Positional uncertainty in the Brown-Peterson paradigm

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Abstract

Since McGeogh's (1932) influential article, no accounts of long-term memory have invoked decay as a cause of forgetting. In contrast, multiple accounts of short-term memory invoke decay, with many appealing to results from the Brown-Peterson paradigm as offering support. Two experiments are reported that used a standard Brown-Peterson task with the data scored in two ways. When scored using traditional measures (was the entire 3-letter consonant trigram recalled?) performance decreased with increasing delay. When scored as if the task were immediate serial recall (e.g., was the first letter recalled first, was the second letter recalled second?), standard looking position error gradients (Experiment 1) and protrusion gradients (Experiment 2) were observed. That is, when the first letter was not recalled first, it was more likely to be recalled second than last. Moreover, if a letter from a previous list was mistakenly recalled in a later list, it most likely retained its original position. The presence of such gradients is inconsistent with claims of decay but is consistent with the claim that forgetting in the Brown-Peterson paradigm follows the same principles observed in other memory tasks.

One theoretical approach to the study of memory is to divide it into multiple different memory systems, each of which operates according to different principles (e.g., Schacter, Wagner, & Buckner, 2000). One common distinction that is made is between a system for retaining information over the short term – variously termed short-term memory or working memory or primary memory or immediate memory – and one that retains information for longer durations, generally termed long-term memory. Although there are many different models of memory for the short term, there are sufficient similarities that one can talk about a "standard" model (see Nairne, 2002). According to this standard model, forgetting occurs due to time-based decay. One frequently cited line of evidence taken in support of time-based decay comes from studies using the Brown-Peterson paradigm (Brown, 1958; Peterson & Peterson, 1959; see also Daniels, 1895). Although there exists a large literature demonstrating numerous problems for the decay account of Brown-Peterson (for a review, see Neath & Surprenant, 2003), the decay interpretation first offered by Brown has been frequently invoked (e.g., Atkinson & Shiffrin, 1968; Baddeley, 1990) and continues to be invoked (e.g., Rai & Harris, 2013; Roll, Gosselke, Lindgren, & Horne, 2013). In this paper, we report two experiments that further question the decay interpretation. Instead, the results support a view in which memory follows the same principles regardless of whether the task is nominally thought to tap short- or long-term memory (Surprenant & Neath, 2009).

In the typical Brown-Peterson experiment, the subject sees a single item (usually three consonants presented simultaneously, a so-called consonant trigram) and is asked to recall the trigram after a delay of between 3 to 20 s. During this delay, the subject engages in a distractor task to prevent rehearsal. The distractor task is carefully chosen to avoid interference, so with recall of letters a common distractor task is counting backwards. The key finding is that performance decreases systematically with increasing delay. Given that the number of to-be-recalled items is substantially below the supposed capacity of short-term memory, this result has been interpreted as showing that items that are not rehearsed in a short-term store fade away or decay over time. Rather than reviewing the literature that shows the many problems with a decay account (see Neath & Surprenant, 2003 for a review of that literature), we focus instead on one aspect of the original task that has not received much attention.

Despite the large literature on the Brown-Peterson paradigm, relatively little experimental work has examined the errors made when a consonant trigram is not correctly recalled. Instead, the majority of studies use all-or-none scoring: the response is scored as correct only if the whole consonant trigram is correctly reproduced.[1] If the trigram is not recalled correctly, the response is scored as incorrect, even though the subject may have correctly recalled one or two of the letters. In contrast, many other tests of short-term memory use a more fine-grained scoring method. For example, in standard serial recall tests, the subject may see a list of five items and be asked to recall them in order. In this task, the first item is scored as correct if it was recalled first, regardless of whether the remaining items were correctly recalled.

In addition to analyzing correct responses, this method of scoring also allows for the analysis of error data from serial recall tasks. Data analyzed in this way yield two common findings.[2] First, when an error is made and an item is not recalled in the correct position, the item is most likely to be recalled in an adjacent position. In general, the probability of recalling the item in an incorrect position when an error is made is inversely related to how far that position is from the original (e.g., Estes, 1972; Healy, 1974). This pattern of errors is usually referred to as a positional uncertainty gradient and is readily observed with both immediate recall and delayed recall (Nairne, 1992). Second, when an item is mistakenly recalled in the wrong list, a so-called protrusion error, the item is most likely to be recalled in its original position (Conrad, 1960; Henson, 1998; Melton & von Lackum, 1941).

Although some researchers have examined whether these patterns are observable in the Brown-Peterson paradigm, the data are not clear. For example, Fuchs and Melton (1974) reported the existence of protrusion gradients in a Brown-Peterson task, but they used words rather than letters as the to-be-remembered stimuli and their method of presentation may have induced the subjects to process them as individual units. In Fuchs and Melton's task, the stimuli were presented in a left-to-right, downward stair-step pattern, such that the subject might see *dome* on one line, *time* on the next line down, *spot* on the next line down, and so on. One purpose of the current studies is to examine both position error gradients and protrusion errors in the Brown-Peterson paradigm when a single consonant trigram is presented.

There are a number of reasons why one would predict that standard-looking position error gradients and protrusion gradients will be observed in a Brown-Peterson task. First, the Brown-Peterson task can be thought of as a delayed serial recall task and such tasks are already known to produce these gradients (e.g., Healy, 1974). There are some differences, including that in serial recall tasks the to-be-remembered items are usually presented items serially whereas in Brown-Peterson tasks the items are usually presented simultaneously, but it seems reasonable to predict that if the two tasks are scored similarly, the same pattern of results will obtain.

A second reason to predict such gradients is that a model of memory that has accounted for many of the Brown-Peterson results predicts them. SIMPLE (Scale Independent Memory, Perception, and Learning; Brown, Neath, & Chater, 2007; Neath & Brown, 2006) views memory as fundamentally a discrimination task: To-be-remembered items are represented as positions along one or more dimensions in psychological space and in general, those items with fewer close neighbours on the relevant dimensions at the time of test are more likely to be recalled than items with more close neighbours. In the typical episodic memory task, the experimenter carefully chooses a set of to-be-remembered stimuli so that they are equated on as many dimensions as possible; as a result, one of the few dimensions along which the stimuli vary systematically is presentation time. Another way of thinking of this is that in a standard episodic task, the subject already knows all of the words or letters that will be shown. What the task really requires is remembering that a particular item was presented at a particular time (i.e., on the list just seen) rather than at another time (i.e., on a list seen several minutes ago). SIMPLE posits that the Brown-Peterson task is essentially an immediate serial recall task. Indeed, there are relatively few changes between when SIMPLE is fit to Brown-Peterson data and when it is fit to immediate serial recall data. The details of fitting SIMPLE have been provided elsewhere. For the main fits, see Brown et al. (2007, pp. 552 onwards; see also Neath & Brown, 2012; Neath, VanWormer, Bireta, & Surprenant, in press).

SIMPLE predicts appropriate position error gradients for serial recall tasks (see Brown et al., 2007, pp. 557 onwards). Because SIMPLE views Brown-Peterson as a type of immediate serial recall, it follows that SIMPLE predicts that position error gradients will be observed. Note that this prediction holds independent of any parameter settings or specific model fits because a central characteristic of the model is that items near to one another in psychological space will be more confusable than items that are more distant.

In addition, SIMPLE predicts appropriate protrusion gradients in serial recall tasks (see Brown et al., 2007, pp. 558 onwards). That is, SIMPLE can represent items on multiple dimensions, one of which indicates position within a list and another of which represents position within a set of trials. Just as position error gradients arise due to increased similarity between close neighbours on the list compared to more distant neighbours, similar gradients arise due to increased similarity with close neighbours across lists. That is, Item 3 of List 3 has close neighbours (relatively speaking) at both positions 2 and 4 of List 3, but also at positions 2, 3, and 4 of List 2.

The two experiments reported here were designed as a first step in assessing whether the predictions of SIMPLE (that both position error and protrusion gradients will be observed in a standard Brown-Peterson task) hold. Experiment 1 was designed to focus on position error gradients and Experiment 2 was designed to focus on protrusion gradients. Neither experiment was designed to produce data suitable for modelling. Rather, should the prediction be confirmed and gradients be observed, then subsequent experiments can focus on the time- and resource-intensive studies necessary to obtain stable data for modelling.

Experiment 1

Experiment 1 was designed to be similar to the method used by Peterson and Peterson (1959). Subjects saw a consonant trigram and then counted backwards, out loud, by 3s for between 3 and 15 s. They were then asked to report either the final number they had counted back to or to report the consonant trigram.

Method

Subjects. Sixty-three students from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium. All reported that English was their first language.

Procedure. Subjects were tested individually in a single session that lasted about 35 minutes. On each trial, three consonants were randomly selected and were presented simultaneously for 1 s. Then, a three-digit number between 200 and 999 (inclusive) was randomly selected to be the start number. The subjects were asked to count backwards by 3s out loud at a rate of 1 answer every 1.5 s. The pace was indicated by a circle that alternated colours once every 1.5 s. The duration of the distractor task was either 3, 6, 9, 12, or 15 s. Following the distractor task, the subject was asked to recall either the consonant trigram or the final number they had said out loud. For both tests, the subject used a mouse to click on appropriately labelled buttons. As in the original Peterson and Peterson (1959) study, the consonant trigram was to be recalled exactly, that is, the first letter reported first, the second letter reported second, and the final letter reported last. Feedback was given after a response for both tasks: for the letter recall, the subject was informed only that the response was correct or not, but for the counting backward task, the correct answer was provided if an incorrect number had been reported. The next trial began when the subject clicked on a button; thus, the experiment was self paced.

There were 40 trials, half of which tested memory for the consonant trigram and half of which tested accuracy in counting backwards. There were 8 trials at each distractor duration. The order of conditions was randomly determined for each subject.

Results and Discussion

The overall accuracy on the math task was 0.495 (*SD* = 0.257). To ensure that the subjects did not neglect the distractor task in order to rehearse the consonants, each subject's responses were included in the analyses reported below only if he or she had a minimum of 50% overall accuracy on the math task. Thirty-two subjects met this criteria, and the math accuracy for these subjects was 0.708 (*SD* = 0.152). The data from all 63 subjects were analyzed and the results and conclusions do not differ in any important way from those reported below from the subset of subjects.[3]

Three different analyses were performed. First, the recall data were scored in the way typical of Brown-Peterson studies: the response was counted as correct only if the entire consonant trigram was recalled in the correct order. As in numerous other demonstrations, recall decreased from 0.664 to 0.382 as the duration of the distractor task increased from 3 s to 15 s. A one-way repeated measures ANOVA revealed a significant effect of delay, $F(4,124) = 9.415$, $MSE = 0.053$, partial $\eta^2 = 0.233$, $p < .001$.

Second, the data were re-scored as if the test was immediate serial recall. That is, each letter was scored correct if it was reported in the correct position regardless of the other letters. A five delay × three serial position repeated measures ANOVA revealed a significant main effect of delay, $F(4,124) = 9.654$, $MSE = 0.096$, partial $\eta^2 = 0.237$, $p < .001$, with recall decreasing from 0.758 at 3 s to 0.510 at 15 s. There was also a significant main effect of position, $F(2,62) = 8.833$, $MSE = 0.037$, partial $\eta^2 = 0.222$, $p < .001$, with better recall for items in the first position (0.648) than in positions 2 (0.573) and 3 (0.567). The interaction was not significant, $F(8,248) < 1$.

INSERT FIGURE 1 ABOUT HERE

Third, in addition to analyzing correct responses, the incorrect responses were also examined. Figure 1 shows the position error gradients collapsed over delay (top left panel) and also the gradients for each delay condition. As can be seen, at all delays, the errors are systematic and not random. When a consonant from the trigram is recalled out of order, it is more likely to be recalled in an adjacent position than a more distance position.

INSERT FIGURE 2 ABOUT HERE

Analysis of the data shown in Figure 1 is easier if the data are re-plotted to show the proportion of errors as a function of the distance between the original position and the reported position. Figure 2 shows the proportion of all movement errors as a function of distance of movement. In this study, an item recalled in the incorrect position could be either 1 or 2 positions distant. The plot also shows chance performance. There are 4 opportunities for movements to adjacent positions (e.g., item 1 could be recalled in position 2; item 2 could be recalled in position 1 or position 3; and item 3 could be recalled in position 2) but only 2 opportunities for movements of distance 2 (e.g., item 1 could be recalled in position 3 and item 3 could be recalled in position 1). A chi-square test revealed that the observed differed significantly from what would be expected by chance, χ^2 (1, N=32) = 30.96, $p < .001$). That is, there are more errors at near positions than one would expect by chance and fewer errors at more distant positions than one would expect by chance.

Brown, Preece and Hulme (2000, Figure 2) plotted movement errors from six different experiments which included studies with no retention interval; studies with a retention interval of up to 24 hours; and studies with list lengths of up to 16 items. In all cases, the pattern plotted by Brown et al. are consistent with that shown in Figure 2. Despite variations in the duration of the retention interval, the method of presentation (whether simultaneous or sequential), and the list length (whether the list has three items or 16 items), the pattern is consistent: more errors occur at close distances and fewer errors at longer distances. In this regard, then, results from Brown-Peterson are the same as those seen in all those other paradigms and are consistent with predictions of SIMPLE.

Experiment 2

The data in Experiment 1 show that recall of consonant trigrams produces movement gradients consistent with those observed from other paradigms. Experiment 2 was designed to measure protrusion errors, where an item from an earlier list is produced as a response to a later list. The same basic design and procedure were used, but some changes were made to increase the number of observations per condition. First, only 3 delays (3 s, 6 s, and 12 s) were used rather than 5, and second, 42 trials were presented rather than 40.

Method

Subjects. Thirty-four different undergraduates from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium. All identified themselves as native speakers of English.

Procedure. The procedure for Experiment 2 did not differ from that of Experiment 1 except in the ways already discussed: namely, the completion of more trials and the use of fewer delay conditions.

Results and Discussion

Overall accuracy on the math task was higher than in Experiment 1, with a mean of 0.666 (*SD* = 0.221). This is most likely due to the elimination of the longest delay. Given this, all 34 subjects were included in the analyses reported below.

As in Experiment 1, Experiment 2 replicated the oft-reported finding that with traditional scoring, recall of consonant trigrams in a Brown-Peterson task decreases with increasing delay, in this case from 0.601 to 0.361. A one-way repeated measures ANOVA revealed a significant effect of delay, $F(2,66) = 18.010$, $MSE = 0.032$, partial $\eta^2 = 0.353$, $p < .001$.

The data were re-scored as if the test was immediate serial recall. A three delay × three serial position repeated measures ANOVA revealed a significant main effect of delay, $F(2,66) = 21.143$, $MSE = 0.067$, partial $\eta^2 = 0.391$, $p < .001$, with recall decreasing from 0.745 at 3 s to 0.524 at 12 s. There was also a significant main effect of position, $F(2,66) = 3.955$, $MSE = 0.066$, partial $\eta^2 = 0.107$, $p < .05$, with recall decreasing with position from 0.634 to 0.616 to 0.584 for positions 1, 2, and 3, respectively. Unlike in Experiment 1, the interaction was significant, $F(4,132) = 3.346$, $MSE = 0.014$, partial $\eta^2 = 0.092$, $p < .05$. For the 12 s delay, recall of the third letter was much worse than recall of the first two whereas in the other two delays, the difference was far smaller.

INSERT FIGURE 3 ABOUT HERE

The main data of interest are the protrusion errors. For this analysis, the only protrusions scored were those from the immediately prior list, as protrusions from lists more remote were too few to produce reliable findings. Figure 3 shows the data in two forms. The left panel shows the frequency that a letter in each position on the prior list was recalled in each of the possible positions on the following list. The right panel shows the data re-plotted as movement gradients along with chance performance. A chi-square test revealed that the observed differed significantly from what would be expected by chance, χ^2 (1, N=34) = 5.53, $p < .02$).

As with the within-list errors, the between-list errors shown in Figure 3 resemble those observed in other paradigms that assess memory for order (e.g., Brown et al., 2000) and are also consistent with the predictions of SIMPE.

General Discussion

The traditional way of scoring data in the Brown-Peterson paradigm is to count a response as correct only if all three letters are reported in the correct order. If one letter is missing, or if two letters swap position, no credit is given for being partially correct. Such scoring yields the classic forgetting function that shows that accuracy decreases rapidly as the duration of the distractor task increases. Both Experiment 1 and 2 found this pattern.

However, the data in both experiments were also scored in a different way, considering the task to be an example of a serial recall task. With this scoring method, subjects are given partial credit for reporting only one or two of the three consonants. With this scoring method, accuracy also decreases with increasing delay, but one can also analyze the pattern of errors. When a letter was not recalled in its original position, it was more likely to be recalled in an adjacent position than a more distant position. Similarly, when a letter from an earlier list was recalled in a later list, it was more likely to be recalled in its correct position (albeit in the wrong list) than in a different position. These error gradients resemble those observed in other serial order tasks (see Figure 2 of Brown et al., 2000). These tasks include both immediate recall (a task thought to tap short-term memory) and recall delayed by as much as 24 hours (a task that must tap long-term memory). The tasks also include lists with as few as 3 or 4 items (within the capacity of short-term memory) and list with as many as 16 items (well beyond the capacity of short-term memory). Moreover, these gradients can be observed with incidental learning, when there is no reason to suppose that a person would be rehearsing an item to maintain it in short-term memory.

Decay theories historically have had difficulty in accounting for both position error gradients and protrusion gradients. As noted by Healy (1974), decay theories predict that when an item cannot be recalled accurately, it is because the information stored about the item has decayed too much so that it is no longer useful. Therefore, the subject is forced to make a guess from a pool of likely responses (e.g., if the lists have all contained consonants, then the guess will be a consonant; if the lists have all contained digits, then the guess will be a digit). This account cannot predict that the subject will be more likely to recall a near neighbour than a more distant neighbour. It also cannot predict that the subject guesses an item that happens to be from the prior list, the item will most likely be placed in its original position. Therefore, observing both position error and protrusion gradients in a typical Brown-Peterson task is consistent with the numerous previous studies showing that decay is not a viable explanation of forgetting in this task.

It may be possible to invoke a multiple store account of the results from Brown-Peterson, in which some aspects of the data are attributable to decay from short-term memory whereas other aspects are attributed to recall from long-term memory. In addition to its lack of parsimony, this account suffers from problems in predicting, a priori, which store will be responsible for which result. Moreover, it seems to us that such an account would need to predict that the store responsible for performance needs to change as a function of the scoring method. For example, decay of information in short-term memory is responsible for the findings when the task is scored using the standard all-or-none method, but not be responsible when the task is scored using the standard serial recall method.

In contrast, SIMPLE posits that the Brown-Peterson task is simply another example of a serial order test. Because SIMPLE is a local relative distinctiveness model (as opposed to a global distinctiveness model; see Neath, Brown, McCormack, Chater, & Freeman, 2006), a central characteristic of the model is that items near to one another in psychological space will be more confusable than items that are more distant. It is this feature that makes SIMPLE predict that both position error gradients and protrusion errors will be observed in the Brown-Peterson task and that both types of gradients will resemble those observed in many different types of tasks.

The results also give additional support to the idea that general principles of memory do exist and do apply widely regardless of the hypothetical underlying memory system (Surprenant & Neath, 2009). It has previously been suggested that the gradients that are the focus of this paper are a general characteristic of human memory whenever the task involves order (Brown &

Vousden, 1998), and indeed, these gradients likely qualify as a "principle" according to the definition offered by Surprenant and Neath. One reason this may qualify as a principle is that these gradients are observed in many different memory tasks, not only serial recall tasks such as memory span and Brown-Peterson, but also in other tasks such as speech production (see Brown et al., 2000). Of importance, these tasks tap a broad range of cognitive activities and are thus inconsistent with a fractionated collection of memory systems, each following its own rules and principles. Instead, the data support the idea that differences in memory arise, not because the information is processed and recalled using different stores, but because the relative distinctiveness of items in memory varies as a function of task, stimulus materials, and individual strategies and capabilities.

We have demonstrated that position error gradients and protrusion gradients are observable in a Brown-Peterson task, a finding consistent with the claim that such gradients may be an example of general principle of memory. While it is not possible to prove that a principle does always apply, it is trivially easy to disprove the generality of a principle. For example, SIMPLE has to predict these gradients, but it could have been the case that the Brown-Peterson task is unique and does not give rise to this pattern of errors. Had this been the case, then the generality of SIMPLE and the generality of the gradient principle would have been severely compromised. Given that it was not, however, it provides yet another demonstration of the similarities that exist over many different kinds of tasks that are thought to tap many different kinds of memory systems.

Author Notes

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Footnotes

[1] There are, of course, experimenters who did not use all-or-none scoring. For example, Kincaid and Wickens (1970) presented trigrams and used a scoring system similar to immediate serial recall: They awarded 1 point for each part of the trigram recalled in the correct position, and also awarded a bonus point if all 3 items were correctly recalled in order.

[2] One influence that led us to this line of research was a study by Mewhort, Campbell, Marchetti, and Campbell (1981) who did a similar analysis on the Sperling task, including an analysis of errors.

[3] For example, with all 63 subjects, Figure 2 remains largely unchanged (e.g., 0.83 vs. 0.86 and 0.17 vs. 0.14) and the chi-square test becomes χ^2 (1, N=63) = 46.12, $p < .001$.

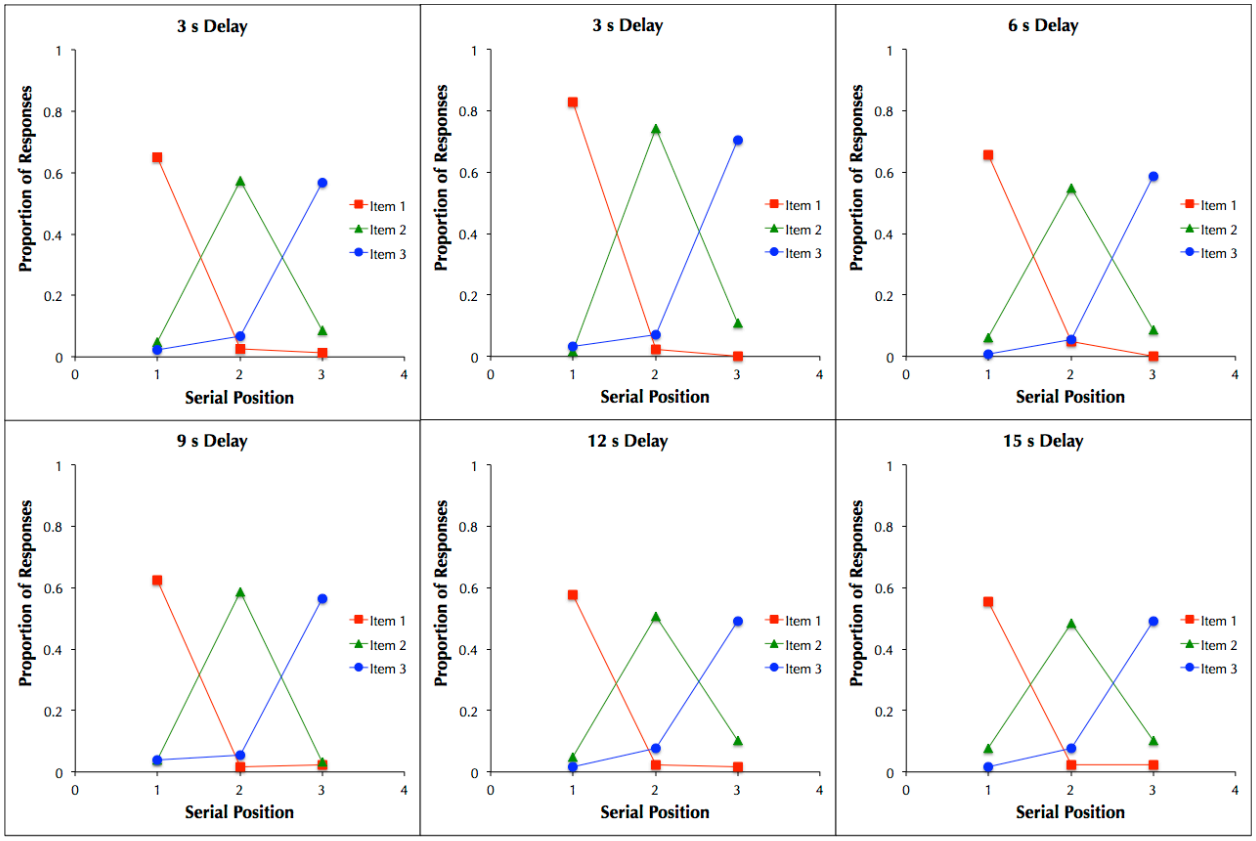

Figure 1: The proportion of times each of the three consonants was recalled in each of the three possible positions. The top left panel shows the data collapsed over delay, and the remaining panels show the gradients for each delay.

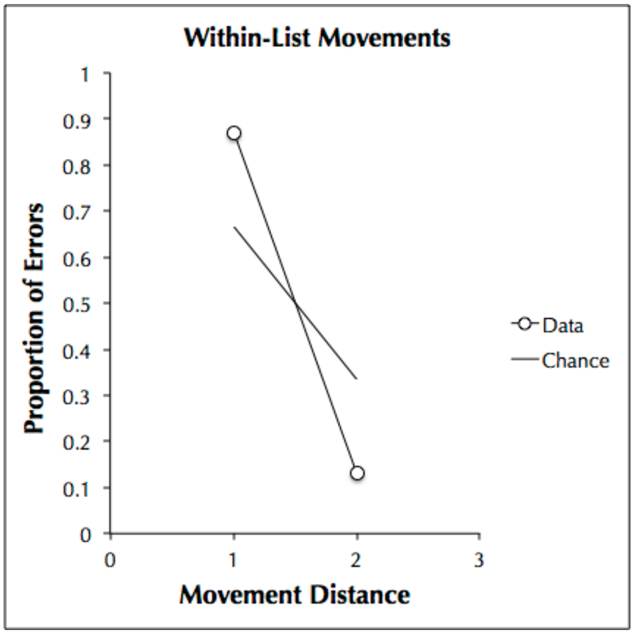

Figure 2: The proportion of errors as a function of the distance between the original position and the reported position in Experiment 1 (data points) and chance performance (line).

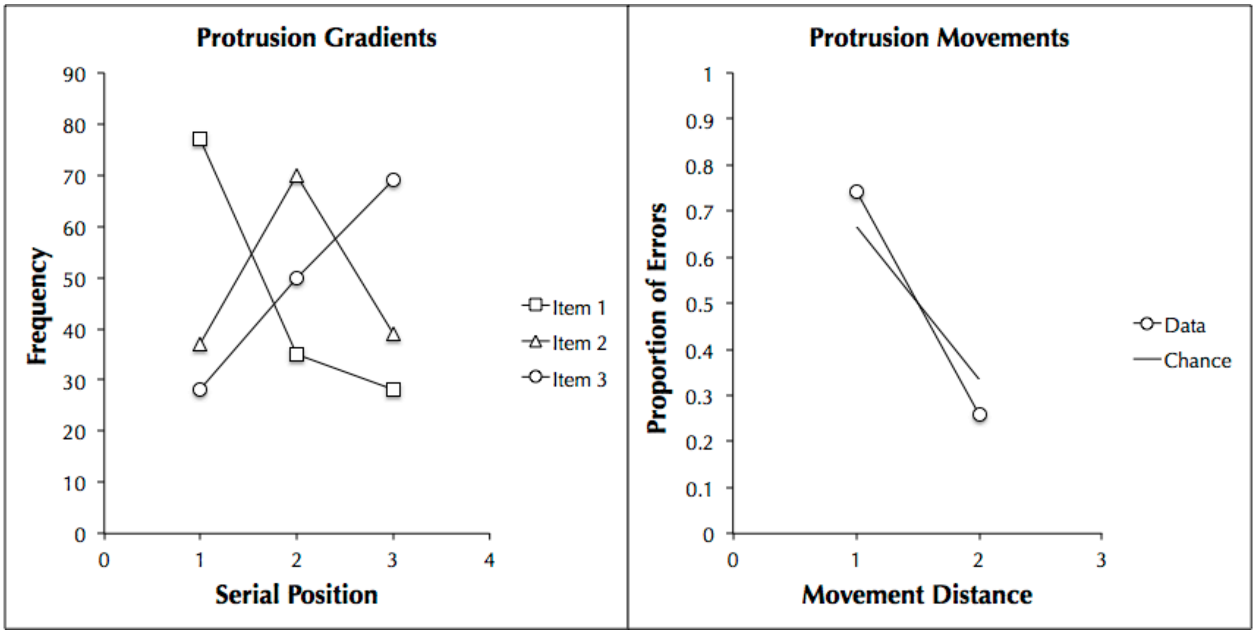

Figure 3: The number of times each item from List *N*-1 was incorrectly recalled in each of the three positions in List *N* (left panel) and the same data replotted as the proportion of errors as a function of the distance between the original position and the reported position in Experiment 2.