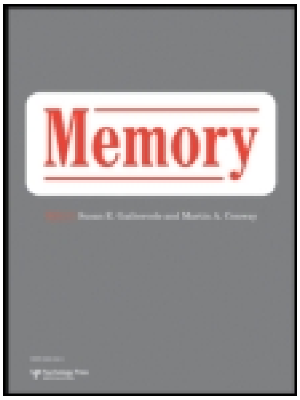

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Evidence for noisy contextual search: Examining the dynamics of list-before-last recall

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Evidence for noisy contextual search: Examining the dynamics of list-before-last recall

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The dynamics of free recall in the list-before-last task were examined in the current study. List-length was manipulated and probability of recall was influenced by target list-length but not by intervening list-length. Participants also performed free recall on control lists matched on target list-length. Critically, list-before-last recall was worse than recall on the control list, suggesting that the mere presence of an intervening list reduced recall. An examination of intrusion errors suggested that participants recalled both prior and intervening list intrusions and retrieval was influenced by the length of the intervening list-length. Finally, an examination of recall latency suggested that target list-length, but not intervening list-length, influenced recall dynamics. However, recall latency in list-before-last recall was longer than in the control lists, suggesting that the mere presence of intervening list influenced recall latency. Taken together, the results are consistent with the notion that in list-before-last recall participants rely on noisy contextual cues that activate both target and non-target items, leading to an increase in their search sets.

Keywords: Free recall; Recall latency; Intrusions.

The ability to recall information from the recent past is an important feature of the memory system. In particular, studies of free recall suggest that individuals are quite adept at selectively targeting items from the most recently presented list. As such, many memory models assume that context (in particular temporal context) plays a large role in allowing the memory system to selectively focus the search such that only a subset of relevant items (the search set) are activated (Anderson & Bower, 1972; Howard & Kahana, 2002; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1980). In such models it is assumed that the search set is determined, in part, by the match between context stored in the items and the context present during retrieval such that the greater the overlap between the two, the more likely an item has in being included in the search set and subsequently recalled (e.g., Mensink & Raaijmakers, 1988). Thus context at retrieval acts as the primary cue and dictates the extent to which relevant items will be recalled. However, what happens when the current context does not match context stored with the desired information? How does the system go about trying to retrieve that prior information? For instance, if asked, ‘‘What did you have for lunch two Tuesdays ago?’’ it is unlikely that your current context would provide much of a match to the context for the Tuesday in question, and thus it should be very difficult to retrieve the desired information if utilising only the current context. Rather, we must somehow attempt to reinstate the prior context to retrieve the desired information. In the current study we examined the nature of recall in the list-before-last

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paradigm (Shiffrin, 1970a) in an attempt to better understand how we utilise context to search for prior memories.

LIST-BEFORE-LAST RECALL

In order to examine whether forgetting was due to trace erosion or retrieval failures, Shiffrin (1970a) devised the list-before-last recall task. In this task participants are asked not to recall the current list of items, but rather to recall the prior list of items. That is, participants are given a list of items, followed by another list of items, and at recall participants are asked to recall the prior list, with the prior and current lists changing with each new list that is presented. Additionally, Shiffrin manipulated both the length of the target list and the length of the intervening list such that sometimes the lists were composed of 5 items and sometimes they were composed of 20 items. Shiffrin reasoned that if forgetting is due to trace degradation due to either decay (the amount time that has passed between presentation and recall) or similarity based interference, then the length of the intervening list should matter, with longer lists leading to more forgetting than shorter lists. If, however, forgetting is due to retrieval failures, then the length of the intervening list should not necessarily matter—rather only the length of the target list should matter, with longer target lists leading to more forgetting than shorter target lists. Consistent with a retrieval failure view, in three experiments Shiffrin found that the length of the target list mattered, but the length of the intervening list had no effect. Shiffrin concluded that participants could focus their search exclusively on the target list (and completely exclude the intervening list) and thus only the size of target list determined the likelihood of recall.

Subsequent studies have largely corroborated Shiffrin's (1970a) findings (although see Smith, 1979). Specifically, in their Experiment 1 Ward and Tan (2004) essentially replicated Shiffrin's findings suggesting that probability of recall was affected by the size of the target list and was unaffected by the size of the intervening list. Using an overt rehearsal procedure in their Experiment 2 Ward and Tan again replicated these effects and further demonstrated that some of the time participants selectively rehearsed target words during the presentation of the intervening list. Ward and Tan took this as evidence that possibly participants were relying on recency information and that recall of target list items were based on how recently those items were rehearsed relative to the recall period. Finally, in their Experiment 3 Ward and Tan found an effect of intervening list-length when participants were cued after list presentation to recall either the current list or the prior list. Specifically, participants tended to recall more words when the intervening list was short compared to when the intervening list was long. Furthermore, in a control condition where participants were given only a single list and asked to recall it, Ward and Tan found that performance was much better than when an intervening list was presented, suggesting that retroactive interference seemed to play a role in recalling the prior list. Thus in two of their experiments there was no evidence for an effect of intervening list-length, yet in a third experiment intervening list-length seemed to have an effect, suggesting that participants could not completely exclude the intervening list.

Recently Jang and Huber (2008) sought to reconcile these discrepant findings by suggesting that testing between lists as in the original Shiffrin (1970a) study led to a change in context allowing for the target list to be isolated and hence no effect of the intervening list. In contrast, Jang and Huber suggested that in Ward and Tan's (2004) third experiment, in which there was no testing between lists, there was an effect of intervening list-length because context was not sufficiently changed and thus the target list was not isolated. To test this, Jang and Huber had participants perform the list-before-last task with either testing occurring between lists or with no testing occurring between the lists. Jang and Huber found that when testing occurred between lists, the results replicated Shiffrin (1970a) and Ward and Tan's (2004) first two experiments suggesting that the size of the intervening list had no effect on the probability of correct recall. However, when there was no testing between lists the results replicated Ward and Tan's (2004) third experiment, suggesting that the size of intervening list did have an effect. In order to account for these results, Jang and Huber suggested that on some retrieval attempts participants can correctly reinstate the target list context leading to an effect of target list-length, but no effect of intervening list-length. On other retrieval attempts participants cannot effectively reinstate the target list context, and thus rely on context present during recall, which activates the intervening list to a greater extent than the target lists given that the intervening list should have more contextual overlap with the recall period than the target list. In this case the size of the intervening list-length does affect recall probability. Thus participants can effectively retrieve from only the target lists some of the time and this is especially true when testing occurs between lists. However, when there is no testing between the lists, participants must rely on context present during the recall period as a cue leading to more interference from the intervening list and the recall of intrusions from the intervening list (e.g., Jang & Huber, 2008; Smith, 1979).

DYNAMICS OF FREE RECALL

The work reviewed thus far has focused almost exclusively on probability of correct recall. However, an examination of recall latency can also be informative in terms of better understanding how participants search for target items in free recall tasks. Recall latency refers to the time point during the recall period when any given item is recalled, and mean recall latency is simply the average time it takes to recall items. For instance, if items are recalled 5 s, 10 s, and 15 s into the recall period, mean recall latency would be 10 s. Prior work has suggested that recall latency distributions provide important information on the dynamics of free recall. In particular, prior work (Bousfield & Sedgewick, 1944; Indow & Togano, 1970; Roediger, Stellon, & Tulving, 1977; Rohrer & Wixted, 1994) has suggested that cumulative recall curves are well described by a cumulative exponential

$$F(t) = N\left(1 - e^{-\lambda t}\right), \tag{1}$$

where *F(t)* represents the cumulative number of items recalled by time t, N represents asymptotic recall, and λ represents the rate of approach to asymptote. Thus, if given enough time to recall, N should equal (or be roughly equal to) the number of items recalled (or probability of recall). However, these items can be recalled either quickly or slowly and this information is captured by λ. Specifically, when items are recalled quickly during the recall period λ is relatively large, whereas when items are recalled slowly during the recall period λ is relatively small. Thus cumulative recall curves provide information not only on how many items are recalled, but also information on how quickly those items are retrieved. Importantly, overall mean recall latency is simply the inverse of λ when the cumulative functions are perfectly exponential (e.g., Wixted, Ghadisha, & Vera, 1997), and thus it is possible to either estimate recall latency from λ or to compute it directly from the latencies associated with each recalled item.

Overall recall latency distributions are consistent with search models of free recall (Rohrer, 1996; Shiffrin, 1970b). In these models it is assumed that during recall a retrieval cue activates a subset of representations in memory that are related to the cue in some fashion. This delimited subset is known as the *search set* and, during recall, item representations are sampled (with replacement) from the search set based on a relative strength rule (Raaijmakers & Shiffrin, 1980; Rohrer, 1996; Shiffrin, 1970b). Specifically, in search models of this type the probability of sampling any particular item is equal to the strength of the item divided by the sum of all item strengths within the search set (e.g., $s_i/\Sigma\, s_j$). After an item has been sampled it must then be recovered into consciousness. In these search models recovery of an item depends on the item's absolute strength rather than on its relative strength. Specifically, items whose strength exceeds some critical threshold will be recovered and can be recalled, whereas weak items that do not exceed the threshold will not be recovered (Rohrer, 1996). Important for models of this type is the notion that all items can be sampled, but only those items whose strength exceeds the threshold can actually be recalled. Thus it is possible to differentiate these two aspects of recall (sampling and recovery). Finally, after an item has been recovered, it is subjected to a monitoring and editing process that determines whether the item is correct and recalled, or incorrect and not recalled.

According to search models of this type, N reflects the number of target items in the search set whose absolute strength exceeds some threshold (i.e., the numerator in the relative strength rule; e.g., Rohrer, 1996). Recall latency, and λ, reflects the number of items within the search and thus reflects relative strength (i.e., the denominator in the relative strength rule). Thus the larger the search set, the longer on average it will take to recall any given item. Importantly, evidence for this type of model as well as for a distinction by N and λ comes from a number of studies that have manipulated aspects of free recall and found that some variables affect *N*, but have no effect on λ, whereas other variables seem to primarily affect λ. For instance, Rohrer and Wixted (1994) manipulated presentation duration and found that this manipulation affected the number of items recalled (*N*), but had no effect on recall latency (λ). Consistent with search model explanations of the presentation duration (e.g., Gillund & Shiffrin, 1984) this is because presentation duration affected the absolute strength of each item, but did not effect the relative strength of items (i.e., all items had the same boost in strength and thus relative strength was unchanged). In another experiment Rohrer and Wixted (1994) manipulated list-length and found that as list-length increased, the number of items recalled increased (although probability correct decreased), and recall latency increased. This is consistent with the notion that as list-length increased, relative strength decreased leading to a drop in probability of recall and an overall increase in recall latency. Further evidence consistent with this notion comes from a study by Wixted and Rohrer (1993) that examined the build and release of proactive interference. In this study Wixted and Rohrer found that as proactive interference increased and probability of recall subsequently decreased, overall recall latency increased. Similar to the list-length effects, this is presumably because as proactive interference built up, more items were included in the search set, and relative strength decreased (i.e., the denominator increased in the relative strength rule). Thus, although N decreased, this was due to a change in relative strength rather than absolute strength given that the search set was likely composed of both target items and intrusions from prior lists. Indeed, in a recent large-scale individual differences study Unsworth (2009) found that recall latency and number of intrusions were positively correlated, whereas both were negatively correlated with recall accuracy. This suggests that the inclusion of intrusion errors into the search set causes an overall increase in search set size leading to a lower probability of sampling target items and increase in the average time to sample target items. Collectively, the results from these studies suggest that recall latency provides an index of overall search set size (see also Shiffrin, 1970b).

THE PRESENT STUDY

The goal of the present study was to examine how individuals recall information from the recent past when other, intervening information better matches context present during retrieval. In particular we were interested in examining four different possible explanations of how individuals search for information within the list-before-last paradigm. In each case predictions for overall probability of recall, recall latency, and intrusions will be given in order to examine which possibility provides the best account of the data. Importantly, as will be seen, each view predicts a different pattern of results in terms of the different recall measures. Thus it is the overall pattern of results across measures, rather than any one measure (i.e., probability of recall) that distinguishes the different views.

The first view, which we will call the *Recent Context view*, suggests that participants rely on context present at recall to search for items (e.g., Jang & Huber, 2008; Ward & Tan, 2004). Items whose context matches context present at recall will receive the strongest activation and will be the most likely to be sampled and recalled. Thus recently presented items will likely share the most context with the retrieval cue and should be the most likely to be recalled. In the list-before-last paradigm this suggests that, in order to search for items from the prior list, participants would search back in time using the recall context as a cue and thus would activate items from the target list as well as all items from the most recently presented intervening list. That is, the search set includes all of the target items as well as all of the intervening items. This predicts that the size of the intervening list should affect probability of recall, recall latency, and number of intrusions to the extent that all items are being included in the search set. Specifically, the larger the intervening list the larger the overall search set size should be, leading to a lower probability of sampling target items, a longer on average time to sample target items, and a greater probability of sampling intrusions from the intervening list. Thus this view predicts that intervening list-length should matter and it should affect all of the recall variables. As noted previously, support for this view largely comes from studies in which there was no testing between lists (e.g., Jang & Huber, 2008; Ward & Tan, 2004) although work by Smith (1979) has also suggested that the size of the intervening list can affect probability of recall and number of intrusions even with tests between lists. Thus, although most of the work with the list-before-last paradigm has not supported this view, there is some evidence to suggest that it is possible.

The second view, the *Isolated Context view*, suggests that at recall participants reconstruct or reinstate the target list context sufficiently such that the target list is isolated and probability of recall is driven by the size of the target list with no interference from the intervening list (Shiffrin, 1970a; see also Klein, Shiffrin, & Criss, 2007; Shiffrin, 1971). Thus this view suggests that the size of the search set is wholly determined by the size of the target list and there is no influence from the intervening list. That is, the search set is correctly delimited to only the target list and the search set includes only target list items. This predicts that probability of recall and recall latency should be driven by the list-length of the target list (leading to list-length effects) and nothing else. That is, longer target list-lengths should have lower probabilities of recall and longer recall latencies than short list-lengths (Rohrer & Wixted, 1994). Importantly, this view predicts that the size of the intervening list-length should not matter and there should be no intrusions. Furthermore, this view predicts that probability of recall and recall latency should be the same (for a given list-length) when one is required to recall the prior list or from a control list. That is, if there is no interference from the intervening list and participants can isolate their search to only the target list, then probability of recall and recall latency should be the same when asked to recall the prior list as well as when asked to recall control lists with no intervening list (e.g., Shiffrin, 1971). As noted previously, most of the prior work examining list-before-last recall has provided support for this view in that the size of the intervening list does not matter (at least when testing is required between lists). Problematic for this view, however, is the finding that participants do emit intrusions from the intervening list, suggesting that the target list is not perfectly isolated (e.g., Jang & Huber, 2008; Smith, 1979).

The third view, the *Mixed Context view*, suggests that both the *Recent Context* and *Isolated Context* views are correct to some extent (Jang & Huber, 2008). Specifically, this view suggests that individuals either correctly reinstate the target list context and isolate only the target list, or they cannot reinstate the target list context and instead rely on context present during recall. Thus participants rely on a mix of different contexts throughout recall. On some retrieval attempts participants delimit the search set to only the target list. On other retrieval attempts participants cannot properly reinstate the target list context and thus participants must rely on context present during recall to search for items. This view therefore predicts that sometimes the intervening list-length should matter (when the target list is not isolated as when there are no tests between lists) and other times it should not (when the target list is isolated as when there are tests between lists). In terms of the classic list-before-last paradigm where there are tests between lists, this view essentially predicts the same results as the *Isolated Context view*, in that the intervening list-length should not affect probability of recall, recall latency, or intrusions. But, given that there should still be a small amount of mixing, this view also predicts that prior list recall should sometimes be affected by intervening items, leading to slightly longer recall latencies and, at least, some intrusion errors. That is, on those occasions where the target list context could not be reinstated, participants will rely on the current context at recall leading to increases in recall latency and a greater likelihood of recalling intrusions.

An alternative to these views, which we call the *Noisy Context view*, suggests that participants are generally able to reconstruct the target list context but this reconstruction is noisy, leading to the inclusion of not only some intervening items (those whose context is similar to the prior list) but also items from the list recalled just prior to the target list. That is, like the *Isolated Context view*, we suggest that participants can generally reconstruct the context for the prior list, but given that there is some uncertainty about which items were actually presented on that list relative to other list items (intrusions), participants cast a wider net to ensure that the target information will be included in the search set. The search set is centred on the target information but other, contextually similar, information is also activated and included in the search set. Thus the reconstruction of context is noisy, leading to a slightly larger than normal (that is, relative to control lists) search set that encompasses target items, intervening intrusions, as well as intrusions from the list prior to the target list. Because this view is a variant of the *Isolated Context view*, it predicts that there should be no effect of intervening list-length given that it is not the size of the intervening list that matters, but rather what matters is that there is an intervening list. Thus intervening list-length should not account for probability correct or recall latency just like the *Isolated Context view*. However, both of these should be affected by the presence of an intervening list such that probability correct should be lower and recall latency should be longer compared to control lists (cf. the *Isolated Context view*). Furthermore, in terms of intrusion errors, this view predicts that not only should participants intrude items from the intervening list, but participants should also intrude items from the list immediately preceding the target list. Thus both retroactive and proactive interference should be occurring for the target list, leading to resulting in changes in probability of recall, recall latency, and intrusions.

Initial evidence for examining these different views comes from Ward and Tan's (2004) Experiment 3, in which participants were given two lists and were either instructed to recall the prior list or the current list, and performance on these lists was compared with control lists where only one list was presented. Important for the current discussion is the fact that Ward and Tan examined the cumulative recall of items throughout the recall period. Although Ward and Tan did not actually fit the cumulative exponential to their cumulative curves and estimate N and λ, we estimated the data from their Figure 5 and fitted the cumulative exponential to the data. Shown in Figure 1 are the data for target list-lengths of 20 for the control list (20), a target list-length of 20 followed by a list-length of 5 (20–5), and a target list-length of 20 followed by a list-length of 20 (20–20). As reported by Ward and Tan (2004), when there was an intervening list, performance was worse compared to the control list. That is, N was larger for the control list ($N = 4.54$) compared to when either a short list intervened ($N = 1.90$) or when a long list intervened ($N = 1.56$). Furthermore, as shown in Figure 1, participants reached asymptotic performance faster for the control list compared to when an intervening list was presented. Specifically, λ was larger for the control list ($\lambda = .12$) compared to when either there was a short intervening list ($\lambda = .09$) or a long intervening list ($\lambda = .08$). Indeed, estimating recall latency from λ, suggests that mean recall latency was approximately 3–4 s faster for control lists compared to when an intervening list was presented. Thus this provides initial evidence for the notion that participants

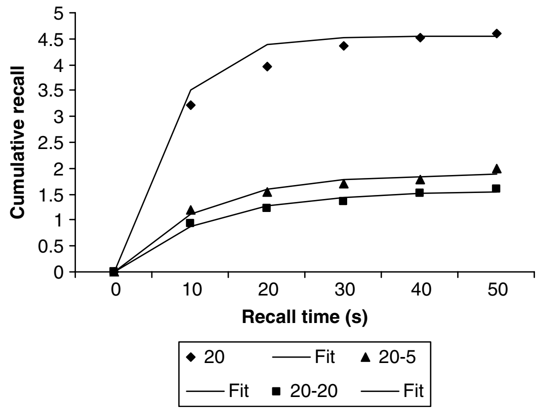

Figure 1. Cumulative recall functions for target list-lengths of 20 with no intervening list (20), a 5-item intervening list (20–5), or a 20-item intervening list (20–20) from Ward and Tan (2004). The symbols represent the observed data (estimated from their Figure 5), and the solid lines represent the best fitting exponential (Equation 1).

could reconstruct the target list, but that the intervening list interfered somewhat compared to control lists, consistent with the *Mixed* and *Noisy Context* views. At the same time the results also provide evidence that the size of the intervening list matters. That is, as reported by Ward and Tan there is a clear effect of size of intervening list on probability of recall, and hence N. Likewise, our fits suggest that λ was larger when there was smaller intervening list, suggesting that larger intervening list-lengths led to larger search sets. Thus, these analyses are consistent with nearly all the views except for the *IsolatedContext* view.

However, as noted previously, one potential issue with these results is that there was no testing between the lists. Furthermore, there was no examination of intrusions. Thus, in order to fully examine the four views, we had participants perform a more traditional version of the list-before-last paradigm (i.e., tests between lists), and like Ward and Tan we included control lists to better determine if the presence of an intervening list would affect performance. Furthermore we directly measured recall latency in each condition to better test for possible differences in the conditions. Likewise intrusions (both prior-list and intervening list) were examined to determine which types of intrusions were recalled and whether this changed as a function of condition. Importantly, no prior study has directly examined recall latency as well as both prior-list and intervening list intrusions in the context of the list-before-last task. As noted previously, an examination of all three recall variables should provide the best evidence in favour of one of these views or possibly an as yet unspecified alternative view.

METHOD

Participants and design

Participants were 24 undergraduate students recruited from the subject-pool at the University of Georgia. Participants were between the ages of 18 and 35 and received course credit for their participation. Words were nouns selected from the Toronto word pool (Friendly, Franklin, Hoffman, & Rubin, 1982). Words were initially randomised and placed into the lists and all participants received the exact same lists of words. There were two within-participant factors. These were length of the target list (5 or 20 words) and length of the intervening list (0, 5, or 20 words). In the list-before-last component of the task there were 13 lists in the order of 5–20–20–5–5–20–20–5–5–20–20–5–5, and participants were tested for the prior list after the presentation of each list (e.g., Ward & Tan, 2004). Note that there was no test for the last presented list. For the control component of the task participants were asked to recall each list after its presentation and participants received six lists in the order of 5–20–5–20–5–20. Thus there were three lists for each within-subjects condition.

Procedure

Participants were tested individually. Items were presented visually alone for 1 s each with a 1-s blank screen in between the presentation of each word. First participants performed the list-before-last component and then they performed the control task. In the list-before-last component all participants were given lists of varying lengths and during recall were instructed to recall the list prior to the mostly recently presented list. In the control component participants were given lists of varying lengths and were instructed to recall items from the mostly recently presented list. In all conditions participants had 60 s to recall as many words from the prior list as possible. Participants typed their responses and pressed Enter after each response clearing the screen.

RESULTS

Proportion recalled

First we examined proportion of correct items recalled from the target lists as a function of length of target list (5 or 20) and length of the intervening list (0, 5, or 20). As can be seen in Figure 2, there was an effect of target list-length in which a greater proportion of items were recalled from the 5-item target list than from the 20-item target list, $F(1, 46) = 427.81$, $MSE = .02$, $p < .01$, $\eta^2_p = .95$. There was also an effect of length of intervening list, $F(2, 46) = 73.65$, $MSE = .02$, $p < .01$, $\eta^2_p = .76$. As can be seen, for both target list-length conditions a greater proportion of items were recalled when there was no intervening list (i.e., 0) than when there was an intervening list, $t(23) = 10.03$, $p < .01$. However, there was no difference as a function of length of intervening list when there was an intervening list, $t(23) = 1.74$, $p > .09$. Finally there was a significant target length by intervening length interaction, $F(2, 46) = 15.17$, $MSE = .01$, $p < .01$, $\eta^2_p = .40$, suggesting that the influence of an intervening list affected short target list-lengths more than long target list-lengths. Thus these results suggest that an intervening list hurt performance compared to control lists where there was no intervening list. Furthermore, it does not seem like the length of the intervening list mattered.

To examine this more thoroughly, and to ensure that we replicated prior results (e.g., Shiffrin, 1970a), we only examined list-before-last recall as function of target list and intervening list. That is, we reran the analyses excluding the control lists. Consistent with prior research, these analyses suggested that there was only an effect of

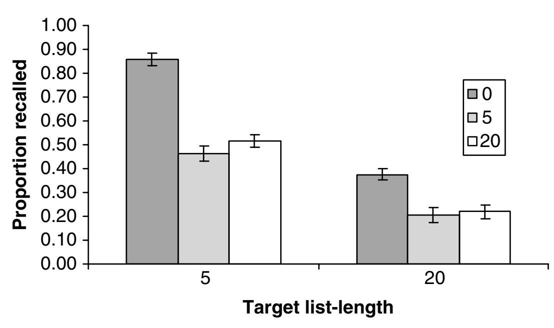

Figure 2. Proportion recalled as a function of target list-length (5 or 20) and intervening list-length (0, 5, or 20). Error bars represent one standard error of the mean.

target list-length, $F(1,\ 23) = 148.32$, $MSE = .01$, $p < .01$, $\eta_p^2 = .87$, and no effect of intervening list-length or an interaction, both *p*s > .10. Thus the current results replicated prior work suggesting the probability of recall is due to the length of target list and there is no effect of the length of the intervening list (Jang & Huber, 2008; Shiffrin, 1970a; Ward & Tan, 2004). However, although the length of the intervening list did not matter, the mere presence of an intervening list did matter (e.g., Ward & Tan, 2004; cf. Shiffrin, 1971), suggesting that there was some retroactive interference from the intervening list.[1]

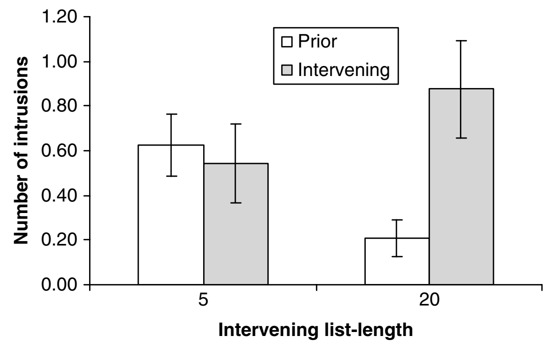

Figure 3. Number of intrusions as a function of intervening list-length (5 or 20) and lag (prior vs intervening list). Error bars represent one standard error of the mean.

Intrusions

Next we examined the intrusions in the list-before-last task as a function of lag (prior or intervening list intrusion), target list-length (5 or 20), and intervening list-length (5 or 20). There was a marginal effect of lag with slightly more intrusions coming from the intervening list ($M = .71$, $SE = .17$) than the prior list ($M = .42$, $SE = .08$), $F(1,\ 23) = 3.93$, $MSE = .52$, $p < .06$, $\eta_p^2 = .15$. Additionally, as shown in Figure 3, there was a significant lag (Prior vs Intervening) by intervening list-length (5 vs 20) interaction, $F(1,\ 23) = 6.75$, $MSE = 1.05$, $p < .05$, $\eta_p^2 = .22$. Specifically, when the intervening list-length was short there was no difference between prior and intervening intrusions, $t(23) = .41$, $p > .68$. However, when the intervening list-length was long, there were more intervening list intrusions than prior list intrusions, $t(23) = 3.08$, $p < .01$. No other effects reached conventional levels of significance, all *p*s > .36.

Recall latency

Our final set of analyses focused on recall latency. First in these analyses we examined cumulative recall functions for each of the conditions. The observed cumulative recall functions for each condition were fit by a cumulative exponential according to least-squares estimation procedure. All of the fits were acceptable with the functions each accounting for 94–99% of the variance and Kolmogorov-Smirnov tests were non-significant ($p > .43$).[2] Shown in Figure 4a are the cumulative recall functions for when the target list-length was 5 items and shown in Figure 4b are the cumulative recall functions for when the target list-length was 20 items. As can be seen, when there was an intervening list, fewer items were recalled compared to when there was no intervening list. Furthermore, when there was an intervening list, rate of approach to asymptotic performance (λ) was slightly slower compared to when there was no intervening list. Shown in Table 1 are the parameter estimates for each condition after fitting a cumulative exponential to the cumulative recall curves. As can be seen, λ was smaller when there was an intervening list compared to when there was no intervening list. However, there was no difference in λ as a function of the size of the intervening list. Although slight, these differences in λ suggest that mean recall latency was increased by a few seconds when there was an intervening list compared to when there was no intervening list. Finally, consistent with prior research (Rohrer & Wixted, 1994; Unsworth, 2007) there are clear list-length effects such that λ decreased as overall list-length increased.

To get a better sense of the data we directly computed mean recall latency for each participant in each condition. This provides a more direct examination of differences in recall latency than the cumulative recall functions and also for direct

[1]All of the proportion recalled analyses were redone using raw total number of correct items recalled. All of the results were identical to those reported. Because prior research has mostly focused on proportion recalled we report those results in order to maintain consistency across studies.

[2]Note that although the cumulative exponential fit the data well, there are clear systematic deviations of fit. Specifically, the cumulative exponential tends to miss the early part of the curve. As shown by Vorberg and Ulrich (1987) this pattern is expected when item strengths vary and recall is not entirely random. Despite these variations the simple search model still provides a useful interpretation of the data.

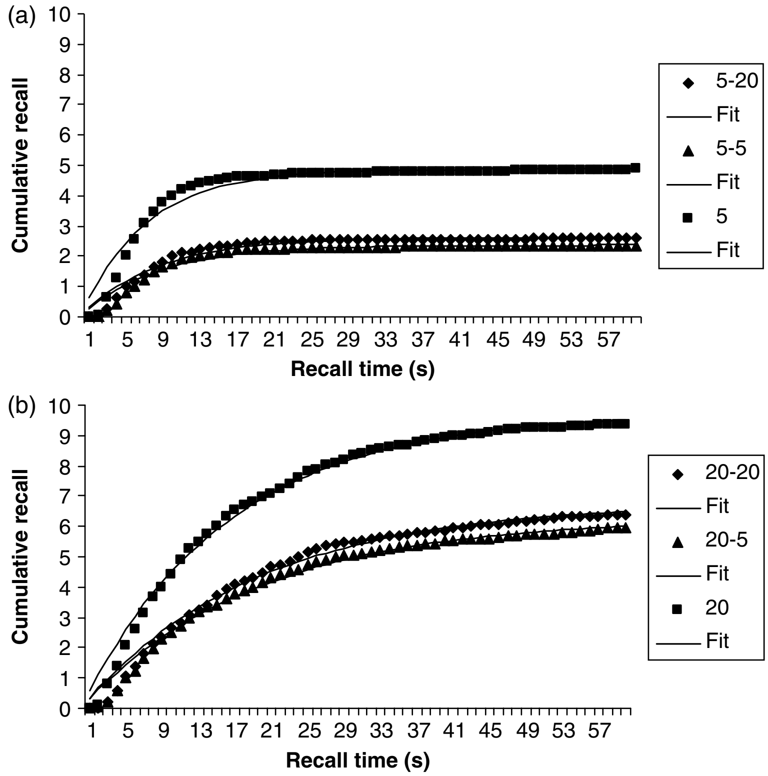

Figure 4. (a) Cumulative recall functions for target list-lengths of 5 with no intervening list (5), a 5-item intervening list (5–5), or a 20-item intervening list (5–20). The symbols represent the observed data, and the solid lines represent the best fitting exponential (Equation 1). (b) Cumulative recall functions for target list-lengths of 20 with no intervening list (20), a 5-item intervening list (20–5), or a 20-item intervening list (20–20). The symbols represent the observed data, and the solid lines represent the best fitting exponential (Equation 1).

statistical comparisons between conditions. Recall latency was examined as a function of length of target list (5 or 20) and length of the intervening list (0, 5, or 20). As can be seen in Figure 5, there was an effect of target list-length in which recall latency was shorter for the 5-item target list than for the 20-item target list, $F(1, 46) = 135.42$, $MSE = 15110000$, $p < .01$, $\eta_p^2 = .86$. There was also an effect of length of intervening list, $F(2, 46) = 9.87$, $MSE = 15110000$, $p < .01$, $\eta_p^2 = .30$. As can be seen, for both target list-length conditions recall latency was shorter when there was no intervening list (i.e., 0) than when there was an intervening list, $t(23) = 4.12$, $p < .01$. However, there was no difference as a function of length of intervening list when there was an intervening list, $t(23) = .177$, $p > .86$. The interaction did not reach conventional levels of significance, $F < 1$. These results suggest that an intervening list increased recall latency compared to control lists where there was no intervening list. Furthermore, the length of the intervening list did not matter.

An examination of only list-before-last recall suggested a significant effect of target list-length, $F(1, 46) = 49.21$, $MSE = 12700000$, $p < .01$, $\eta_p^2 = .68$, suggesting that the length of the target list mattered, but there was no difference as a function of intervening list-length. No other effects reached conventional levels of significance, all Fs < 1.

TABLE 1
Parameter estimates obtained from fitting the cumulative recall curves to a cumulative exponential

Condition	λ	*N*	*VAF*
5	.14	4.88	.94
5–5	.12	2.37	.94
5–20	.12	2.62	.95
20	.06	9.75	.99
20–5	.05	6.28	.99
20–20	.05	6.79	.99

The first number in the condition column indicates target list-length. λ = rate of approach to asymptotic performance; N = asymptotic performance; VAF = variance accounted for.

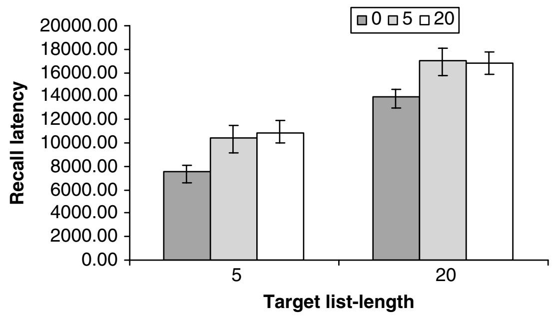

Figure 5. Mean recall latency as a function of target list-length (5 or 20) and intervening list-length (0, 5, or 20). Error bars represent one standard error of the mean.

GENERAL DISCUSSION

The present experiment was concerned with examining possible explanations for recall in the list-before-last paradigm. Participants performed the list-before-last task with target list-lengths of either 5 or 20. In addition participants were tested on control lists of either 5 or 20 items. Probability of recall results replicated prior work (Jang & Huber, 2008; Shiffrin, 1970a; Ward & Tan, 2004) demonstrating that the length of the target list influenced list-before-last recall, but the length of the intervening list did not. Examining list-before-last recall and recall on the control list suggested that, although the size of the intervening list did not matter, the mere presence of an intervening list did reduce probability of recall (retroactive interference) consistent with prior work by Ward and Tan (2004).

An examination of both prior list and intervening list intrusions in list-before-last recall suggested that participants emitted both prior list and intervening list intrusions. Furthermore, these results suggested that when the target list-length was short (i.e., 5 items) participants recalled an equal number of prior and intervening list intrusions. However, when the target list-length was long (i.e., 20 items) participants were more likely to recall intervening list items than prior list items. Thus participants not only recalled intervening list intrusions (Jang & Huber, 2008; Smith, 1979), but participants also recalled prior list intrusions, and the tendency to recall the two types of intrusions differed as a function of intervening list-length. This suggests that the length of intervening list influenced which type of intrusion was included in the search set.

Finally an examination of recall latency suggested that participants recalled items at a faster rate when the target list-length was short than when target list-length was long (Rohrer & Wixted, 1994; Unsworth, 2007). Additionally, consistent with the probability of recall results, intervening list-length did not affect recall latency (cf. Ward & Tan, 2004). However, the mere presence of an intervening list did influence recall latency such that items were recalled at a faster rate in the control lists compared to list-before-last recall.

Although the data are not in complete agreement with any one view, the results seem to be most consistent with the *Noisy Context view*. Specifically, the *Noisy Context view* suggests that participants reconstruct the target list context, but this reconstruction is noisy to the extent that both prior and intervening list items are included in the search set. Thus probability of recall is reduced in list-before-last recall because prior and intervening list items are included in the search set thereby reducing relative strength compared to control lists. Likewise this view predicts that not only should intervening list items intrude, but so should prior list items to the extent that the search set will be centred on the target list, but items presented (or recalled) in close temporal proximity to the target list will also be included in the search set. Importantly, not all intruding items will be in the search set, but rather only those items that share enough contextual features will be included. Finally, given that intrusions are included in the search set and relative strength has decreased, this view predicts that recall latency should be longer for list-before-last recall than for control lists. That is, given that the search set is larger in list-before-last recall than the control lists, overall recall latency should be longer and participants' rate of approach to asymptotic performance should be slower. As reviewed above, the pattern of data reported herein were very much in line with predictions from the *Noisy Context view*. One problem for the *Noisy Context view*, however, was the finding that the size of the intervening list-length did have an influence on the type of intrusions recalled. Specifically, when the intervening list-length was long, more intervening list intrusions were recalled than prior list intrusions. Thus this suggests that the size of the intervening list does have some influence on what is included in the search set. As yet it is unclear how the *Noisy Context view* would be able to account for this pattern of results.

For the most part the results are generally not consistent with the other accounts of list-before last recall. In particular, the results are inconsistent with the *Recent Context view* given that this view suggests participants rely on context present during the recall period. As such this view predicts that the size of the intervening list should matter for probability of recall and recall latency. However, length of the intervening list did not affect either of these variables in list-before-last recall in the current study. As noted by Jang and Huber (2008) such a view is consistent with results from list-before-last recall, when there is no testing between lists. Thus, although this view can be ruled out for the current results, the *Recent Context view* is still important when examining recall when there is no dramatic difference between the current context and the target context.

The results are also inconsistent with the *Isolated Context view*, given that this view suggests that participants can fully reinstate the target list context and exclude the other lists. This view predicts that probability of recall and recall latency should be wholly determined by the target list-length with no influence from the intervening list-length. Furthermore, this view predicts that list-before-last recall and recall from control lists should be equivalent in terms of both probability of recall and recall latency (Shiffrin, 1971). Likewise, this view predicts that there should be no intrusions from either the prior list or the intervening list. Although the *Isolated Context view* correctly predicts that the length of the intervening list should not matter, the fact that participants do recall intrusions and the fact that list-before-last recall is not equivalent with recall from control lists is inconsistent with this view.

Finally, the results are generally inconsistent with the *Mixed Context view*, given that this view suggests that when there is testing between the lists (as was done in the current experiment) recall should be in line with the *Isolated Context view* and the predictions should be the same. Given that the results are inconsistent with the *Isolated Context view*, the *Mixed Context view* would seem to be ruled out as well. However, it is possible that the *Mixed Context view* is still viable if we assume that for the most part the target list is isolated, but on a small subset of trials participants rely on recent context. Thus, on some trials (or some retrieval attempts), probability of recall would be reduced and recall latency would be increased compared to control lists. This small proportion of trials (or recall attempts) might be enough to generate the observed pattern of results. However, one additional assumption would have to be added to this view to obtain the full pattern of results. Namely, it would have to be assumed that on some trials (or retrieval attempts) participants reinstated the context for the prior list allowing for prior list intrusions, and the probability that this was done would have to be contingent on the intervening list-length. Thus, an additional mixing component would have to be added to this view to account for observed results. Furthermore, because the current study exclusively examined recall when there was testing between lists, it is not entirely clear how what the overall pattern of results (proportion recalled, intrusions, and recall latency) will look like when recall is examined with no testing between lists as in Jang and Huber (2008) and Ward and Tan (2004). More work is needed to examine differences between these views in other recall conditions as well as with more computationally explicit versions of the different possible views.

For now, the results from the current study seem to be most consistent with the *Noisy Context view*. This view suggests that when attempting to recall information in the presence of intervening information, participants attempt to reconstruct the context of the target information. But given that there is some ambiguity about target information; participants cast a wide net to ensure that the target information is included. Doing so allows for intrusions to be included in the search set leading to the observed pattern of results. This notion that memory search is noisy and that the search set includes some irrelevant information is consistent with recent accounts of free recall where participants are asked to recall only the most recent list of items (e.g., Mensink & Raaijmakers, 1988; Sirotin, Kimball, & Kahana, 2005; Unsworth, 2007, 2009; Zaromb et al., 2006). That is, even when the context present at recall overlaps with the encoding context, the search set includes not only target items, but also prior list intrusions. Thus, even in standard free recall, the search would seem to be noisy with the inclusion of some irrelevant information. Furthermore, the notion that search is noisy is consistent with recent models of forgetting suggesting that, as the delay between encoding and retrieval increases, more irrelevant information is included in the search set, leading to lower probabilities of recall (e.g., Lansdale & Baguley, 2008; Mensink & Raaijmakers, 1988). For instance, in the population dilution model (Lansdale & Baguley, 2008) it is assumed that when searching for information, temporal-contextual information is used to centre the search on the target information. However, the greater the delay between encoding and retrieval, the wider the search set becomes around the target information leading to the inclusion of more irrelevant information into the search set. Consequently, when a sample is made from the search set, the probability of selecting the target information is reduced as a function of number of irrelevant representations included in the search set.

Recent work is converging on the notion that that the search set is not generally targeted on only the desired information (i.e., the target list), but rather memory search is noisy and the search set includes the desired information as well as irrelevant information. This irrelevant information includes not only representations that share temporal-contextual features with the target representations, but also target representations that share semantic and phonological features with the target representation (e.g., Kimball, Smith, & Kahana, 2007). Importantly, this work suggests that when searching for information participants can reconstruct some aspects of the target information's context and use that information as a cue to further aid in their search. Future work is needed to better understand the situations in which the search set can and cannot be focused on only target information, as well as the processes that are utilised in order to reconstruct context for events without relying exclusively on the present context.

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