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Inhibition and interference in the think/no-think task

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Abstract Five experiments using the think/no-think (TNT) procedure investigated the effect of the *no-think* and *substitute* instructions on cued recall. In Experiment 1, when unrelated A–B paired associates were studied and cued for recall with A items, recall rates were reliably enhanced in the think condition and reliably impaired below baseline in the no-think condition. In Experiments 2 and 5, final recall was cued with B items, leading to reliably higher recall rates, as compared with baseline, in both the think and no-think conditions. This pattern indicates backward priming of no-think items. In Experiments 3 and 4, the no-think instruction was replaced with a thought substitution instruction, and participants were asked to think of another word instead of the studied one when they saw the no-think cued items. As in Experiments 1 and 2, the same amount of forgetting of B items was observed when A items were the cues, but in contrast to Experiment 2, there was no increase in the recall performance of A items when B items were the cues. These results suggest that not thinking of studied items or, alternatively, thinking of a substitute item to avoid a target item may involve different processes: the former featuring inhibition and the latter interference.

Keywords Inhibition · Episodic · Memory content · Backward facilitation · Priming · Executive control · Interference/inhibition in memory retrieval · Memory · Recall

Remembering is driven, channeled, or controlled by cues that feature in the retrieval process. This has been extensively explored in, arguably, one of its simplest forms, the cued recall of paired associates. A person who learns a list of unrelated A–B terms, such as *bread–hat*, when cued with the A term, *bread* is often able to recall the B term with which it was originally paired—that is, *hat* in this example (for reviews, see Baddeley, 1976; Crowder, 1976; Murdock, 1974; for a contemporary overview, see Kahana, Howard, & Polyn, 2008). Indeed, the principle that retrieval is based on specific cue–target associations—the cue being an item in the retrieval environment and the target a sought-for item in long-term memory—is so fundamental that it is virtually axiomatic to our understanding of retrieval processes (Thomson & Tulving, 1970; Tulving & Osler, 1968). Some recent and intriguing experiments have, however, demonstrated that cues might also be used to *avoid*, rather than access, items in memory with which they are associated (Anderson & Green, 2001; Anderson et al., 2004; Depue, Banich, & Curran, 2006; Depue, Curran, & Banich, 2007; Hanslmayr, Leipold, & Bauml, 2010).

In the think/no-think (TNT) procedure introduced by Anderson and Green (2001), a list of paired associates were first learned to a criterion such that participants could readily recall B terms when presented with A terms. Following acquisition, there then followed a practice phase in which an A term was presented and either its corresponding B term was thought about (the *think* condition) or participants were cued not to think about the previously paired B term (the *no-*

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think condition). These TNT trials were repeated a number of times so that thinking and not thinking about associated B terms were practiced. There was also a subset of baseline control items that were neither thought about nor not thought about. The important finding in the subsequent cued recall test, in which A terms acted as cues to B terms, was that recall of B terms that had been thought about was high, recall of baseline items was intermediate, and recall of no-think items was reliably lower than baseline, suggesting inhibition of these items and showing how cues might be shaped to either promote remembering or hinder it.

These controversial results prompted a lively debate about the reliability and the possible explanations of TNT. Anderson and colleagues demonstrated a reliable amount of forgetting in the TNT procedure (see Anderson & Green, 2001; Anderson et al., 2004; for a summary of results from 687 participants, see Levy &, Anderson, 2008), while Bulevich, Roediger, Balota, and Butler (2006), Hertel and Calcaterra (2005), Mecklinger, Parra, and Waldhauser (2009), and Bergström, Velmans, de Fockert, and Richardson-Klavehn (2007) were not able to reproduce the TNT effect. There are two alternative explanations for TNT and the memory effects observed in it (when present). According to an inhibitory explanation, favored by Anderson and colleagues, intentionally avoiding and practicing avoiding the recall of a specific target memory (no-think B items in the TNT task) inhibit the representation of the B item and so reduce access to the items in the test phase.

Additional support for this suggestion has come from the attenuation of recall performance for no-think items when cued with a so-called *independent cue*. If, in recall, a no-think B term such as *hat* is cued with *clothing*, a previously unpresented item, memory for the B term is still reliably lower than baseline (Anderson & Green, 2001; see also Bergström, de Fockert, & Richardson-Klavehn, 2009). However, in several studies in which the TNT procedure has been used, only tests where no-think items were tested with the original learning cues have been reported (Hertel & Gerstle, 2003); or, when independent probes have been used, the TNT effect has been absent (Algarabel, Luciano, & Martínez, 2006; Bulevich et al., 2006; Wessel, Wetzels, Jelicic, & Merckelbach, 2005). In our own laboratory, in unpublished studies, we have not been able to obtain the TNT effect using independent probes. One problem with the notion of *independent probes* is the assumption that they were not, in fact, present in the original study and/or practice phases. It is possible that these "independent probes," which are always semantically related to the B terms they cue, were in fact activated when the B terms were processed at study and/or practice and have become part of the resulting memory representation of the list. If so, they might provide an alternative route to the "inhibited" item and so facilitate, rather than inhibit, recall (see Racsmány & Conway, 2006).

A second and alternative explanation of the TNT phenomenon is based on interference theory, which argues that the accessibility of items in memory can be reduced if there are other related or associated items in memory that compete and so interfere with access to and retrieval of a target item. Thus, it may be the case that following the no-think instruction during the practice phase, participants adopt a strategy of thinking of some other item—for example, another word (see Bulevich et al., 2006). Thinking about an alternative will create interference for the cue–target relationship similar to the interference seen in the well-established A–B, A–C procedure. Thus, learning *bread–hat* and then *bread–lamp* reduces the efficiency with which the A terms elicit the target B term. It is this interference that will, not surprisingly, cause attenuated recall performance for target items on the final test, and concepts such as *inhibition* need not then be invoked.

In the present experiments, we investigated both the inhibition and interference accounts of TNT. The inhibition account proposes that the effect of not thinking about selected B items in the practice phase leads to the inhibition of those items (Anderson & Green, 2001; Anderson et al., 2004). A strong prediction that follows is that in addition to being poorly recalled to A item cues, inhibited B items should themselves also be relatively ineffective cues to recalling A items. Experiments 2 and 5 tested this prediction. According to the interference account, the effects of thinking about alternative items (C items) to no-think B cues in the practice phase should lead to the poorer recall of B items in the test phase. In other words, the effects of not thinking or thinking about another item should produce identical effects in later recall. In Experiments 3 and 4, we tested this prediction too.

Experiment 1

The aim of this experiment was to replicate the original result of Anderson and Green (2001) and produce a reliable decrease in recall performance, relative to baseline, following eight cycles of suppression (not thinking). Pilot work indicated that, at least among our participants, eight cycles of suppression were sufficient to produce a robust no-think effect. We note that the TNT procedure has not always proved effective in attenuating later memory in the no-think condition (Bulevich et al., 2006), and for this reason, we wanted to establish that we could, in fact, obtain the effect.

Method

Participants Data were obtained from 31 native Hungarian speakers. We ran the experiment until we had data from 30 participants who reached the 51% learning criterion in five cycles. (One participant did not reach the criterion and was not used for this reason.)

Procedure and materials Participants first took part in a learning task in which they were asked to learn 40 semantically unrelated word pairs. The stimuli consisted of 80 unrelated Hungarian words with a moderate word frequency, as measured by Szószablya, a Hungarian Web Corpus (Halácsy et al., 2004). The items were randomly paired and then inspected. Any related pairs were re-paired to produce the 40 unrelated paired associates (PAs). The PAs were randomly allocated to four sets of 10 assigned to the think, no-think, baseline, and filler conditions. All items were presented on a computer screen, and order of presentation in each phase of study, practice, and cued recall was random. The PAs were displayed individually in white uppercase letters for 5 s in the center of the screen. In the study phase, participants attempted to learn all the word pairs. Test–feedback cycles followed in which participants recalled the word pairs in a cued recall task. One cycle consisted of 40 cued recall trial cue–target pairs. On each trial, after the cue appeared on the screen, there were 5 s in which to recall the target word aloud. When a response was omitted or when the 5 s had passed, the target word appeared on the screen to the right of the cue word. The next trial followed with a 1-s intertrial interval. After all 40 cues had been presented, another test–feedback cycle followed, until a minimum of 51% of the target words had been correctly recalled.

After the learning phase, participants took part in the TNT practice phase and were given the following instructions: “You are going to see the left-hand side members of the previously presented word pairs in different colors on the computer screen. If you see a word in ‘Green,’ try to recall the other word previously seen together with this word and say it out loud. If you see a word in ‘Red,’ try not to think of the other word previously seen together with this word and do not say it out loud.” Participants first practiced this instruction with the filler words. There were eight cycles of this task. Only think and no-think words were used in this task; that is, 160 trials were performed altogether. Finally, participants took part in a cued recall test in which the cues of think, no-think, and baseline words were presented and participants were asked to recall the targets to each cue word. The procedure of this phase was identical to that of the test–feedback cycles of the initial learning phase. In sum, the task was to recall B items of the word pair cued A items.

Results

The 30 participants who finished the experiment reached the learning criterion in 3.1 cycles (*SD* = 1.15). A one-factor ANOVA showed a main effect of item type, $F(2, 58) = 6.5$, $p < .01$. As can be seen in Table 1, row 1, the recall percentage for the no-think items was lower than that for the baseline items, and this effect was reliable, $F(1, 29) = 6.99$, $p < .01$. This finding shows attenuation and, possibly, inhibition of no-think items. The percentage of recalled baseline items was significantly lower than the percentage of recalled think items $F(1, 29) = 15.59$, $p < .01$, showing the benefits of rehearsal. These results are highly consistent with those of Anderson and Green (2001) and show a robust TNT effect.

Experiment 2

This experiment used the same procedure and analysis as in Experiment 1, with the following single modification: In the final cued recall test, target words (B items) served as cues, and cue words (A items) were to be recalled. Thirty new right-handed native Hungarian speakers with normal or corrected-to-normal vision were recruited for this experiment. The mean age was 22 years (range, 19–26), and there were 20 women and 10 men. In all other respects, the design and analyses were identical to those in Experiment 1. Data were obtained from 30 native Hungarian speakers. All participants reached the 51% learning criterion in 5 cycles ($M = 2.9$, $SD = 1.29$).

The one-factor ANOVA again showed a reliable main effect of item type, $F(2, 58) = 9.2$, $p < .01$). However, as can be seen from Table 1 (second row), the recall percentage of the no-think items was significantly higher than that of the baseline items $F(1, 29) = 5.9$, $p < .05$. The percentage of recalled baseline items was significantly lower than the percentage of recalled think items, $F(1, 29) = 6.99$, $p < .01$. There was no reliable difference between no-think and think items. Thus, B items in the no-think condition can be effective cues to the recall of A items, as effective as A items are to B items in the standard procedure.

Table 1 Mean cued recall from five cued recall experiments using the think/no-think (TNT) task

Standard TNT: Experiments 1 and 2				
Experiment	Cues at Test	Think	No-Think	Baseline
Experiment 1	A cues	.77 (.14)*	.61 (.15)	.70 (.17)
Experiment 2	B cues	.76 (.21)	.74 (.20)	.63 (.17)
TNT With Substitution: Experiments 3 and 4				
		Think	Substitute	Baseline
Experiment 3	A cues	.83 (.11)	.57 (.21)	.70 (.14)
Experiment 4	B cues	.84 (.17)	.66 (.21)	.71 (.14)
Standard TNT: Experiment 5				
		Think	No-Think	Baseline
Experiment 5	B cues	.83 (.13)	.78 (.19)	.70 (.15)

*Standard deviations are shown in parentheses.

In Experiment 1, the association A→ B in previously learned unrelated paired associates was attenuated by not thinking about B, given A, being repeatedly practiced. Later cued recall, using A items as cues, showed recall of B items to be reliably lower in the no-think condition, as compared with recall of baseline and practiced items (Table 1). In contrast, in the practice or think trials, the association A→ B was strengthened, and recall was found to be higher than baseline following the think trials. One explanation of this pattern of recall is that the effect of the no-think trials is to inhibit the previously acquired B items—hence, the lower recall. The effect of the think trials, on the other hand, is to strengthen, by rehearsal, the representation in memory of the A–B pairs and so enhance their later recall (Anderson & Green, 2001). However, in Experiment 2, it was found that when B items were used as cues, recall of A items in the no-think condition was as high as recall of A items in the think condition, and both were reliably higher than baseline. Assuming that the effect of the no-think trials was the same in both experiments, and given that they were identical in other respects, it cannot be the case that B items are themselves inhibited. Indeed, the level of recall of items in the no-think condition suggests that the association of B items to A items is, in fact, primed.

An alternative explanation, and our original hypothesis, is that it is the *relation* between the word pairs that is affected by the no-think trials and, in particular, the unidirectional relationship A→ B (Hertel & Calcaterra, 2005). Thus, when A items are used as cues to memory for no-think items, they are comparatively ineffective (Experiment 1). In sharp contrast, quite the reverse was found when A items, in the no-think condition, were cued by B items in the present experiment. This suggests that the association A← B is primed by the no-think trials but that the relation A→ B is suppressed by them. Thus, paradoxically, an item can be inhibited and primed at the same time, depending on its association with other items.

However, there is an alternative explanation of these findings that derives from interference theory: In the practice phase, when presented with an A cue (e.g., *grass*) in a no-think trial, participants may avoid thinking of the target word *orange* by thinking of a different word (e.g., *kiwi*). To the extent that this occurs, it constitutes a version of the A–B, A–D, interference procedure, and B items, such as *orange*, become less retrievable to A cues, because the A cues are associated with more B items that compete for and, in the process, interfere with retrieval. Thus, an interference account of the low memory performance following the no-think trials in Experiment 1 is a possibility. How an interference account would apply to the enhanced memory levels following the no-think trials and recall cued with B items in Experiment 2 is, however, not clear (see Table 1). Assuming that participants routinely and covertly generate alternative words to B items on no-think trials, then, according to interference theory, these B cues should be less efficient in accessing A items simply because of the A–B, A–D relations present in memory. Because, in Experiment 2, memory levels for B-cued no-think items were significantly above baseline and equivalent to memory levels for think items, it would seem, following the reasoning above, that B items are effective cues of A items *despite* the interfering effects of covertly generating an alternative word on the no-think practice trials. Given the paradoxical nature of these findings, it was decided to explicitly investigate the suggestion that participants achieve not thinking about or not retrieving a cued word by blocking retrieval with an alternative. In the following two experiments, we tested this idea by replacing the no-think instruction with a thought substitution instruction. This simply required participants to think of another word whenever they saw an item that was cued not to be thought of and spoken about. Note that this procedure was also used by Bergström and colleagues in an event-related potential study (Bergström et al., 2009). They found that their participants with the substitution strategy produced cue-dependent but no cue-independent forgetting, in contrast to participants with the standard no-think instruction (Bergström et al., 2009).

Experiment 3

Experiment 3 was identical in all aspects to Experiment 1, with one crucial modification in the instructions given for the think/no-think phase. For words appearing in green, participants were given the same instructions as in Experiment 1. For red words, however, participants were given the following instructions: "When you see a word in red, say out loud the first word that comes to your mind that this red word reminds you of." So, for example, if the A item was *orange*, the word *apple* might be generated. Further instructions emphasized that the word the cue had previously been paired with (the original B item) should not be spoken. Data were obtained from 33 native Hungarian speakers, 30 of whom reached the 51% learning criterion in 5 cycles. Three participants did not reach the criterion and were not used, for this reason. The 30 participants who completed the experiment reached the learning criterion in 2.5 cycles (SD = 1.13). Their mean age was 20 years (range, 19–22), and 6 were females.

The ANOVA was the same as that used previously, with item type the single within-subjects variable consisting of three levels: baseline, think, and substitute. Mauchly's test of sphericity was significant, $\chi^2(2) = 8.78$, $p < .05$; therefore, we used degrees of freedom corrected with Greenhouse–Geisser estimates of sphericity ($\varepsilon = .71$). Item type had a significant effect on recall performance, F(1.57, 45.54) = 25.19, *p* < .001. As can be seen in Table 1, row 3, the average recall percentage for the think items was higher than that for the baseline items, while recall of substitute words was lower than the baseline. Planned contrasts confirmed that recall in the think condition was significantly higher than baseline, *F*(1, 29) = 28.29, *p* < .001, and recall in the substitute condition was significantly lower, *F*(1, 29) = 9.61, *p* = .01. These findings then mirror those of Experiment 1 (see Table 1, rows 1 and 3).

Experiment 4

Experiment 4 was the same as Experiment 2, but with the no-think instruction replaced with the same generate-a-substitute instruction as in Experiment 3. Data were obtained from 32 native Hungarian speakers. Two participants did not reach the learning criterion in 5 cycles and so took no further part. The 30 participants who finished the experiment reached the learning criterion in 2.27 cycles (*SD* = 1.33). Their mean age was 21.4 years (range, 19–26), and 6 were female. A reliable effect of item type was observed, *F*(2, 58) = 17.58, *p* < .001. As can be seen in Table 1, row 4, recall of items in the think condition was higher than baseline, but recall in the substitute condition was not substantially different from baseline. Planned contrasts confirmed that only recall in the think condition differed significantly from baseline, *F*(1, 29) = 24.9, *p* < .001. It can be seen in Table 1 that mean recall in the substitute condition was lower than baseline, but this was not found to be a reliable difference.

Experiment 3 demonstrates that virtually exactly the same effect can be produced by thinking about a substitute item as by not thinking about a target item in memory (see Table 1, rows 1 and 3). In contrast, thinking about a substitute item when the item substituted is subsequently used as a cue does hurt memory (Experiment 4), as compared with simply not thinking about an item that is later used as a cue, where recall is facilitated (Experiment 2). This suggests that different processes might underlie not thinking versus thinking about a substitute. The results of Experiments 3 and 4 only partially replicated the results of Bergström et al. (2009), who found that using substitution, instead of a no-think strategy, produced the same cue-dependent effect, but only the no-think strategy produced cue-independent forgetting. The results of Experiments 3 and 4 support our original hypothesis that not thinking of a specific target, when presented with its cue, harms only this specific cue–item relationship and primes all other relationships of this specific target item; in other words, the no-think effect is not independent of the retrieval cue. This is not the case for the substitution strategy, which probably alters the cue–target relationship by generating interference for this cue, and hence, participants will not access and prime the target items during the TNT phase.

Experiment 5

One problem with the findings above, and it is a problem in all TNT studies, is that the baseline levels of performance frequently shift across experiments. So, for instance, the baseline level of performance in Experiment 2, above, was considerably less than the baseline level of performance in the other experiments. If the baseline in Experiment 2 had been similar to the baseline in the other experiments, our main results may not have been reliable, and there would be no significantly higher recall of no-think items when B items are used as cues, relative to baseline. Why baselines vary from experiment to experiment and across studies, too, is not known, but it seems likely that there may be many factors in play relating to participants, environment, slight variations in procedure, time of day, and other uncontrolled chance influences. It is, therefore, possible that in Experiment 2, we observed reliable above-baseline recall of no-think items simply because of a baseline that was low by chance.[1]

To exclude this possibility, in Experiment 5, we repeated Experiment 2. In this control experiment, all aspects of the procedure, design, and analyses were identical to those in Experiment 2, with one single exception: A new set of word stimuli were used. These were a set of word pairs taken from other TNT studies in our laboratory. These word pairs had consistently produced a TNT across several studies. We decided to use a different material because we wanted to show that the effect we found is reliable over different materials, too, (even if we failed to reproduce a baseline similar to that in our other experiments). Also, in this experiment, we used a questionnaire (a Hungarian version) developed by Bulevich et al. (2006), in order to exclude participants who did not follow the TNT instructions. Data were obtained from 46 native Hungarian speakers. The mean age of participants was 21.6 years (range, 18–30), and 13 were female. One participant did not reach the 51% learning criterion in 5 cycles and was not used. The 45 participants who finished the experiment reached the learning criterion in 1.89 cycles (*SD* = 0.93). More participants were included on the assumption that some would have to be excluded on the basis of their questionnaire responses. On the basis of questionnaire responses, data from 8 participants were excluded. But note that including this excluded data in the analyses did not change the pattern of results. A significant effect of item type was observed, *F*(2, 72) = 17.07, *p* < .001. As can be seen in Table 1, row 5, recall of both think and no-think items was higher than baseline. Planned contrasts confirmed that just as in Experiment 2, these differences were significant [*F*(1, 36) = 43.40, *p* < .001, for the contrast between think and baseline items, and *F*(1, 36) = 7.86, *p* < .01, for the contrast between no-think and

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[1] We thank an anonymous reviewer for pointing this out.

baseline items]. Note that this pattern of findings exactly replicates the findings of Experiment 2 with a higher baseline. Baseline performance notwithstanding, then, the critical effect observed in Experiment 2, of B items priming recall of A items, is robust.

Additional analyses

The experiments above were conducted in relatively simple between-subjects designs, with each successive experiment changing a variable of theoretical interest. We adopted this approach in order to ensure compatibility with the original TNT experiments (Anderson & Green, 2001). One drawback to this approach is that of changing baselines from study to study.[2] However, given that the changes between the experiments were in the experimental variables and all other conditions remained the same—for example, different groups of participants in the different experiments were drawn from the same pool of participants, all of similar ages, educational levels, and socioeconomic backgrounds; the experiments were conducted in the same laboratory at the same time of day by the same experimenters; and stimuli were held constant—it seems reasonable to treat Experiment 1–4 as a single experiment. In this analysis, a mixed design 2 × 3 × 2 ANOVA was employed in which instruction (suppress vs. substitute) formed a between-subjects variable and item type (think, no-think, and baseline) and cue type (A cues and B cues) formed within-subjects variables. A strong and highly reliable (observed power of .919) interaction of instruction with item type was found, $F(2, 232) = 6.85$, $p < .001$, highly consistent with the earlier analyses. Also reliable (observed power .943) was the item type × cue type interaction, $F(2, 232) = 7.57$, $p < .001$, demonstrating across experiments impaired memory for no-think B items when cued with A items after either suppress or substitute instructions, and the reverse when recall of A items were cued with no-think B items after suppress but not after substitute instructions. Exploring these interactions further with planned contrasts of think and no-think items with baseline, we found that the cue type × item type interaction effect was due to the differential effect of the forward versus backward cue manipulation on the no-think items ($p < .001$; power, .936), and not the think items ($p = .38$). Similarly the instruction × item type interaction was due to the differential effect of the suppress versus substitute instruction manipulation on the no-think items ($p < .05$; power, .71), and not the think items ($p = .32$). This overall analysis confirms that despite changing baselines, the pattern of reliable effects is consistent over analyses.

General discussion

Two important findings emerged in these experiments. The first is that recalling two associated items can be simultaneously attenuated or primed depending on how the association is accessed (Experiments 1, 2 and 5). The second is that not thinking about a target item, as compared with thinking about an alternative, can produce the same decrements in cued recall (Experiments 1 and 3) or, sometimes, differences (Experiment 4). These findings are summarized in Fig. 1, and here we consider each in turn and their implications for the nature of the underlying memory representations that mediate them.

Episodic inhibition and the representation of paired associates

According to our account of *episodic inhibition* (Racsmány & Conway, 2006) in TNT and procedures like it, partic-

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[2] Another way in which to obviate the problem of changing baselines over experiments would be to conduct a fully within-subjects design. But such a design requires considerably more items, leading to possible floor effects in some conditions and contamination between conditions at test. As a preliminary pilot study, we ran a within-subjects replication of Experiment 1 and 2—that is, using the suppress instruction only and involving cue type as a within-subjects variable. We ran two groups and tested with blocks of cues. One group had B cues first for half the items, followed by A cues for the other half of items, and the other group had the reverse of this order. The learning and practice phases were the same as in the present experiments. In this experiment, the group tested with A cues first corresponded to that in the standard TNT experiment (Experiment 1 in the present series), and the pattern of findings was as expected: think, .82; no-think, .62; and baseline, .70. For the group that then received B cues to recall A items, the pattern was as follows: think, .85; no-think, .70; and baseline, .65—also in line with the pattern of recall seen in Experiments 2 and 5 above. These differences, although consistent with the earlier patterns of means, did not reach statistical significance. Removing participants on the basis of the Bulevich et al. (2006) questionnaire and 2 participants with outlying scores, a reliable 2 (no-think vs. baseline) ×2 (A vs. B cuing) interaction is present. This interaction is due to a below-baseline performance for no-think B items when cued with A items (the TNT effect) and above-baseline performance for A items when cued with no-think B items—effects consistent with the findings of Experiments 1 and 2/5. Supportive though these findings are, we believe that this within-subjects type of design needs considerable development in order to find a procedure that does not increase individual differences and has the appropriate power.

In the presentation order condition in which participants were first tested with a block of B cues and subsequently with a block of A cues, the means were the following: B cues, think .85, no-think .69, and baseline .56; A cues, think .65, no-think .73, baseline .53. Interestingly, planned contrasts to baseline showed both think and no-think (irrespective of cue) to be reliably higher than baseline, $F(1, 10) = 6.60$ and $F(1, 10) = 7.64$, $p < .05$ in both cases. The pattern for B cues is consistent with Experiments 2/5. The pattern for A cues is, however, anomalous and is not consistent with any of the findings above–in particular, with those of Experiment 1 and the TNT effect. We tentatively suggest that this may reflect some type of carryover from having successfully used B no-think items in the first block of the test to recall A items. What form this might take will require further research. Clearly, a within-subjects and/or mixed approach is of value, and the preliminary findings reported here (full details are available from the first author) are broadly consistent with the findings using between-subjects designs (Experiments 1–5).

ipants first form an episodic memory of the study phase that contains some of the items activated during study, contextual, and possibly other associated information (Conway, 2009; Kahana et al., 2008). During the practice phase, items represented in the episodic memory of the study phase are accessed or access is resisted, and this establishes a pattern of activation/inhibition over the contents of the memory. In other words, the effects of selectively thinking and not thinking about different items alters their activation levels to render them highly accessible or comparatively inaccessible. This pattern of accessibility subsequently determines performance in the cued recall test phase. Items highly activated (think items) are readily accessible and can be recalled to a high level. Items activated but not so strongly can be recalled to a moderate level (baseline items), and items that are inhibited (no-think items) are difficult to access and, as a consequence, are recalled to the lowest levels. Thus, it is the pattern of activation/inhibition over the contents of the episodic memory of the study phase resulting from the effects of the practice phase that determines the various levels of cued recall.

What is clear from Experiment 2/5 is that this account needs modifying because, when no-think B items are used as cues at test, they lead to high levels of recall of associated A items. In fact, they can lead to levels of recall equivalent to recall of the think items, indicating priming of no-think B items (Experiment 2/5; see Fig. 1). It would be paradoxical to propose that an item in memory could be simultaneously inhibited and primed, and we certainly do not propose this. Rather, we consider how the nature of the underlying representations in memory could support such an apparently contradictory finding. In earlier thinking in PA learning, the A–B relation has been viewed as *associatively symmetric* (see Asch & Ebenholtz, 1962). In a recent review, Kahana et al. (2008) concluded that although there is some evidence that the A–B relation may be associatively asymmetric, the evidence overwhelmingly favors the symmetric view. In further support of this, a recent study (Carpenter, Pashler, & Vul, 2006)[3] found that under certain practice conditions, cuing with either term, A or B, enhanced recall of the other. Thus, a model of the representation of PAs may take the form of A←→B. In this model, there is a single bidirectional connection between the representation of the A and B terms in the PA. The present findings suggest, however, that this model, too, requires modification.

The finding that no-think B terms can be inhibited when cued by A terms but facilitate recall of A terms when they themselves are used as cues indicates that the B term's representation in memory cannot be inhibited. This is a finding and conclusion that runs counter to other accounts of inhibition in the TNT task (e.g., Anderson & Green, 2001) that posit inhibition of no-think items. Instead, it might be proposed that what is inhibited is the bidirectional link between A and B, A←///→B, while the representations of the two terms remain at some raised level of activation. But this, too, fails to account for the effectiveness of no-think B items in cuing recall of A items (see Fig. 1). The model that seems to us to account for the findings is one in which the associations A→ B and A← B are *both* independently represented in an episodic memory of the study phase. It may be that the repeated practice in list learning during the initial study phase facilitates the development of a memory representation in which independent unidirectional links exist among representations of PAs in a specific and detailed episodic memory created during the learning trials (see Conway, 2009, for a recent account of specific episodic memories).[4]

Assuming that a memory resulting from the study phase contains A→ B and A← B representation of PAs, the effect of the practice phase might be as follows: The think trials raise the activation levels of all items and their various associations, making them more accessible to retrieval processes and, eventually, leading to high levels of recall. The no-think trials decrease activation of the A→ B association while increasing activation of the items themselves and of their other associations—for example, A← B. This may occur because in order to decrease activation of, or inhibit, the relation A→ B, both items must be accessed, as must other associations between them that are not targeted by no-think strategies for attenuation.[5] If this is the case, recall of B given A will be attenuated, whereas recall of A given B will be facilitated. Essentially, this explanation posits inhibition of the unidirectional association A→ B, while all other representations in association with the memory of the A–B pairs remain activated above the activation levels of baseline items (see Grison, Tipper, & Hewitt, 2005, for a similar explanation of negative priming). Furthermore, this model of *independent associa-*

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[3] We thank Henry Roediger III for drawing this work to our attention and for a number of other important comments and suggestions that helped develop the present article.

[4] Indeed, one interesting manipulation suggested by this would be to have learning trials that alternate between learning B given A and A given B and explicitly foster memory representations in which the two terms are associated by independent unidirectional links that together act as a (virtual) bidirectional link. Selective priming/inhibition following later processing of the list items in memory might be optimized by such a procedure.

[5] Note that this may be conscious on some trials, particularly on the first few no-think trials, and on later trials become nonconscious. Interestingly, a pattern like this is seen in the 'White Bear' procedure (Wegner, 1994), where not thinking about the concept of a white bear for a 5-min period is marked by strong intrusions in the first 2 to 3 min but by virtually no intrusions in the last 2 or so minutes of the 5-min period.

tions, A→ B and A← B, not only explains the effectiveness of "inhibited" no-think B cues in the recall of A items, but also preserves associative asymmetry, since any pair of unidirectional associations can act together as a bidirectional association.

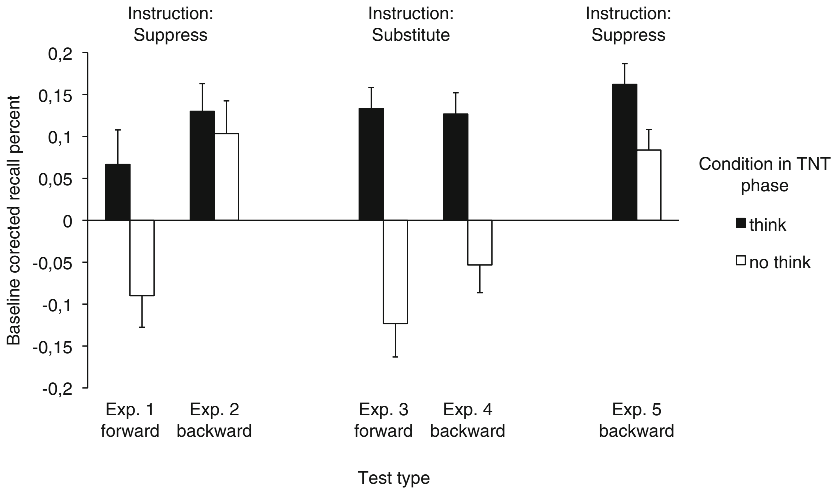
One further feature of the model is that because inhibition is assumed to be directed at associations between representations of A and B terms, it is possible for representations of the terms themselves to remain above some resting level of activation, as can other associations between them not targeted for inhibition. For instance, the PA *bread–lamp* might be represented with independent associations, as described earlier, but also with other, additional (semantic) associations. Consider the case where, quite spontaneously and as part of processing not controlled in the study phase, the B term *lamp* has, in memory, the associations *lamp* → *light* and *lamp* ← *light*. If, at test, the A cue *bread* were now substituted with the cue *light*, a so called *independent cue* (Anderson & Green, 2001), there would be no inhibition and, instead, *light* would cue recall of *lamp*. This would occur, according to the independent associations view, because the representation of *light* in the episodic memory is above a resting level of activation and so are its other associates (to varying degrees). This line of reasoning may explain why it has proved so difficult to produce inhibitory effects with semantically associated "independent cues" (see, e.g., Bulevich et al., 2006).

Inhibition and interference

The two main competing accounts of the TNT effect posit that no-think items are hard to recall because they are inhibited (Anderson & Green, 2001) or because access to them in memory is blocked by substitutes covertly generated during the practice phase (Bulevich et al., 2006; Hertel & Calcaterra, 2005). Experiment 3 in the present series found, definitively, that explicitly generating substitutes can produce a TNT effect that is indistinguishable from that often observed (see Fig. 1). Given that this is the case, it seems reasonable to ask how the two views could ever be distinguished.

One way might be to simply ask participants what they are aware of doing when they encounter a not-to-be-thought-about item. Levy and Anderson (2008) reported some data on this, and we routinely ask our own participants. The predominant reply is that they "just go blank"; importantly, very few participants ever report thinking about other words. Indeed, thinking about substitutes in the practice phase is a difficult task, as participants in Experiments 3 and 4 all reported. Also relevant here are the findings of Experiment 4, in which a substitution strategy did not produce effects that paralleled those of Experiments 2. In Experiment 4, generating substitutes and then being cued to recall A items to (blocked) B cues did not lead to the striking and reliable increase in recall observed in Experiments 2 and 5 (see Table 1). Experiment 4 found that using substitution rather than no-think, B-cued recall of no-think (substituted) items did not reach the level of think items; indeed, it was reliably lower but did not differ from baseline. Perhaps, what is occurring in the substitution task is an attenuation of B items, rather than an inhibitory dysfacilitation/weakening of the representation of the AB associations. In the substitution task, B items become associated in memory with their substitute, and during cued recall, the substitute competes for recall with the B items, causing interference and attenuating access to A items. Interestingly, however, this interference is not sufficiently strong to reliably depress B-cued recall of A items below baseline. On the other hand, the interference was strong enough to reduce A-cued B substitute items below baseline (Experiment 3; see Table 1). Why this is so and why this pattern is so strikingly different from that in

Fig. 1 Baseline corrected recall performances for think and no-think items in 5 experiments using TNT



Experiments 1 and 2 are unclear. One possibility is that when B is the cue, accessing B representations in memory is not as attenuated as when A is the cue. This may be because, when A is the cue, a more complex discrimination must be made during retrieval.

Whatever the case, the patterns of cued recall seen in Experiments 1 and 2/5 are determined by the nature of activation/inhibition over the contents of an episodic memory of the study list, as described earlier, whereas the patterns of cued recall observed in Experiments 3 and 4 are a product of interference in access caused by representations of substitute items and their associations in memory with representations of B items. In other words, the comparatively poor performance observed in the no-think conditions can be caused by either inhibition or interference, with interference somewhat less effective in depressing recall than is inhibition, at least in the present experiments. Furthermore, it may be possible to distinguish inhibition and interference by examining the processing that inhibited versus blocked items can differentially contribute to—that is, in acting as cues to associated items (Experiment 4, as compared with Experiment 2). The positive effects of B items in the recall of A items are not as strong when other items and associations are represented with B items.

In conclusion, the present findings suggest that the locus of inhibition in the TNT task is not the representation of the items themselves in memory but, rather, the associations between them and, in particular, the A→ B association. Using a substitute rather than a no-think task can produce identical effects (Fig. 1), but a substitute task produces different effects from a no-think task when B items are used as cues. Taken together, the latter findings suggest that both inhibition and interference can hurt memory in similar ways but differ in their wider effects.

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