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BRIEF REPORT

Lost Thoughts: Implicit Semantic Interference Impairs Reflective Access to Currently Active Information

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Why do we lose, or have trouble accessing, an idea that was in the focus of attention only a moment ago, especially in the absence of any apparent distraction? We tested the hypothesis that accessing a single item that is already active is affected by implicit interference (interference of which we have little or no awareness). We presented masked words that were semantically related or unrelated to a single visible target word that participants were cued to think of (*refresh*) a half second after its offset. Masked related but not unrelated words increased time to refresh the target but did not influence time required to read a target that was physically present. These findings provide novel evidence that an item in the focus of attention is subject to semantic interference. We suggest that such implicit semantic interference may contribute to the common "lost thought" experience and to cognitive deficits in populations in which refreshing is impaired.

Keywords: refreshing, focal attention, working memory, implicit interference, semantic relatedness

Cognition sometimes fails us, but we are most surprised when the task is seemingly easy. For example, why would we have trouble reviving an idea that was in the focus of attention only a moment ago? Common examples of such "lost thoughts" include rushing to the kitchen with a sense of purpose, then wondering why you are there, or forgetting an idea in the time it takes to pick up a pencil to record it. One mechanism for bridging short gaps in ongoing cognition is the process of *refreshing* (Johnson, Reeder, Raye, & Mitchell, 2002). Refreshing is a reflective act that keeps a representation briefly in the focus of attention (Cowan, 1999; Oberauer, 2002), analogous to perceptual attention (Chun, Golomb, & Turk-Browne, 2011; Chun & Johnson, 2011; Johnson & Hirst, 1993). A disruption in the process of refreshing could give rise to the "lost thought" experience. Furthermore, difficulty refreshing could have multiple consequences as refreshing is needed in more complex cognition, such as language processing, decision making, problem solving, and memory encoding and retrieval (Johnson & Hirst). Because refreshing may play a key role in a broad range of cognitive tasks, and refreshing is disrupted in populations showing cognitive deficits in more complex tasks (older adults, Johnson et al., 2002; patients with schizophrenia, Grillon et al., 2005; brooders, Bernblum & Mor, 2010), it is important to identify the conditions that produce interference during refreshing.

Surprisingly, theoretical views about the mechanisms of working memory (WM) do not provide a ready account for difficulty accessing a focal thought. Classic early studies of short-term memory found little or no forgetting of single items over as long as 3–4 s (Keppel & Underwood, 1962; Melton, 1963; Peterson & Peterson, 1959). More recently, Cowan and colleagues proposed that the items in WM that are in the focus of attention (limited to 3–4 items) are not subject to decay or interference (Cowan, Johnson, & Saults, 2005; Gilchrist & Cowan, 2011). This view has been challenged by Ralph et al. (2011), who found proactive interference (PI) during immediate recall of set sizes within the presumed limits of the focus of attention (e.g., three words). Notably, PI depended on the presence of phonological, but not semantic, similarity between target items and items from the previous trial, suggesting that the primary codes for items in the focus of attention are phonological. However, *phonological* PI from items recently experienced seems like an insufficiently general mechanism to account for the common phenomenal experience of losing a thought from focal attention.

Recent findings by Higgins and Johnson (2009) indicates there may be semantic competition among items in the focus of attention. Three related or unrelated words were presented on each trial. On critical trials, one item was randomly cued, and participants were instructed to think of (refresh) and say aloud the just-seen item that corresponded to the cue's location. Refreshing one of the remaining, unselected items on the next trial (from the same set of three items) was impaired relative to control trials, and this impairment was greater for related than unrelated sets. This result suggested that semantic interference that was present when the

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first item was refreshed triggered cognitive control, reducing the accessibility of the related distractors (either by inhibiting them, Anderson, Bjork, & Bjork, 1994, or by enhancing the initial target, Higgins & Johnson).

The Higgins and Johnson (2009) findings suggest a potential mechanism underlying lost thoughts. Since activation of semantic associates is ubiquitous (e.g., positive priming effects in perception, Meyer & Schvaneveldt, 1971), perhaps representations that are concurrently active (even if we are not aware of them) produce interference. This would constitute a type of implicit interference from partially active items analogous to the interference among multiple items in an explicit memory set (Melton, 1963). However, a problem with this line of thinking is that Higgins and Johnson did not find an effect of distractor relatedness on time to refresh the initial target. If semantic competition was present, why should it only be detected on the second item refreshed from the set?

One possibility is that in the Higgins and Johnson (2009) study, control processes engaged to counter explicit competition limited interference, the effects of which were only seen later, once inhibition and/or enhancement occurred. This raises the question: If conscious control is not engaged when we are not aware of interference (Ansorge, Fuchs, Khalid, & Kunde, 2011; Kunde, 2003), would interference from concurrently active representations be observed during refreshing? Recent neuroimaging findings showing differences in neural activation depending on whether interference is conscious or unconscious in other contexts (Bunge, Ochsner, Desmond, Glover, & Gabrieli, 2001; Dehaene et al., 2003), suggest that this is a plausible hypothesis.

In the current study, we asked whether related distractors impair reflective access to a single just-seen target item when conscious control processes are not triggered. To avoid triggering conscious control, we visually masked distractors. If refreshing is impaired by masked related distractors, it would support the hypothesis that one mechanism by which refreshing a single, active representation may be disrupted is the implicit activation of competing representations.

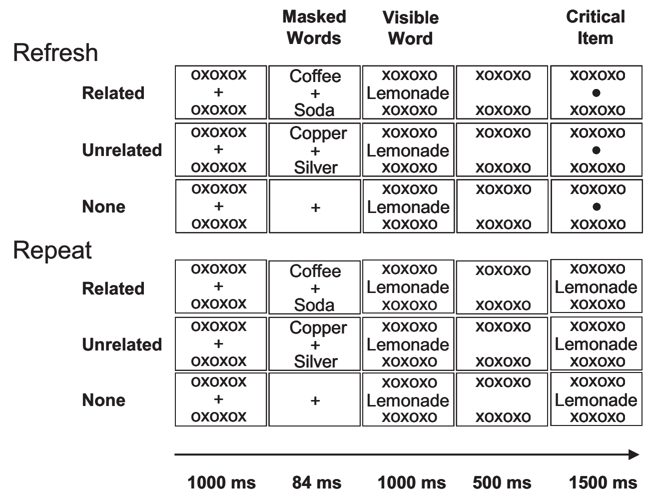

Figure 1. Sample stimuli and timing in refresh and repeat conditions. The masked words were forward and backward masked. Participants read aloud the centrally presented visible word, after which they were cued with a dot to think of and say aloud the just-seen word (refresh condition), or they saw and read aloud the word again (repeat condition). For the none trials, blank spaces were presented in place of the masked words. On read filler trials (not depicted), the target word (*lemonade*) appeared as the critical item, while an unrelated filler word (e.g., *table*) appeared as the visible word. Note: *oxoxox* and *xoxoxo* represent that masks were presented in those locations. Actual masks contained alternating rows of *x*s and *o*s.

Method

Participants

Thirty-six native English-speaking young adults from the Yale community participated for course credit or pay. Participants were randomly assigned to the refresh ($N = 18$; 12 female) or repeat ($N = 18$; 10 female) group. Mean age (refresh = 19.72 years; repeat = 20.56 years) did not differ between groups, $t(34) = 1.22$, $p = .23$. Two additional participants (refresh group) were excluded because they reported on a posttask questionnaire being aware of the masked words. One additional participant (repeat group) was excluded for being insufficiently familiar with English.

Materials and Procedure

Word stimuli were category exemplars from 96 distinct semantic categories (Battig & Montague, 1969; Shapiro & Palermo, 1970). Three exemplars of each category were chosen (one each of high, low, and medium prototypicality). Two exemplars were designated as the masked words and one as the target item. A fourth exemplar, of similar prototypicality as the target, served as a filler item on read trials. Targets were rotated across trial type across participants to equate words for which critical response times (RTs) were recorded. Prototypicality, word length, and average frequency (Kucera & Francis, 1967) were balanced across trial type. Stimuli were centered horizontally at the top (6.0° above center), center, and bottom (6.0° below center; see Figure 1) of the screen. Each trial began with forward masks (four alternating rows of *O*s and *X*s) appearing in the top and bottom locations with a black cross in the center. When these masks disappeared, two different words or two rows of blank spaces (none trials) were briefly flashed, one at the top and one at the bottom of the screen. The two words were always semantically related to each other and were either semantically related (e.g., *coffee, soda*) or unrelated (e.g., *copper, silver*) to the target (e.g., *lemonade*). The words or spaces were immediately followed by backward masks at the top and bottom of the screen and a word replaced the center cross. The order of *O*s and *X*s in the backward masks were reversed from the forward masks, which resulted in the masks appearing to flicker briefly, even on the none trials. Participants read aloud the center word, which was then replaced by the target item. On the refresh trials, the target was a dot cuing participants to think of the just-seen center word and say it aloud. On the repeat and read trials, the target was the same word (repeat) or a novel word (read) that participants read aloud. Repeat trials served as control trials, in that (as for refresh trials) participants said aloud the word a second time but did so in response to seeing it again (i.e., perceptual processing of the critical item) as opposed to refreshing an item that was no longer present. Read trials served as filler trials so that on half the trials, the target was a novel word reducing the likelihood that participants would attempt to prepare responses in advance and, as such, were not analyzed. The refresh group received 48 refresh and 48 read trials; the repeat group received 48 repeat and 48 read trials. Participants spoke into a microphone interfaced with a voice key that measured the time between the presentation of the target and the participant's response.

Awareness Tests

Following the main task, we assessed the extent to which participants were aware of the masked items.[1] This task included 12 refresh/repeat trials (depending on group) and 12 read trials. For refresh/repeat and read trials, 25% were masked related, 25% were masked unrelated, and 50% were none trials. Participants were instructed to perform the task exactly as they had the main task, but they were told that letters would sometimes flash behind the masks and they should press a button if they were able to identify a word. Additionally, participants completed a posttask questionnaire querying their awareness of the masked items during the main task.

Results

Main Task

Errors were rare and were classified as *response* (e.g., stuttering) or *technical* (e.g., microphone failure) errors. Average proportions of response (technical) errors in the none, unrelated, and related conditions were, respectively: refresh =. 00 (.01), .00 (.01), and .01 (.00); repeat = .02 (.01), .01 (.01), and .01 (.00). Error trials were excluded from further analysis.

Mean RTs to say the target in the none, unrelated, and related conditions were, respectively: refresh = 540 ms, 539 ms, and 559 ms; repeat = 482 ms, 490 ms, and 491 ms. To compare the effect of masked words on refresh and repeat trials, we submitted interference scores (i.e., related − none, unrelated − none; see Figure 2) to a mixed-factor analysis of variance with condition (related, unrelated) as a within-subject factor and task (refresh, repeat) as a between-subjects factor. The main effect of task was not significant, $F(1, 34) = 0.01$, mean square error (MSE) = 693.59, $p = .94$, but there was a main effect of condition, $F(1, 34) = 7.53$, $MSE = 250.90$, $p < .05$, $\eta_p^2 = .18$, qualified by a condition × task interaction, $F(1, 34) = 5.96$, $MSE = 250.90$, $p < .05$, $\eta_p^2 = .15$. While the interference scores for related versus unrelated items did not differ for repeat trials, $t(17) = 0.22$, $p = .83$, the interference scores for related items were greater than for unrelated items for refresh trials, $t(17) = 3.63$, $p < .01$, Cohen's $d = 0.86$.

Awareness Tests

On the posttask survey, no participants reported being aware of the masked words during the main task. On the objective awareness test, corrected detection scores (hits – false alarms) did not differ between refresh (.28) and repeat (.25) groups, $t(34) = 0.44$, $p = .66$. Proportion hits on critical trials did not differ by condition in either the refresh group—related = .35; unrelated = .30; $t(17) = 1.00$, $p = .33$—or the repeat group—related = .28; unrelated = .35; $t(17) = 1.09$, $p = .29$. Most participants with detection scores greater than .00 reported that, in trying to detect the words, they attended more to the masks and less to the center stimuli compared with the main task. Data for participants whose detection score was .00 mirrored that of the entire sample. For the refresh group participants with detection scores of .00 ($N = 7$), interference scores were greater for related (14 ms) versus unrelated (−5 ms) trials, $t(6) = 1.84$, $p = .12$, Cohen's $d = 0.70$. For the repeat group participants with detection scores of .00 ($N = 6$), the interference scores for related trials (7 ms) and unrelated (7 ms) trials did not differ, $t(5) = 0.01$, $p = 1.0$.

Results from an unpublished study (Higgins, 2008), containing a refresh group drawn from a similar participant pool and tested with a procedure identical to the one used here, were similar to those reported here. Combining participants with detection scores of .00 from the two studies resulted in a total of 18 participants. Refresh RTs for these 18 nondetecting participants for the none, unrelated, and related conditions were 561 ms, 565 ms, and 578 ms respectively. Related RTs were significantly longer than none RTs, $t(17) = 2.37$, $p < .05$, Cohen's $d = 0.56$, while unrelated RTs were not, $t(17) = 0.58$, $p = .57$. These results suggest that the masking during the main task was largely successful and that it is unlikely that the participants who eventually became more aware during the awareness test (i.e., whose detection scores were greater than .00) accounted for the current results.

Discussion

The current results demonstrate that refreshing a just-seen and readily available item is impaired by interference from concurrently active, semantically related items of which we have little or no subjective experience. Presumably, concepts that are semantically related to those in the focus of our attention are constantly being activated (e.g., Collins & Loftus, 1975), requiring selection from these potential distractors to keep the target item within the focus of attention. As we navigate the world, such implicit interference may induce the subjective experience that a thought we just had in mind suddenly disappears and arises again slowly, if at all.

The present findings argue against the proposal that items within the focus of attention are immune to interference (Cowan et al., 2005). They also challenge the idea that focal items are subject primarily to phonological interference (Ralph et al., 2011). Of course, the conditions under which items within the focus of attention are influenced by interference may differ depending on whether the interference is explicitly or implicitly experienced.

The implicit interference demonstrated here could be considered a type of implicit intraitem interference (analogous to interference among items in a multiitem WM set; Melton, 1963) but could also be considered a type of PI (Underwood, 1957) from semantic relations acquired during prior learning. The important point is that ongoing cognition generates its own distractors, of which we are often unaware, distractors that may be a source of interference for our simplest reflective acts. Such implicit interference has implications for groups (e.g., older adults) who have greater than normal interference in WM due to an inability to filter out distracting information (because they cannot prevent items from entering WM and/or they cannot remove items from WM once they have been identified as irrelevant; Lustig, Hasher, & Zacks, 2007). Such

[1] Our goal was to verify that masking produced low levels of subjective experience of seeing masked items, not to operationalize a conscious versus unconscious dichotomy (e.g., see Merikle & Daneman, 2000).

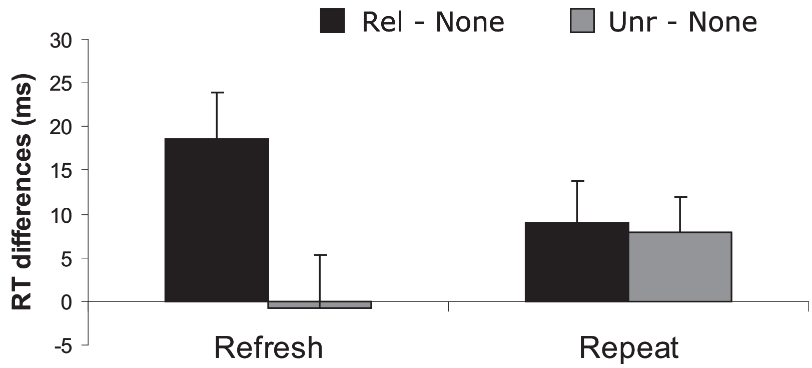

Figure 2. Increase in response times in milliseconds when related and unrelated masked words were present relative to trials in which no masked words were present on critical trials in the refresh and repeat groups. The related–none difference was larger than the unrelated–none difference on refresh, but not repeat, trials. Bars represent standard errors of the difference scores. RT = response time; Rel = related; Unr = unrelated.

distractors may result in a cascade of interference arising, not only from the distractors, but also implicit interference from partially activated items associated with the distractors.

Insofar as refreshing, like rehearsal, is a component process of WM, our findings add to a growing body of research suggesting that WM is vulnerable to implicit interference. For example, in a short-term item recognition study by Bunge et al. (2001), participants were slower to reject a probe if it had appeared in a recent trial. In this case, interfering items were consciously experienced (during the preceding trial), but the PI created was implicit as most participants were unaware that these familiar probes were influencing their performance. In another study, participants were slower to reject lures that were semantically related to the memoranda after a brief (3–4 s) retention interval than those that were not related (Atkins & Reuter-Lorenz, 2008; see also Coane, McBride, Raulerson, & Jordan, 2007). Additionally, during recall, participants were more likely to make semantically related intrusions compared with other types of errors. The authors suggested that these results may reflect familiarity-based PI from semantically related words that were implicitly activated during the task. However, it is important to note that familiar lures or implicitly activated representations may cause intrusions but may not directly impair access to targets. For example, in short-term recall, Tehan (2010) showed that although participants falsely recalled related lures, they still recalled more related than unrelated target words. In contrast, the present study provides direct evidence of a reduction in accessibility of a single target item, arising from interference that was not strong enough to be subjectively experienced. The current results clearly suggest that reduced availability of a target may arise from semantic associates that may inadvertently become partially activated due to their association with a target that is already in the focus of reflective attention.

The effects of masked semantic primes have been shown to be short lived, generally lasting less than 500 ms (Greenwald, Draine, & Abrams, 1996; Mattler, 2005). Here, we observed interference when participants were cued to refresh the target word 1,500 ms after the presentation of the masked words. It seems likely that the currently active target word played a role in maintaining the activation of the masked primes, preventing them from returning to baseline but not increasing them above threshold. Hence, keeping a target within the focus of attention may extend the duration over which masked related primes have an effect.

With respect to underlying mechanism(s), one possibility is that the greater increase in RTs on related than unrelated refresh trials resulted from habituation of the semantic category (Huber, 2008; Huber & O'Reilly, 2003). However, given that semantic habituation is thought to take seconds to emerge (see also Tian & Huber, 2010), it seems unlikely that semantic habituation can account for the current findings, given the brief durations of the masked items used here. More likely possibilities are that (a) masked related items are more strongly activated (due to their relation to the target word) than unrelated items and/or (b) overlap in semantic features between the masked and target items make the target representation difficult to differentiate. The former suggests that any masked items with an activation advantage would have a similar effect (e.g., masked unrelated emotional items vs masked unrelated neutral items). The latter suggests that interference during refreshing depends on reduced discriminability of the target because of feature similarity between targets and distractors.

Our results suggest that refreshing a current thought or idea will be most vulnerable to disruption when implicit interference is particularly strong, as when, for example, refreshing an idea that has many related associates in semantic memory (i.e., rich semantic neighborhoods; Nelson, McKinney, Gee, & Janczura, 1998). Similarly, refreshing would be particularly disrupted in individuals with cognitive impairments that would cause greater implicit semantic interference. For example, implicit semantic interference during refreshing should be magnified if there is greater than normal activation of associates (e.g., as in Alzheimer's disease; Milberg, McGlinchey-Berroth, Duncan, & Higgins, 1999) or with greater activation of distally related items (e.g., as in schizophrenia; Kerns & Berenbaum, 2002). Also, the effect of implicit interference on refreshing should be influenced by context. For example, inducing participants to focus on semantic meaning may magnify the effect of the masked words (as occurs in other tasks, Kiefer & Martens, 2010; Martens, Ansorge, & Kiefer, 2011). Such moment-by-moment fluctuations in interference are likely to have wide-ranging effects on cognition; disruption or dysfunction in resolving implicit interference during refreshing may contribute to cognitive deficits in more complex cognitive tasks.

We speculated that semantic interference as participants refreshed the initial target in the Higgins and Johnson (2009) study was offset by control processes engaged by explicit semantic interference. Consistent with this theory, in the present study, we observed the predicted interference during refreshing from masked related distractors, presumably because the masked distractors did not trigger conscious control processes. Although explicit and implicit interference may arise from the same sources (e.g., semantic relations, similarity, and so on), that they may be resolved by different control mechanisms is suggested by evidence that different brain regions are engaged by conscious compared with unconscious interference in a motor priming task (Dehaene et al., 2003). On the other hand, that the same control mechanisms, once engaged, may operate on both types of interference is suggested by a study by Kunde (2003; see also Ansorge et al., 2011). Using a motor priming task, Kunde found that if explicit conflict was present on a prior trial, interference from a prime on the subsequent trial was reduced, even if the prime was masked. In contrast, if the prime on the prior trial was masked, cognitive control was not engaged (i.e., there was no carry-over effect on the next trial). Whether explicit or implicit interference (or both) can trigger control processes that help resolve both types of interference is an important question. For example, if the threshold for awareness is elevated (e.g., as in schizophrenia, Del Cul, Dehaene, & Leboyer, 2006, and multiple sclerosis, Reuter et al., 2007), cognitive deficits may derive from weaker cues to trigger control processes necessary to resolve both implicit and explicit interference. Thus, whether conscious and unconscious interference arise from the same sources, are resolved by the same or different mechanisms, or interact remain open questions. In any event, given that engaging control in one context may influence availability of control in other contexts (Schmeichel, 2007; but see Healey, Hasher, & Danilova, 2011), and that implicit interference is likely ubiquitous, a control system that is not too easily triggered by implicit interference may conserve some types of cognitive control for situations when it may be more needed (explicit interference). Lost thoughts may be an unfortunate, but unavoidable, side effect of a reasonably efficient balance between mechanisms for resolving implicit and explicit interference.

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