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Out of Mind, Out of Sight: Perceptual Consequences of Memory Suppression

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Abstract

In the present study, the effect of memory suppression on subsequent perceptual processing of visual objects was examined within a modified think/no-think paradigm. Suppressing memories of visual objects significantly impaired subsequent perceptual identification of those objects when they were briefly encountered (Experiment 1) and when they were presented in noise (Experiment 2), relative to performance on baseline items for which participants did not undergo suppression training. However, in Experiment 3, when perceptual identification was performed on mirror-reversed images of to-be-suppressed objects, no impairment was observed. These findings, analogous to those showing forgetting of suppressed words in long-term memory, suggest that suppressing memories of visual objects might be mediated by direct inhibition of perceptual representations, which, in turn, impairs later perception of them. This study provides strong support for the role of inhibitory mechanisms in memory control and suggests a tight link between higher-order cognitive operations and perceptual processing.

Keywords

memory, visual perception, cognitive ability, object recognition

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Selection of a weak but goal-relevant behavior over a prepotent habitual response requires cognitive inhibitory control (Knight, Grabowecky, & Scabini, 1995; Logan, 1994). Cognitive mechanisms that control overt actions have also been proposed to control internal actions, such as memory retrieval (Anderson, 2003; Anderson & Levy, 2009). Substantial evidence suggests that the capacity to have selective control over what to retrieve or what to stop retrieving is mediated by inhibitory processes (Anderson & Green, 2001; Anderson & Huddleston, 2011; Anderson et al., 2004; Bergström, de Fockert, & Richardson-Klavehn, 2009; Depue, Curran, & Banich, 2007; Kuhl, Kahn, Dudukovic, & Wagner, 2008).

The voluntary control of memory retrieval has been investigated using the think/no-think paradigm, which requires participants to respectively retrieve or suppress memories. In the original paradigm reported in Anderson and Green (2001), participants initially learned cue-target word pairs. They were then shown the cues repeatedly and trained to either retrieve or suppress the memories of the corresponding targets. A later cued-recall test revealed that participants' memory for suppressed items was impaired relative to their memory for baseline items that they did not see during no-think training. Crucially, this forgetting effect was cue independent in that participants' recall performance was still impaired when they were provided with novel, semantically related cues. This forgetting effect has been interpreted in terms of direct inhibition of memory representations: Avoiding conscious awareness of an item via inhibitory control reduces its activation level in long-term memory, which causes impairment when later recalling the item.

In the present study, we tested whether the forgetting effect resulting from memory suppression extends to the perceptual domain. That memory and perception share common neural substrates has been demonstrated in numerous studies. Memory retrieval of specific perceptual details of an event involves "reinstatement" of perceptual processes related to the initial perception of the event. Across various modalities, it has been reliably found that the brain regions associated with processing an event are reactivated during retrieval in a sensory-specific manner (e.g., Vaidya, Zhao, Desmond, & Gabrieli, 2002; Wheeler, Petersen, & Buckner, 2000). Corresponding evidence in the perceptual domain comes from studies on visual object identification. For objects to be identified, bottom-up information about stimulus characteristics must be compared with stored representations of objects. Identification

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occurs only when a given percept shows sufficient match with a specific internal representation. Indeed, various short- and long-term processes of episodic memory affect object-identification time and naming accuracy (e.g., Bentin & McCarthy, 1994; Stuss, Picton, Cerri, Leech, & Stethem, 1992; Verfaellie, Gabrieli, Vaidya, Croce, & Reminger, 1996).

Following literature suggesting common neural substrates for memory and perception, we investigated whether inhibitory control exerted on memory representations might affect later perception of suppressed items. In three experiments, we used a modified think/no-think paradigm, in which a perceptual-identification task replaced the final cued-recall task of the original paradigm. We hypothesized that if inhibitory mechanisms exert direct control over perceptual representations, then successful suppression of object memories would accompany impaired subsequent identification of the objects.

Experiment 1

In our first experiment, we briefly presented object images to test individuals' ability to perceptually identify memory-suppressed items.

Method

Twenty-five undergraduates with normal or corrected-to-normal vision and normal color perception participated in exchange for course credit. The stimuli were 40 critical and 10 filler pairs of a noun and a line drawing of an unrelated familiar object (Snodgrass & Vanderwart, 1980). The word and drawing in each pair were affectively neutral. Among critical pairs, 10 pairs each were randomly assigned to think and no-think conditions, and the remaining 20 pairs were assigned to the baseline condition. The design of the experiment consisted of a single factor with three levels (baseline, think, or no-think) that was manipulated within participants. Experiment 1 consisted of four phases: pretraining object identification, associative learning, think/no-think training, and posttraining object identification.

Pretraining object identification. To account for excessive individual differences, we first measured participants' ability to identify briefly presented objects. Twenty line drawings of objects different from the critical stimuli were presented individually for 33 ms each in the center of a screen. Presentation was preceded by a 400-ms fixation period and followed by a 100-ms pattern mask of random line segments. Participants were asked to write down the names of each object on an answer sheet. Trials were self-paced.

Associative learning. In the associative-learning phase, the two items in each stimulus pair were presented concurrently for 5 s. Pairs were presented individually, with a 600-ms interstimulus interval between each presentation. Participants were instructed to memorize each association for a later memory test. After the initial learning cycle, participants were asked to recall corresponding target objects when probed with cue words. The learning phase was repeated up to four times until cued-recall accuracy reached 50% at minimum.

Think/no-think training. Each trial of think/no-think training consisted of a 200-ms fixation cross (either green or red) and a 4-s cue word. In the think condition (indicated by a green fixation cross), participants were instructed to think of the target drawing when the cue word appeared. In the no-think condition (indicated by a red fixation cross) participants were instructed not to think of the target drawing when the cue word appeared, thus preventing it from entering their consciousness. Twenty cue words (10 each for the think and no-think conditions) were presented 12 times in random order. Trials were separated by 400-ms intertrial intervals. Cue words assigned to the baseline condition were not presented during the training.

Posttraining object identification. The procedure for posttraining object identification was identical to the procedure for the pretraining phase except that 40 critical target drawings were presented individually either on the left or the right side of a screen. The location and order of presentation were randomly determined.

Results and discussion

Data from 5 participants whose identification performance during pretraining was excessively low (accuracy $\leq$ 10%) were excluded from the main analysis, which left data from 20 participants for the analysis. The percentage of correctly identified objects in posttraining in the three conditions was submitted to a one-way repeated measures analysis of variance (ANOVA).[1] The effect of condition was significant, $F(2, 38) = 3.35$, $MSE = 164.45$, $p = .046$, $\eta_p^2 = .15$ (Fig. 1). Participants identified significantly fewer objects in the no-think condition ($M = 35\%$) than in the baseline condition ($M = 42.8\%$), $t(19) = 2.55$, $p = .02$, $d = 0.85$. In contrast, no significant difference was observed between the percentage of objects identified in the think condition ($M = 45\%$) and in the baseline condition, $p > .5$. These results indicate that suppressing memories of visual objects impairs subsequent identification of those objects when they are briefly presented.

Experiment 2

To generalize the results of Experiment 1, we presented noise-occluded images in the object-identification phase and compared the amounts of information required for correct identification between conditions.

Method

Twenty-six undergraduates with normal or corrected-to-normal vision and normal color perception participated for course credit. In this experiment, we used the same stimuli and

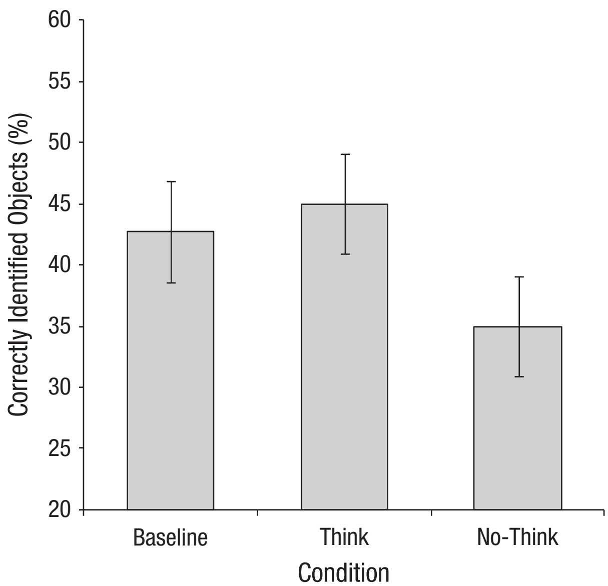

Fig. 1. Results from Experiment 1: mean percentage of correctly identified objects as a function of condition. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

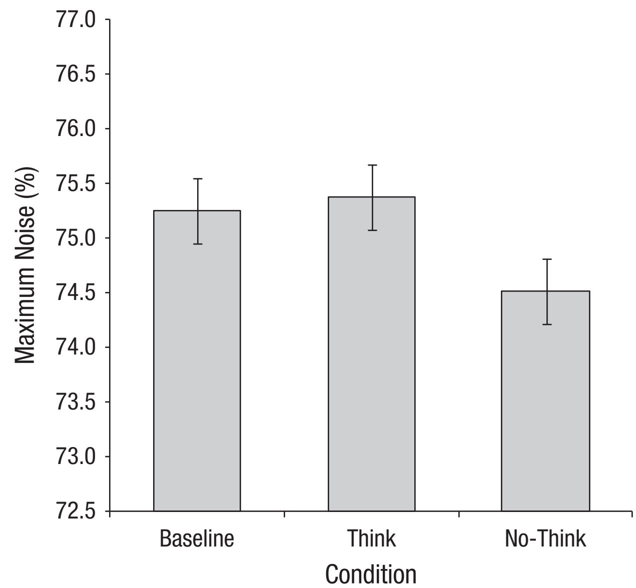

Fig. 2. Results from Experiment 2: mean maximum percentage of noise allowing for objects to be correctly identified as a function of condition. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

design as in Experiment 1 but only three of the phases (associative learning, think/no-think training, and object identification).[2] The first two phases were identical to those in Experiment 1. In the object-identification phase, each target drawing was initially presented with 100% black-and-white pixel noise. Participants were instructed to reduce the noise level by pressing a button until they could identify the object in the drawing. One button press was equivalent to 1% noise reduction. On reaching the point of object identification, participants wrote down the name of the object. Trials were self-paced.

Results and discussion

The mean maximum percentage of noise allowing for correct object identification in each of the three conditions was submitted to a one-way repeated measures ANOVA. This analysis yielded a significant effect of condition, $F(2, 50) = 4.83$, $MSE = 1.16$, $p = .012$, $\eta_p^2 = .16$ (Fig. 2). The maximum noise level was significantly lower in the no-think condition (M = 74.5%) than in the baseline condition (M = 75.3%), $t(25) = 2.31$, $p = .029$, $d = 0.59$. No difference was found between the maximum noise level in the think condition (M = 75.4%) and in the baseline condition, $p > .2$. These results again demonstrate impaired identification of memory-suppressed objects by showing that more perceptual evidence (i.e., noise reduction) is needed for correct identification.

In a separate supplemental experiment with 9 participants, we tested whether the .8% lower maximum noise level in the no-think condition than in the baseline condition was functionally meaningful in object identification. The procedure was identical to the one used in the pretraining phase of Experiment 1, except that 40 critical target drawings, covered with either 75.3% or 74.5% noise, were presented for 400 ms, each followed by a 600-ms mask. Paired-samples t tests revealed that target objects covered with 74.5% noise were significantly better identified than those covered with 75.3% noise (Ms = 42.2% vs. 31.7%, respectively), $t(8) = 2.41$, $p = .042$, $d = 2.52$ (Fig. 3). This result confirms that the 0.8% noise reduction found in Experiment 2 bears significance in improving perceptual-identification performance.

Experiment 3

Impaired object identification resulting from suppression training could be due to inhibition of perceptual representations, inhibition of conceptual representations, or both. In Experiment 3, we examined the relative contribution of these factors on impaired identification by presenting mirror-reversed images of target objects in the object-identification phase. We predicted that if the observed impairment were mainly due to the inhibition of conceptual representations, participants would show a similar amount of identification impairment as in Experiment 2, irrespective of slight changes in perceptual information. However, if the inhibition of perceptual representations was the main factor contributing to the impaired identification, the effects of memory suppression on object identification should disappear in Experiment 3.

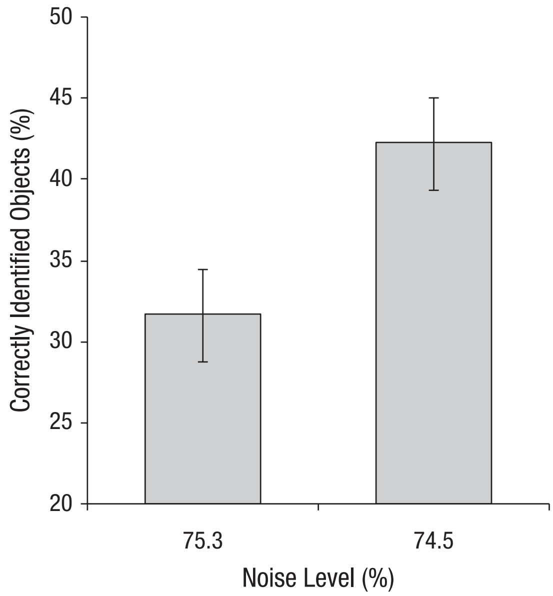

Fig. 3. Results from the supplemental experiment supporting the conclusion of Experiment 2: mean percentage of correctly identified objects as a function of the noise level in which those objects were presented. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

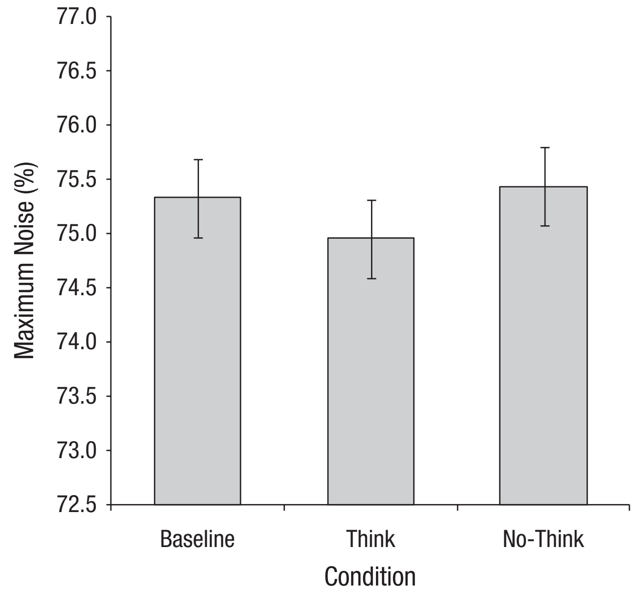

Fig. 4. Results from Experiment 3: mean maximum percentage of noise allowing for objects to be correctly identified as a function of condition. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Method

Twenty-five participants with normal or corrected-to-normal vision and normal color perception were tested in exchange for course credit. The procedure and stimuli were identical to those used in Experiment 2, except that mirror-reversed images of each target drawing were used in the object-identification phase.

Results and discussion

The mean maximum percentage of noise allowing for correct object identification was submitted to a two-way mixed-design ANOVA, with experiment (Experiment 2 vs. Experiment 3) as a between-participants factor and condition (baseline, think, or no-think) as a within-participants factor. This analysis yielded only a significant interaction between the two factors, $F(2, 98) = 4.22$, $MSE = 1.38$, $p = .017$, $\eta_p^2 = .079$.

In a follow-up one-way repeated measures ANOVA separately performed on Experiment 3, the effect of condition was not significant, $F < 1$. Unlike in Experiment 2, the maximum noise levels between the no-think condition ($M = 75.4\%$) and the baseline condition ($M = 75.3\%$) were not significantly different, $p > .7$. We observed no significant difference between maximum noise levels in the think condition ($M = 75\%$) and in the baseline condition, $p > .3$ (Fig. 4). These results suggest that the suppression observed in Experiments 1 and 2 is perceptual rather than conceptual.

General Discussion

The present study provides novel evidence that the effects of inhibition during memory control extend to perceptual processing by demonstrating that suppressing memories of visual objects impairs subsequent perceptual processing of them. Memory suppression resulted in impaired identification of the objects when they were briefly encountered (Experiment 1) and when they were presented in noise (Experiment 2). Crucially, we demonstrated that the memory-suppression effect was directly linked to the inhibition of the perceptual representation. When the perceptual identification was performed on mirror-reversed images of target objects, individuals showed no object-identification impairment (Experiment 3).

The current findings provide strong support for inhibitory control that leads to reduced accessibility of perceptual representations of suppressed memories. However, the exact mechanism underlying the observed memory-suppression effects remains to be elucidated. Recently, using electroencephalogram pattern classification to measure trial-by-trial stimulus-processing fluctuations, Newman and Norman (2010) found that moderate, but not low or high, levels of to-be-ignored stimulus processing were associated with slower subsequent responding to the stimulus (i.e., negative priming; Tipper, 1985). Of critical relevance to our findings, a weakening of the neural representation of a stimulus following a moderate excitation of the representation can result in diminished accessibility of perceptual representation. The effect of memory suppression on subsequent perceptual processing shown here may also vary as a function of the excitation level of a to-be-suppressed representation during the think/no-think training phase. That is, the degree to which to-be-suppressed memories are activated during memory-suppression attempts (i.e., memory intrusions) may be directly linked to the amount of impairment in subsequent perceptual processing of the suppressed items. Future studies can explore whether the perceptual-identification impairment (as well as successful forgetting) would occur only for items that are subjected to suppression but nevertheless are processed at a moderate level during the think/no-think training.

Recently, it was suggested that the typical forgetting effect found in the think/no-think paradigm can be accounted for by a two-stage interference model of cued-recall rather than direct inhibition of memory representations (Tomlinson, Huber, Rieth, & Davelaar, 2009). According to this account, forgetting arises in the recovery stage as a result of interference from the newly learned behavior (e.g., "sitting quietly") associated with the partially activated target-memory representation during the think/no-think training. Given that we provided direct visual cues of the object identity during the object-identification phase, thereby enabling the release of recovery interference, this account, though viable, cannot alone explain the current findings.

It should be noted that we did not find any enhancement in the identification of the objects after 12 repetitions in the think condition. The absence of repetition priming in the current study may be due to our use of a relatively long stimulus-presentation duration (5 s) in the learning phase, which might have resulted in a "suboptimal" priming effect (for discussion of the effect of stimulus-exposure duration on priming effects, see Zago, Fenske, Aminoff, & Bar, 2005). Also, presentation of object drawings up to four times during the learning phase may have diluted the behavioral-facilitation effect in the subsequent perceptual-identification performance. That is, the memory representation of each object in the baseline condition might have been already exhibiting a higher level of activation. Indeed, it has been suggested that priming effects plateau after about four stimulus repetitions (Buckner et al., 1998). However, it is likely that priming effects would have been seen in all three experimental conditions in the current study relative to a nonexposed baseline condition (in which object drawings would not be presented prior to the object-identification phase).

The modulatory effect of higher-order cognitive control on the processing of sensory inputs directly available in the environment has been found in numerous behavioral and neuroimaging studies (Chun, Golomb, & Turk-Browne, 2011; Desimone & Duncan, 1995). Yet relatively scarce evidence exists for the corresponding role of executive function in maintaining or manipulating internal representations and the resulting perceptual consequences (e.g., refreshing; Higgins & Johnson, 2009; Yi, Turk-Browne, Chun, & Johnson, 2008; see Anderson & Spellman, 1995, for a review of the potential interplay between attention, memory, and perception). Overall, by demonstrating a negative consequence of memory suppression in perceptual processing of to-be-suppressed objects, the current study expands the understanding of inhibitory control of memory retrieval and further supports a tight link between higher-order cognitive operations and perceptual processing.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. Presentation location (left or right) was included as a factor in an initial analysis but was removed from subsequent analyses because none of its effects was significant.
2. We expected individual differences to have less influence in Experiments 2 and 3, in which the critical measure was self-adjusted noise levels at the time of object identification, than in Experiment 1, in which identification accuracy was the critical measure. Thus, the pretraining object-identification phase was omitted from Experiments 2 and 3.

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