RUNNING HEAD: DIRECTED FORGETTING AND RECOGNITION MEMORY

Directed Forgetting in the List Method Affects Recognition Memory for Source

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Abstract

The effects of list-method directed forgetting on recognition memory were explored. In Experiment 1 (N = 40), observers were instructed to remember words and their type-cases; in Experiment 2 (N = 80), the instruction was to remember words and their colors. Two lists of ten words were presented; after the first list, half of the observers (*forget*) were instructed to forget that list, and the other half (*remember*) were not given the forget instruction. Recognition of items (words) as well as source (encoding list + case/color) was measured for *forget* and *remember* observers. The forget instruction affected case/color memory more consistently than item and list memory; a multinomial analysis indicated that source information was affected by the forget instructions. The results indicated that recognition of source information may be a more sensitive indicator of forgetting than recognition of items.

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"Forget that." Over 30 years of research on *directed forgetting* has shown that this simple instruction can be very effective. The forget instruction (F cue) typically lowers memory of the to-be-forgotten (TBF) information, and often increases memory of to-be-remembered (TBR) information that is presented along with the TBF information (for a recent edited volume see Golding & MacLeod, 1998; for recent reviews see R. A. Bjork, 1998; Golding & Long, 1998; MacLeod, 1998). The attenuation in TBF information memory is not the result of demand characteristics (i.e., observers simply withholding TBF items during testing; R. A. Bjork & Woodward, 1973; MacLeod, 1999). Thus, directed (or intentional) forgetting allows us to deal effectively with multiple demands on memory by prioritizing one memory set over another.

There are two common presentation methods used to investigate directed forgetting. In the "item method" (also called the "word method") a list of words is presented and each word is individually cued (usually after the word is presented) as TBF or TBR (e.g., MacLeod, 1975, 1989). Researchers generally agree that the item method leads to the TBF and TBR items being segregated in memory, and to selective encoding of only the TBR items (e.g., R. A. Bjork, 1970; 1972). Because the observer ceases processing each TBF item upon presentation of the "forget" cue, memory traces for TBF words are weaker than for TBR words. Evidence for this selective encoding mechanism is quite robust for both recall and recognition (see MacLeod, 1998).

The “list method” (sometimes called the “block method”) is also used to investigate directed forgetting. Instead of presenting and cuing individual words, the words are presented in two separate lists and the instruction to forget is typically presented to half the observers (F observers) after the initial list, whereas the other half (R observers) are instructed to remember both lists (Epstein, 1972; Geiselman, R. A. Bjork, & Fishman, 1983). In this method, performance on List 1 is compared between F and R observers, and performance on List 2 is also compared between groups. Typically, there is a cost for F observers on List 1, and a gain for F observers on List 2, compared to R observers (MacLeod, 1998). This pattern of results in the list method has not been explained by selective encoding; instead, a variety of mechanisms have been proposed, each dealing with some aspect of storage or retrieval.

Models for directed forgetting in the list method. Geiselman et al. (1983) examined a *retrieval inhibition* hypothesis for list-measure directed forgetting using two measures, recall and recognition. For the recall test, they presented two kinds of words in each list: words which were to be learned intentionally, and words which were only to be judged for pleasantness (if they were learned, it was incidentally). It was assumed that learn words would be rehearsed, but that judge words would not. Geiselman et al. (1983) found that both the learn words and the judge words on List 1 were forgotten by the F observers, which implicated inhibition of the entire list as the forgetting mechanism.

The inhibition hypothesis was supported by results of a recognition task. If a forgetting mechanism acted directly on the memory representations for the words, then the memory traces for List 1 words would be weaker for F observers than for R observers, and there would be a difference in recognition performance. On the other hand, if words were inhibited at retrieval only, then the presentation of the words would overcome this inhibition, and no effect of the forget instruction would be found for recognition. Geiselman et al. (1983) found equivalent recognition accuracy scores for F and R observers, which was interpreted as consistent with retrieval inhibition. Most other researchers who have examined recognition accuracy in list-method directed forgetting have also failed to find differences across F and R observers (e. g., B. H. Basden & D. R. Basden, 1996; MacLeod 1999).

In addition to retrieval inhibition, alternative mechanisms have been proposed for directed forgetting in the list method. According to the *differential rehearsal* hypothesis (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003), recall of List 1 words is reduced by an F cue because their rehearsal is terminated. According to the *context change* hypothesis (Sahakyan & Delaney, 2005; Sahakyan & Kelley, 2002) observers who receive the F cue tend to treat exposure to the F and R lists as separate events, whereas observers in the R condition tend to treat both lists as part of a single event; the changed context produces impaired List 1 retrieval for F observers. According to the *strategy change* hypothesis (Sahakyan & Delaney, 2003; 2005) F observers adopt a more efficient study strategy on List 2 than the R observers, which produces increased List 2 retrieval for F observers.

Directed forgetting and source recognition. Both differential rehearsal and context change mechanisms might lead to differences in recognition accuracy as a by-product of directed forgetting, because they hypothesize differences in the encoding of F and R lists. As stated above, however, researchers in the past have failed to find effects in recognition memory. Were these failures accurate reflections of equivalence in recognition accuracy, or were they due to an insensitivity of the measure? A plausible argument for insensitivity could be made. The previous studies measured recognition memory for items, and it may have been that enough environmental support for list items was provided by the task, such that a small amount of forgetting would not be detectible. In other words, if directed forgetting caused a small decrease in memory strength for a word, re-presentation of the word in the recognition task would increase the memory strength of the word enough to mask any small forgetting effects. (Analogously, in cognitive aging studies, low-load tasks like digit span are not sensitive enough to detect age-group differences, whereas high-load working-memory tasks show large age-group differences.) Recent research has suggested that another component of recognition memory, memory for source, might be a more sensitive measure of list-method directed forgetting than memory for items: Two list-method directed forgetting studies, E. L. Bjork and R. A. Bjork (2003), and Sahakyan and Delaney (2005), measured recognition for list membership, which is a type of source memory.

E. L. Bjork and R. A. Bjork (2003) combined list-method directed forgetting with the false-fame paradigm of Jacoby (Jacoby & Kelley, 1987), and measured recognition for names and source. For both F and R observers, List 1 consisted of non-famous names, and List 2 consisted of mildly-famous names (e.g., *Emily Carr*). List learning was followed by a task in which observers were presented with the names and required to make judgments on whether the names were famous or non-famous. Before the judgment task, observers were reminded that the non-famous names had been presented on List 1, so if they remembered that a name had been presented on List 1, it would definitely be non-famous. E. L. Bjork and R. A. Bjork found that F observers were more prone to the “false fame” effect for List 1 words; they had an increased likelihood of mis-assigning fame to a non-famous name, because the name was familiar (due to the exposure as part of List 1), but it was not remembered as having been seen on List 1. E. L. Bjork and R. A. Bjork concluded that the instruction to forget List 1 also impaired source memory for the List 1 items, possibly as a by-product of retrieval inhibition. In addition to impaired source memory, F observers also had reduced recognition memory for the names presented on List 1.

Sahakyan and Delaney (2005) also measured directed forgetting in recognition scores, examining both items and source. They were exploring a *strategy change* mechanism, which is related to the context-change hypothesis. According to the strategy change hypothesis, F observers, because they are relieved of the burden of remembering List 1, engage in more elaborate encoding of List 2 than the R observers. Sahakyan and Delaney used larger than usual set sizes (16 – 36 words), and found that recognition for List 2 words was higher for the F observers than for the R observers; this F-R difference increased as a function of set size. (There was no F-R difference on List 1 word recognition.) Their results were the first to indicate that list-method directed forgetting could affect item recognition, possibly because the very large set sizes they used had increased the sensitivity of the recognition test. In addition, Sahakyan and Delaney's observers also had to indicate whether each word they recognized came from List 1 or List 2. The analysis of the list (source) memory indicated that directed forgetting produced errors: F observers were more likely than R observers to identify the source of List 1 items as List 2, and conversely, R observers were more likely than F observers to identify the source of List 2 items as List 1.

The most straightforward inference from the Sahakyan and Delaney (2005) source memory analysis would be that directed forgetting caused reduced source memory for List 1 words and increased source memory for List 2 words, consistent with the source-memory findings of E. L. Bjork and R. A. Bjork (2003; although they only found source-memory effects for List 1 words). Sahakyan and Delaney (2005), however, posited two components of source memory for list: ability to discriminate list membership (sensitivity) and list bias. List bias might be due to the fact that, for F observers, all List 1 words are F words, and all List 2 words are R words; if a word is recognized, it may be judged as more likely to have come from List 2. Using a multinomial model (Riefer & Batchelder, 1988) to represent the various kinds of memory and response biases in the recognition task, Sahakyan and Delaney (2005) found that directed forgetting was manifested not in list discrimination, but in list bias. The multinomial model indicated that increased source errors on List 1 words (for F observers) and on List 2 words (for R observers) was due to the lower tendency of F observers (compared to R observers) to assign words to List 1, possibly caused by expectations on the part of F observers that a recognized word is more likely to come from List 2 than List 1. From this analysis, Sahakyan and Delaney (2005) inferred that the source-memory findings of E. L. Bjork and R. A. Bjork (2003) may have been due to effects of list bias and not list discrimination.

Our aim in the current study was to examine the effects of list-method directed forgetting on recognition for items and source. As stated above, most previous studies (e. g. B. H. Basden & D. R. Basden, 1996; Geiselman et al., 1983; MacLeod 1999) did not find any effects of directed forgetting on item recognition. More recently, Bjork & Bjork (2003) and Sahakyan & Delaney (2005) found effects of directed forgetting on recognition of source, measured as memory for list membership. One complication of measuring source memory for list is that, as Sahakyan and Delaney (2005) found, expectations about what will be remembered or forgotten as a result of the *forget* instruction may introduce bias for list. On the other hand, there should be some attributes of words that would be immune to this type of bias. For instance, if word case were presented randomly across F and R words, a *forget* instruction should not systematically affect the propensity for responding *small* instead of *capital.* Similarly, a bias for word color (e.g., *red* vs. *blue*) should not be induced by a forget instruction. In addition, case or color is an attribute of single words, unlike list membership which may emerge from interactions across memory representations for multiple words.

In our study, we measured recognition memory for items and list, but also for attributes of the list words not subject to the same kind of bias as list membership: the case (Experiment 1) and color (Experiment 2) of the list words. Our main goal was to investigate the effect of directed forgetting on source memory; we predicted that memory for case or color would be more sensitive to directed forgetting than memory for items. In addition, we examined the separate influences of discrimination and bias on memory for list.

EXPERIMENT 1

In the first experiment, we investigated directed forgetting using the list method; our measure was recognition of words presented in List 1 and List 2. Item memory was measured by recognition of the list words, and source memory was measured by recognition of list and case. Memory for these three attributes mapped on to four levels of recognition performance: words (irrespective of list or case), words + list (irrespective of case), words + case (irrespective of list), and words + list + case (all three attributes recognized).

Method

Observers

Forty introductory psychology students at the University of Kentucky participated in this study in partial fulfillment of a course requirement.

Design

The experiment was a 2 (List) x 2 (Memory Cue) mixed-factors design. List was a within-subject (repeated) factor, and memory cue was a between-subjects factor. The words comprising the two lists (List 1 and List 2) were counterbalanced, along with whether a particular word was presented in capital or small letters. Memory cue was manipulated between observers (20 to each), and included a remember (R) condition and a forget (F) condition. The words were the same as used in Golding and Gottlob (2005).

Procedure

The stimuli were presented on a computer monitor. Each word was presented for five seconds, with a one-second ISI. Words were presented in random order. Observers were instructed to memorize each word and its case. At the end of the first list, the F observers were instructed on-screen that the first list was practice, and to forget the words. The R observers were instructed to prepare to remember the second list. At the end of the presentation of the word lists, observers were given a 5-minute distractor task of labeling the states on a blank map of the United States, followed by the recognition test. In the recognition test, each observer was given a sheet of paper consisting of two columns of word pairs, each pair of which was a word presented in small letters next to that same word printed in capitals. The ten words from List 1 were included; also included were the ten words from List 2, along with 20 foil word pairs (all in random order). Observers were first instructed to circle all of the words that had been seen in List 1, making sure to circle the word that was the same case as the word they had seen. Following recognition of List 1 words, observers were given the same list and instructed to circle all of the words (and the correct cases) that they had seen in List 2. Observers were given 2 minutes for each list; all observers recognized the List 1 words before the List 2 words. (In Golding & Gottlob, 2005, it was found that recalling List 2 words before List 1 words may artifactually increase the magnitude of directed-forgetting effects.) Observers performed the experiment individually.

Results and Discussion

General results. Recognition performance on each word list is presented in Table 1. Four levels of recognition were measured: words (irrespective of list or case), words + list (irrespective of case), words + case (irrespective of list), and words + list + case (all three attributes recognized). Words circled on both lists (M = .7 words per observer) were scored as a response belonging to the appropriate list. Recognition of words (the first measure in Table 1) was corrected by subtracting intrusions (Macmillan & Creelman, 2005). The words + list + case measure corresponded to a completely correct response; of primary interest were the other three measures, because they parsed out the various contributions of item and source memory.

A 2 x 2 repeated-measures analysis of variance (ANOVA) was conducted on each measure (Table 1). For each test, effect size was measured as η_p^2 (partial eta squared), which is equal to $SS_{effect}/(SS_{effect} + SS_{error})$ (Tabatchnik & Fidell, 1996). Minimum significance level for all tests was defined as $p < .05$. There was no List x Memory Cue interaction for recognition of words (item recognition). In contrast, List x Memory Cue interactions were found for word + list, word + case and word + list + case recognition, indicating directed forgetting for those measures. The only pairwise significant differences were found between F and R groups on List 1 recognition for word + case and word + case + list, indicating a cost (F < R) for List 1, but no corresponding benefit (F > R) for List 2. Apparently, the *forget* instruction caused the memory traces for List 1 words to be weaker, but this was manifested only by changes in source (list and case) information for the words.

Bias for case, defined as the probability of responding “small” given that a word was correctly recognized (Macmillan & Creelman, 2005), was examined next. A value for bias consistent with no preference would be .5. The List x Memory Cue interaction for case bias was not significant, $F(1, 38) = 0.03$, $p > .05$. In addition, in each cell of the List x Memory Cue interaction, bias did not differ from .5, $t(38) < 1.85$, $p > .05$.

Comparisons to previous results. In contrast to the findings of E. L. Bjork and R. A. Bjork (2003; Experiment 2) and Sahakyan and Delaney (2005; Experiment 2), we did not find directed-forgetting effects on item (word) recognition. In both previous experiments, though, the recognition effects on items were rather inconsistent: Bjork and Bjork (2003) found a cost on List 1 but no benefit on List 2, whereas Sahakyan and Delaney (2005) found no cost on List 1 but a benefit on List 2 (and only for larger set sizes). This suggests that the power to find effects of directed forgetting on item recognition may be limited. Sahakyan and Delaney (2005) recognized these power issues, and consequently used larger set sizes (16 – 36 words) than the typical directed forgetting experiment. Perhaps the clearest inference from our failure to replicate the directed-forgetting effect on item recognition is that the measure is relatively insensitive to the small changes caused by directed forgetting.

Confirming the findings of E. L. Bjork and R. A. Bjork (2003) and Sahakyan and Delaney (2005), we found that directed forgetting affected source memory. For list recognition (measured by word + list accuracy), there was a List x Memory Cue interaction, although the simple effects (cost and benefit) were not significant. It is not clear why we failed to find simple effects; although the effects were in the predicted directions, we may have had power limitations. In the previous work examining this issue, Bjork and Bjork (2003) found a cost of list recognition, and Sahakyan and Delaney (2005) found both a cost and a benefit on list recognition. As stated previously, Sahakyan and Delaney (2005) performed a multinomial analysis on their data to investigate the contributions of sensitivity and bias on list recognition, and found that the effects on list recognition were due to bias (in that case the lower tendency of F observers to assign words to List 1). We also examined this issue using a multinomial model. For purposes of clarity, this analysis is deferred to a later section, but to presage our findings, our multinomial analysis was consistent with changes in both sensitivity and bias.

Our findings for case recognition were consistent with those for list recognition, but recognition of case is a more direct measure of source memory than recognition of list, because directed forgetting would not be expected to produce a bias for responding *small* instead of *capital* (which our bias analysis confirmed). The List x Memory Cue interaction on case indicated, therefore, that source information for case was affected by directed forgetting. We found a cost, but no benefit; this finding would be consistent with various forgetting mechanisms, most notably context change (Sahakyan & Kelley, 2002) which would posit that F observers had relative difficulty retrieving the encoding context of List 1, without any corresponding increase in List 2 context. One difficulty with interpreting the present results in terms of previous theories, is that they were formulated to account for effects of directed forgetting on recall and list recognition, which may be affected differently than source memory for attributes such as case. For example, differential rehearsal (MacLeod et al., 2003) explains costs and benefits for recall, but it would have difficulty explaining these results for case, mainly because rehearsal of a word involves re-activating item (and list) information, but probably not the actual physical appearance of each word.

Summary. To summarize, in Experiment 1 we found that item (word) memory was not affected by directed forgetting, but source (list and case) memory was affected. In order to replicate and extend our findings, we tested another type of source information: color. In addition, we increased the power by doubling the *n*. It was predicted that source memory for color would be affected by directed forgetting, again as measured by recognition memory.

EXPERIMENT 2

Method

The procedure was similar to that of Experiment 1, except that all words were presented in capitals, in either red or blue. Observers were instructed to memorize words and their colors. Eighty naïve observers (40 F and 40 R), screened for color-blindness, were tested. As in Experiment 1, there were two identical recognition sheets with List 1, List 2, and foil words; the first sheet that was presented was for recognition of List 1 words, and the second sheet presented was for recognition of the List 2 words. Each recognition sheet consisted of two columns of word pairs as in Experiment 1, each pair of which was a word presented in red next to that same word printed in blue (color order was random).

Results and Discussion

General results. As was also done for Experiment 1, 2 x 2 repeated-measures analyses of variance (ANOVA) were conducted on words (irrespective of list or case), words + list (irrespective of case), words + color (irrespective of list), and words + list + color (all three attributes recognized; Table 2). Words circled on both lists (*M* = .8 words per observer) were scored as a response belonging to the appropriate list. Recognition of words (the first measure in Table 1) was corrected by subtracting intrusions (MacMillan & Creelman, 2005). As in Experiment 1, the measures of primary interest were those of words, words + list, and words + color, because they isolated the contributions of item and source memory.

Significant List x Memory Cue interactions were obtained for words, words + color, and words + list + color. Pairwise comparisons on those interactions indicated F < R for List 1 on words and words + list + color, with F-R differences for List 1 and List 2 word + color just short of significance ($p < .052$). Bias for color (probability of responding *red* given correct word recognition) was also examined: The List x Memory Cue interaction for color bias was not significant, $F(1, 38) = 0.11$, $p > .05$, with no cell differing from .5 (no color preference), $t(78) < 1.75$, $p > .05$. This result indicated that forgetting did not affect bias for color.

Comparisons to previous results. In Experiment 2, unlike in Experiment 1, we found an effect of directed forgetting on items (words), perhaps because of the added load imposed by the requirement to encode the color, or possibly due to the increase in sample size (and power) over Experiment 1. This effect was manifested by a cost but no benefit, although the non-significant benefit was in the predicted direction. Thus, these results were similar to those of Bjork and Bjork (2003) who found only a cost, but they were unlike those of Sahakyan and Delaney (2005) who found only a benefit. A finding of cost but no benefit would be consistent with differential rehearsal (MacLeod et al., 2003) and context change (Sahakyan & Kelley, 2002). Another difference from Experiment 1, and from Bjork and Bjork (2003) and Sahakyan and Delaney (2005), was the lack of a directed-forgetting effect on list recognition, perhaps illustrating that this is a weak effect that will not always be apparent.

Summary. The directed-forgetting effect on color (List x Memory Cue interaction) replicated the case findings from Experiment 1, although the simple-effects tests for both cost and benefit fell just short of significance. Because this effect cannot be attributed to systematic bias caused by the forget instruction, these results provide additional evidence that directed forgetting causes a loss in memory for source.

GENERAL DISCUSSION

In two experiments, we found that recognition for two types of source memory (case and color) was affected by directed forgetting. Our findings for recognition of items, as well as list (another kind of source memory) were not as consistent: For item memory, there was an effect in Experiment 2, but not in Experiment 1, whereas for list memory, the converse pattern held. The item and list results partially confirm two previous studies: E. L. Bjork and R. A. Bjork (2003) found effects for item and list recognition; Sahakyan and Delaney (2005) found effects for item and list, but their multinomial analysis indicated that the list effects were due to bias and not changes in list discrimination as a result of the forget instructions. In directed forgetting, bias for list may come about because of expectations on the part of F observers that a recognized word is more likely to come from List 2 than List 1. In contrast, no biases were observed for case or color, which confirmed our expectation that there would be no reason for directed forgetting to affect the propensity to respond *small* instead of *capital* or *green* instead of *blue*. Thus, it is clear that source information can be lost as a function of the forget instruction.

Multinomial model. Because we used several different outcome measures, following Sahakyan and Delaney (2005) we fitted multinomial processing models to the data (Batchelder & Riefer, 1990; Dodson, Prinzmetal, & Shimamura, 1998; Riefer & Batchelder, 1988). Multinomial models can be used to estimate unobservable processes (both detection and guessing) involved in recognizing item and source information. It is assumed that each component of the recognition process is independent, and that there are often multiple pathways that would lead to a particular response. A theoretical explanation is given in Batchelder & Riefer (1990), and a lucid practical tutorial is presented in Dodson et al. (1998). Multinomial models aggregate a number of decisions, each determined by a threshold (all-or-none) mechanism. Threshold theories of recognition memory posit that responses are determined by a comparison between memory strength and the criterion level for a particular attribute (MacMillan & Creelman, 2005). Recent research on recognition has found support for continuous models, which are constructed from overlapping density distributions as in standard Signal Detection Theory: Yonelinas (1999) found that a continuous model was preferred for item recognition, while a threshold model was preferred for source recognition, whereas Slotnick & Dodson (2005) found that an unequal-variance continuous model could account for both item and source recognition. On a micro level, therefore, the threshold mechanism as represented in the multinomial model may be less sufficient than a continuous mechanism. Comparing threshold and continuous models, however, requires the examination of ROC curves (Slotnick & Dodson, 2005; Yonelinas, 1999), and it is not clear that the two mechanisms would be identifiable at the level of a multinomial model, which aggregates many different decisions. For a number of reasons, therefore (e.g. computational simplicity, reduction of free parameters), the threshold assumption was retained in our multinomial model. In addition, we wanted to compare our item and list results to those of Sahakyan & Delaney

(2005), whose (threshold-based) multinomial model did provide a good fit to their directed-forgetting data.

The multinomial model we used is presented in Figure 1. Each parameter is a probability. Parameters in capital letters represent detection probabilities; parameters in small letters represent bias (probability of guessing a particular attribute value). Subscripted parameters are free to differ across List 1 and 2; non-subscripted parameters are fixed across lists. Despite the structure implied in the diagram, the steps involved after the first can be executed in any order (with guessing steps nested within detection steps). All probabilities subsequent to item detection are conditional upon item detection; i.e., one cannot recognize the list for a word if the word itself was not recognized. We fixed the probability for guessing the correct case or color at .5, because the probabilities of responding *small* (Experiment 1) and *red* (Experiment 2) were .5, both overall and within each cell, indicating no bias for case or color.

This model is different from previous multinomial models for source memory (e.g., Dodson et al., 1998; Sahakyan & Delaney, 2005) in two ways. First, the other studies only had one type of source information (list), whereas we had two (list, plus case or color). Second, in previous studies the old and new words were presented serially, and the observers made two judgments (old vs. new word, and if old, list 1 or list 2). In the current study, observers were presented with two identical response lists corresponding to encoding lists 1 and 2. When a word was viewed on response List 1, the observer decided if it was old or new; if old, then had it been presented in encoding list 1 and what case/color was it presented in? The left branch in Figure 1a presents one possible chain of events: A List 1 word was recognized, correctly assigned to List 1, and the case/color was correctly recognized. Thus, a correct response was emitted (response L1C; recorded in Tables 1 and 2 as word + list + case correct). There are five other possible paths resulting in response L1C; for instance, the observer may recognize the word and list, fail to recognize the case/color, but correctly guess the case/color.

Other branches represent all of the various possibilities for detection and guessing. The outcomes are listed in the bottom row. One feature of this multinomial model differs from previous multinomial models for source memory: All of the detection and guessing parameters include both the parameter and its complement (e.g., C and 1-C), except for parameters e1 and e2 which represent respectively guessing that a word was on encoding list 1 or 2. That is because when filling out a response list, there is no response associated with guessing that a word belongs on the other list. Yet the event of assigning a word to the incorrect list has to be included in the model. That event is represented by the branches headed by e2 in the List 1 model and e1 in the List 2 model. These branches, although pictorially represented in a particular list, are actually executed while responding to the other list. This “crossover” structure allows all of the possible events to be represented in the model.

The models were fitted using Excel’s Solver (Dodson et al., 1998). The loss function (measure of deviation between data and model) was G^2, defined as

$$\sum(2*ObservedFrequency)*\ln\left(\frac{ObservedFrequency}{\Pr edictedFrequency}\right) \quad (1)$$

(Riefer & Batchelder, 1988). Best fit parameter values are presented in Table 3 (Experiment 1) and Table 4 (Experiment 2). All parameters, because they were probabilities, were constrained to take values between 0 and 1. The data from both Forget and Remember groups were combined. For each group, there were 10 possible responses (e.g. for List 1 words, word + case + list correct, word + case correct, word correct, miss, intrusion) creating 20 data points. The unrestricted model had 20 free parameters; this would not be identifiable, so the model was restricted by setting all four parameters for intrusion rate equal, to create a “base” model with 3 degrees of freedom (20 data points fitted with 17 free parameters; listed in Tables 3 & 4). Hypotheses were tested by restricting certain subsets of parameters to create models nested within the base model. A restricted model can be compared to the base model by comparing the respective G^2 values; if the two models are equivalent, the difference in G^2 is distributed as X^2 with degrees-of-freedom determined by the difference in the numbers of free parameters in the two models.

Experiment 1 data was analyzed first. Because the directed-forgetting effects in Table 1 were manifested mainly in terms of significant interactions, hypotheses were tested by restricting two pairs of parameters at a time and comparing the restricted fits to the base-model fit. For instance, to test the hypothesis that the List x Memory Cue interaction on word + list recognition for Experiment 1 (Table 1) was reflected in the multinomial model, L1 was yoked across F and R observers, and L2 was yoked across F and R observers. In Experiment 1, only one pair of parameters produced a significant reduction in fit: Constraining case identification (C1 and C2) resulted in a significantly poorer fit than the base model, $G^2(2) = 9.06$, $p < .05$, which indicated that forgetting affected case information. This result was consistent with the ANOVA results, in that jointly constraining C1 and C2 replicated the List x Memory Cue interaction on word + case, and word + list + case recognition (Table 1). Follow-up tests on single case parameters indicated that constraining C1 (color identification for List 1) did not provide a significantly poorer fit than the base model, $G^2(1) = 2.16$, $p > .05$, whereas constraining C2 did result in a poorer fit, $G^2(1) = 7.04$, $p < .05$, implying that there was a difference in C2 across groups, but no difference in C1. It is not clear why the multinomial model and ANOVA results for the List x Memory Cue interaction were manifested differently, but it is important to note that the multinomial results mirrored the gross results of the ANOVA, as Sahakyan and Delaney (2005) also found.

We also restricted four-parameter sets and examined the fits. Although, when tested in isolation, neither list identification (L1 and L2) nor guessing (e1 and e2) parameters affected fit, restricting all four parameters did result in a poorer fit than the base model, $G^2(4) = 21.43$, $p < .001$. This result indicated that, in the model, forgetting was manifested in both discrimination and bias for list membership, but possibly there was insufficient power to detect the effects of restricting discrimination or bias alone. Inspecting the parameter values for the base model, discrimination (L1 & L2) mirrored the recognition measures for word

+ list (Table 1), but bias (e1 & e2) was manifested in a greater tendency for F observers (compared to R observers) to assign a List 1 word to List 1. This result was different from that of Sahakyan and Delaney (2005), who found that list identification was equivalent across F and R groups, but that F observers were more likely than R observers to guess that any word (List 1 or List 2) belonged to List 2. The observers in Sahakyan and Delaney (2005) assigned a list to words presented serially on a computer screen, so when F observers identified a word whose source was not known, they may have had a greater tendency to assume that the word had come from List 2 (because they knew the probability of identifying a word from List 1 was lower). It is not clear why our results did not mirror those of Sahakyan & Delaney (2005), but it may have been related to our method of presenting separate List 1 and List 2 response sheets.

Experiment 2 was analyzed next. Of all the two-parameter sets, only color identification (C1 and C2) was significant, $G^2(2) = 12.58$, $p < .01$, which confirmed the List x Memory Cue interactions on word + color and word + list + color (Table 2). As was done for Experiment 1, follow-up analyses were performed for C1 and C2 alone. Constraining C1 (color identification for List 1) did not provide a significantly poorer fit than the base model, $G^2(1) = 1.71$, $p > .05$, whereas constraining C2 did result in a poorer fit, $G^2(1) = 10.01$, $p < .05$. These simple effect analyses partially replicated those from the ANOVA, in which we found F-R differences for both List 1 and List 2 to be just short of significant (p < .052). Even though there was a List x Memory Cue interaction on word recognition (Table 2), it did not result in a significant effect on the parameter estimates for detection rate (L1 and L2), $G^2(2) = 2.65$, $p > .05$, possibly due to power limitations. For list membership, restricting both sensitivity (L1 and L2) and bias (e1 and e2) did not produce a significantly poorer fit, $G^2(4) = 3.65$, $p > .05$.

The model fits can be summarized as the following: For both experiments, recognition of case (Experiment 1) and color (Experiment 2) were affected by directed forgetting; these effects were manifested in List 2 benefits for F observers compared to R observers. No other pairs of parameters had significant effects in the models; however, for Experiment 1, the effects of both list sensitivity and list bias were significant, but only when considered together. The multinomial fits, therefore, supported the hypothesis that source information is reduced as a function of directed forgetting. (It should be noted again, however, that the threshold assumption underlying the multinomial model has been questioned by researchers including Yonelinas, 1999, and Slotnick & Dodson, 2005.)

ANOVA vs. multinomial fits. The ANOVA results and the multinomial fits had many similarities, but also some differences. For Experiment 1, the ANOVA indicated directed-forgetting effects on list and case recognition; the multinomial fit also indicated effects on list and case. The effects on list recognition were similar across the ANOVA and the multinomial model, as both were manifested in List x Memory Cue interactions only with no simple effects. The ANOVA effect on case recognition was manifested in a List x Memory Cue interaction, with an F-R difference in List 1 (costs) only, although the F-R difference in List 2 (benefits) was in the predicted direction (but non-significant). The multinomial model fit was slightly different: It also indicated a List x Memory Cue interaction for case, but this was manifested in a benefit but no cost.

For Experiment 2, the ANOVA indicated an effect on color recognition, and this was manifested in a significant List x Memory Cue interaction, with the simple effects just short of significance but in the predicted directions. The multinomial model also indicated a List x Memory Cue interaction for color; however, this was manifested in a benefit but no cost. On the other hand, the ANOVA indicated an effect of directed forgetting on item recognition, but this was not replicated in the multinomial model.

In summary, we found that the multinomial models were able to accommodate most of the effects found in the ANOVA for both experiments, although it is not clear why the two tests did not mirror each other precisely in the patterns of costs and benefits for case and color. The multinomial model is complex, and although the fits converged to reasonable parameter values in each case, its behavior may have been unusually sensitive to small fluctuations in the data. For instance, although there was no indication that the bias toward responding *small* or *blue* was anything other than .5, it may be that freeing these parameters (to range between .4 and .6 for example) would allow a closer correspondence between ANOVA and multinomial model (although increasing the number of free parameters would not be practical in the current case).

Comparisons to previous studies. As discussed above, many of our findings were consistent with those of E. L Bjork and R. A. Bjork (2003) and Sahakyan and Delaney (2005). Both of the previous studies found directed-forgetting effects on item recognition, which we found in Experiment 2 but not Experiment 1. Both also found directed-forgetting effects in list recognition (which Sahakyan & Delaney, 2005, attributed to changes in bias), which we found in Experiment 1 but not Experiment 2. The critical findings in the current study were the directed-forgetting effects on case and color. These effects clearly indicated that source information is lost as a consequence of directed forgetting; we may therefore suggest that source memory for physical attributes of words is a relatively sensitive indicator of directed forgetting compared to item and list memory (especially given the indications in Sahakyan and Delaney, 2005, and the current study, that a large component of directed-forgetting effects on list recognition is due to bias).

The current results are in agreement with the context-change hypothesis of Sahakyan & Kelley (2002), which predicts a cost, and they are also in agreement with the strategy-change hypothesis of Sahakyan and Delaney (2003), which predicts a benefit. On the other hand, it would be difficult to reconcile our results for case and color recognition with the differential rehearsal hypothesis of MacLeod et al. (2003), because it is unlikely that memory for case or color is directly strengthened by rehearsal (of course, rehearsal could cause indirect effects on case or color recognition by strengthening item memory, but changes in item memory were not observed in Experiment 1).

<u>Other related studies.</u> A related paradigm (Bjork, 1989; Neumann & DeSchepper, 1992; Zacks, Radvansky, & Hasher, 1996) has revealed recognition differences in list-method directed forgetting, possibly due to

impairment of source memory in TBF words. In this design, observers are presented with blocks of TBR and TBF words, and are later presented with probes consisting of the TBR, TBF and new words. Observers are required to respond *yes* (in the remember set) to TBR probes, and to respond *no* (not in the remember set*)* to new and TBF probes. In this type of study, time to recognize the probe is not actually measured, rather, the dependent variable is time to classify the probe as corresponding to a *remember* or *not remember* word. Typically, classification times to TBR and new words are equivalent, whereas classification times to TBF words are slowed, implicating weaker source memory for the TBF words.

The results of the current study can also be compared to predictions from fuzzy trace theory (Brainerd & Reyna, 1993; Gerkens & Smith, 2004). Gist and verbatim memory from fuzzy-trace theory would map onto item and source memory respectively. Fuzzy trace theory holds that gist memory is more permanent and less subject to degradation than verbatim memory (Brainerd & Reyna, 1993), which would be consistent with our results. Although there is evidence for separate gist and verbatim systems (Brainerd & Reyna, 1993), we do not make any commitments regarding independence, because in our paradigm the source memory for a word is dependent on the item memory.

The source-monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993) is more explicit about the relationship between item and source memories. According to this framework, source memory is derived primarily from perceptual details contained in episodic memories, although it also includes more abstract codes. Johnson et al. (1993) review many memory processes that seem to impact especially on source memory. Source monitoring and old/new (item) recognition are partially separable in that more episodic detail is required for source memory; furthermore, different mechanisms may underlie source judgments and item recognition (Yonelinas, 1999). Our results, therefore, may indicate that source memory, because it contains a higher level of episodic detail, is more vulnerable to disruption than item memory.

Another theoretical framework that maps onto the distinction between source and item memory is the remember/know dichotomy (Tulving, 1985). B. H. Basden & D. R. Basden (1996) examined *recollect* (consciously remember; similar to source memory) and *know* (appears familiar; similar to item memory) recognition in directed forgetting, using both the item method and the list method. They found a greater number of recollect responses for TBR than for TBF words, but only for the item method. They found no F-R difference for the list method, for either know or recollect responses. Their failure to find an effect of list-method directed forgetting may have been related to the measure they used. For observers to judge their own memories of the words (know *vs.* recollect), they probably used some kind of internal criterion of strength or familiarity. It may have been that the criterion for a recollect response was set low enough such that mild forgetting did not affect the response, i.e., an observer could “feel” that he recollected a word, even if case or color information was lost. In contrast, the source/item recognition in the current study is based on a forced choice (e.g., shark vs. SHARK), and apparently, is sensitive enough to reflect the effects of small amounts of forgetting.

Conclusion. In summary, two experiments showed that list-method directed forgetting affected the recognition of source (case or color) information. In addition, memory for list (Experiment 1) and item (Experiment 2) were affected. These findings are consistent with those of E. L. Bjork and R. A. Bjork (2003), who found that directed forgetting affected recognition memory for both items and lists. Sahakyan and Delaney (2005) also found an effect on item and list memory, but concluded from a multinomial analysis that their list effects were due to changes in bias, not discrimination. In our Experiment 1, we also found evidence for bias in list recognition, although we could not simultaneously reject the possibility of changes in list discrimination. The current findings of differences in case and color recognition do, however, point unambiguously to losses in source memory as a consequence of directed forgetting, because changes in bias for case and color were ruled out.

Our effects of directed forgetting were expressed primarily in List x Memory Cue interactions; when simple effects within list were found by ANOVA, they were always manifested in costs (F < R for List 1), but not in benefits (F > R for List 2). These results are mostly consistent with the two prior studies examining recognition accuracy in directed forgetting: E. L. Bjork and R. A. Bjork (2003) found only a cost, whereas Sahakyan and Delaney (2005) found only a benefit, but this was confined to very large set sizes. Thus, while we would not claim that benefits are absent in this design (although not significant, all of the F-R differences in List 2 were in the predicted direction), it is apparent that the benefits were smaller than the costs.

The results of our multinomial modeling were mostly consistent with the ANOVA results. For Experiment 1, the model fits suggested that a combination of list identification and list bias was affected by forgetting, which was compatible with the findings of both E. L. Bjork and R. A. Bjork (2003) and Sahakyan and Delaney (2005). In addition, the model fits indicated that case recognition was affected by the forget instruction, although this effect was manifested in a benefit (F > R for List 2) rather than a cost (F < R for List 1) as was found in the ANOVA. For Experiment 2, the model fits indicated that color recognition was affected by forgetting; again this was manifested in a benefit rather than a cost (the ANOVA produced non-significant costs and benefits). The word detection parameters in the multinomial model, however, did not reflect the item effect found in the ANOVA for Experiment 2. It is not clear why the multinomial model fits did not correspond exactly to the ANOVA findings, but it is encouraging that the two analyses mapped onto each other to a first-order approximation. The multinomial fits, overall, confirmed that source information for list, case, and color are affected by directed forgetting.

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Table 1. Recognition Measures from Experiment 1.

	Word [a]	Word + List	Word + Case	Word + List + Case
List 1 (F Group) [b,c]	7.90 (0.35)	6.25 (0.52)	6.35 (0.45)	4.90 (0.48)
List 1 (R Group) [b,c]	8.30 (0.38)	7.25 (0.41)	7.70 (0.43)	6.65 (0.45)
List 2 (F Group) [b,c]	7.20 (0.43)	6.45 (0.53)	6.40 (0.51)	5.30 (0.36)
List 2 (R Group) [b,c]	7.30 (0.43)	5.85 (0.45)	6.10 (0.40)	4.65 (0.43)
List x Memory Cue Interaction [F(1, 38)] [d]	0.29 (.01)	**4.46*** (.11)	**6.10*** (.14)	**9.09**** (.19)
F vs. R List 1 [t(38)] [e]	0.77	1.5	**2.20***	**2.68***
F vs. R List 2 [t(38)] [e]	0.17	0.86	0.46	0.90

[a]Raw hits minus intrusions. [b] Number of words out of 10 on each list. [c] Standard error in parentheses.

[d]Partial eta squared in parentheses. [e]One-way test, using Bonferroni correction.

*$p < .05$, ** $p < .01$.

Table 2. Recognition Measures from Experiment 2.

	Word [a]	Word + List	Word + Color	Word + List + Color
List 1 (F Group) [b,c]	7.10 (0.28)	5.73 (0.31)	5.35 (0.35)	4.15 (0.36)
List 1 (R Group) [b,c]	7.95 (0.25)	6.57 (0.30)	6.28 (0.31)	5.15 (0.31)
List 2 (F Group) [b,c]	6.45 (0.34)	5.73 (0.34)	5.55 (0.35)	4.68 (0.37)
List 2 (R Group) [b,c]	5.50 (0.46)	5.60 (0.33)	4.55 (0.37)	3.70 (0.37)
List x Memory Cue Interaction [F(1, 78)] [d]	**7.01*** (.08)	3.14 (.04)	**11.28**** (.14)	**13.29**** (.15)
F vs. R List 1 [t(78)] [e]	**2.22***	1.95	1.98	**2.12***
F vs. R List 2 [t(78)] [e]	1.66	0.27	1.98	1.88

[a]Raw hits minus intrusions. [b] Number of words out of 10 on each list. [c] Standard error in parentheses.

[d]Partial eta squared in parentheses. [e]One-way test, using Bonferroni correction.

*$p < .05$, ** $p < .01$.

Table 3. Multinomial Model Parameter Estimates for Experiment 1

Parameter	Forget	Remember	Label
D1	.82	.89	Detect rate for List 1 words
D2	.78	.76	Detect rate for List 2 words
L1	.67	.79	List discrimination for List 1 words
L2	.77	.59	List discrimination for List 2 words
e1	.75	.60	Guess word is from List 1 (bias)
e2	.68	.67	Guess word is from List 2 (bias)
C1	.64	.75	Case identification for List 1 words
C2	.69	.36	Case identification for List 2 words
d1, d2	.02		Intrusion rate (yoked across cells)

Table 4. Multinomial Model Parameter Estimates for Experiment 2

Parameter	Forget	Remember	Label
D1	.73	.77	Detect rate for List 1 words
D2	.70	.58	Detect rate for List 2 words
L1	.65	.77	List discrimination for List 1 words
L2	.76	.73	List discrimination for List 2 words
e1	.77	.79	Guess word is from List 1 (bias)
e2	.68	.88	Guess word is from List 2 (bias)
C1	.54	.52	Color identification for List 1 words
C2	.61	.12	Color identification for List 2 words
d1, d2	.04		Intrusion rate (yoked across cells)

FIGURE CAPTION

Figure 1. Multinomial model for List 1 (Figure 1A) and List 2 (Figure 1B) words. Parameters D1 and D2 refer to detect rates for List 1 and List 1 words. Parameters L1 and L2 refer to list discrimination rate for List 1 and List 2 words. Parameters e1 and e2 refer to bias toward responding that the word belongs to List 1 and List 2, respectively. Parameters C1 and C2 refer to case (Exp. 1) and color (Exp. 2) identification rate. Parameters d1 and d2 refer to intrusion rates (guessing that a new word is old) for List 1 and List 2 respectively. The nodes labeled ".5" refer to the probability of guessing the correct case or color. Labels at the bottom indicate the response produced by each pathway, e.g., L1C = List 1 correct case/color, L1IN = List1 incorrect case/color, N = no response (list word not circled), Intrusion = new word circled as old.

FIG. 1

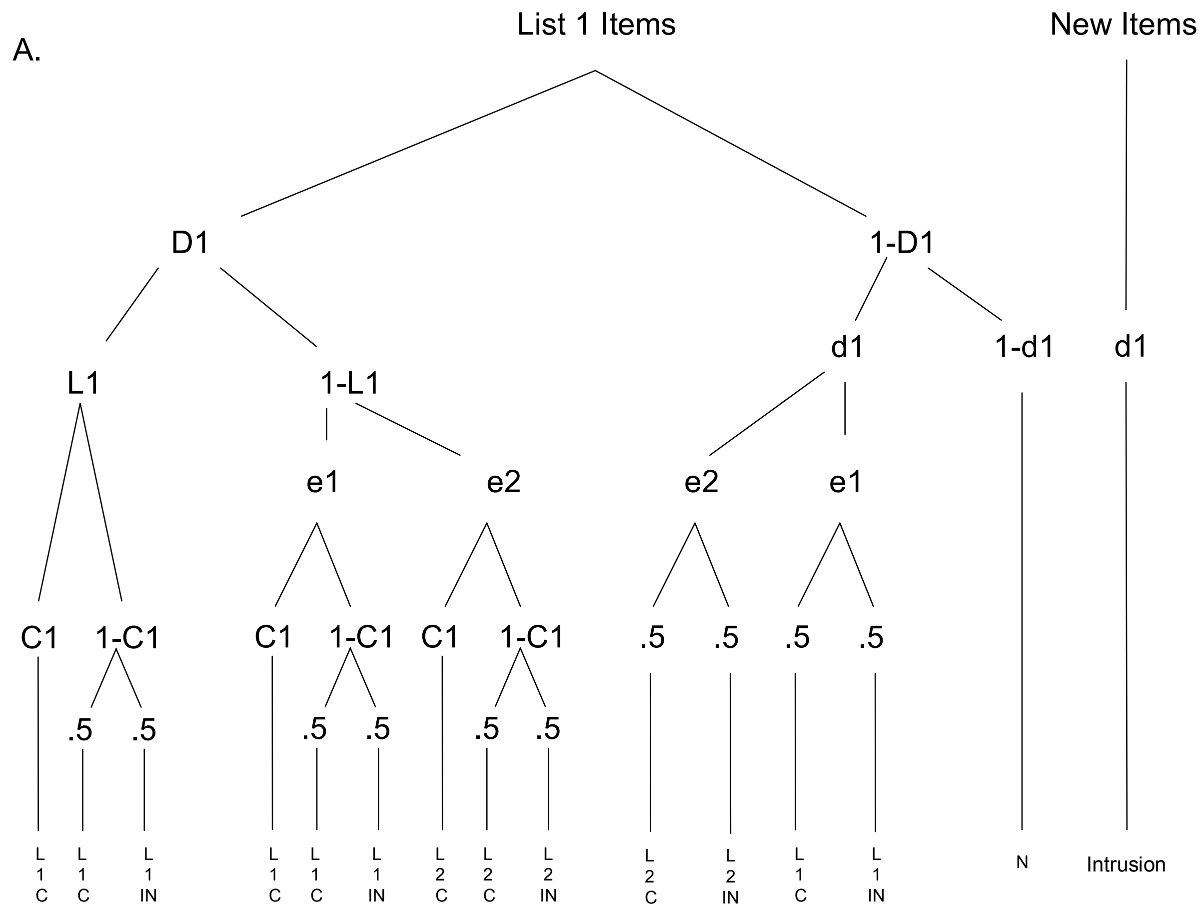
A.
List 1 Items
New Items
D1
1-D1
L1
1-L1
d1
1-d1
d1
e1
e2
e2
e1
C1
1-C1
C1
1-C1
C1
1-C1
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
L1C
L1C
L1IN
L1C
L1C
L1IN
L2C
L2C
L2IN
L2C
L2IN
L1C
L1IN
N
Intrusion

FIG. 3A

B.

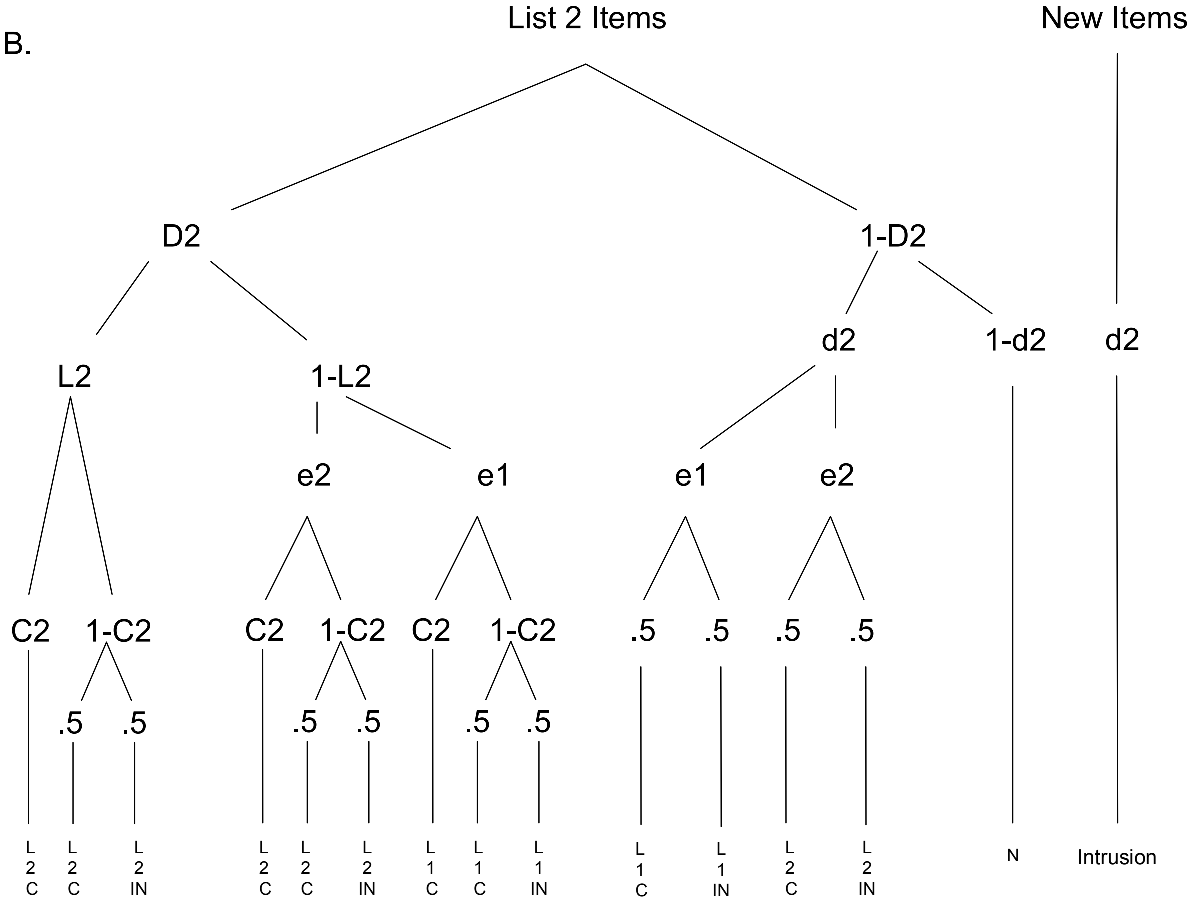
List 2 Items
New Items
D2
1-D2
L2
1-L2
d2
1-d2
d2
e2
e1
e1
e2
C2
1-C2
C2
1-C2
C2
1-C2
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
L2C
L2C
L2IN
L2C
L2C
L2IN
L1C
L1C
L1IN
L1C
L1IN
L2C
L2IN
N
Intrusion

FIG. 3B

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