The free recall search process introduces errors in short term memory but apparently not in long term memory

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Abstract:

Here it is reported that the free recall search process increases the error rate for short term memory (about 1% per second in data from Murdock & Okada (1970)) but not for long term memory (in data from McDermott (1996)). If the short term memory search process introduces random excitations, which would account for the search errors, the subjects should be unaware of making such errors. This is in agreement with DRM findings (Gallo, 2010) and the new finding that the error terminated distributions in Murdock (1962) are the same as those terminated by studied items.

Introduction

Free recall errors in short term memory often arise from proactive interference (Wixted & Rohrer (1993) and Zaromb et al (2006)) and items that are closely associated with the presented items (Bartlett (1932), Deese (1959), Roediger & McDermott (1995), and McDermott (1996)). Free recall errors may also arise from the search process itself. Murdock & Okada (1970) considered the short term memory free recall search process. They concluded that the search could be described by a random sampling process because they found that inter-response times were inversely related to the number of items left to be recalled. If one believes that short term memory is activated long term memories, after the neuronal firing stops there is presumably only one way to randomly search and identify decaying memories: <u>sampling the memory by random excitations to reactivate the original pattern of firings</u>. If a search consists of injecting random excitations to probe what memories may still be active, then the search process itself should create errors. We are going to find out whether this is the case.

Methods

This article does not itself involve any new experiments but rather makes use of existing experiments and statistically synthesizes their data. Below are summaries of the experimental processes undertaken to arrive at the four existing datasets used in this paper.

The Murdock (1962) data can be downloaded from the Computational Memory Lab at the University of Pennsylvania (http://memory.psych.upenn.edu/DataArchive). In this experiment, 103 undergraduate subjects were read 80 lists of words devised from a random selection of the approximately 4,000 of the most common English words at the time. The subjects were read the lists 20 at a time in groups of five over four sessions, each spaced by a period of 2-7 days. There were six types of word quantity/presentation rate combinations that subjects could have heard: 10 words per list at a presentation rate of .5 words per second, 20 words per list at a presentation rate of one word per second, 15 words per list at a presentation rate of .5 words per second, 30 words per list at a presentation rate of one word per second, 20 words per list at a presentation rate of .5 words per second, and 40 words per list at a presentation rate of one word per second. A metronome was used during the sessions to ensure the accuracy of the presentation rates. After each list was read, subjects were given 1.5 minutes to recall as many words as they could. A verbal “Ready” signal was used to terminate each recall period and indicate 5-10 seconds until the beginning of the next list-reading.

Murdock and Okada (1970) investigated inter-response times in single-trial free recall. Each of 72 subjects was tested with 20 20-item word lists presented visually at a presentation rate of either 1 or 2 words per second. Spoken recall was tape-recorded and timed afterwards. The data can also be downloaded from the Computational Memory Lab at University of Pennsylvania (http://memory.psych.upenn.edu/DataArchive).

The Roediger & McDermott (1995) experiment consisted of 36 undergraduate subjects who were read six lists (the six that produced the highest level of erroneous recall in the Deese (1959) experiment) at a presentation rate one of word per 1.5 seconds. The experiment was administered to the subjects as a group during a normal class period. They were instructed to recall the words given on a particular list after that list was read to them, having to write down the words in a series of examination booklets. Specifically, they were told to recall the last few items on the list first and the remainder of the words in any order, a standard practice. They were given 2.5

minutes for the recall phase. Before any list was read, the experimenter would say “list” followed by the corresponding number of the list such as “list one” for the first or “list two” for the second. After the list was read, the experimenter would say “recall” to indicate the beginning of the recall phase.

In McDermott (1996) 45 undergraduate or summer student subjects were each paid $5 dollars an hour to participate. They were read 24 15-item word lists (the lists were generated in Roediger & McDermott (1995) to be similar to the six lists that produced the highest level of erroneous recall in the Deese (1959) experiment). The presentation rate was 1.5 words per second, and the tests were performed individually or in groups of four or fewer. After hearing one set of 8 lists, the subjects received an immediate free recall test (1.5 minutes long); after a second set of 8 lists they received a 30 second delayed free recall test (1.5 minutes long), and after a third set of 8 lists they received no test. After an additional two days the corresponding long term memory was tested on all 24 lists during a period of 15 minutes. The tests were written, and the verbal cue of “recall” was used to initiate the recall process.

Results

From the Murdock & Okada (1970) data we see that the probability of an erroneous identification is proportional to the search time (Fig. 1). That the intercept is so close to zero shows that transcription errors are negligible, as are, at least initially, errors from proactive interference and from items associated with the presented items. The proportionality is consistent with a search mechanism of random excitation as mentioned above: as the search progresses in time, errors are created by the search process itself. The error rate increases about 1% per second search time. Note, however, that errors can plausibly increase also because of subjects' increased willingness to be less cautious as time passes and allow more errors. That this is likely not the case is shown in Fig. 2 which displays the probability of an erroneous identification in long term memory two days after the presentation of list items (McDermott, 1996). Note the difference in time scales – even after 15 minutes the subjects are not becoming less cautious and the error remains near 17%, much lower than most of Fig. 1. This also shows that the search mechanisms of short term and long term memory are different and that searching long term memory does not introduce errors, at least not on the fifteen minute time scale (experimental data shows that after 15 minutes most of short term memory is gone, see Tarnow, 2008).

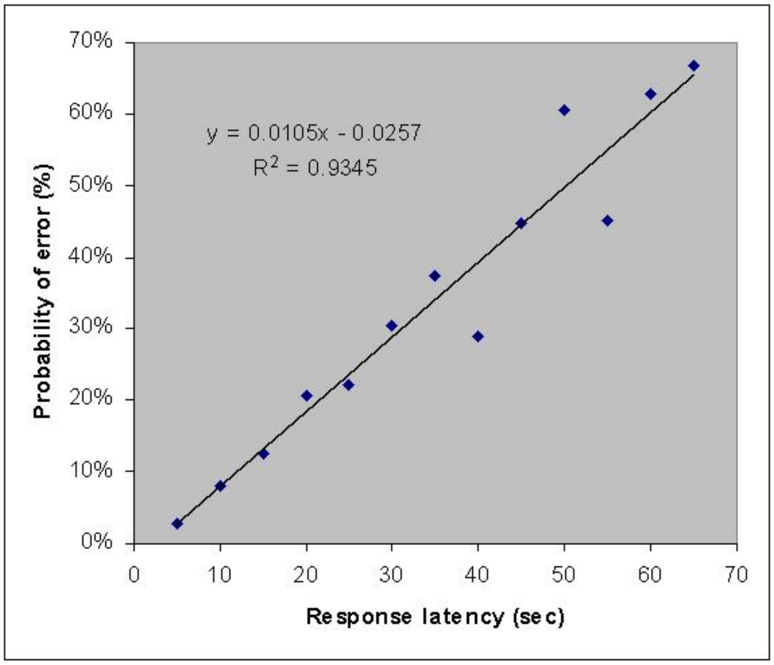

Fig. 1. Probability that a response is erroneous versus response latency. Data from Murdock & Okada (1970). The time to read a word was not recorded in the data and set to 1 second. Changing this time parameter to 0.5 seconds did not change the results.

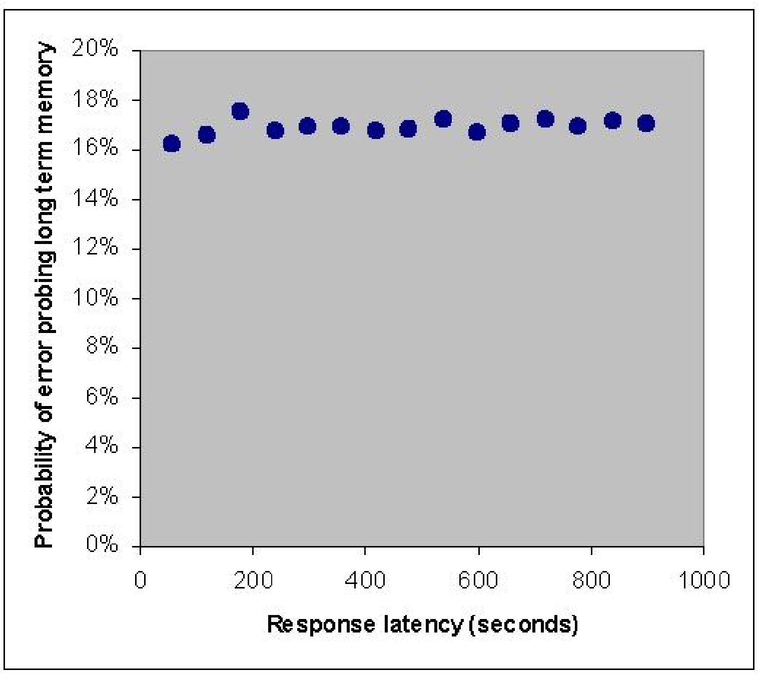

Fig. 2. Probability that a response is erroneous versus response latency when probing long term memory (two days after list items were presented). Data read off from figure 4 in McDermott (1996).

The short term memory search process thus might introduces random excitations which also activates erroneous items. The subject judges an item as a “presented” item perhaps when the activation level of an erroneous item is as high as the activation level of a presented item (indeed, the probability of closely related items to be erroneously detected is at least the same as the probability of the least remembered list item in Roediger & McDermott, 1995 and McDermott, 1996). In other words, as long as the activation level of an erroneous item is the same as the activation level of presented items, subjects might not be able to tell the difference between erroneous and presented items and recalls an error.

If erroneous items are not distinguishable from presented items, one would expect that the subjects' response distributions ending in errors would be no different from response distributions ending in presented items. That this is indeed the case is shown in Fig. 3. Here is presented the distribution of the total number of words written down in (bottom panel) and the distribution of the total number of words written down if the last word was an error (top panel), both from the Murdock (1962) data. The two-sided Student t-test for identical variances is 0.00082 and the probability that two equal distributions would have given that result is 99.94%. In Table 1 is shown the results of the Student t tests for each of the six sets of data. That the distributions are the same is also shown in Figure 4 in which they are plotted directly against each other for same recall lengths.

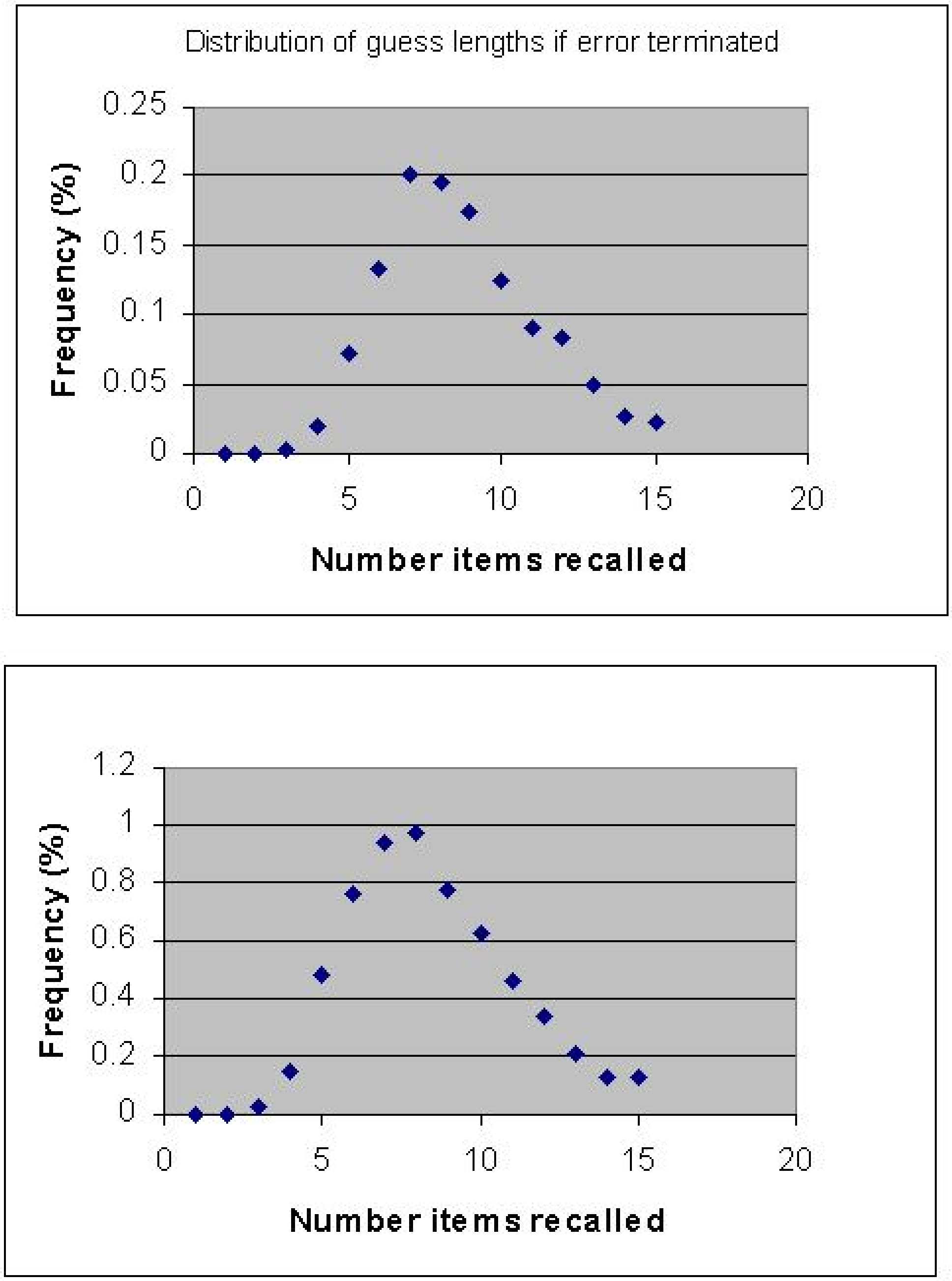

Fig. 3. The distribution of error terminated series (upper panel) and non-error terminated series (lower panel) are the same. Average over all Murdock (1962) data.

Experimental series	t	t distribution
10-2	0.57	57%
15-2	0.000005	100.00%
20-2	0.05	96%
20-1	0.62	54%
30-1	0.87	38%
40-1	0.09	93%
All together	0.00082	99.94%

Table 1. Values of t and the corresponding chance that two identical distributions would have given that t value.

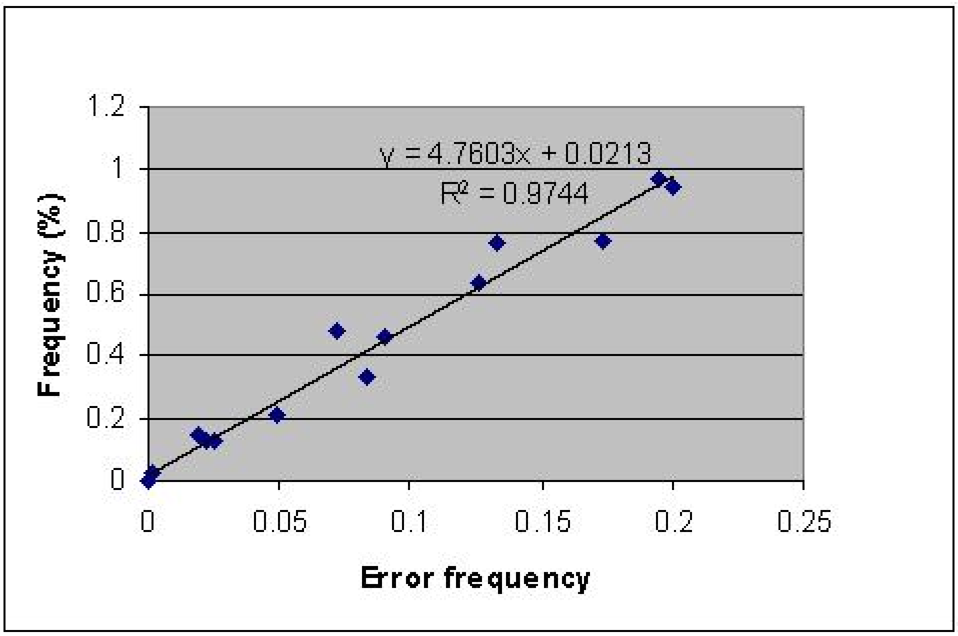

Fig. 4. Frequencies of recall of error terminated and non-error terminated sets plotted against each other for same item total numbers which also shows that the two distributions are equal. Average over all Murdock (1962) data.

To compare error rates for different presentation rates, Figure 5 displays the probability of making an error as a function of the recall position from the Murdock (1962) data. The left panel displays the data for the slower presentation rate and the right panel the data for the faster presentation rate. The probability of a recall error increases close to linearly with the recall position. There is also an offset – even the first item recalled has an error (which also sets a limit on the transcription error of at most 2.5%). In Fig. 6 is shown the differences in the number of errors as a function of recall position with the lower presentation rate errors subtracted from the higher presentation rate errors. The higher presentation rate increases the probability of error, both the offset and the slope.

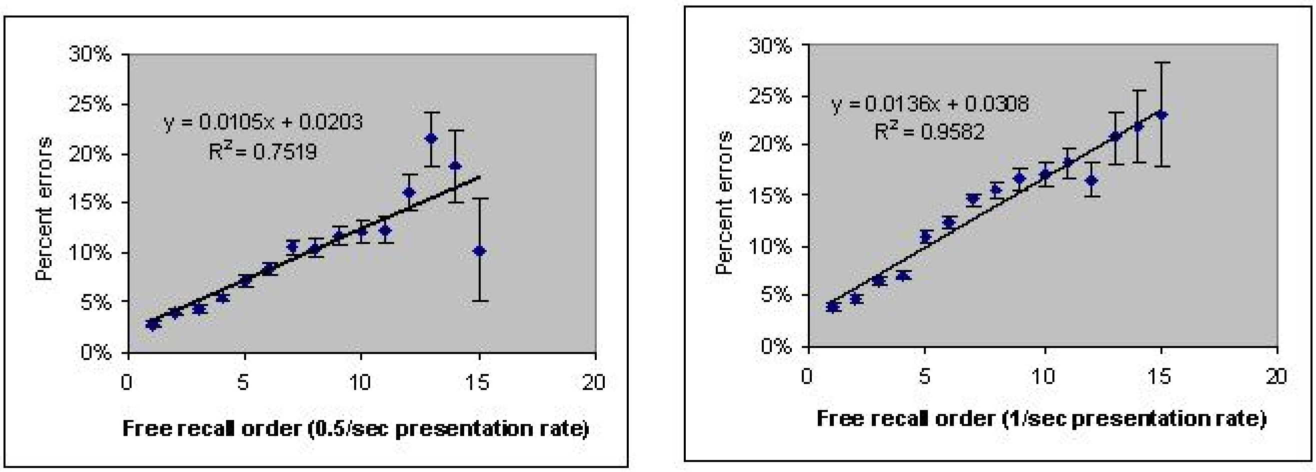

Fig. 5. Recall errors as a function of the recall position for the data in Murdock (1962). The left panel shows the average over the data with 0.5/second presentation rate and the right panel shows the average over the data with 1/second presentation rate. Note that the error rate increases linearly with the free recall order. The error bars in each direction are the standard deviation of a Poisson distribution.

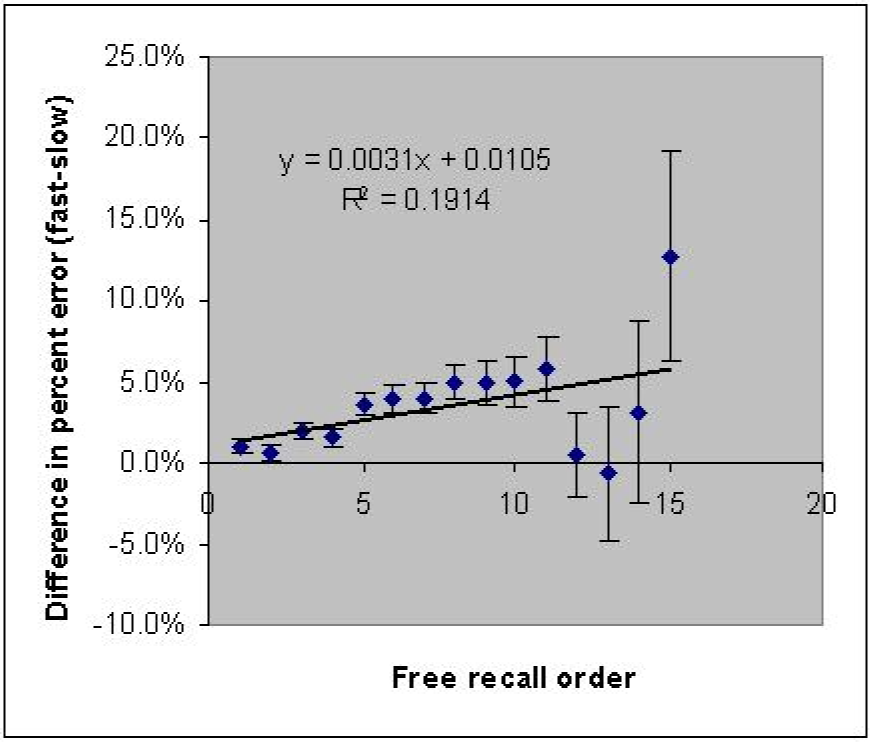

Fig. 6. Difference in number of recall errors for the two presentation rates in Murdock (1962) (low presentation rate subtracted from the high presentation rate). The error bars in each direction are the standard deviation of a Poisson distribution.

In Fig. 1 we displayed how the search introduces errors if the presented items are relatively unrelated. If the presented items are strongly related, the error rate as a function of time seems to increase quicker. In contrast to Fig. 1, Roediger & McDermott (1995) and McDermott (1996) show a free recall error rate that one can calculate to be exponential as a function of the output position (Fig. 7, left and right panels, note the logarithmic vertical axis, it is not clear why there is a difference in slope).

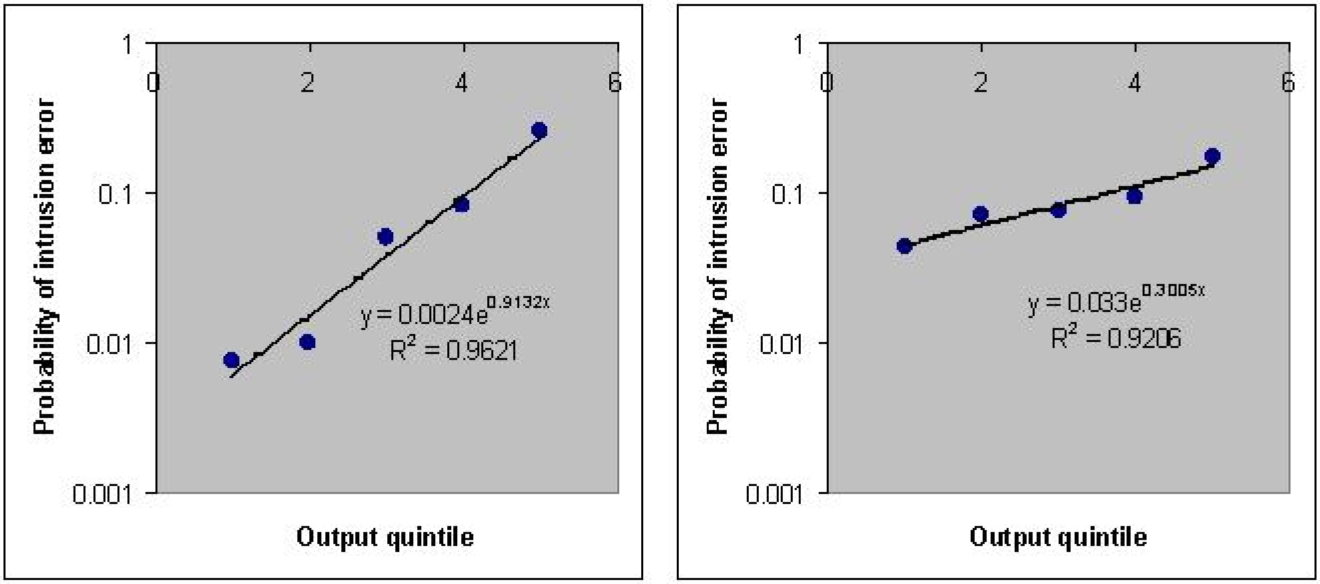

Fig. 7. Probability of particular intrusion error in Roediger & McDermott (1995), left panel, and McDermott (1996), right panel. In both cases the errors form not a linear function but an exponential function (the y-axis is logarithmic so an exponential function will display as a straight line). It is not clear why the two graphs are different. Note that we plot the probability of error, not the accumulated error as in the two original references.

Discussion

Many interesting findings came out of our analysis of the data of Murdock (1962), Murdock & Okada (1970), Roediger & McDermott (1995), and McDermott (1996):

First, short term memory errors in free recall are introduced by the search. That search of short term memory should introduce errors makes sense. We know that the search appears to be random (Murdock & Okada, 1970) and a search mechanism of random excitation (or amplification like in Posner, 1994,) to see which short term memories are most quickly reactivated is plausible.

Second, the search mechanisms of short term memory and long term memory must be different: the short term memory search introduces errors (error rate proportional to the search time for time scales up to 60 seconds with a proportionality constant of 1% per second) while the search of long term memory does not (on the time scale of 15 minutes). This also makes sense. While activation can make erroneous items look the same as presented items, long term memories take longer to create. The search process would have at least have to be on the order of the time scale of protein synthesis (Kandell, 2001) to create erroneous items that look equivalent to the presented items.

Third, if the search occurs by random excitations that reactivate previous list items or increase the activation level of related items, the subjects have no way to tell the difference between erroneous and presented items. That subjects were unaware of making the errors was suggested by the error-terminated output item distributions being the same as those terminated by presented items and was earlier observed by others for closely related items (for a review, see, for example, Gallo (2010)). The only way an insightful subject can decrease the error rate is to limit the search time which would unfortunately also limit the number of correct items reported.

Fourth, we found an indication that the error rate may increase faster than linearly with time if the presented items are closely related items (Fig. 7). This may be a result of the search process not being random when the items are closely related. Murdock & Okada (1970) concluded that the search process is random because their data indicated that the search speed being inversely proportional to the number items remaining to be found.

Tarnow (2010) shows that the search speed even in the Murdock & Okada (1970) data is only inversely proportional the the number of remaining items for output item 4 and later so it is not completely surprising that the search speed for closely related items is different as well.

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