FREE RECALL: HAVE WE BEEN LOOKING AT THE WRONG CURVE?

Eugen Tarnow

Avalon Business Systems
18-11 Radburn Road, Fair Lawn, NJ 07410, USA

I show that without the serial position curve, free recall can appear just as simple as integer recognition. The total search in word free recall, averaged over item position, increases linearly with the number of items recalled. Thus the word free recall search algorithm scales the same as the low-error recognition of integers [13]. The linear scaling of the search algorithm is different from what is commonly assumed to be the word free recall search algorithm, search by random sampling. The proportionality constant of 2-4 seconds per item (a hundred times larger than for integer recognition) is a power function of the average proportion not remembered and seems to be explicitly independent of subject age, presentation rate and whether there is a delay after the list presentation or not. The linearity of the word free recall extends down to 3 items which presents a challenge to the prevalent working memory theory in which 3-5 items are proposed to be stored in a separate high-availability store.

Key words: Free recall; short term memory; memory search, Sternberg

Free recall experiments typically display a list of words and then ask the subjects to recall as many of the words as possible. In a very colorful article, Hintzman [4] wrote of free recall: "the overlay of study and retrieval strategies makes the task a grotesque, neither-fish-nor-fowl creature of the laboratory —corresponding to nothing people do in everyday life and too complex to be of much use." As a result, he noted that interest in free recall peaked in 1970 and has since been low. Recognition, on the other hand, he points out is still of interest to the research community.

Well, this difference between free recall and recognition may go away, since it probably came about because we started out with the "difficult curve", the serial-position curve with the fascinating primacy and recency effects (Fig. 1). Just like the Sternberg [13] beautiful straight lines from integer recognition can make recognition appear simple, free recall can appear just as simple as I will show next.

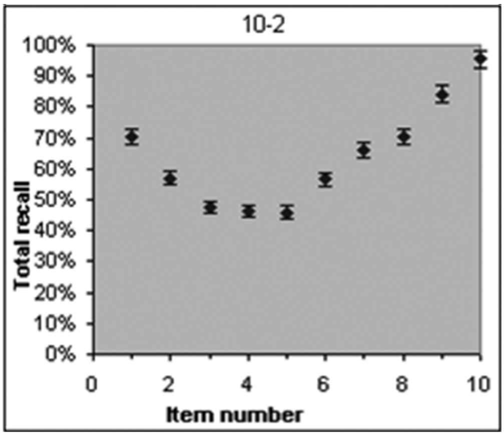

Fig. 1. The famous bowed curve of total recall versus word number [10]. Ten items were displayed at a rate of one item per two seconds

Thus in the word free recall data of Murdock & Okada [11], and Kahana, Zaromb & Wingfield, [6] (Fig. 2) I find that there is a linear relationship between the total free recall search time, defined as the sum of all response times, including the first. The linear regression accounts for 90—99% of the variance in the word free recall response times while in the Sternberg data the linear regression accounts for 99.4% of variance in the recognition response time. The slope of 2—4 seconds, which is the additional time needed to respond if there is an additional item that can be recalled, is a hundred times larger than the 38 msec per item in Sternberg [13]. The slope varies between different experimental subjects and delays: it is smaller for slow compared to fast presentation rates, it is smaller for young compared to old subjects and also smaller if the free recall starts immediately than if the recall is delayed.

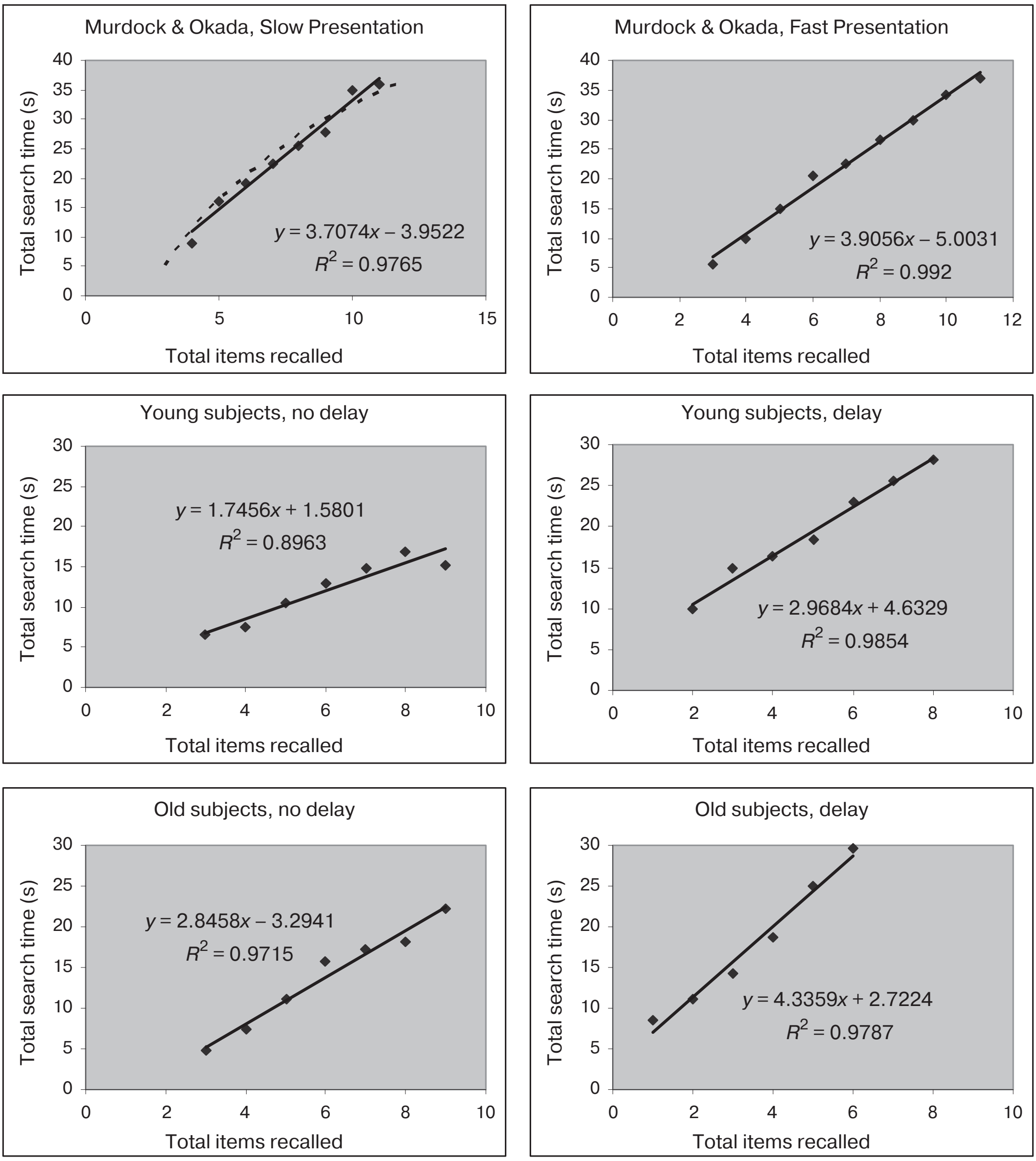

Fig. 2. The sum of all RTs, i.e. the total search time, is a linear function of the total number of items recalled. The top graph corresponds to the immediate free recall data in the Mudock & Okada [11] and the four graphs below to the data in Kahana, Zaromb and Wingfield [6]. The top graph also has dashed line indicating the expected behavior of a search by random sampling. The middle left graph corresponds to immediate free recall by young subjects, the middle right graph corresponds to delayed free recall by young subjects, the lower left graph corresponds to immediate free recall by old subjects and the remaining graph in the lower right hand corner corresponds to delayed free recall by old subjects. Note that the slope increases from young to old and from immediate to delayed free recall in the Kahana, Zaromb and Wingfield [6] data

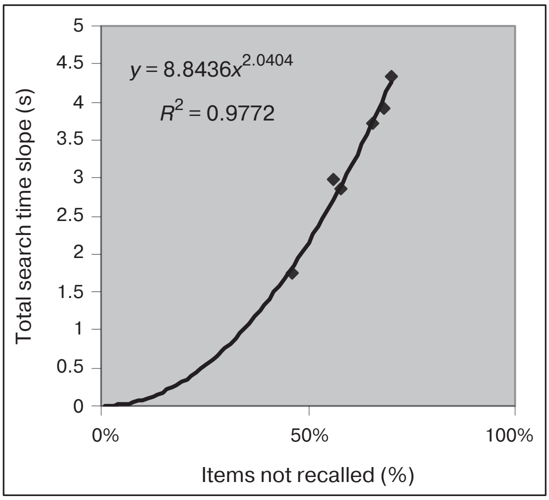

Fig. 3. Average time to find an additional item as a function of the average total percent words not recalled. The more likely the complete word list is to be recalled the shorter the additional search time. The power law fit suggests that the longest average search time for words that are very hard to recall is 8.8 seconds per word. To find out the true form of the relationship between the slope and overall recall, one would need additional data for experiments in which the overall number of words not recalled is 0—25%. The Sternberg [13] data would fall close to the origin of the graph

In Fig. 3 is shown that the slope is closely related to the average overall number of words not recalled. A high slope is correlated with many words not recalled. This relationship, that words with low probability of recall take a long time to recall, is similar to what activation theory would have it [14]: a word that is not in a highly activated state has a low probability of being recalled and takes time to reactivate. If the presented word items formed a sentence presumably the number of words not recalled would be close to 0% and the delay per item would be similarly close to zero (simply reciting the sentence), suggesting a power law (the line in Fig. 3) if not a proportionality. The exact relationship cannot be inferred from the rather small range of overall recall, experiments in which the overall number of words not recalled is closer to 0—25% would be better able to pin down the relationship.

The linear relationships in Fig. 2 give some food for thought. First they are surprising considering Hintzman's [4] pessimistic point about different individuals using different search algorithms. Second, they are also surprising considering that individual response times vary widely from half a second to ten seconds or even longer. Third, that these relationships occur both for extremely simple recognition and for word free recall, that the corresponding search algorithms both scale linearly with the number of items, suggests that both processes just might use the same search algorithm. Fourth, the linear scaling of the word free recall search shows that previous assumptions of a random sampling algorithm [12] are incorrect. If the latter was correct, the bowing of the dashed curve in the top graph of Figure 2 would apply and an additional item would only take const/(N+1) to find [5]. Fifth, the actual algorithm subjects use scales worse than random sampling. Sixth, the data may contradict the prevalent working memory theory [2] in which 3—5 items are thought to be stored in a separate store from subsequent items: the corresponding discontinuity in the slope at 3—5 items is not there, in fact, the slope is the same for 3 items as for 9 items (see also papers by D. Laming [8], E. Tarnow [15; 16], who noticed other discrepancies with the working memory model in the same free recall data).

The relationship in Fig. 3 is interesting as well. It seems to suggest that the underlying structure of retrieval is the same for young and old subjects since both data points lie on the same line. It would be interesting to see whether this relationship might be different if the subjects have a qualitatively different brain, for example from a neurological disease like Alzheimer's.

Appendix: The recall data. The Murdock & Okada [11] data can be downloaded from the Computational Memory Lab at University of Pennsylvania (http://memory.psych.upenn.edu/DataArchive). Lists of words were read to groups of subjects to the accompaniment of a metronome (to fix the word presentation rate) after which the subjects wrote down as many of the words as they could remember in any order for a period of 1.5 minutes. There were two presentation rates: 1 or 2 seconds and there were five word list lengths — 10, 15, 20 for the two second presentation rate and 20, 30 and 40 for the one second presentation rate. The six sets of data that resulted are typically labeled M-N in which M is the number of list words and N is the number of seconds between word presentations (1 or 2).

In Kahana et al [6] two groups of 25 subjects, one older (74 mean age) and one younger (19 mean age), studied lists of ten word words displayed on a computer screen. Immediately following the list presentation participants were given a 16-s arithmetic distractor task and only after this delay were the subjects asked to recall the words. This data can also be downloaded from the Computational Memory Lab at University of Pennsylvania (http://memory.psych.upenn.edu/DataArchive).

For both sets of data, trials with errors were discarded in order to keep the number of items to be remembered or having been recalled well defined. Data points with fewer than 10 measurements were not included in the graphs to minimize noise.

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СВОБОДНОЕ ВОСПРОИЗВЕДЕНИЕ СЛОВ ИЗ КРАТКОВРЕМЕННОЙ ПАМЯТИ: ЛИНЕЙНЫЙ ИЛИ КРИВОЛИНЕЙНЫЙ АЛГОРИТМ?

Юджин Тарноу

Авалон Бизнес Систем
18-11 Рэдбэрн Роад, Фэйр Лоун, 07410, США

Статья посвящена проблеме нахождения алгоритма воспроизведения слов из кратковременной памяти. Автор считает, что общее время воспроизведения слов увеличивается линейно в зависимости от количества воспроизведенных слов. Он считает, что алгоритм поиска слов аналогичен алгоритму поиска цифр, который был открыт в экспериментах Стернберга [13]. Линейный характер алгоритма поиска слов, о котором идет речь в статье, отличается от принятого алгоритма поиска по случайной выборке. Приведенные в статье данные свидетельствуют о том, что на поиск каждого пункта из списка слов затрачивается 2—4 секунды (в сотни раз больше, чем при поиске цифр) и эта константа относительно не зависима от возраста испытуемых, темпа предъявления списка, наличия или отсутствия дополнительной задачи перед воспроизведением слов. По мнению автора, описанный линейный характер воспроизведения слов из кратковременной памяти противоречит распространенной теории оперативной памяти, которая предполагает наличие «доступного хранилища» для 3—5 единиц воспроизводимого материала.

Ключевые слова: свободное воспроизведение, кратковременная память, поиск в памяти, Стернберг.