Research Article

Evidence Against Associative Blocking as a Cause of Cue-Independent Retrieval-Induced Forgetting

Justin C. Hulbert,[1,2] Geeta Shivde,[3] and Michael C. Anderson[1]

[1]MRC Cognition and Brain Sciences Unit, Cambridge, UK, [2]University of Cambridge, UK, [3]West Chester University, PA, USA

Abstract. Selectively retrieving an item from long-term memory reduces the accessibility of competing traces, a phenomenon known as *retrieval-induced forgetting* (RIF). RIF exhibits cue independence, or the tendency for forgetting to generalize to novel test cues, suggesting an inhibitory basis for this phenomenon. An alternative view (Camp, Pecher, & Schmidt, 2007; Camp et al., 2009; Perfect et al., 2004) suggests that using novel test cues to measure cue independence actually engenders associative interference when participants covertly supplement retrieval with practiced cues that then associatively block retrieval. Accordingly, the *covert-cueing hypothesis* assumes that the relative strength of the practiced items at final test – and not the inhibition levied on the unpracticed items during retrieval practice – underlies cue-independent forgetting. As such, this perspective predicts that strengthening practiced items by any means, even if not via retrieval practice, should induce forgetting. Contrary to these predictions, however, we present clear evidence that cue-independent forgetting is induced by retrieval practice and not by repeated study exposures. This dissociation occurred despite significant, comparable levels of strengthening of practiced items in each case, and despite the use of Anderson and Spellman's original (1995) independent probe method criticized by covert-cueing theorists as being especially conducive to associative blocking. These results demonstrate that cue-independent RIF is unrelated to the strengthening of practiced items, and thereby fail to support a key prediction of the covert-cueing hypothesis. The results, instead, favor a role of inhibition in resolving retrieval interference.

Keywords: memory, retrieval-induced forgetting, inhibition, cue independence, retrieval specificity, covert cueing, associative blocking, cognitive control

People are often reminded of past experiences with seemingly little effort. Automatic retrieval is considerably less useful, however, whenever one seeks to recall something other than the very first thing that comes to mind given a reminder. In fact, when a cue is linked to many different memories, activation of these alternatives is known to interfere with retrieval of a particular trace (Anderson, 1974; Watkins, 1978). Thus, automatic retrieval often threatens to undermine our goals when selective retrieval of a particular experience is required, demanding an explanation as to how we manage to successfully recall particular memories. According to one perspective, the retrieval of a target memory can be advanced by reducing the activation of competing memories through inhibition, thereby limiting the interference those competitors beget. Once inhibited, it follows that those items should remain less accessible even on later occasions when they are required.

Evidence in favor of the inhibition view comes, in part, from a well-established behavioral aftereffect of selective retrieval: *retrieval-induced forgetting* (hereinafter RIF). RIF refers to the phenomenon whereby selectively retrieving a desired memory impairs access to related memories on a later test (Anderson, Bjork, & Bjork, 1994; see Anderson, 2003; Levy & Anderson, 2002 for reviews), an effect thought to be produced by inhibition. The inhibitory control interpretation of RIF is supported by the tendency for this form of memory impairment to be observable even when measured with novel test cues designed to bypass non-inhibitory sources of forgetting, such as associative interference. Concerns have been raised, however, about whether the novel test cues, termed *independent probes*, truly eliminate associative interference, or might instead prompt participants to covertly generate additional cues that cause interference. Here we test a key prediction of this *covert-cueing hypothesis* to distinguish it from an inhibition view by examining whether cross-category RIF arises from a process specific to the act of recall, a property of RIF known as *retrieval specificity* (Anderson, 2003).

Evidence for Inhibitory Processes in RIF

To investigate the role of inhibitory processes in episodic retrieval, Anderson et al. (1994) developed the

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Table 1. Final recall accuracy for the *Retrieval Practice* (RP) and *Extra Presentation* (EP) groups, by condition, with examples of each in parentheses and standard deviations in brackets. Measures of within-category facilitation and inhibition involved the comparison of *Unrelated P+* or *P−* items to *Unrelated NP-Dissimilar* or *-Similar* items, respectively. Overall cross-category inhibition was computed by comparing the *Unrelated NP-Combined* result to the *Related NP-Combined* score, within each group. The data for the critical interaction between group (RP or EP) and cross-category inhibition are highlighted in gray

	Retrieval practice (RP) condition				
	Practiced category (RED)		Unpracticed category (FOOD)		
Category relatedness	RP+ (BLOOD)	RP− (TOMATO)	NRP-similar (STRAWBERRY)	NRP-dissimilar (CRACKERS)	NRP-combined
Unrelated	65% [23]	22% [25]	35% [28]	42% [26]	38% [19]
Related	65% [27]	25% [22]	24% [26]	37% [29]	30% [21]
	Extra presentations (EP) condition				
	Practiced category (RED)		Unpracticed category (FOOD)		
Category relatedness	EP+ (BLOOD)	EP− (TOMATO)	NEP-similar (STRAWBERRY)	NEP-dissimilar (CRACKERS)	NEP-combined
Unrelated	69% [29]	28% [27]	30% [25]	39% [27]	34% [20]
Related	63% [20]	26% [23]	28% [26]	42% [27]	35% [20]

retrieval-practice paradigm. In this procedure, participants first encode a list of category-exemplar pairs (e.g., FRUITS-BANANA, DRINKS-SCOTCH, and FRUITS-ORANGE). Participants are then prompted to retrieve half of the exemplars from half of the categories a number of times each, given category and word-stem cues (e.g., FRUITS-OR__). Of key interest is the effect this selective retrieval practice has on the retention of the remaining unpracticed members of practiced categories (FRUITS-BANANA) relative to the retention of items from baseline categories that were also studied but for which no members received retrieval practice (DRINKS-SCOTCH). To measure these effects, a category-cued recall test for all studied items is administered following a short delay. As one might expect, participants' recall performance is enhanced for practiced items (hereinafter referred to as *RP+* items, like ORANGE), compared to performance on *NRP* items whose categories received no retrieval practice, such as SCOTCH. More interestingly, unpracticed items from practiced categories (labeled *RP−* items, e.g., BANANA) are recalled more poorly than are the baseline *NRP* items.

Forgetting under these circumstances is consistent with an inhibitory control process that resolves interference during retrieval practice. These basic findings could also be explained by non-inhibitory mechanisms, however. Consider McGeoch's (1942) response competition theory and the later relative-strength/ratio-rule models it has inspired (e.g., Anderson, 1983; Mensink & Raaijmakers, 1988). From such perspectives, strengthening a cue-target association should make it harder to recall other associates of that cue because the stronger associate is recalled persistently, blocking weaker ones. In this way, *associative blocking* (see Anderson & Bjork, 1994 for a discussion) can account for impaired recall of *RP−* items without appealing to inhibition.

Clearly, retrieval strengthens practiced memories; nevertheless, other data suggest that RIF is not directly linked to biasing effects of strengthening. For instance, RIF has been observed in the absence of any significant facilitation effects for practiced items (Gomez-Ariza, Lechuga, Pelegrina, & Bajo, 2005; Veling & van Knippenberg, 2004) and under conditions in which retrieval-based strengthening is rendered impossible (Storm, Bjork, Bjork, & Nestojko, 2006; Storm & Nestojko, 2009). Conversely, strengthening *RP+* items has failed to induce RIF when *RP−* items have weak preexisting associations to the shared cue (Anderson et al., 1994; Bäuml, 1998; Shivde & Anderson, 2001), when participants are induced into a negative mood (Bäuml & Kuhbandner, 2007), are placed under stress (Kössler, Engler, Reiether, & Kissler, 2009) or divided attention (Román, Soriano, Gomez-Ariza, & Bajo, 2009) during retrieval practice, or when procedural manipulations lessen the interference of *RP−* items prior to retrieval practice (Storm, Bjork, & Bjork, 2007). Together, these findings suggest that strengthening practiced items is neither necessary nor sufficient to produce RIF, contrary to predictions of an associative blocking hypothesis.

Failures to identify correlations between behavioral strengthening and forgetting (e.g., Aslan & Bäuml, in press; Staudigl, Hanslmayr, & Bäuml, 2010) have been complemented by recent functional neuroimaging and electrophysiological findings that demonstrate correspondences between the reduction in the neural markers of competition and greater levels of forgetting that are dissociable from the effects of target facilitation (Kuhl, Dudukovic, Kahn, & Wagner, 2007; Spitzer, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2009; Staudigl et al., 2010; Wimber et al., 2008; Wimber, Rutschmann, Greenlee, & Bäuml, 2009). Such evidence suggests that common neural processes do not support the strengthening of practiced items and forgetting of competitors.

A further source of evidence favoring the inhibition view is the observation that RIF occurs even when associative interference processes ought to be ruled out by the testing conditions of the experiment. According to the inhibition view, inhibition reduces the level of activation of the competing item itself, rather than influencing the associative bonds linking it to the original category. In contrast, the associative blocking perspective holds that difficulty recalling *RP−* exemplars arises because the category cue used to perform retrieval practice (FRUIT) reappears during the final test and overwhelmingly elicits the exemplar that had been practiced with that category (ORANGE) during the retrieval practice phase. Thus, if a final test is constructed so that the accessibility of the unpracticed competitor (BANANA) is measured with a novel cue unrelated to practiced items (MONKEY-B__), retrieval should progress unimpeded by the stronger FRUIT-ORANGE association. Inhibition, on the other hand, predicts that RIF should be cue independent and generalize to novel test cues.

The cue-independence property of RIF has been demonstrated numerous times. Anderson and Spellman (1995) found, for example, that when participants performed retrieval practice on some members of a category (e.g., RED-BLOOD), it not only caused *within-category RIF* of other members studied under that category (RED-TOMATO), but also of other red things that happened to be studied and tested under an entirely different category cue (FOOD-STRAWBERRY; hereinafter, first-order inhibition). Moreover, the memory impairment extended to cross-category items that were merely similar to unpracticed competitors without being members of the practiced category (CRACKERS studied under the FOOD category, which is similar to TOMATO studied under the RED category, in that both exemplars are foods; hereinafter, second-order inhibition).

Both types of *cross-category inhibition* (first- and second-order) indicate that RIF is observable even when recall is tested with a different cue from that used during retrieval practice. Likewise, a broad base of empirical studies has identified cue independence under a variety of conditions in both episodic and semantic memory and for materials ranging from homographs to propositions, orthographic representations, phonological information, and taxonomic categories (e.g., Anderson & Bell, 2001; Anderson, Green, & McCulloch, 2000; Aslan, Bäuml, & Grundgeiger, 2007; Camp, Pecher, & Schmidt, 2005; Levy, McVeigh, Marful, & Anderson, 2007; MacLeod & Saunders, 2005; Saunders & MacLeod, 2006; Shivde & Anderson, 2001; see, however, Camp, Pecher, & Schmidt, 2007; Perfect et al., 2004; Williams & Zacks, 2001 for exceptions). More generally, converging evidence for cue independence comes from the observation of RIF on tests involving item-specific cues designed to circumvent associative blocking, including item recognition tests (e.g., Ford, Keating, & Patel, 2004; Gomez-Ariza et al., 2005; Hicks & Starns, 2004; Román et al., 2009; Soriano, Jiménez, Román, & Bajo, 2009; Spitzer & Bäuml, 2007; Starns & Hicks, 2004; Veling & van Knippenberg, 2004; Verde, 2004; but see Koutstaal, Schacter, Johnson, & Galluccio, 1999; and also Butler, Williams, Zacks, & Maki, 2001; Perfect, Moulin, Conway, & Perry, 2002 for potential distinctions), fragment completion (Bajo, Gomez-Ariza, Fernandez, & Marful, 2006), and lexical decision (Veling & van Knippenberg, 2004). Hence, retrieval practice appears to induce forgetting that reflects changes to the state of the item itself, consistent with an inhibitory underpinning.

Although the property of cue independence enjoys broad support, some authors have questioned whether evidence for cue-independent forgetting might reflect blocking rather than inhibition. Of key concern is the extent to which putatively independent test cues intended to circumvent associative blocking are truly independent. For instance, the presumed independence of category cues in Anderson and Spellman's (1995) cross-category inhibition paradigm has been disputed by Perfect et al. (2004) in addition to Camp and colleagues (2007, 2009). They argue that in trying to recall a target item (e.g., FOOD-STRAWBERRY), participants may supplement the explicitly presented category cue (FOOD) with additional cues, like the practiced category (RED). In so doing, they may unintentionally instigate blocking from the strong, practiced items (e.g., RED-BLOOD) even though the overtly provided cue (FOOD) is not related to the practiced item (RED-BLOOD). By this view, when trying to recall FOOD-STRAWBERRY, participants should persistently intrude BLOOD to the exclusion of STRAWBERRY.

In fact, it has been argued that the cross-category inhibition procedure, in which cue independence was first established, is especially ripe for covert cueing. In this procedure, independent probes are studied in relation to multiple exemplars (e.g., FOOD-STRAWBERRY; FOOD-RADISH) that are implicitly related to other cross-category exemplars (RED-TOMATO). Thus, the FOOD category may become associated with RED because they contain similar exemplars. Indeed, when the cross-category semantic probes of Anderson and Spellman (1995) are replaced with item-specific, episodic, independent probes designed to minimize covert cueing, RIF has sometimes been eliminated (Camp et al., 2007; Perfect et al., 2004; but see, however, Anderson & Bell, 2001; Anderson, Green, et al., 2000; Aslan, Bäuml, & Pastotter, 2007; Saunders & MacLeod, 2006; Shivde & Anderson, 2001 for examples of item-specific episodic or semantic independent probes that, nevertheless, reveal cue-independent forgetting). If associative blocking instigated by covert cueing contributes to cue-independent forgetting in the cross-category inhibition procedure (and perhaps more generally), one cannot clearly attribute these findings to inhibition. But if associative blocking causes cross-category inhibition, one would have to predict that strengthening the practiced items by any means – not just retrieval practice – should also give rise to blocking and, in turn RIF. This underlying premise – that strengthening causes blocking – is inconsistent with findings indicating that RIF is specifically induced by competitive retrieval practice, to which we next turn our attention.

Evidence for Inhibition Processes Specific to Retrieval

According to inhibition accounts, the need to isolate a target trace in the face of interference from highly active competitors triggers inhibition. Consequently, competitive retrieval should place disproportionate demands on inhibitory mechanisms and drive the memory deficits observed in RIF.

The most straightforward evidence for this prediction comes from studies that contrast the effects of retrieval practice with those of repeated reexposure to the same stimuli. Here all aspects of the retrieval-practice paradigm are matched across two groups of participants, except for the events during the practice phase. One group performs *Retrieval Practice* trials, as usual (e.g., recalling ORANGE given FRUITS-OR__), whereas the *Extra Presentations* group is instead provided with the intact category-exemplar pair for additional study (FRUITS-ORANGE). Importantly, the inhibition account predicts that, to the extent that reexposure poses very few demands on interference resolution, additional presentations should not induce forgetting. In contrast, non-inhibitory explanations, such as blocking, predict that forgetting should occur regardless of how the practiced items are strengthened.

Studies pitting these predictions against each other have generally found RIF after *Retrieval Practice* but not after *Extra Presentations*, provided that output interference is controlled (Bäuml, 1996, 1997, 2002; Saunders, Fernandes, & Kosnes, 2009). The dependency of RIF on active retrieval generalizes to retrieval of visuospatial information (Ciranni & Shimamura, 1999), homograph meanings (Shivde & Anderson, 2001), propositions (Anderson & Bell, 2001), and arithmetic facts (Campbell & Phenix, 2009), suggesting that it is a general attribute of RIF (see, however, Verde, 2009, for a case in which repeated study exposures appear to induce impairment, with unrelated pairings). This pattern of behavioral findings converges with event-related potential (Johansson, Aslan, Bäuml, Gabel, & Mecklinger, 2007), oscillatory (Staudigl et al., 2010), and functional magnetic resonance imaging (Wimber et al., 2009) indicators that RIF is tied to neural processes other than those involved in simple reexposure and strengthening.

Just as *Extra Presentations* typically circumvent RIF by reducing or eliminating the rivalry between competitors, *Retrieval Practice* should produce inhibitory forgetting only to the extent it involves competition between associates. Indeed, Anderson, Bjork, and Bjork (2000) discovered that asking their participants to recall a category name, given an intact exemplar (FR__-ORANGE), fails to induce forgetting of related but unpracticed FRUITS, despite engaging retrieval. This and other methods of manipulating the degree of competition (e.g., Bajo et al., 2006) have uncovered significant differences in forgetting, despite nearly identical amounts of retrieval-based strengthening on practiced items.

Despite the evidence for the retrieval specificity of within-category RIF, no study has yet examined whether retrieval specificity generalizes to cue-independent forgetting. Generalizing retrieval specificity to cue-independent forgetting is of fundamental import to understanding RIF. Because the inhibition and covert-cueing accounts make starkly different predictions on this matter, we endeavored to replicate cue-independent forgetting and test whether or not the forgetting is retrieval specific using a paradigm that critics have suggested produces RIF largely on the basis of covert cueing.

The Current Study

Prior evidence for retrieval specificity and strength independence is at odds with the covert-cueing account of RIF, inasmuch as this theory presupposes that strengthening underlies RIF, as Camp et al. (2007) acknowledged. Nevertheless, the present study sought to explicitly address the ongoing debate over whether associative blocking underlies cue-independent forgetting. To do so, we adopted the very paradigm that has been identified in discussions of covert cueing as being among the most likely to incite covert cueing: The cross-category paradigm used in Experiment 1 of Anderson and Spellman (1995). As such, we aimed to provide fertile ground for testing whether the covert-cueing hypothesis is tenable as the driving mechanism behind cue-independent RIF.

In the current experiment, half of our participants performed the standard *Retrieval Practice* task. A separate group was given an equal number of opportunities to restudy the intact to-be-practiced pairings. Assuming that *Retrieval Practice* and *Extra Presentations* strengthen the to-be-practiced items to similar degrees, then the associative blocking hypothesis predicts that cross-category RIF should occur for both groups. This prediction follows because there is no reason to suppose these two groups would differ in how often they use covert cueing during the final test and because strong practiced items are present in each case. If, however, cross-category RIF is caused by inhibition, this effect should be specific to the retrieval practice group, wherein competition needs to be resolved, despite the fact that both methods of practice strengthen practiced items.

On our final test, we retained the original, category-cued recall test used by Anderson and Spellman (1995) and similarly opted against the inclusion of item-specific word stems. Notably, word stems previously have been employed expressly to reduce the tendency for subjects to use covert cueing (e.g., Anderson, Green, et al., 2000). Because we wanted to encourage this process, if it occurs, we omitted stem cues, thus helping us to avoid prejudicing our ability to detect forgetting in the *Extra Presentations* condition. Likewise, the recall test remained unpaced to encourage sufficient time to use more elaborate covert-cueing strategies (Anderson, 2003).

Method

The design, stimuli, and procedures used in the present study were adopted, in full, from Experiment 1 of Anderson and Spellman (1995), except where noted.

Participants

Ninety-six undergraduates participated in partial fulfillment of a requirement for an introductory psychology course. Half were randomly assigned to each of the two practice conditions.

Design and Procedure

All participants initially studied six exemplars from each of four categories (two *Related* and two *Unrelated*) on a pseudorandom learning schedule for 5 s each. Several filler categories were also included. In the *Related* condition, each category contained three exemplars that, while studied under only one category, were cross-categorizable under the other heading (e.g., RED-CHERRY; FOOD-STRAWBERRY) and three that were not (e.g., RED-BLOOD; FOOD-CRACKERS). In the *Unrelated* condition, the categories were entirely discrete. The stimulus set included three pairs of *Related* categories (RED and FOOD; FLY and ANIMAL; LOUD and TOOL). To manipulate category relatedness, any given participant studied only one interconnected pair of categories forming the *Related* condition and one category from each of the other related pairs (such as FLY and LOUD), forming the *Unrelated* condition. Inclusion of a given category in the *Related* or *Unrelated* conditions was counterbalanced across participants.

In the phase that directly followed study, participants practiced exemplars from half of the experimental categories and all of the filler categories. Within each critical *Practiced* category, participants practiced three of its six exemplars, three times each (hereinafter referred to as *P*+ items; e.g., RED-BLOOD), with the remaining three items serving as unpracticed competitors (hereinafter, *P*–, e.g., RED-TOMATO). In *Unpracticed* categories, no items were practiced; however, three exemplars (hereinafter, *NP-Similar*; e.g., FOOD-STRAWBERRY) were cross-categorizable with the *Practiced* category and, thus, were similar to the *Practiced* items; the remaining three were dissimilar (hereinafter, *NP-Dissimilar* items, such as FOOD-CRACKERS).[1] See Figure 1 for a schematic of the general design.

Practice Type was manipulated between participants. During the practice phase, participants randomly assigned to the *Retrieval Practice* (RP) group were allowed 7 s to try to remember the exemplar they had studied when given the studied category and two-letter-stem as cues. Specifically, they were to write both words of the pair to the right of the provided cue. The *Extra Presentations* (EP) group was afforded the same length of time to copy both the category and exemplar from the supplied, intact word pair and to use any remaining time to continue studying that pairing. We refer to items studied by the *Retrieval Practice* group as *RP*+, *RP*–, *NRP-Similar*, and *NRP-Dissimilar*, with items studied by the *Extra Presentations* group being designated *EP*+, *EP*–, *NEP-Similar*, and *NEP-Dissimilar*.

After a 16-min distractor phase, during which participants completed an unrelated questionnaire, a test booklet was distributed with a single category name appearing at the top of each page. Participants were asked to write down as many exemplars as they could remember having studied together with that category cue. A beep sounded every 30 s, signaling participants to turn the page.

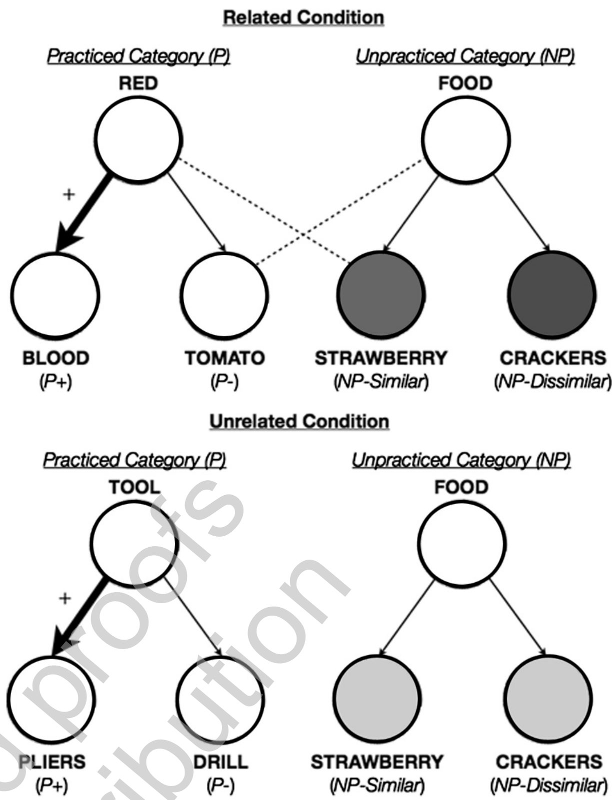

Figure 1. General design of the cross-category retrieval practice procedure, originally developed by Anderson and Spellman (1995). Solid lines indicate studied category-exemplar pairs; heavier lines indicate the subset of those pairs that received practice; thin dashed lines indicate a preexisting, semantic relationship between a particular category cue and an exemplar originally studied under another category. The dark shaded circles (representing *Related* items from nonpracticed categories) are averaged and then compared to the mean of the light gray circles (representing *Unrelated* items from nonpracticed categories) to quantify the overall level of cross-category RIF.

The percentage of critical items correctly recalled on the final category-cued recall test was assessed off-line. Crucially, we employed the measures of within- and cross-category inhibition established by Anderson and Spellman (1995). It is worth highlighting that, in this design, *P*– and *NP-Similar* items were identical across counterbalancing conditions, as are *P*+ and *NP-Dissimilar* items. Thus, for a clean assessment of within-category inhibition, it is necessary to compare *Unrelated P*– items to the *Unrelated NP-Similar* condition, which bypasses the confounding effects of *Relatedness* and intrinsic item differences. Using a similar logic to assess facilitation of practiced items, we contrasted *P*+ with *Unrelated NP-Dissimilar* items, which were not linked

[1] Of course, this between-category similarity only existed in the *Related* condition; in the *Unrelated* condition, the *Practiced* and *Unpracticed* categories were dissimilar. Nevertheless, we retain the names, *NP-Similar* and *NP-Dissimilar* in the *Unrelated* condition, to highlight that these items provide baselines with matching, counterbalanced items against which we compare performance of the corresponding conditions in the *Related* condition.

to any practiced exemplars and involve the same items, across participants.

First-order cross-category inhibition is measured by comparing *NP-Similar* items (STRAWBERRY, for instance) in the *Related* condition to the same set of items (including STRAWBERRY) in the *Unrelated NP-Similar* condition.[2] In order to capture both first- and second-order cross-category inhibition, in the analyses that follow we combined *Related NP-Similar* and *Related NP-Dissimilar* together for each participant and tested that value against their *Unrelated NP* composite score, thereby comparing the same sets of items that differ only in their semantic relatedness to a practiced category.

Analogous comparisons were applied to the *Retrieval Practice* and *Extra Presentations* conditions. To test whether cross-category RIF is specific to retrieval, we analyzed whether the hypothesized difference between *Related NRP-Similar* and *Unrelated NRP-Similar* conditions reliably interacted with practice type (*RP* or *EP*).

Results

Analyses included learning list, retrieval practice, and final test order counterbalancing as between-participants factors in a repeated-measures, mixed analysis of variance (ANOVA). These factors did not interact with any comparisons of interest.

Retrieval practice success rate. No reliable differences in retrieval practice success were found between *Related* categories (M = 76%, SD = 21) and *Unrelated* categories (M = 71%, SD = 22), $F(1, 24) = 2.05$, $MSE = .03$, $p = .165$.

Facilitation of practiced items on the final recall test. Performing *Retrieval Practice* facilitated final recall of practiced items relative to the *Unrelated NRP-Dissimilar* baseline (M = 42%) in both the *Unrelated RF+* (M = 65%), $F(1, 48) = 20.76$, $MSE = .12$, $p < .001$, and in the *Related RP+* conditions, (M = 65%), $F(1, 48) = 26.27$, $MSE = .10$, $p < .001$. *Extra Presentations* also facilitated final recall of practiced items when compared to the *Unrelated NEP-Dissimilar* baseline (M = 39%) in the *Unrelated EP+* (M = 69%), $F(1, 48) = 36.88$, $MSE = .12$, $p < .001$, and *Related EP+* conditions (M = 63%), $F(1, 48) = 26.27$, $MSE = .10$, $p < .001$. We found no evidence that the amount of facilitation (on either the *Related* or the *Unrelated* measure) reliably interacted with *Practice Type* (*RP* or *EP*), p values > .28. With comparable degrees of strengthening across groups, we were well positioned to ascertain whether the type of influences whether cross-category forgetting is observed.

Cue-independent forgetting on the final test. The central question in this experiment concerned whether cross-category RIF varied with the method of practice. We found that *Retrieval Practice* impaired *NRP* items in the *Related* condition (M = 30%) compared to *NRP* items in the *Unrelated* condition (M = 38%), $F(1, 48) = 7.90$, $MSE = .04$, $p = .007$, reflecting a robust 8% cross-category RIF effect that replicates prior work (Anderson & Spellman, 1995). In striking contrast, participants who received *Extra Presentations* showed no evidence of impairment on *Related NEP* items (M = 35%) compared to *Unrelated NEP* items (M = 34%), $F < 1$. This apparent difference in the level of cross-category inhibition between these two groups was supported by a significant interaction of cross-category inhibition by *Practice Type*, $F(1, 48) = 4.34$, $MSE = .02$, $p = .04$, establishing that cross-category inhibition reliably depends on method of practice. Extra study exposures did not induce RIF.

Other findings. Based on the abundance of prior work demonstrating that within-category impairment is retrieval specific, we expected to replicate this widely established result. Indeed, *Retrieval Practice* impaired the recall of *Unrelated RP−* items (M = 22%) compared to their corresponding baseline (*Unrelated NRP-Similar*, M = 35%), demonstrating robust within-category RIF, $F(1, 48) = 7.37$, $MSE = .11$, $p = .009$. *Extra Presentations*, by contrast, did not impair the later recall of *EP−* items (M = 28%) compared to baseline (*Unrelated NEP-Similar*, M = 30%), $F < 1$.[3] The interaction of within-category RIF across these two groups did not reach significance, $F(1, 48) = 2.37$, $MSE = .11$, $p = .13$, potentially because we opted for a category-cued recall test that did not constrain recall order. Though motivated, this decision also allowed for early retrieval of some *EP+* items to induce some level of output interference in the *Extra Presentations* group.

Relation between strengthening and forgetting. In the *Extra Presentations* condition, we observed no correlation between strengthening of *EP+* items and, either within-category RIF ($r = .14$, $p = .34$) or cross-category RIF ($r = .12$, $p = .42$). Similarly, in the *Retrieval-Practice* condition, strengthening of *RP+* items failed to correlate significantly with within-category RIF ($r = .12$, $p = .42$) or with cross-category RIF ($r = .11$, $p = .46$). The failure to observe a relationship between strengthening and RIF is unlikely to be due to a restricted range of strengthening, as facilitation above baseline in the *Extra Presentations* group grew to as high as 67% for 11 subjects, who nevertheless showed no reliable RIF (within- and cross-category RIF effects were 3% and 8% facilitation, respectively). Similarly, even those 13 participants in the *Retrieval-Practice* condition who exhibited the greatest facilitation (67%) relative to baseline

[2] Readers will note that the *Related NP-Dissimilar* condition does not represent a valid baseline for the *Related NP-Similar* items because (1) the conditions are made up of intrinsically different items that can be neither cross-categorized nor counterbalanced with items in the *Related Practiced* category; and (2) retrieval inhibition is known to yield second-order forgetting of *Related NRP-Dissimilar* items (defined in relation to an *Unrelated NRP-Dissimilar* baseline) by way of semantic generalization from the associated *Related NRP-Similar* item (Anderson & Spellman, 1995).

[3] The 5% numerical difference in NRP-Similar baseline recall across groups, likely due to random variation in our samples, was found to be nonsignificant, $t(94) = .89$, $p = .38$.

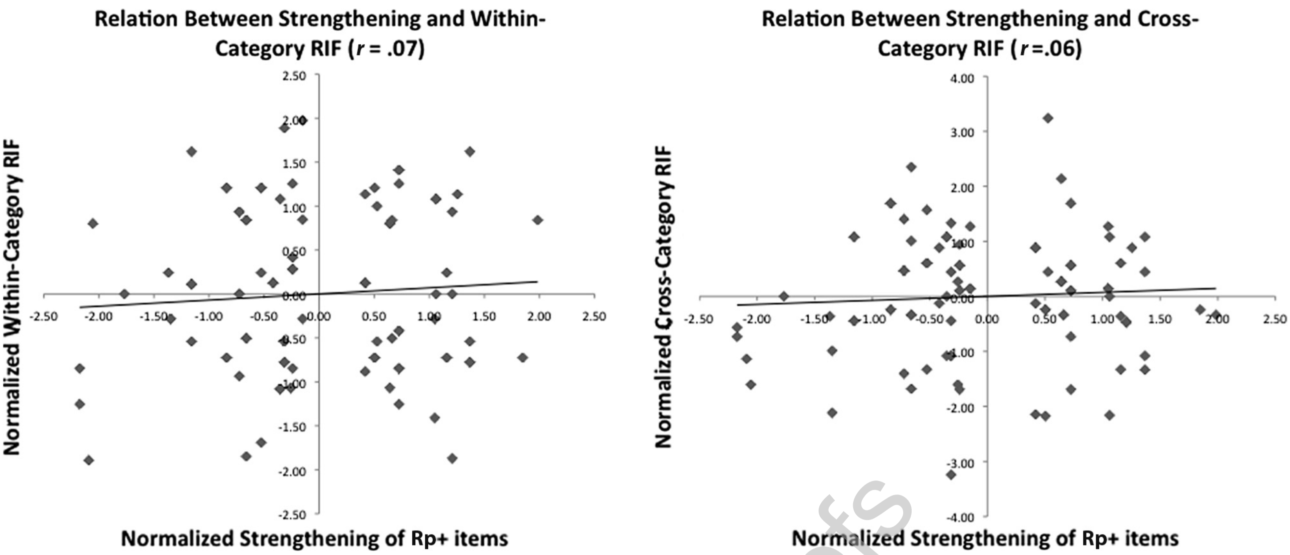

Figure 2. Correlations between the normalized strengthening of practiced items (combined across *Retrieval Practice* and *Extra Presentations*, $N = 96$) and our z-normalized measures of within- and cross-category RIF.

showed RIF (10% and 13% for within- and cross-category RIF, respectively) that was no greater than it was on average, across all participants.

In an effort to further improve our power to detect a possible relationship between strengthening and forgetting, we then normalized our measures of facilitation, within-, and cross-category RIF in a manner that accounted for variability due to item counterbalancing, which could otherwise mask such a correspondence. Specifically, we expressed each individual participant's facilitation or inhibition score in z-units, with respect to all scores in that counterbalancing condition and entered them into a common analysis with all 96 participants. Thus, each z-normalized score represents a measure of how unusual a participant's facilitation (or inhibition) effect was with respect to a perfectly matched cohort of individuals who received identical items under the same conditions. As can be seen in Figure 2, which plots the normalized inhibition and facilitation scores of all 96 participants, we still failed to detect any evidence of a relationship between strengthening and RIF. Despite a relatively high level of statistical power, the overall correlations of strengthening with within-category RIF ($r = .07$, $p = .5$) and cross-category RIF ($r = .06$, $p = .56$) were still not reliable.

Thus, the failure to observe a relationship between strengthening and RIF is extremely unlikely to be due to an inadequate range of facilitation values, special retrieval-based strengthening, a failure to consider item variability, or a lack of statistical power. In the present study, at least, strengthening did not appear to predict forgetting, converging with the conclusions evident in the experimental comparison of *Retrieval Practice* and *Extra Presentations*.

Discussion

In the current experiment, we tested a critical prediction of the covert-cueing hypothesis of cue-independent forgetting: That cross-category inhibition should be fundamentally related to the strengthening of to-be-practiced items. If so, cross-category inhibition should be observed regardless of whether strengthening stems from retrieval practice or extra study, and the size of this effect should be related to the degree of strengthening. Conversely, an inhibition account maintains that cross-category forgetting should, in fact, be specific to the process of competitive retrieval.

The present findings strongly favor the view that both within- and cross-category RIF exhibit the retrieval specificity predicted by inhibition models. Specifically, whereas *Retrieval Practice* on some category members (e.g., RED-BLOOD) impaired the later recall of both within-category competitors (e.g., RED-TOMATO) and cross-category items tested under a different retrieval cue (e.g., FOOD-STRAWBERRY), *Extra Presentations* induced no measurable forgetting. As such, these findings build upon abundant evidence of retrieval specificity observed in many prior RIF studies (Anderson & Bell, 2001; Bäuml, 2002; Blaxton & Neely, 1983; Campbell & Phenix, 2009; Ciranni & Shimamura, 1999; Johansson et al., 2007; Saunders et al., 2009; Shivde & Anderson, 2001; Wimber et al., 2009) and generalize this property to cue-independent forgetting. Importantly, cross-category forgetting only occurred as a result of *Retrieval Practice.*

We found that both *Retrieval Practice* and *Extra Presentations* produced highly reliable and substantial facilitation effects on practiced items as measured by the delayed recall test. Indeed, the facilitatory effects of practice were comparable across both conditions.[4] Thus, retrieval specificity cannot be attributed to a failure of repeated study exposures to strengthen items in memory. Simply stated, the presence of cross-category RIF does not appear to be contingent on the degree the practiced items are strengthened. This conclusion was further supported by the lack of a reliable correlation between the degree of strengthening and either within- or cross-category RIF in the present experiment, adding to the growing array of published noncorrelations between measures of facilitation and forgetting (Aslan & Bäuml, in press; Staudigl et al., 2010).

The specificity of RIF to retrieval follows from the perspective that an inhibitory process contributes to the ability to resolve retrieval interference (Anderson, 2003) and is also consistent with an oscillating-inhibition model of RIF (Norman, Newman, & Detre, 2007). Because practiced associates in our *Extra Presentations* condition were fully specified, the chance that competitors would interfere with target processing and summon inhibitory mechanisms was minimized. In contrast, *Retrieval Practice* requires participants to access a particular trace based on partial cues, a process which is not guaranteed to succeed. If related exemplars are activated, retrieval interference may ensue, hindering target access and triggering inhibition to resolve interference. To the extent that inhibition persists beyond the retrieval attempt, aftereffects of this process should materialize as forgetting even when memory is tested later from a different cue than the one used to perform retrieval practice.

The present findings provide little support for the possibility that associative blocking induced by covert cueing contributes to cue-independent RIF. Such an argument entails that cross-category items (e.g., FOOD-STRAWBERRY) would suffer RIF because people use the independent category cue (here FOOD) to covertly generate the practiced category (RED), and, in so doing, inflict upon themselves associative blocking from practiced items (RED-BLOOD). Fundamentally, this hypothesis rests on a broader view of forgetting in which items strongly linked to a retrieval cue block access to weaker items. The most straightforward implication of this hypothesis received no support, as strengthening items with extra study exposures failed even to produce within-category RIF, despite the objective cueing conditions on the final test strongly favoring blocking. Furthermore, we found no cross-category impairment in the *Extra Presentations* condition, under which the circumstances again should have been ideal to foster apparent forgetting due to covert cueing, given that (a) the practiced category cues were strongly elevated in accessibility relative to baseline categories and (b) the practiced items were demonstrably strengthened. Thus, our findings indicate that covert cueing did not occur in this paradigm, or if it did, it was insufficient to generate RIF through blocking mechanisms. The present data thus suggest that covert cueing does not play an important role in causing cue-independent forgetting.

Nonetheless, there may be cases in which covert cueing contributes to performance when using the independent probe method. As discussed elsewhere (Anderson, 2003), when extra-list cues are only weakly related to the target, participants are more likely to supplement their recall through covert cueing, especially when time limits are overly generous and no item-specific cues are utilized (e.g., word stems). Such cueing has, in fact, been identified in a recall study (Anderson, Green, et al., 2000). Yet in this case, those participants reporting the least covert cueing, if anything, showed *more* evidence of cue-independent forgetting, contrary to associative blocking explanations.

The provision of item-specific, episodic independent probes has, on some occasions, been known to eliminate RIF effects (Camp et al., 2007; Perfect et al., 2004). Though the methodologies in those instances were designed to reduce covert cueing, in neither case was the use of the strategy actually measured or manipulated. The reasons underlying these failures to produce cue-independent RIF, therefore, require further investigation, especially as there have been numerous reports of cue-independent RIF with item-specific episodic and semantic probes (Anderson & Bell, 2001; Anderson, Green, et al., 2000; Aslan et al., 2007; Saunders & MacLeod, 2006; Shivde & Anderson, 2001). It remains possible that the outcome is somehow related to peculiarities in the stimuli or the degree of match between the retrieval practice and the final test phases (Perfect et al., 2004), described by Anderson (2003, p. 431) as "masking through transfer inappropriate testing effects."[5] Currently, the best evidence that covert cueing may sometimes affect the independence of nominally independent probes comes from a markedly distinct procedure that does not measure RIF (Camp et al., 2009). Going forward, it would be desirable to directly manipulate covert cueing within the retrieval-practice paradigm. Nevertheless, although this strategy may sometimes occur, there is no empirical indication that it produces cue-independent forgetting.

The present evidence for retrieval specificity extends the generality of this property to cue-independent RIF. Still, there are some cases in which certain types of study re-exposures may induce high amounts of retrieval. Anderson and Bell (2001) noted that some participants engaged in covert retrieval practice during extra study exposures, essentially "quizzing themselves" and creating competition (as well as RIF) when there would otherwise be none. The relatedness of the pairings may also be of relevance. Whereas extra study exposures of category-exemplar pairings, in which the

[4] The beneficial effects of retrieval on memory are well documented (e.g., Bjork, 1975), but *Retrieval Practice,* in contrast to *Extra Presentations,* is not guaranteed to end in successfully bringing the target associate to mind. Thus, the similar level of facilitation observed across our two methods of practice most likely reflects this trade-off between the added benefit of *Retrieval Practice* and its increased potential of failure, compared to *Extra Practice.* Still, the comparable facilitation in these groups is convenient in that the two groups can be said, based on objective criteria, to have undergone similar degrees of strengthening.

[5] In fact, it should be noted that, despite our best efforts to equate the *Retrieval Practice* and *Extra Presentation* conditions, the match between the practice conditions and the final test was unavoidably higher for the former than for the latter.

categorical relation is always the same, place few demands on interference control, pairs composed of entirely unrelated words may engage more demanding semantic generation processes known to induce inhibition of competitors (Bäuml, 2002; Johnson & Anderson, 2004; Storm & Nestojko, 2009; Storm et al., 2007). For instance, asking participants to generate mental imagery to help link otherwise disparate associates may account, in part, for the rare instances in which *Extra Presentations* has yielded forgetting (Saunders et al., 2009; Verde, 2009).

Finally, the present findings should not be taken to indicate that item strengthening is incapable of producing blocking. Indeed, we have argued elsewhere that strength-dependent competition slows retrieval of target items and plays a role in a range of special conditions (Anderson, 2003; Anderson & Levy, 2007). Indeed, on category-cued recall tests that lack item-specific information, blocking and inhibition may jointly contribute to within-category RIF to a degree that varies with the participants' inhibitory control abilities. For example, individuals with excellent inhibitory functioning who successfully inhibit competitors during retrieval practice should be better equipped to later inhibit the dominant practiced items on the final test and avert blocking when faced with the need to recall unpracticed items. Thus, for high-functioning individuals, blocking may be negligible. On the other hand, individuals who are less able to inhibit competitors during retrieval practice (e.g., frontal patients) should be relatively more susceptible to blocking from the practiced items on the final test, as well. In both of these populations, within-category RIF should be observed, though for different reasons. To disentangle these components, independent probe measurements are helpful in reducing contributions of blocking (Anderson & Levy, 2007).

Indeed, recent attempts to mitigate blocking on the final test by controlling output interference or by using item recognition as a type of independent probe have greatly improved the ability to detect inhibitory control deficits arising either when attention is divided (Román et al., 2009), or when RIF is measured in ADHD patients (Storm & White, 2010), young children (Aslan & Bäuml, 2010), or schizophrenics (Soriano et al., 2009). Thus, the present results do not indicate that blocking never occurs; rather, they underscore that it has a limited role in determining recall probability in young adults.

In sum, the retrieval specificity of cue-independent RIF not only speaks strongly against the plausibility of the covert-cueing hypothesis, but also favors the broad idea that inhibitory processes are engaged to help people confront the influence of undesirable accessibility. RIF may reflect the enduring outcome of a trade-off, orchestrated through executive control, between the potential that a competitor may once again become relevant and the threat that it may continue to hamper recall of a target repeatedly proven contextually appropriate in the past. Retrieval specificity is consistent with the existence of functional forgetting that, while inconvenient at times, represents an adaptive feature of a flexible cognitive system (Bjork, 1988; see also Anderson & Levy, 2010; Benjamin, 2010; Levy & Anderson, 2002).

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Justin Hulbert

MRC Cognition and Brain Sciences Unit
15 Chaucer Road
Cambridge
Cambridgeshire
CB2 7EF
UK
E-mail jch68@cam.ac.uk

