, number of strokes, and familiarity were matched between word-pair sets. The 16 single words were used as filling stimuli for the EEG experiment during the TNT task.

The TNT task consisted of three phases (learning, TNT task, and test). The learning phase was divided into three sub-phases (presentation, test-feedback, and criterion test). Among the three phases, EEG signals were only recorded in the TNT phase. During all phases, the presentation of the stimulus was preceded by a fixed cross on a black screen for 1000 ms. The presentation of experimental stimuli and the recording of participants' responses were programmed with the Psychotoolbox software package (MatLab).

In the initial presentation phase, 60 word pairs were presented in random order in white on a black background for 3000 ms (interstimulus interval (ISI): 500 ms). Participants were asked to form an

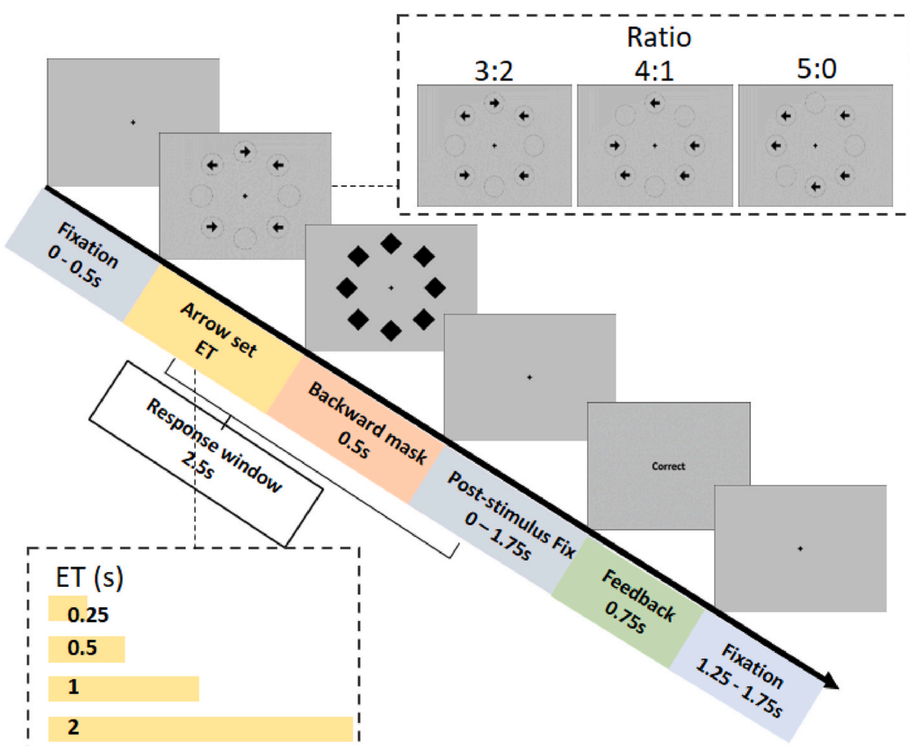

Fig. 1. Schematic of the MFT-M. Participants were required to report the majority of arrow directions in each trial. Upper right panel: ratios of possible congruency (majority: minority) of arrow sets. Lower left panel: different exposure times (ET) of the arrow set. The response window begins with the presentation of ET and lasts 2.5 s in total.

association between the two words so that they could recall the right-hand word (the matching target) when given the left-hand word (the cue word) later. Besides, 16 single words were presented on the left side of the screen sequentially, as filling stimuli in the TNT phase. Afterward, a test with feedback was performed. The cue word was presented for 3000 ms. Participants were asked to recall the corresponding target word once they saw the cue. They were also told to press the "N" key if they could think of the target word, or to press the "M" key if they could not think of the target or were unsure of their memory. Following a 500-ms ISI, the corresponding target word was displayed for 1000 ms. The recall test with feedback was repeated in an adaptive manner until participants reported remembering all word pairs. Finally, a criterion test without feedback was implemented. Each cue was presented for 3000 ms (ISI: 1000 ms) in random order and participants were asked to type the corresponding target word into the computer. Participants were allowed to proceed with subsequent phases if they remembered >90% of the word pairs on the criterion test.

The trial diagram of the TNT phase is illustrated in Fig. 2A. This phase was divided into 8 blocks, and the EEG signal was recorded during this phase. Each block included 48 cue words, 16 each for the Think and No-think conditions, and 16 as filling stimuli. Each cue was displayed for 3000 ms in green (think trial), in red (no-think trial), or in yellow (filler trial), in the center of the screen. When a cue was presented in green, the task was to recall the associated target word as soon as possible and keep it in mind until the cue disappeared. When a cue was presented in red, the task was to avoid thinking about the associated target word while sustaining attention on the cue word until it disappeared. Moreover, participants were asked not to replace the target word with any other distracting ideas or images, but simply to stop themselves from retrieving the target. Besides, when a cue was presented in yellow, the task was to read the word and pay attention to it until it disappeared. Following each trial, participants rated the extent to which they thought of the associated target on a scale from 1 to 3 (never, briefly, often) by pressing keys. The keys were balanced between participants on the left and right hands (left: never S, briefly D, often F; right: never J, briefly K, often L). Yellow words had no associated target words, so we asked participants to report the occurrence of thoughts other than the cue. To ensure that participants have fully understood these instructions, practice with structured feedback interviews (same as Wang et al., 2019) was conducted using 12 fillers prior to the TNT phase.

In the final test phase, a surprising cue test was performed, which was the same as the criterion test in the learning phase. All previously learned cue words were presented in random order. The participants were asked to recall the corresponding target word of each cue and type it into the computer.

2.2.3. EEG recording, preprocessing, and ERP analysis

During the TNT task, EEG (Brain Products system) was recorded continuously using a 64-lead Ag/AgCl electrode cap based on the international 10–20 system (EASYCAP, GmbH, Germany). The ground electrode was between Fpz and Fz, and the reference electrode for online recording was between Fz and Cz. Eye blinks and vertical eye movements were monitored using electrodes above the right eye. The EEG traces were digitized at 500 Hz and an online band-pass filter of 0.01–100 Hz was used. The electrode resistance <5 kΩ by applying EEG paste when needed during recording.

Acquired data were preprocessed using EEGLAB 9.0 (Delorme and Makeig, 2004; Swartz Center for Computational Neurosciences, LaJolla, CA; http://sccn.ucsd.edu/eeglab), an open-source toolbox for EEG analysis in MatLab (MathWorks, Inc., Natick, MA). The offline data were re-referenced and analyzed using the average of the bilateral ear papillae (TP9, TP10) as a reference. After that, a bandpass filter of 0.05–30 Hz was applied to the offline data. Independent component analysis was used to decompose the EEG data and to correct artifacts

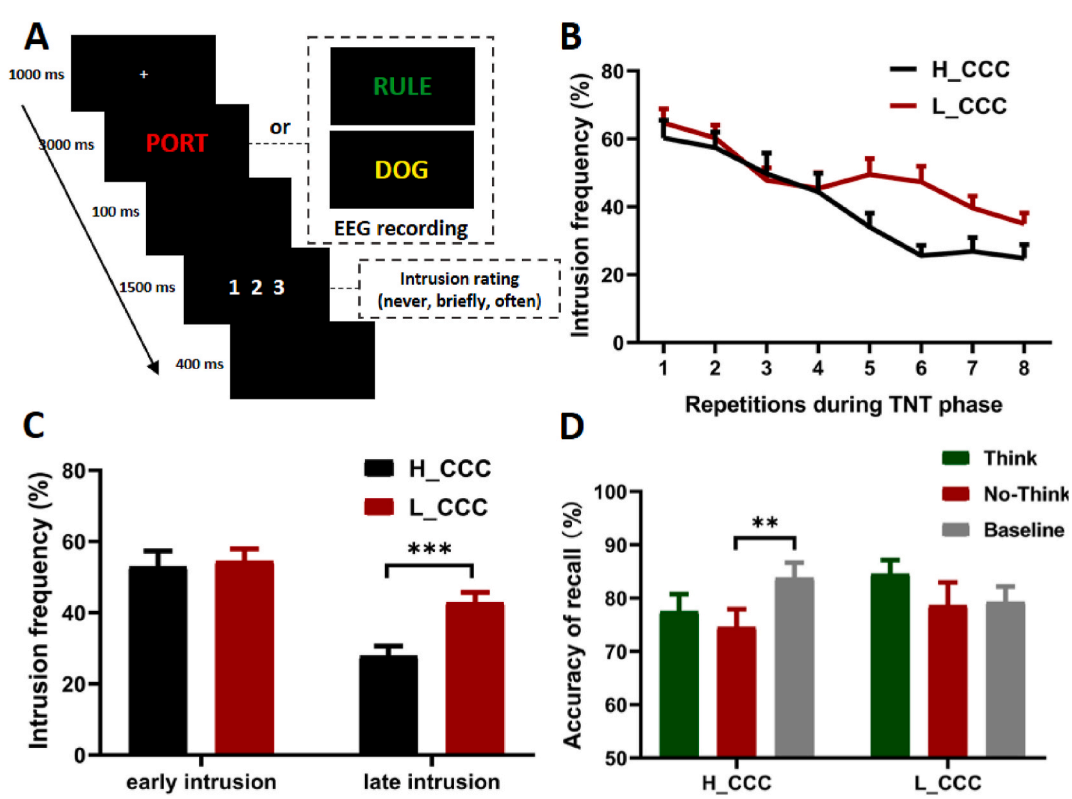

Fig. 2. Procedure and behavioral results in the TNT task. (A) Trial procedure of the TNT phase (red, no-think condition; green, think condition; yellow, filling trials. (B) Frequency of reported intrusion experiences over the 8 repetitions of think and no-think conditions in the TNT phase. (C) Frequency of reported intrusion for the early stage (first 4 repetitions) and last stage (last 4 repetitions) during the TNT phase. (D) Recall rates in the final test for participants in the high and low CCC groups. Error bars represent SEM. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

such as blinking, horizontal eye movement, ECG, and EMG. The segmentation standard took the occurrence time of the cue word as the zero point to intercept the TNT phase –500~3000 ms as the epoch, and the total length was 3500 ms. Five hundred milliseconds before the appearance of the cue word were used as the baseline for baseline correction, and trials exceeding ±100 μV were tagged as artifacts for removal. The average number of accepted trials was 122 (artifact removal rate 4.75%) in the think condition and 122 (artifact removal rate 4.66%) in the no-think condition.

ERP waveforms for the think and no-think trials were extracted from the mean amplitudes of four time windows (220–300 ms, 350–450 ms, 500–700 ms, and 1000–1500 ms). These windows were chosen based on visual inspection and previous ERP studies (Mecklinger et al., 2009). We included the 220–300 ms window to quantify the P2 effect, the 350–450 ms window to capture the FN400 effect, 500–700 ms to capture the onset of the LPP effect, and the 1000–1500 ms window to capture the FSW effect. Statistical analysis of the ERP data was based on the mean amplitude at specific electrodes according to topographic maps, fronto-central (Fz, FC1, FC2) for P2, centro-parietal (Cz, FC1, FC2, CPz) for FN400, parietal (Pz, CPz, CP1, CP2) for LPP, and frontal (Fz, F1, F2) for FSW. The data analysis used repeated-measures ANOVA of Group (high CCC *versus* low CCC) × Condition (think *vs* no-think), to correct the data with the Greenhouse-Geisser method when necessary. To investigate the relationship between CCC and suppression-related ERPs, we calculated robust Pearson correlations between the differences of ERP across conditions (think minus no-think) and CCC.

3. Results

3.1. Behavioral results

In the criterion test, the average correct rate of the high CCC group was 92.5%, and that of the low CCC group was 91.8% (no significant difference, paired *t*-test). There was no difference in the initial memory strength between the two groups.

3.1.1. Intrusions during the think/no-think task

First, we determined whether intrusions occurred during the TNT phase, and how they were affected by repetition and CCC. Since we focused on the intrusions during extraction inhibition, only the intrusions in the no-think condition were covered. Based on the literature, "briefly" and "often" responses were counted as intrusions, while "never" responses were coded as non-intrusions (Levy and Anderson, 2012). Using the sum of intrusions as the numerator, and the total number of no-think trials per block as the denominator, the result is the frequency of intrusive memories. There were 8 blocks in the experiment. The intrusion rate declined with the repeated effort of suppressing retrieval in both the high and low CCC groups, although the decline was greater in the high CCC group (Table 1, Fig. 2B).

To further determine the impact of the repetition stages on the intrusions, we divided the 8 blocks into early and late stages. The data of the first four blocks were averaged as the frequency of early intrusive memories, and the data of the last four blocks were averaged as the frequency of late intrusive memories (Table 2). We performed a 2 (Group: low CCC group *vs* high CCC group) × 2 (Stage: early *vs* late) repeated measures ANOVA, which showed significant main effects of Stage, $F(1, 40) = 43.39$, $p < .001$, $\eta_p^2 = 0.52$, and Group, $F(1, 40) = 4.50$, $p = .040$, $\eta_p^2 = 0.10$. The interaction of Group and Stage was significant (Fig. 2C), $F(1, 40) = 5.78$, $p = .021$, $\eta_p^2 = 0.13$. Subsequent pairwise comparisons revealed that for the early stage, the differences in intrusions of two groups were not significant, $MD = 0.016$, $p = .776$; however, for the late stage, the differences in intrusions of two groups were significant, $MD = 0.150$, $p < .001$. These results showed that the intrusion rate declined with suppression effort and that CCC can moderate this decline. In the high CCC group, the intrusion rate decreased more than in the low CCC group.

Table 1
The mean frequencies (standard deviation) of intrusion in 8 blocks.

Block	1	2	3	4	5	6	7	8
H_CCC group	.60 (.05)	.57 (.04)	.50 (.05)	.44 (.05)	.34 (.04)	.26 (.04)	.27 (.04)	.25 (.04)
L_CCC group	.65 (.05)	.60 (.04)	.48 (.05)	.45 (.05)	50 (.04)	.47 (.04)	.40 (.04)	.35 (.04)

Table 2
Cognitive control capacity (CCC) and memory performance of two groups.

Group	Mean CCC (bit/s)	Think (%)	No-think (%)	Baseline (%)	Early intrusion	Late intrusion
H_CCC group	4.30 (.32)	.78 (.15)	.75 (.15)	.84 (.13)	.53 (.20)	.28 (.13)
L_CCC group	3.52 (.32)	.85 (.12)	.79 (.20)	.79 (.13)	54 (.16)	.43 (.13)

3.1.2. Memory performance in the final test

Next, we examined whether the memory performance in the recall test was affected by suppression in the think/no-think task and CCC (Table 2). We performed a 2 (Group: high CCC group *vs* low CCC group) × 3 (Condition: think *vs* no-think *vs* baseline) two-factor repeated measures ANOVA analysis (Fig. 2D). Replicating previous studies, the results showed a reliable main effect of Condition, $F(2, 80) = 3.85$, $p = .025$, $\eta_p^2 = 0.09$. The recall accuracy was lower in the No-think condition than in the baseline condition, $MD = -0.05$, $t(41) = -2.44$, $p = .044$. There were no significant differences between the recall accuracy in the No-think condition *vs* the Think condition and the baseline condition *vs* the think condition ($p = .096$, $p = .999$).

Besides, the ANOVA analysis showed a significant interaction effect between Group and Condition, $F(2, 80) = 4.73$, $p = .011$, $\eta_p^2 = 0.11$. The post-hoc comparison of the high CCC group (Bonferroni) showed that compared with the baseline conditions, the recall accuracy rate under the no-think condition was significantly lower, $MD = .09$, $t(20) = 3.40$, $p = .005$. There were no significant differences between the comparisons of think condition *vs* the behavioral baseline, and think condition *vs* no-think condition ($ps > .05$). The post-hoc comparison (Bonferroni) of the low CCC group showed that there were no significant differences between the recall accuracy rate of the behavioral baseline condition, think condition and no-think condition ($ps > .05$, Fig. 2B). The results showed that there was a reliable suppression-induced forgetting effect for the high CCC group. However, for the low CCC group, this effect was not found.

3.1.3. Relationships between CCC, the reduction in intrusion, and SIF

To reduce the influence of individual differences, we controlled for the recall rate of the baseline condition and the intrusion rate of the first block (Hellerstedt et al., 2016; Meyer and Benoit, 2022). Specifically, we calculated the index of SIF by subtracting the recall rate of the no-think condition form the recall rate of the baseline condition, and dividing the difference by the baseline recall rate (to control for individual differences in the baseline). Then, we subtracted the intrusion rate of the first block from that of the eighth block and divided the difference by the intrusion rate of the first block (to control for individual differences in the intrusion during the first block). Consistent with previous results (Levy and Anderson, 2012), we found a correlation between the reduction in intrusion and SIF ($r = 0.418$ [0.174, 0.649], $p = .006$). In addition, the correlation between CCC and the reduction in intrusion was also significant ($r = 0.326$ [0.007, 0.589], $p = .035$). The correlation between CCC and SIF was marginally significant (Fig. 3; $r = 0.368$ [−0.050, 0.697], $p = .017$). However, the correlation between CCC and unadjusted SIF (baseline minus no-think) is significant ($r = 0.666$

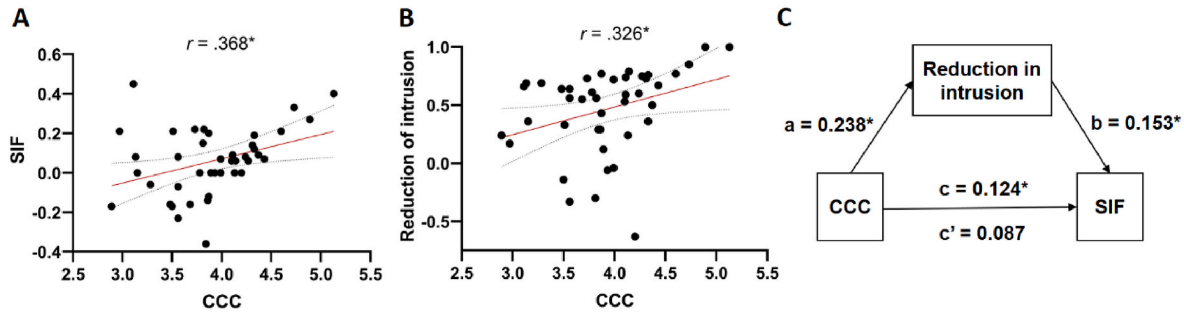

Fig. 3. (A, B) Association between cognitive control capacity (CCC) and suppression-induced forgetting (SIF) (A) and reduction in intrusion (B). (C) Mediation model for the direct and indirect effects of CCC on forgetting; reduction in intrusive memories partially mediates their relationship (*$p < .05$).

[0.420, 0.857], $p < .001$). These findings suggested that a higher CCC could predict both a larger reduction in memory intrusion during repeated retrieval inhibition attempts and a greater final suppression-induced forgetting. The greater reduction in memory intrusion, in turn, further predicted SIF.

To examine whether the effect of CCC on forgetting is mediated by a decline in intrusion, we used a bootstrapping procedure on the participants' data to compute the 95% CI around the indirect effect (i.e., the path through the mediator) using the PROCESS macro in SPSS (Model 4; Hayes, 2013). We conducted a test of indirect effects for all participants, with CCC as the independent variable, SIF as the outcome variable, and the decline in intrusion as the mediator variable (see Fig. 3C). The path from CCC to the decline in intrusion was significant (a = 0.238 [0.028, 0.408], $p = .035$), as was the path from the decline in intrusion to SIF (b = 0.153 [0.030, 0.314], $p = .030$). In addition, the results of mediation analyses showed that reduction in intrusion mediated the relationship

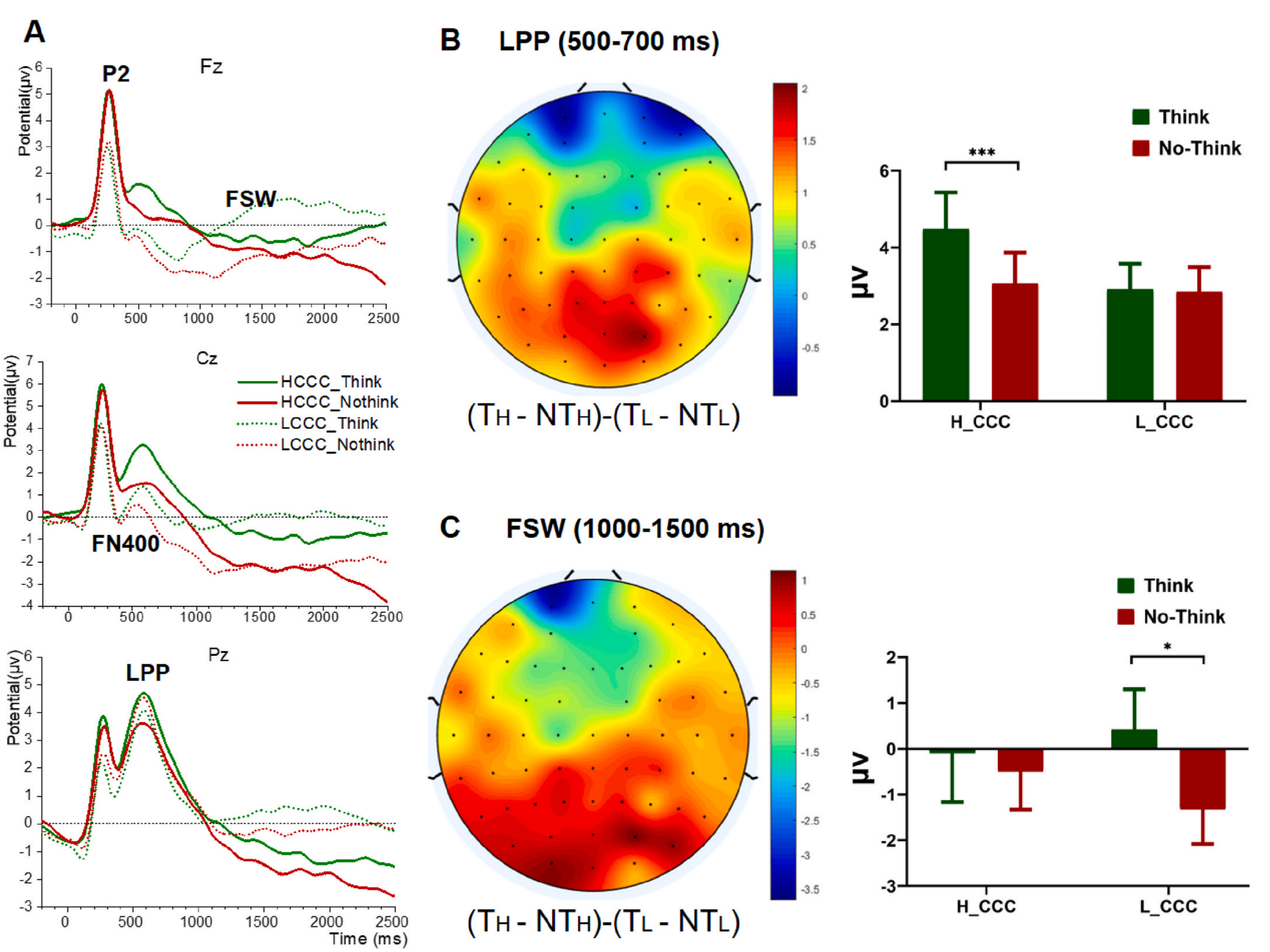

Fig. 4. ERP results. (A) Grand average ERPs from the Think/no-think phase of two groups from three electrode sites (FZ, Cz, and Pz). HCCC, high CCC group; LCCC, low CCC group. (B) Topographical map of the Group × Condition interaction of late parietal positivity (LPP) and mean LPP amplitudes for different conditions and different groups. (C) Topographical map of Group × Condition interaction of frontal negative slow wave (FSW) and mean FSW amplitudes for different conditions and different groups (T: think condition; NT: no-think condition; H: high CCC group; L: low CCC group).

between CCC and SIF (total effect: c = 0.124 [0.024, 0.224], $p = .017$; direct effect: c' = 0.087 [-0.014, 0.188], $p = .088$; indirect effect: a × b = 0.037 [0.0007, 0.093], $p = .024$). These results suggested that the decline in intrusion partially mediated the effect of CCC on SIF.

3.2. ERP results

The grand average of ERPs for the think (high and low CCC) and no-think (high and low CCC) conditions are shown in Fig. 4A. Firstly, negative FN400 effect emerged during the 350–450 ms window. Inconsistent with previous studies (Mecklinger et al., 2009), the main effect of condition was not significant, $F(1, 40) = 0.030$, $p = .863$, $\eta_p^2 = 0.001$; and the main effect of Group was not significant, $F(1, 40) = 2.172$, $p = .148$, $\eta_p^2 = 0.051$. Thus, an FN400 occurred in both groups and both conditions when the cue was presented.

Then, an LPP effect for recollection emerged during the 500–700 ms window (Fig. 4A). Analysis of the LPP revealed a significant Group × Condition interaction, $F(1, 40) = 6.908$, $p = .012$, $\eta_p^2 = 0.147$. Further pairwise comparison showed that, for the high CCC group, the LPP of the no-think was much lower than that of the think condition, $MD = -1.422$, $p < .001$ (Fig. 4B); however, in the low CCC group, the difference of conditions was not significant, $MD = -.367$, $p = .872$. Our results showed that the no-think condition has a reduced LPP amplitude compared to the think condition, but only in the high CCC group. No significant main effects were found ($ps > .05$). What's more, to check if the LPP reflected the level of recollection, we calculated the correlation between reduced LPP (think minus no-think) and the decline in intrusion and it was significant ($r = 0.437$ [0.122, 0.697], $p = .004$). The results revealed a consistency between neural indicators of recollection and verbal reports of intrusion.

A continued frontal positive effect emerged during the 1000–1500 ms window, and analysis revealed a significant Group × Condition interaction for FSW (Fig. 4C) [$F(1, 40) = 4.087$, $p = .049$, $\eta_p^2 = 0.079$]. Further pairwise comparison showed that, in the low CCC group, the FSW of the no-think was much lower than that of the think condition, $MD = -1.748$, $p = .037$. However, for in high CCC group, the difference between conditions was not significant, $MD = -.402$, $p = .812$. No significant main effects were found for Condition or Group.

In addition, a positive P2 effect emerged during the 220–300 ms window. The main effect of Group was significant, $F(1, 40) = 5.233$, $p = .028$, $\eta_p^2 = 0.116$. A stronger P2 effect emerged in the high CCC group than in the low CCC group (for both active recall and suppression retrieval trials). The main effect of Condition and the interaction of Group × Condition were both not significant.

Finally, the correlations of CCC and ERP effects were explored. The individuals' CCC correlated with the difference of LPP (Think minus No-think), $r = 0.306$ [0.042, 0.513], $p = .05$. There were no relationships between CCC and the differences of P2 ($r = 0.199$ [-0.095, 0.452]), FN400 ($r = 0.142$ [-0.221, 0.461]), or FSW ($r = -0.026$ [-0.279, 0.229]).

4. Discussion

Many people develop intrusive memories after a traumatic event. Some survivors can easily manage their intrusive memories, while others are continually plagued by them. In the present study, we investigated the relationship between cognitive control capacity and controlling unwanted memories. In particular, we examined whether CCC predicted a reduction in intrusion memories and later SIF. Besides, we used the high temporal resolution of ERPs to measure the temporal influence of CCC on ERP components of retrieval suppression. As expected, we replicated the typical results found in previous studies (Anderson and Green, 2001). Repeated retrieval suppression attempts during the TNT phase caused SIF in the high CCC group. The participants' CCC predicted their later SIF: the higher the CCC, the worse memory recall for suppressed targets. In line with other studies that verbally reported intrusive thoughts during the TNT phase (Hu et al., 2017), the frequency of intrusion declined gradually with repeated suppression. In addition, the CCC predicted the reduction of intrusion. Future mediation analysis verified that increased CCC promoted SIF partly *via* its influence on memory intrusions. ANOVA analysis of ERP data showed that there was a reduced recollection-related LPP (500–700 ms) in the high CCC group and a reduced FSW (1000–1500 ms) in the low CCC group.

Consistent with previous research demonstrating the important role of cognitive control in successful intentional forgetting (Noreen et al., 2020; Noreen and de Fockert, 2017), people in the high CCC group showed impaired recall for associated targets under the no-think condition, while those in the low CCC group did not. Furthermore, the correlation between CCC and SIF verified that a higher CCC promoted a later SIF. Similarly, in a very recent study participants were asked to perform an exhaustive inhibition task or a non-exhaustive inhibition task before the retrieval-induced forgetting (RIF) task. Their results showed that the RIF effect was eliminated when the cognitive control capacity was exhausted (Tumen and Ikier, 2021). Taken together, these results confirmed that people with a high CCC can have better active control of unwanted memory.

To effectively control intrusive memories is essential for psychological well-being (Krans et al., 2009). As expected, individuals with a high CCC had a lower frequency of intrusive memories than individuals with a low CCC. The correlation between the reduction of oral intrusion reports and CCC revealed that people with a high CCC had better control over intrusive thoughts. These finding were in line with the executive deficit hypothesis (Levy and Anderson, 2008), which states that the differences in regulating intrusive memories arise partly from the differences in executive control ability. Consistently, Brewin and Beaton (2002) conducted the standard "white bear" paradigm and reported that greater working memory was related to fewer intrusions in the suppression condition (Brewin and Beaton, 2002). Thus, these results imply that people with a high CCC perform better at eliminating unwanted memories from awareness, as well as reducing their tendency to intrude again.

In addition, this study explored the relationship between the reduction in intrusion and SIF. SIF is believed to be consequence of an inhibition mechanism which disrupts the availability of the unwanted memory and renders it inaccessible later (Anderson and Hanslmayr, 2014). In line with this account, Hellerstedt et al. (2016) used a modified TNT task and found that those with a steeper decline in intrusive experiences (reported entry) over repeated retrieval suppression attempts showed greater forgetting in later tests (Hellerstedt et al., 2016). The present study replicated this finding and further found that the reduction in intrusion served as a mediator that partly explained the effect of CCC on SIF. These results provide an explanation for the mechanism by which CCC affects SIF: people with high CCC have better coordination of multiple cognitive processes during suppression thus could effectively reduce the strength of memory traces with repeated suppression attempts, making it hard to retrieve. We could answer the question of why people are disturbed differently by intrusive memories after traumatic events: People with poor cognitive control capacities, either reflecting a vulnerability factor or a consequence of stress-related dysfunction (Mary et al., 2020), fail to reduce the strength of memory traces and it's easy for highly accessible memories to be extracted, leading to further reinforcement of them.

Additional support for the inhibition account comes from the ERP results. The LPP difference in the 500–700 ms window between the think and no-think trials was larger in the high CCC group. Insistently, there was a positive correlation between CCC and the reduction of LPP (think minus no-think). These findings are in line with previous studies showing that retrieval suppression attempts in the no-think task are related to a reduction of the LPP effect (Cano and Knight, 2016; Chen et al., 2012; Hellerstedt et al., 2016; Lopez-Caneda et al., 2019). As the LPP effect has been associated with recollection in previous studies

(Lopez-Caneda et al., 2019), these findings may suggest that people with high CCC performed better in avoiding retrieval and preventing unwanted memories entering consciousness. Moreover, being aware of intrusive memory meaned that the memory was reactivated at least briefly during the trial. The correlation between the reduced LPP effect and the reduced intrusion may indicate the consistency between the level of oral reported memory reactivation and the neurological indicators related to recognition. Both of them may reflect the reduction of memory strength and accessibility (Meyer and Benoit, 2022). Therefore, these results indicate that people with low CCC perform poorly in preventing the memory from entering consciousness and reducing the strength of the memory trace, which leads to a failure in forgetting.

FSW have been thought to be engaged in the strategic control of memory retrieval and in regulating the accessibility of unwanted memories (Mecklinger et al., 2009; Waldhauser et al., 2012). Our results showed a reduced FSW in the 1000–1500 ms window in the low CCC group. Given the higher intrusion and increased level of LPP in the low CCC group, the decreased FSW may reflect a failure to regulate competing memories. In line with our results, Hellerstedt proposed that the FSW effect could index the intrusion of an unwanted memory into working memory (Hellerstedt et al., 2016). Anderson proposed that the inhibitory process that occurs after the appearance of an intrusive memory is a process of reactive cognitive control, which is a late correction process (Anderson et al., 2016; Crespo García et al., 2021). Therefore, we speculate that the continued FSW in the high CCC group may indicate an intrusion-related reactive control, which contributes to their success of memory suppression. However, we did not find a correlation between CCC and NSW difference between think and no-think condition. Therefore, further investigations are needed to determine whether CCC would influence the use of reactive control strategy.

However, we failed to replicate the difference in the FN400 effect between the think and no-think conditions (Streb et al., 2016; Waldhauser et al., 2012). We also failed to find a correlation between CCC and FN400. The FN400 also known as the N2 effect in some studies (Chen et al., 2012; Mecklinger et al., 2009). Apparently, our results do not support the view that the fronto-central FN400/N2 is involved in the avoidance of memory retrieval (Bergstrom et al., 2009; Hellerstedt et al., 2016; Mecklinger et al., 2009). It is worth noting that this component is also thought to distinguish unfamiliar items from familiar ones in some studies (Curran and Cleary, 2003). As the think and no-think items are equally familiar, the lack of difference in FN400 amplitude between the two conditions may imply that this component is functionally related to familiar recognition rather than to retrieval inhibition. Also, several studies reported similar results as ours that the FN400 was attenuated for both think and no-think conditions (Hellerstedt et al., 2016; Lopez-Caneda et al., 2019). Therefore, it is necessary to explain the conflicting FN400/N2 findings using TNT task. What is more, the P2 effect is thought to reflect the amount of attention allocated to color-coded cue words (Bergström et al., 2007; Mecklinger et al., 2009). The correlation of CCC and P2 difference between conditions was not significant. However, there was higher P2 effect in the high CCC group than in the low CCC group, which may reflect stronger selective attention triggered by cues of both conditions in the high CCC group.

The present study displays some limitations that deserve consideration. First, because the sample consisted solely of non-clinical participants, the influence of CCC on SIF of clinical and subclinical participants was not included in this study. Clinical researches indicated that SIF was reduced in most forms of psychopathology (Snyder et al., 2015; Stramaccia et al., 2020), including those with trait worry (Gustavson et al., 2020), depression (Zetsche et al., 2012), and PTSD (Aupperle et al., 2012). Future studies could explore whether the CCC of them is also decreased and whether decreased CCC are related with failure of regulating intrusive thoughts. Second, the causality between cognitive impairments and intrusive symptoms cannot be confirmed yet (Costanzi et al., 2021; Pacheco et al., 2019). Does impaired cognitive control lead to more intrusions, or do intrusive thoughts and unpleasant moods disrupt cognitive control? As a cross-sectional study, we cannot answer this question yet. However, understanding the mechanism by which cognitive control affects SIF may contribute to better preventions and interventions (Mary et al., 2020). Third, the intrusive memories in the TNT task are different from those in real life. Therefore, the effect of CCC on intrusive memories should be identified in a more general context of intrusive memories. Lastly, the current study confirms that high cognitive control capacity is necessary for memory control. Thus, the efficiency of cognitive control training needs to be further investigated in order to better intervene a range of psychiatric disorders characterized by persisting intrusive memories and thoughts.

To conclude, participants with higher cognitive control capacity exhibited a greater reduction in intrusive thoughts and larger suppression-induced forgetting after repeated suppression attempts. These findings reveal that cognitive control can regulate the cognitive process during suppression and affect later forgetting. The results of the LPP provide evidence that people with a higher CCC are more successful in controlling memory awareness during the think/no-think phase. Therefore, cognitive control capacity is one of the key factors that determine the control of intrusive memory and then affects the suppression-induced forgetting effect. The present study represents a significant contribution to the understanding of the impact of cognitive control on intentional forgetting and its underlying mechanisms. It suggests that, training in CCC may be an way to help people better control intrusive memories.

Credit author statement

Suya Chen: Conceptualization, Data curation, Formal analysis, Writing – original draft, Project administration. **Xinrui Mao:** Methodology, Investigation, Data curation, Formal analysis. **Yanhong Wu**: Conceptualization, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare no competing financial interests.

Acknowledgements

We thank Dr. Iain C. Bruce for the English language polishing.

This work was supported by the National Natural Science Foundation of China under Grant No. 32171050, 31771205, and 61690205.

References

Anderson, M.C., Bunce, J.G., Barbas, H., 2016. Prefrontal-hippocampal pathways underlying inhibitory control over memory. Neurobiol. Learn. Mem. 134 Pt A, 145–161. https://doi.org/10.1016/j.nlm.2015.11.008.

Anderson, M.C., Green, C., 2001. Suppressing unwanted memories by executive control. Nature 410, 366. https://doi.org/10.1038/35066572.

Anderson, M.C., Hanslmayr, S., 2014. Neural mechanisms of motivated forgetting. Trends Cognit. Sci. 18 (6), 279–292. https://doi.org/10.1016/j.tics.2014.03.002.

Anderson, M.C., Hulbert, J.C., 2021. Active forgetting: adaptation of memory by prefrontal control. Annu. Rev. Psychol. 72, 1–36. https://doi.org/10.1146/annurev-psych-072720-094140.

Anderson, M.C., Ochsner, K.N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S.W., Glover, G.H., Gabrieli, J.D.E., 2004. Neural systems underlying the suppression of unwanted memories. Science 303 (5655), 232–235. https://doi.org/10.1126/science.1089504.

Aupperle, R.L., Melrose, A.J., Stein, M.B., Paulus, M.P., 2012. Executive function and PTSD: disengaging from trauma. Neuropharmacology 62 (2), 686–694. https://doi.org/10.1016/j.neuropharm.2011.02.008.

Badre, D., 2008. Cognitive control, hierarchy, and the rostro-caudal organization of the frontal lobes. Trends Cognit. Sci. 12 (5), 193–200. https://doi.org/10.1016/j.tics.2008.02.004.

Benoit, R.G., Anderson, M.C., 2012. Opposing mechanisms support the voluntary forgetting of unwanted memories. Neuron 76 (2), 450–460. https://doi.org/10.1016/j.neuron.2012.07.025.

Benoit, R.G., Hulbert, J.C., Huddleston, E., Anderson, M.C., 2015. Adaptive top-down suppression of hippocampal activity and the purging of intrusive memories from consciousness. J. Cognit. Neurosci. 27 (1), 96–111. https://doi.org/10.1162/jocn_a_00696.

Bergstrom, Z.M., de Fockert, J.W., Richardson-Klavehn, A., 2009. ERP and behavioural evidence for direct suppression of unwanted memories. Neuroimage 48 (4), 726–737. https://doi.org/10.1016/j.neuroimage.2009.06.051.

Bergström, Z.M., Velmans, M., de Fockert, J., Richardson-Klavehn, A., 2007. ERP evidence for successful voluntary avoidance of conscious recollection. Brain Res. 1151, 119–133. https://doi.org/10.1016/j.brainres.2007.03.014.

Braver, T.S., 2012. The variable nature of cognitive control: a dual mechanisms framework. Trends Cognit. Sci. 16 (2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010.

Braver, T.S., Paxton, J.L., Locke, H.S., Barch, D.M., 2009. Flexible neural mechanisms of cognitive control within human prefrontal cortex. Proc. Natl. Acad. Sci. U. S. A 106 (18), 7351–7356. https://doi.org/10.1073/pnas.0808187106.

Brewin, C.R., Beaton, A., 2002. Thought suppression, intelligence, and working memory capacity. Behav. Res. Ther. 40 (8), 923–930. https://doi.org/10.1016/S0005-7967(01)00127-9.

Cano, M.E., Knight, R.T., 2016. Behavioral and EEG evidence for auditory memory suppression. Front. Hum. Neurosci. 10, 133. https://doi.org/10.3389/fnhum.2016.00133.

Catarino, A., Kupper, C.S., Werner-Seidler, A., Dalgleish, T., Anderson, M.C., 2015. Failing to forget: inhibitory-control deficits compromise memory suppression in posttraumatic stress disorder. Psychol. Sci. 26 (5), 604–616. https://doi.org/10.1177/0956797615569889.

Chen, C., Liu, C., Huang, R., Cheng, D., Wu, H., Xu, P., Mai, X., Luo, Y.J., 2012. Suppression of aversive memories associates with changes in early and late stages of neurocognitive processing. Neuropsychologia 50 (12), 2839–2848. https://doi.org/10.1016/j.neuropsychologia.2012.08.004.

Chen, Y., Chen, C., Wu, T., Qiu, B., Zhang, W., Fan, J., 2020. Accessing the development and heritability of the capacity of cognitive control. Neuropsychologia 139, 107361. https://doi.org/10.1016/j.neuropsychologia.2020.107361.

Chen, Y., Spagna, A., Wu, T., Kim, T.H., Wu, Q., Chen, C., Wu, Y., Fan, J., 2019. Testing a cognitive control model of human intelligence. Sci. Rep. 9 (1), 2898. https://doi.org/10.1038/s41598-019-39685-2.

Costanzi, M., Cianfanelli, B., Santirocchi, A., Lasaponara, S., Spataro, P., Rossi-Arnaud, C., Cestari, V., 2021. Forgetting unwanted memories: active forgetting and implications for the development of psychological disorders. J. Personalized Med. 11 (4) https://doi.org/10.3390/jpm11040241.

Crespo García, M., Wang, Y., Jiang, M., Anderson, M., Lei, X., 2021. Anterior Cingulate Cortex Signals the Need to Control Intrusive Thoughts during Motivated Forgetting ([preprint]).

Curran, T., Cleary, A.M., 2003. Using ERPs to dissociate recollection from familiarity in picture recognition. Cognit. Brain Res. 15 (2), 191–205. https://doi.org/10.1016/S0926-6410(02)00192-1.

Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J. Neurosci. Methods 134 (1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009.

Depue, B.E., Curran, T., Banich, M.T., 2007. Prefrontal regions orchestrate suppression of emotional memories via a two-phase process. Science 317 (5835), 215–219. https://doi.org/10.1126/science.1139560.

Dutra, C.A., Beria, F.M., Ligório, I.S., Gauer, G., 2019. Electroencephalogram Evidence for Memory Suppression: A Systematic Review, vol. 27. Trends in Psychology. https://doi.org/10.9788/TP2019.3-01.

Engen, H.G., Anderson, M.C., 2018. Memory control: a fundamental mechanism of emotion regulation. Trends Cognit. Sci. 22 (11), 982–995. https://doi.org/10.1016/j.tics.2018.07.015.

Fan, J., 2014. An information theory account of cognitive control. Front. Hum. Neurosci. 8, 680. https://doi.org/10.3389/fnhum.2014.00680.

Friedman, D., Johnson Jr., R., 2000. Event-related potential (ERP) studies of memory encoding and retrieval: a selective review. Microsc. Res. Tech. 51 (1), 6–28. https://doi.org/10.1002/1097-0029(20001001)51:1<6::AID-JEMT2>3.0.CO;2-R.

Gagnepain, P., Hulbert, J., Anderson, M.C., 2017. Parallel regulation of memory and emotion supports the suppression of intrusive memories. J. Neurosci. 37 (27), 6423–6441. https://doi.org/10.1523/JNEUROSCI.2732-16.2017.

Goschke, T., 2014. Dysfunctions of decision-making and cognitive control as transdiagnostic mechanisms of mental disorders: advances, gaps, and needs in current research. Int. J. Methods Psychiatr. Res. 23 (Suppl. 1), 41–57. https://doi.org/10.1002/mpr.1410.

Gustavson, D.E., Lurquin, J.H., Michaelson, L.E., Barker, J.E., Carruth, N.P., von Bastian, C.C., Miyake, A., 2020. Lower general executive function is primarily associated with trait worry: a latent variable analysis of negative thought/affect measures. Emotion 20 (4), 557–571. https://doi.org/10.1037/emo0000584.

Hampshire, A., Chamberlain, S.R., Monti, M.M., Duncan, J., Owen, A.M., 2010. The role of the right inferior frontal gyrus: inhibition and attentional control. Neuroimage 50 (3), 1313–1319. https://doi.org/10.1016/j.neuroimage.2009.12.109.

Hellerstedt, R., Johansson, M., Anderson, M.C., 2016. Tracking the intrusion of unwanted memories into awareness with event-related potentials. Neuropsychologia 89, 510–523. https://doi.org/10.1016/j.neuropsychologia.2016.07.008.

Hertel, P.T., 1997. On the contributions of deficent cognitive control to memory impairments in depression. Cognit. Emot. 11 (5–6), 569–583. https://doi.org/10.1080/026999397379890a.

Hertel, P.T., 1998. Relation between rumination and impaired memory in dysphoric moods. J. Abnorm. Psychol. 107 (1), 166–172. https://doi.org/10.1037//0021-843x.107.1.166.

Hertel, P.T., 2007. Impairments in inhibition or cognitive control in psychological disorders. Appl. Prev. Psychol. 12 (3), 149–153. https://doi.org/10.1016/j.appsy.2007.09.006.

Hu, X., Bergstrom, Z.M., Gagnepain, P., Anderson, M.C., 2017. Suppressing unwanted memories reduces their unintended influences. Curr. Dir. Psychol. Sci. 26 (2), 197–206. https://doi.org/10.1177/0963721417689881.

Iacobucci, D., Posavac, S.S., Kardes, F.R., Schneider, M.J., Popovich, D.L., 2015. The median split: robust, refined, and revived. J. Consum. Psychol. 25 (4), 690–704. https://doi.org/10.1016/j.jcps.2015.06.014.

Krans, J., Näring, G., Becker, E.S., Holmes, E.A., 2009. Intrusive trauma memory: a review and functional analysis. Appl. Cognit. Psychol. 23 (8), 1076–1088. https://doi.org/10.1002/acp.1611.

Levy, B.J., Anderson, M., 2008. Individual differences in the suppression of unwanted memories: the executive deficit hypothesis. Acta Psychol. 127 (3), 623–635. https://doi.org/10.1016/j.actpsy.2007.12.004.

Levy, B.J., Anderson, M.C., 2012. Purging of memories from conscious awareness tracked in the human brain. J. Neurosci. 32 (47), 16785–16794. https://doi.org/10.1523/JNEUROSCI.2640-12.2012.

Lopez-Caneda, E., Crego, A., Campos, A.D., Gonzalez-Villar, A., Sampaio, A., 2019. The think/No-think alcohol task: a new paradigm for assessing memory suppression in alcohol-related contexts. Alcohol Clin. Exp. Res. 43 (1), 36–47. https://doi.org/10.1111/acer.13916.

Mackie, M.-A., Fan, J., 2017. Chapter 11 - functional neuroimaging of deficits in cognitive control. In: Goldberg, E. (Ed.), Executive Functions in Health and Disease. Academic Press, pp. 249–300. https://doi.org/10.1016/B978-0-12-803676-1.00011-8.

Mackie, M.-A., Van Dam, N.T., Fan, J., 2013. Cognitive control and attentional functions. Brain Cognit. 82 (3), 301–312. https://doi.org/10.1016/j.bandc.2013.05.004.

Mackie, M.A., Fan, J., 2016. Reduced efficiency and capacity of cognitive control in autism spectrum disorder. Autism Res. 9 (3), 403–414. https://doi.org/10.1002/aur.1517.

Mary, A., Dayan, J., Leone, G., Postel, C., Fraisse, F., Malle, C., Vallee, T., Klein-Peschanski, C., Viader, F., de la Sayette, V., Peschanski, D., Eustache, F., Gagnepain, P., 2020. Resilience after trauma: The role of memory suppression. Science 367 (6479). https://doi.org/10.1126/science.aay8477.

McTeague, L.M., Goodkind, M.S., Etkin, A., 2016. Transdiagnostic impairment of cognitive control in mental illness. J. Psychiatr. Res. 83, 37–46. https://doi.org/10.1016/j.jpsychires.2016.08.001.

Mecklinger, A., Parra, M., Waldhauser, G.T., 2009. ERP correlates of intentional forgetting. Brain Res. 1255, 132–147. https://doi.org/10.1016/j.brainres.2008.11.073.

Meyer, A.K., Benoit, R.G., 2022. Suppression weakens unwanted memories via a sustained reduction of neural reactivation. Elife 11. https://doi.org/10.7554/eLife.71309.

Miller, E.K., 2000. The prefontral cortex and cognitive control. Nat. Rev. Neurosci. 1 (1), 59–65. https://doi.org/10.1038/35036228.

Miller, E.K., Cohen, J.D., 2001. An integrative theory of prefrontal cortex function. Annu. Rev. Neurosci. 24, 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167, 0147-006X(Print)).

Noreen, S., Bierman, R.N., MacLeod, M.D., 2014. Forgiving you is hard, but forgetting seems easy: can forgiveness facilitate forgetting? Psychol. Sci. 25 (7), 1295–1302. https://doi.org/10.1177/0956797614531602.

Noreen, S., Cooke, R., Ridout, N., 2020. Investigating the mediating effect of working memory on intentional forgetting in dysphoria. Psychol. Res. 84 (8), 2273–2286. https://doi.org/10.1007/s00426-019-01225-y.

Noreen, S., de Fockert, J.W., 2017. The role of cognitive load in intentional forgetting using the think/No-think task. Exp. Psychol. 64 (1), 14–26. https://doi.org/10.1027/1618-3169/a000347.

Noreen, S., Macleod, M.D., 2013. It's all in the detail: intentional forgetting of autobiographical memories using the autobiographical think/no-think task. J. Exp. Psychol. Learn. Mem. Cogn. 39 (2), 375–393. https://doi.org/10.1037/a0028888.

Noreen, S., MacLeod, M.D., 2014. To think or not to think, that is the question: individual differences in suppression and rebound effects in autobiographical memory. Acta Psychol. 145, 84–97. https://doi.org/10.1016/j.actpsy.2013.10.011.

Pacheco, L.B., Figueira, J.S., Pereira, M.G., Oliveira, L., David, I.A., 2019. Controlling unpleasant thoughts: adjustments of cognitive control based on previous-trial load in a working memory task. Front. Hum. Neurosci. 13, 469. https://doi.org/10.3389/fnhum.2019.00469.

Snyder, H.R., Miyake, A., Hankin, B.L., 2015. Advancing understanding of executive function impairments and psychopathology: bridging the gap between clinical and cognitive approaches. Front. Psychol. 6, 328. https://doi.org/10.3389/fpsyg.2015.00328.

Stramaccia, D.F., Meyer, A.K., Rischer, K.M., Fawcett, J.M., Benoit, R.G., 2020. Memory suppression and its deficiency in psychological disorders: a focused meta-analysis. J. Exp. Psychol. Gen. https://doi.org/10.1037/xge0000971.

Streb, M., Mecklinger, A., Anderson, M.C., Johanna, L.H., Michael, T., 2016. Memory control ability modulates intrusive memories after analogue trauma. J. Affect. Disord. 192, 134–142. https://doi.org/10.1016/j.jad.2015.12.032.

Tumen, C., Ikier, S., 2021. Exhaustion of the executive control capacity eliminates retrieval induced forgetting. Psychol. Rep. https://doi.org/10.1177/00332941211018776, 332941211018776.

Waldhauser, G.T., Lindgren, M., Johansson, M., 2012. Intentional suppression can lead to a reduction of memory strength: behavioral and electrophysiological findings. Front. Psychol. 3, 401. https://doi.org/10.3389/fpsyg.2012.00401.

Wang, Y., Luppi, A., Fawcett, J., Anderson, M.C., 2019. Reconsidering unconscious persistence: suppressing unwanted memories reduces their indirect expression in later thoughts. Cognition 187, 78–94. https://doi.org/10.1016/j.cognition.2019.02.016.

Waskom, M.L., Frank, M.C., Wagner, A.D., 2017. Adaptive engagement of cognitive control in context-dependent decision making. Cerebr. Cortex 27 (2), 1270–1284. https://doi.org/10.1093/cercor/bhv333.

Watkins, E.R., 2008. Constructive and unconstructive repetitive thought. Psychol. Bull. 134 (2), 163–206. https://doi.org/10.1037/0033-2909.134.2.163.

Wu, T., Dufford, A.J., Mackie, M.A., Egan, L.J., Fan, J., 2016. The capacity of cognitive control estimated from a perceptual decision making task. Sci. Rep. 6, 34025. https://doi.org/10.1038/srep34025.

Wu, T., Wang, X., Wu, Q., Spagna, A., Yang, J., Yuan, C., Wu, Y., Gao, Z., Hof, P.R., Fan, J., 2019. Anterior insular cortex is a bottleneck of cognitive control. Neuroimage 195, 490–504. https://doi.org/10.1016/j.neuroimage.2019.02.042.

Zabelina, D.L., Ganis, G., 2018. Creativity and cognitive control: behavioral and ERP evidence that divergent thinking, but not real-life creative achievement, relates to better cognitive control. Neuropsychologia 118 (Pt A), 20–28. https://doi.org/10.1016/j.neuropsychologia.2018.02.014.

Zetsche, U., D'Avanzato, C., Joormann, J., 2012. Depression and rumination: relation to components of inhibition. Cognit. Emot. 26 (4), 758–767. https://doi.org/10.1080/02699931.2011.613919.

Zhu, Z., Wang, Y., Cao, Z., Chen, B., Cai, H., Wu, Y., Rao, Y., 2016. Cue-independent memory impairment by reactivation-coupled interference in human declarative memory. Cognition 155, 125–134. https://doi.org/10.1016/j.cognition.2016.06.015.