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The Effect of an Executive Functioning Training Program on Working Memory Capacity and Intrusive Thoughts

Jessica Bomyea and
Department of Psychiatry, University of California, San Diego Joint Doctoral Program in Clinical Psychology, 8939 Villa Jolla Dr. Suite 200, San Diego, CA 92037, USA

Nader Amir
Department of Psychology, San Diego State University, San Diego, CA 92120, USA

Nader Amir: namir@sciences.sdsu.edu

Abstract

Recurrent intrusive thoughts are apparent across numerous clinical disorders, including depression (i.e., rumination) and anxiety disorders (e.g., worry, obsessions; Brewin et al. 2010). Theoretical accounts of intrusive thoughts suggest that individual differences in executive functioning, specifically poor inhibitory control, may account for the persistence of these thoughts in some individuals (e.g., Anderson and Levy 2009). The present study examined the causal effect of inhibitory control on intrusive thoughts by experimentally manipulating inhibition requirements in a working memory capacity (WMC) task and evaluating the effect of this training on intrusive thoughts during a thought suppression task. Unselected undergraduate participants were randomly assigned to repeatedly practice a task requiring either high inhibitory control (training condition) or low inhibitory control (control condition). Results indicated that individuals in the training condition demonstrated significantly greater WMC performance improvements from pre to post assessment relative to the control group. Moreover, individuals in the training group experienced fewer intrusions during a thought suppression task. These results provide support for theoretical accounts positing a relationship between inhibitory control and intrusive thoughts. Moreover, improving inhibitory control through computerized training programs may have clinical utility in disorders characterized by recurrent intrusive thoughts (e.g., depression, PTSD).

Keywords

Executive functioning; Working memory; Intrusions; Training; Thought suppression

Intrusions are defined as thoughts, memories or images that come to mind repeatedly, spontaneously and involuntarily, without the individual's deliberate intent (Trinder and Salkovskis 1994). Most individuals experience this type of cognition occasionally (Bywaters et al. 2004). However, individuals diagnosed with anxiety and depression are characterized by persistent, distressing intrusive thoughts that are perceived as difficult to eliminate in spite of deliberate control attempts (Brewin et al. 2010). Thus, a hallmark of these disorders is the presence of recurrent cognitions that are difficult to suppress or inhibit.

Recent theoretical accounts of intrusions posit that the persistence of these thoughts in clinical disorders stems from deficits in basic cognitive systems that regulate the inhibition

Correspondence to: Nader Amir, namir@sciences.sdsu.edunamir@mail.sdsu.edu.

of information (e.g., Anderson and Levy 2009; Joormann et al. 2010; Verwoerd et al. 2008). Specifically, these cognitive theories suggest that individual differences in executive functioning processes may lead to differential ability to regulate and control cognitions. Although components of executive functioning have taken a variety of names based on different cognitive models (e.g., attention control, central executive, cognitive control; see Wessel et al. 2008), for the sake of simplicity we will refer to domain-general cognitive abilities as *executive functions*, and use *inhibitory control* to refer to the specific sub-function designed to inhibit irrelevant information. Thus, from this perspective, individuals with poor inhibitory control are predicted to be less able to regulate the occurrence of unwanted thoughts.

Empirical data support these theoretical models. A number of disorders characterized by recurrent intrusive cognitions also demonstrate inhibitory control deficits (e.g., depression, Gohier et al. 2009; PTSD, Falconer et al. 2008). Moreover, performance on tasks requiring inhibitory control is associated with frequency of intrusive thoughts (e.g. Verwoerd et al. 2008; Wessel et al. 2008). Few studies have evaluated the role of specific types of inhibitory processes in the context of intrusive thoughts. However, inhibitory control specifically over *proactive interference* (i.e., difficulty remembering recently learned stimuli when they are similar to other, previously learned stimuli) appears to be associated with intrusive thoughts (Verwoerd et al. 2009; Verwoerd et al. in press).

One type of cognitive assessment thought to tap control over proactive interference is working memory capacity (WMC) tasks. Working memory provides temporary mental storage to hold and manipulate information during learning, reasoning, and comprehension tasks and thus determines what information is available for conscious use at a given time (e.g., Conway et al. 2005). WMC reflects one's control over the contents of this capacity-limited storage, or the ability to utilize executive functioning resources to keep relevant information active while inhibiting irrelevant information or behavioral actions (Miyake et al. 2000). Performance on WMC tasks depends partially on one's ability to control proactive interference that builds as trials progress (Bunting 2006; Friedman and Miyake 2004; Lustig et al. 2001). That is, one must inhibit previously learned, irrelevant information (stimuli from prior trials) to prevent these contents from interfering with accurate recall of more recent information (stimuli from current trials).

A number of studies document a relationship between performance on WMC tasks and inhibitory control. For example, individuals with higher WMC experience less proactive interference from previously learned information during cognitive tasks (e.g., Rosen and Engle 1998). Moreover, individuals with greater WMC are better able to deliberately suppress neutral (Brewin and Beaton 2002) and negative, personally relevant thoughts during thought suppression tasks (Brewin and Smart 2005). However, extant literature is limited by correlational study designs and cannot speak to causal relationships between WMC and intrusive thoughts. If performance on WMC tasks is related to inhibitory control over cognitions, then improving this cognitive ability should lead to decreased frequency of intrusive thoughts. Although research has shown that performance on executive functioning tasks can be improved over time using training programs (e.g., Olesen et al. 2004) and that proactive interference control specifically may be malleable (Persson and Reuter-Lorenz 2008), to date no published study has evaluated the effect of manipulating proactive interference control demands of WMC on intrusive thoughts.

The purpose of the present study was to evaluate a single-session program designed to train inhibitory control using a modified WMC task with varying levels of proactive interference. Consistent with the interference control training program outlined by Persson and Reuter-Lorenz (2008), participants completed one of two WMC tasks with the same working

memory storage requirements but differing levels of required proactive interference control. We hypothesized that individuals who completed the high interference control (HIC) condition would demonstrate an increase in WMC performance from baseline to post-training, relative to the individuals completing the low interference control (LIC) condition. Given that proactive interference control is theorized to play a primary role in controlling intrusive cognitions (e.g., Friedman and Miyake 2004; Verwoerd et al. 2008) we also hypothesized that the HIC would lead to relatively improved ability to suppress unwanted cognitions during an idiographic thought suppression task (Wegner et al. 1987).

Method

Participants

Participants were 50 undergraduate students recruited from the San Diego State University subject pool (See Table 1). Racial makeup of the sample was: 52% Caucasian, 10% Asian, 20% Hispanic/Latino, 2% Black, and 16% other. Two participants who indicated that they were more comfortable speaking, reading or writing in a language other than English were excluded from data analysis. Participants were randomized to the HIC (n = 25) or LIC (n = 23) conditions.

Assessments and Measures

Given that anxiety and depression may influence both cognitive performance and suppression ability (e.g., Brewin and Smart 2005) we assessed these variables at baseline and during the manipulation and thought suppression tasks. The State Trait Anxiety Inventory (STAI; Spielberger et al. 1983) was used to measure trait and state anxiety. Depression was assessed using the Beck Depression Inventory – II (BDI-II; Beck et al. 1996). Because we asked participants to describe a negative personal memory when selecting the thought suppression target (see Procedure for details), we also assessed trauma history and PTSD symptoms (i.e., in the event that individuals with trauma histories or PTSD symptoms wrote about more negative experiences, or had differential ability to suppress thoughts about such memories). PTSD symptoms were assessed using the Posttraumatic Diagnostic Scale (PDS; Foa et al. 1997). These measures possess adequate psychometric properties (Beck et al. 1996; Foa et al. 1997, Spielberger et al. 1983). To assess participants' pre-existing tendency to experience intrusive thoughts, we administered the White Bear Suppression Inventory (WBSI; Wegner and Zanakos 1994). The WBSI comprises 15 items designed to measure individuals' frequency of intrusive thoughts (i.e., suppression failures), as well as trait-like tendency to attempt to suppress these thoughts. This measure has adequate psychometric properties (Wegner and Zanakos 1994). Participants also completed a brief demographic questionnaire.

Working Memory Capacity Assessment—WMC was assessed before and after the training program using a computerized Operation Span assessment (Ospan; Unsworth et al. 2005). Each trial began with a fixation cross in the center of the screen for 500 ms. Then, a letter was presented on the screen for 500 ms, followed by a completed math problem (e.g., 1 + 3 = 6). Participants indicated accuracy by selecting a corresponding mouse button. During the task, the participant's math accuracy was displayed in the lower left-hand corner of the screen. Participants were tested on working memory span sizes varying from two to six memoranda (Engle et al. 1999). At the end of each set participants saw a recall screen listing twelve letters. Using the mouse, participants selected the letters they had seen in serial order of presentation. Sets and trials were presented in a different random order for each participant.

Training Program

To manipulate proactive interference, participants completed one of two modified Reading Span tasks (Rspan; Lustig et al. 2001). Similar to the Ospan, Rspan tasks require participants to simultaneously remember items while concurrently performing a secondary task. However unlike Ospan, Rspan involved reading a sentence and verifying its semantic accuracy (e.g., "Jane walked her car in the park," correct answer: no) instead of verifying math accuracy. Participants completed three blocks of training in a single session. Within each block, participants were trained on span sizes of two to six, with three repetitions of each span size presented in random order (45 trials lasting approximately 30 min).

HIC Condition—The HIC condition was designed to contain high proactive interference across trials. To this end, memoranda for all trials in the HIC were words (Bunting 2006). Words were one-syllable, high frequency words (e.g., arm, blue, sea). Thus, in order to perform well on the task participants were required to use proactive interference control to distinguish their memories of words from prior trials from those on each current trial.

LIC Condition—The LIC condition was designed to contain relatively greater release from proactive interference. Consistent with prior research indicating that changing the type of memoranda decreases the amount of proactive interference in WMC tasks, memoranda for trials in the LIC alternated between words and numbers (digits one through 12) every three trials (Bunting 2006). Thus, although participants were required to remember the *same* total number of items as in the HIC (i.e., storage requirements were equivalent), there was relatively less proactive interference inherent in the task.

Filler Task—Prior research indicates that participants may experience fatigue when completing multiple within-session cognitive tasks (e.g., Persson et al. 2007). To minimize effects of fatigue, participants were given a brief break between the training program and the post-WMC assessment and before the thought suppression task. During these times, participants watched neutral film clips used in prior studies of emotion (Gross and Levenson 1995) that depicted a series of nature scenes. Participants were informed that the purpose of the video was to provide a break between different portions of the study.

Thought Monitoring Task—In order to assess thought regulation ability, participants completed a thought suppression task (Wegner et al. 1987). They were asked to select a negative personal memory as the target thought, and to indicate with a hand-held event marker each time they experienced the target thought (see Procedure for details).

Memory Questionnaire—Participants completed a questionnaire consisting of 10-point single-item ratings assessing the emotional valence of the memory and their emotional reactions on several dimensions (unpleasant, distressing, disgusting, angry, sad).

Procedure

Participants first read and signed the study informed consent and completed the baseline self report questionnaires. Participants then completed the working memory assessment, the training program, neutral film, and the post-WMC assessment. Participants watched the second neutral video immediately after the post-WMC assessment. Next, participants completed the thought suppression task (derived from Markowitz and Borton 2002; Rosenthal and Follette 2007). Participants were first given a definition of intrusive thoughts (Salkovskis and Campbell 1994). They were then instructed to identify a negative personal experience that had led them to experience intrusive thoughts. Participants were given a blank piece of paper, and were asked to write about their memory of the experience for 3 min. Participants were informed that the content of this narrative would be confidential, and

that no one would see this content until the conclusion of the study. When 3 min had elapsed, the experimenter gave participants an envelope marked "Confidential" to put the paper in. Participants then completed a STAI-S and the memory questionnaire.

Next, participants completed the 15 min thought suppression task (Wegner et al. 1987; all instructions adapted from Najmi et al. 2009). During this task, participants were asked to indicate the number of intrusive thoughts they experienced using a hand-held event marker. For the first and third five minute period, participants were told they could think about anything they wished. For the second five minute period, participants were asked to suppress thoughts about the memory. After the final period, participants were debriefed.

Results

Baseline Characteristics

Participants who failed to maintain the 85% math accuracy criterion on the WMC tasks were removed from data analyses (Conway et al. 2005). This resulted in the removal of four participants in the HIC condition, and four in the LIC condition. Remaining individuals in the two groups did not differ on demographic (*ps* > .30) or clinical characteristics (*ps* > .16; See Table 1).

Ratings of Narrative and Post-Narrative Anxiety

Independent sample *t* tests indicated that groups did not differ significantly in their ratings of the narrative's emotionality, *t* (38) = 1.24, *P* = .22 (HIC: M = 5.22 SD = 2.0; LIC: M = 5.94 SD = 1.67) or post-narrative anxiety, *t*(38) = 1.08, *P* = .29 (see Table 1).

Ospan Performance

We submitted Ospan item recall to a 2 (Group: HIC, LIC) ×2 (Time: Pre-training, Post-training) analysis of variance (ANOVA) with repeated measurement on the second factor. The main effect of Group was not significant, $F(1, 38) = .07$, $P = .80$. There was a significant main effect of Time, $F(1, 38) = 20.40$, $P < .001$, $\eta_p^2 = .35$, that was modified by a significant interaction of Group X Time, $F(1, 38) = 5.69$, $P = .022$, $\eta_p^2 = .13$. Follow-up paired samples *t* tests revealed that individuals in the HIC condition improved in WMC from pre to post assessment, $t(20) = 4.79$, $P < .001$, $d = .53$, while individuals in the LIC group did not, $t(18) = 1.55$, $P = .14$. Table 1 presents the means for WMC performance.

Intrusions

Number of intrusions during each period were submitted to a 2 (Group: HIC, LIC) ×3 (Time: Monitoring, Suppression, Monitoring) ANOVA with repeated measurement on the last factor.1 Results revealed a marginally significant main effect of Group, $F(1, 38) = 3.84$, $P = .058$, $\eta_p^2 = .09$ and a significant effect of Time, $F(2, 76) = 3.84$, $P = .026$, $\eta_p^2 = .10$, that was modified by a significant interaction of Group X Time, $F(2, 76) = 4.10$, $P = .02$, $\eta_p^2 = .10$. Follow-up independent samples *t* tests between the groups revealed that individuals in the HIC and LIC conditions did not experience a significantly different number of intrusions during the initial thought monitoring period, $t(38) = .32$, $P = .75$. However, individuals in

[1]Data for number of intrusions at each time point were positively skewed. Consistent with prior work in this area (e.g., Brewin and Smart 2005), outliers more than 3.3 SDs were adjusted to one value greater than the next highest value, and data were subjected to a square root transformation (Tabachnick & Fidell, 2001). All analyses using the transformed data did not differ. To facilitate interpretability, we report raw data in the body of the manuscript. All statistical tests are reported for unequal variances (Greenhouse-Geisser for ANOVA, equal variances not assumed for *t* tests).

the HIC condition experienced significantly fewer intrusive thoughts during the suppression period, $t(38) = 2.23$, $P = .045$, $d = .51$, and during the post-suppression thought monitoring period, $t(38) = 2.22$, $P = .046$, $d = .51$. Paired sample t tests in each group indicated that participants in the LIC group did not demonstrate a significant change in intrusive thoughts from the baseline to the suppression period, $t(18) = 1.25$, $P = .23$. Individuals in the HIC condition, however, experienced significantly fewer intrusive thoughts during the suppression period relative to the monitoring period, $t(20) = 3.39$, $P = .003$. From the suppression period to the final monitoring period, individuals in the LIC condition demonstrated a marginally significant decrease in intrusive thoughts $t(18) = 2.08$, $P = .053$, while individuals in the HIC group demonstrated a non-significant decrease in intrusive thoughts, $t(20) = 1.51$, $P = .15$. Figure 1 illustrates intrusions by group and time period.

Discussion

The goal of the current study was to examine the malleability of inhibitory control processes using a modified WMC task and to evaluate the effect of this training on the ability to regulate intrusive thoughts. Consistent with hypotheses, results indicated that participants in the HIC condition demonstrated significantly greater improvements on WMC performance relative to those in the LIC condition. The pattern of WMC scores of participants in the LIC condition are consistent with prior studies that administered repeated Ospan tasks to assess test–retest reliability, suggesting that individuals in this condition performed similar to individuals who did not receive any manipulation (Unsworth et al. 2005). Participants in the HIC condition experienced fewer intrusive thoughts during and after suppression than did individuals in the LIC condition and only participants in the HIC condition experienced a significant decrease in intrusive thoughts when instructed to suppress their thoughts.

These findings suggest that modifying participants' control of proactive interference using these WMC tasks resulted in greater ability to inhibit unwanted thoughts during the thought suppression task for those in the HIC relative to the LIC. Results from this study converge with research demonstrating malleability of executive functioning with practice (e.g., Persson and Reuter-Lorenz 2008) and extend this literature by demonstrating that improvements in WMC (rather than absolute levels of WMC) influenced the regulation of intrusive thoughts. Moreover, the present findings support theoretical accounts of a relationship between domain-general executive functioning and the regulation of intrusive cognitions (e.g., Verwoerd et al. 2008).

Clinical disorders, and emotional distress in general, are associated with deficits in specific aspects of executive functioning (e.g., poor attention control in anxiety, Eysenck et al. 2007; difficulty removing negative information from working memory in depression, Joormann and Gotlib 2008). A growing body of evidence indicates that computer based interventions can effectively modify etiologically significant cognitive biases (e.g., attention bias) and decrease anxiety symptoms (for a recent meta-analysis see Hakamata et al. 2010). Given the role of inhibitory control in regulating cognitions, this form of executive functioning might be targeted using similar interventions. We are currently evaluating the effects of a 4-week version of the present cognitive training program in a sample of women with PTSD (see author note). Results from this study will provide further evidence regarding the clinical utility of executive functioning training programs.

Although the present results supported the study hypotheses, a number of limitations deserve consideration. First, replication of these findings is needed in patient populations to evaluate the effect of such training on intrusive thoughts in individuals with psychopathology. Second, the generalizability of the training procedures to other inhibitory control tasks remains unclear. While some executive functioning training studies have found that effects

transfer to novel types of tasks, these findings are scarce (Persson and Reuter-Lorenz 2008). Further research is needed to determine whether and how these effects extend to other types of cognitive tasks that rely on inhibitory control. Additionally, the assessment of intrusions in the present study was limited to a within-laboratory suppression task. We selected this task as to index of cognitive control but cannot speak to the effectiveness or benefit of using suppression as an emotion regulation strategy. It is possible that cognitive control increases the likelihood of *successful* suppression, but that unsuccessful suppression alone or coupled with negative beliefs about the suppression failure creates or perpetuates negative emotion. Although this approach offered experimental control, other approaches such as an intrusion diary might offer a more ecologically valid assessment of the presence of unwanted cognitions, as well as the duration of the effects of the manipulation.

In summary, the present experiment represents the first examination of the effect of WMC training on intrusive thoughts. Results indicate that a WMC training program that contains high levels of proactive interference may improve cognitive performance on WMC tasks. Individuals who underwent this training experienced fewer intrusive thoughts about a negative, personally relevant thought during and after attempting to suppress this memory. Findings support theoretical models of intrusive thoughts as failures of inhibitory control and suggest that variations of these training procedures may have utility in clinical populations.

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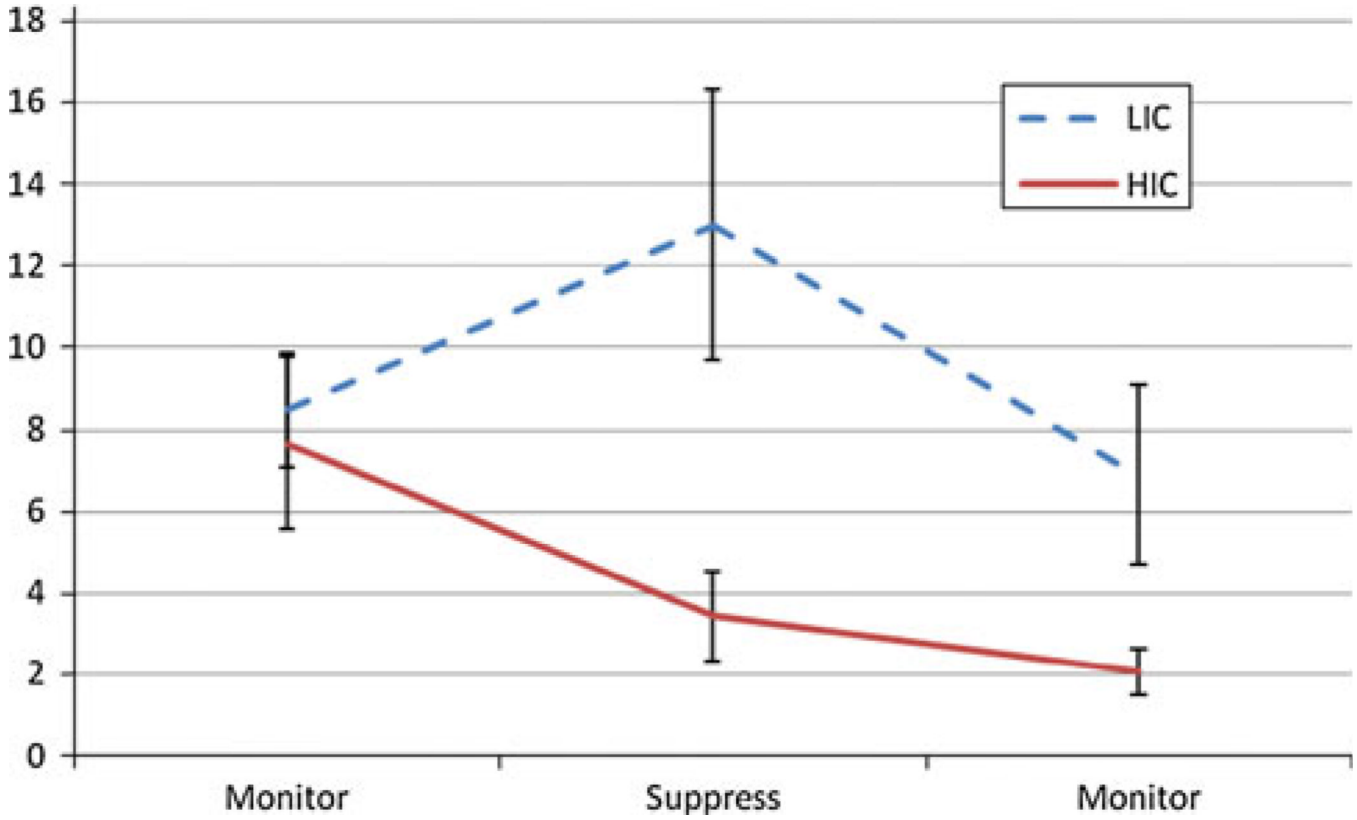

Fig. 1.
Mean number of intrusions at each time point during thought suppression task (bars represent *standard errors*)

Table 1

Demographic and clinical characteristics

	Group	
	LIC (*n* = 19)	**HIC (*n* = 21)**
% Female	58	60
Age	19.0 (1.1)	19.6 (2.4)
Education	13 (1.1)	14 (2.2)
STAI-T	38.8 (12.3)	36.0 (9.3)
STAI-S	37.2 (10.3)	33.1 (7.4)
BDI-II	9.0 (8.9)	7.0 (4.2)
PDS	6.4 (7.8)	3.2 (4.0)
WBSI	49.5 (11.0)	46.2 (8.1)
STAI-S (post-narrative)	42.9 (16.5)	38.1 (11.3)
WMC (pre)	46.7(11.5)	43.1 (14.6)
WMC (post)	49.1 (10.9)	50.8 (10.6)

STAI-T Spielberger State Trait Anxiety Inventory (Trait), *STAI-S* Spielberger State Trait Anxiety Inventory (State), (Spielberger et al. 1983); *BDI-II* Beck Depression Inventory-II, (Beck et al. 1996); *PDS* Posttraumatic Diagnostic Scale (PDS; Foa et al. 1997); *WBSI* White Bear Suppression Inventory (Wegner and Zanakos 1994); WMC (pre) = Operation span scores at pre-assessment; WMC(post) = Operation span scores at post-assessment