Components of Short-Term Proactive Interference[1]

GEOFFREY R. LOFTUS[2] AND KENNETH K. PATTERSON

University of Washington and Stanford University

A classical short-term memory finding is that asymptotic performance in the Brown–Peterson paradigm decreases over the first few trials. Three experiments investigated the extent to which this performance decrease is due to a decrease in information being transferred to long-term store. Each experiment consisted of two parts. The first part utilized a Brown–Peterson paradigm with word triads as stimuli. The second part was a final free recall test in which subjects attempted to recall the words they had seen in the first part. The results showed no decrease in final recall probability as a function of short-term trial number, suggesting that the short-term decrease in performance is due to increasing retrieval difficulties. A model is proposed which handles the present results as well as other basic characteristics of the Brown–Peterson paradigm.

In a paradigm introduced by Brown (1958) and Peterson and Peterson (1959) a subject is briefly shown an item, like a consonant trigram. Following a filled retention interval, memory performance for the item is measured. The universal finding in this paradigm is that memory performance declines from nearly perfect at very short retention intervals to some asymptotic value at a retention interval of about 15 seconds. The asymptotic performance value is highly variable and depends, in part, on experimental manipulations taking place at the time items are originally presented (Melton, 1963).

Two-store models of memory (Atkinson & Shiffrin, 1968; Glanzer, 1972) ascribe the declining portion of the Brown–Peterson curve to forgetting from short-term store. Asymptotic performance, on the other hand, is assumed to be based on information transferred to long-term store at the time the item was originally presented. Hence, any variable affecting the amount of information transferred to long-term store may be expected to affect asymptotic performance. Transfer of information from short- to long-term store may, in turn, be viewed in terms of rehearsal.[3] The more rehearsals per chunk (Miller, 1956) the more information per chunk is transferred to long-term store (Waugh & Norman, 1965; Atkinson & Shiffrin, 1968; Rundus & Atkinson, 1970; Rundus, Loftus, & Atkinson, 1970; Rundus, 1971). In accordance with this rehearsal notion, Hellyer (1962) found that asymptotic performance in the Brown–Peterson paradigm varies directly with the number of rehearsals given a three-chunk item. Likewise, Murdock (1961) showed that one-chunk items (single words) produced better asymptotic performance than three-chunk items (word triads).

[2] Present Address: Department of Psychology, University of Washington, Seattle, Washington 98195.

[3] Recent theorists have substituted the notion of depth of processing for rehearsal as a framework for discussing long-term memory performance. The arguments in this paper are made within a rehearsal framework, but they would be equally valid within a depth-of-processing framework. This is primarily because the arguments revolve around the fact that more processing time will lead to better long-term performance. More processing time allows either more rehearsal or greater depth of processing.

Again, this result follows from a rehearsal notion since one chunk presented for a given amount of time can be rehearsed more than three chunks presented for the same amount of time. There is, however, one classical and pervasive finding to which the above reasoning cannot be applied in so straightforward a manner: Asymptotic performance for a particular item in the Brown–Peterson paradigm is highly dependent on the number of prior items presented (Keppel & Underwood, 1962; Loess, 1964). For example, Keppel and Underwood (1962, Experiment 2) presented subjects with three Brown–Peterson trials at varying retention intervals. The asymptotic value of the retention curve on Trial 1 was .99, whereas by Trial 3 the asymptote had dropped to .58.

The primary purpose of the present experiments was to determine whether this decline in asymptotic performance over trials is due to a corresponding decline over trials in the amount of information transferred to long-term store. To investigate this question, a final free recall procedure introduced by Craik (1970) was employed. Specifically, each experiment was divided into two parts. In Part 1 (hereafter referred to as the short-term part) a subject was presented with a series of Brown–Peterson trials using word triads as stimuli. Items were tested at a 15 second retention interval during which the subject carried out a number-shadowing task to prevent rehearsal. In Part 2, the subject was given an unexpected final free recall test in which he was asked to recall as many as possible of the words from the short-term part. The results of interest involved the probability of a word's being recalled as a function of that word's short-term trial number. If the decrease in short-term asymptotic performance is due to a decline in the amount of long-term store information over trials, then this decrease should be reflected in final free recall.

Three experiments were run. The experiments were all very similar and the procedural differences among them have no bearing on

the arguments to be made in this paper. Thus, the experiments should be viewed primarily as replications of one another. The only reason for reporting all three experiments rather than just one is to demonstrate the consistency of the reported results over a somewhat varying set of experimental procedures.

METHOD

General Paradigm

The procedure common to the three experiments was as follows. The short-term part consisted of 24 Brown–Peterson trials divided into eight blocks of three trials per block. All three trials in a given block utilized word triads composed of instances from a given taxonomic category. The taxonomic category was different for each block. Hence, a release from proactive inhibition was expected to occur at the beginning of each block in accordance with the findings of Wickens, Born, and Allen (1963) and Wickens (1970). The variation in performance over blocks was not of interest in the present experiments. What was of interest was the variation in performance over trials within a block.

Following the last Brown–Peterson trial, the subject was told that the experiment was over but that there would be another, unrelated memory experiment. The experimenter then administered standard free recall instructions and read aloud a list of 20 countries, following which the subject wrote down all the countries he could remember from the list. This procedure was a means of acquainting the subject with a free recall task as well as a distractor task designed to eliminate any short-term retention of words presented in the short-term part of the experiment.

At this point, the subject was asked to write down, in any order, all the words he could remember from the short-term part of the experiment and was given as much time as he wanted. Following this final free recall test was a cued recall test. The subject was given a

sheet of paper with the names of the eight categories used in the short-term part of the experiment and was again given as much time as he wanted to write down all the words he could remember. (Hereafter, final free recall and cued recall are collectively designated final recall.)

A methodological problem in the experiments involved the choice of an appropriate dependent variable in final recall. It was expected that in the short-term part of the experiments the number of words recalled would decrease over trials. The act of recalling a word affords extra rehearsal for that word. Therefore, number of rehearsals, long-term memory strength, and final recall performance would be expected to decrease on this basis alone. A possible solution would be to consider final recall performance only for words which had been correctly recalled in short-term. But this leads to an item selection problem. Different words vary in the ease with which they can be encoded by the subject. On Trial 1, almost all words are correctly recalled in short-term, whereas by Trial 3, only words which are in some sense easy to encode are correctly recalled. By this reasoning, final recall performance would be expected to increase over trials. An actual decrease in final recall performance could then be construed as strong support for the notion that the amount of information transferred to long-term store decreases over trials. Lack of a trial effect, or an increase over trials would, however, be uninterpretable.

To solve this problem, the following procedure was introduced. Each short-term trial was randomly determined to be a "recall" or a "no-recall" trial. On a recall trial, the subject had a 10-sec period to recall the words in the triad at the end of the 15-sec retention interval. On a no-recall trial, the subject was instructed to continue number shadowing for the 10-sec "recall period." The dependent variable of interest in final recall was then the probability of recalling words from no-recall trials. Any differences in final recall performance as a function of no-recall trial number must be due to differences in amounts of information originally transferred to long-term store.

Subjects

Two hundred and fifty-six subjects were used in the three experiments. All subjects were students enrolled in Introductory Psychology courses at the University of Washington, participating either as volunteers or for course credit.

Stimuli

The eight taxonomic categories used were body parts, kitchen utensils, types of cloth, four-legged animals, geographical features, metals, pieces of clothing, and parts of buildings. The nine most dominant members of each category (Battig & Montague, 1969) were chosen as stimuli. For each experiment, the nine members of each category were randomly grouped into three triads.

Apparatus

When stimuli were presented visually, a Gerbrands tachistoscope was used. On each trial, a 5 × 8 card was exposed in the viewer for the appropriate amount of time, following which the subject looked up to see another 5 × 8 card containing random digits, placed in a specially constructed card holder on the top of the tachistoscope.

Procedure

All experiments began with five practice trials (using consonant trigrams as stimuli) followed by the 24 experimental trials. Table 1 shows the sequences of events for the three experiments. Experiment I had two conditions which involved either auditory or visual presentation of stimuli. As can be seen in Table 1, all experiments were very similar except for small variations taking place at the time the items were originally presented.

TABLE 1

Sequence of Events on a Trial for Experiments I, II, and III

| Sequence | Experiment I | | Experiment II | Experiment III |
	Visual	Auditory		
Presentation of stimuli	Three words in a triad are presented simultaneously in a tachistoscope for 2 sec. Subject reads words aloud.	Experimenter takes 2 sec to read all three words to the subject.	Three words in a triad are presented simultaneously in a tachistoscope for 2 sec. Subject reads words aloud	Three words in a triad are presented simultaneously in a tachistoscope for 1.5 sec. Subject reads words silently.
Retention interval	Subject looks up and sees a card filled with random digits. Subject shadows digits as quickly as possible for 15 sec.			
	Recall		No-Recall	
Test phase	Experimenter says "recall' which signals the subject that he has 10 sec to recall the three words from the triad. Recall is spoken and the words may be output in any order.		Experimenter says "continue" which signals the subject that he is to continue number shadowing for another 10 sec.	
Intertrial interval	Experimenter says, "Stop . . . ready" and then pauses for 2 sec, followed by the start of the next trial.			

Designs

Experiment I. Sixty-four subjects were run in Experiment I, 32 of whom received visual presentation of stimuli, and the other 32 of whom received auditory presentation. For the 32 subjects in the visual condition, the design was as follows. First, within a given three-trial block, there are eight possible sequences of recall and no-recall trials (for example, recall, recall, recall; recall, recall, no-recall; etc.) and each subject received all eight sequences over his eight blocks. Assignment of sequences to categories was determined by a randomized, 8 × 8 Latin Square; thus over a group of eight subjects, each category was assigned to all eight sequences. For each subject, there corresponded a mirror-image subject whose sequence of trials was exactly the same except that recall trials were substituted for no-recall trials and vice versa. For each subject and his mirror image, ordering of triads within a block and ordering of categories over blocks was determined randomly. Two independent re-

plications of this design were run, accounting for the 8(sequences) × 2(mirror images) × 2(replications) = 32 subjects.

Each of the 32 subjects in the auditory condition had exactly the same study sequence as the corresponding subject in the visual condition.

Experiment II. Experiment II was actually one condition of a larger experiment. Ninety-six subjects were run in Experiment II. Each subject had eight, three-trial blocks; however, only four of the blocks used word triads as stimuli. The other four blocks used single words as stimuli. As in Experiment I, every subject received all eight three-trial, recall–no-recall sequences over eight blocks; each subject had a mirror image differing only in that recall and no-recall trials were reversed; assignment of sequences to categories was determined by a randomized 8 × 8 Latin Square and ordering of triads within blocks and categories over blocks were determined randomly for each subject and his mirror image. Addi-

tionally, to each subject and his mirror image, there corresponded another pair of subjects whose study sequences were identical except that triads were substituted for single words as stimuli, and vice versa. Three independent replications of this design were run which accounted for the 8(sequences) × 2(mirror images) × 2(stimulus types–words versus triads) × 3(replications) = 96 subjects. Only the data from the triad blocks are of interest in the present report.

Experiment III. Ninety-six subjects were run in Experiment III. As in the first two experiments, each subject received all eight possible recall–no-recall sequences over his eight blocks; assignment of sequences to categories was determined by a randomized 8 × 8 Latin Square; and for each subject, there corresponded a mirror-image subject differing only in that recall and no-recall trials were reversed. Two additional counterbalancing measures were taken in Experiment III. First, assignment of categories to block number was determined by a second randomized 8 × 8 Latin Square superimposed over the first. Secondly, within a given category, there are six possible orderings of the three triads. These six orderings were combined factorially over subjects with the eight recall–no-recall sequences. One replication of this design was run, accounting for the 8(sequences) × 2(mirror images) × 6(triad orderings) = 96 subjects.

RESULTS

Statistical Analyses

Since all dependent variables to be discussed are probabilities, all statistical analyses were performed on arcsine transformations as suggested by Winer (1971, pp. 399–400). Two somewhat nonstandard forms of analysis were used in the present study.

The unit of analysis. Each experiment is basically a trials × blocks repeated measures design with three dependent variables of primary interest: the probability of short-term recall for words presented on recall trials,

$p(STR)$, and the probabilities of final free and cued recall for words presented on no-recall trials, $p(FR|NR)$ and $p(CR|NR)$. It was considered desirable to perform a standard, two-way repeated-measures analysis of variance for each of the dependent variables; however, due to the nature of the design, each subject is missing data from half the cells for each dependent variable. It was to solve this problem that the mirror-image subject scheme was devised. Note that each *pair* of subjects, a subject and his mirror image, contributes data to all cells for each dependent variable. Hence, in all analyses, the unit of analysis is a pair of subjects rather than a single subject.

Combining probabilities. Since the experiments are to be viewed primarily as replications of each other, it is desirable to combine statistical analyses over all three of them. Winer (1962, pp. 43–44) suggests two methods for doing this. The first method (Fisher's method) results in a χ^2, and the second method (Stauffer's method) results in a z-score. For both methods, a significant value of the test statistic is commensurate with a statistically significant effect, taking into account all experiments under consideration. Both of these tests were performed for all statistical analyses to be reported.[4] Using the conventional .05 significance level, the results were blessed with agreement between the two tests for every analysis.

Trial Number Data

Table 2 shows the values of seven pertinent dependent variables as functions of short-term trial number. The first three, $p(STR)$, $p(FR|NR)$, and $p(CR|NR)$ have been mentioned above. The two bottom sections of Table 2 show probabilities of final free and cued recall

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[4] The two tests have somewhat different emphases. Using Stauffer's method, one "very significant" result (for example, one very large t-value) generally suffices to produce a significant z. With Fisher's method, however, one "very nonsignificant result" suffices to produce a nonsignificant χ^2. It was felt that because of these somewhat different emphases, it would be productive to carry out both tests.

TABLE 2

RESPONSE PROBABILITIES AS FUNCTIONS OF TRIALS FOR SEVEN DEPENDENT VARIABLES

Dependent variable	Experiment	Trial 1	Trial 2	Trial 3	F values	Percent Variance	Test statistics for percent variance
$p(STR|R)$	Expt. I	.897	.697	.633	$(2,62) = 54.4^*$	84.4	$(1,62) = 99.5^*$
	Expt. II	.891	.721	.606	$(2,94) = 48.3^*$	98.3	$(1,94) = 94.9^*$
	Expt. III	.845	.673	.595	$(2,94) = 101.0^*$	94.5	$(1,94) = 192.0^*$
	Average	.878	.697	.611			$\chi^2(6) = .006^*$ and $z = 19.4^*$
$p(FR|NR)$	Expt. I	.282	.275	.249	$(2,62) = 1.04$	90.6	$(1,62) = 1.88$
	Expt. II	.278	.292	.292	$(2,94) < 1$	75.0	$(1,94) = .23$
	Expt. III	.337	.325	.313	$(2,94) < 1$	99.1	$(1,94) = 1.48$
	Average	.299	.297	.284			$\chi^2(6) = 2.71$ and $z = 1.22$
$p(CR|NR)$	Expt. I	.418	.424	.369	$(2,62) = 3.32^*$	69.5	$(1,62) = 4.61^*$
	Expt. II	.370	.437	.370	$(2,94) = 3.07$	.8	$(1,94) = .05$
	Expt. III	.491	.447	.418	$(2,94) = 4.53^*$	98.4	$(1,94) = 8.92^*$
	Average	.426	.436	.385			$\chi^2(6) = 1.14^*$ and $z = 3.03^*$
$p(FR|NR)$ (intrusions subtracted)	Expt. I	.249	.265	.250	$(2,62) < 1$	6.1	$(1,62) = .01$
	Expt. II	.260	.274	.292	$(2,94) < 1$	95.4	$(1,94) = 1.49$
	Expt. III	.317	.301	.313	$(2,94) < 1$	46.6	$(1,94) = .41$
	Average	.275	.280	.284			$\chi^2(6) = 6.29$ and $z = -.29$
$p(CR|NR)$ (intrusions subtracted)	Expt. I	.387	.399	.369	$(2,62) < 1$	62.7	$(1,62) = .28$
	Expt. II	.347	.418	.370	$(2,94) = 2.41$	17.3	$(1,94) = .83$
	Expt. III	.459	.418	.418	$(2,94) < 1$	53.5	$(1,94) = .93$
	Average	.398	.411	.385			$\chi^2(6) = 4.53$ and $z = .34$
$p(FR|C)$	Expt. I	.433	.505	.519	$(2,62) = 1.38$	32.4	$(1,62) = .90$
	Expt. II	.485	.530	.599	$(2,94) = 1.85$	99.5	$(1,94) = 3.69$
	Expt. III	.522	.588	.588	$(2,94) = 1.54$	84.7	$(1,94) = 2.62$
	Average	.480	.541	.569			$\chi^2(6) = .54^*$ and $x = 2.69^*$
$p(CR|C)$	Expt. I	.614	.684	.714	$(2,62) = 1.00$	62.6	$(1,62) = 1.25$
	Expt. II	.608	.607	.719	$(2,94) = 2.13$	67.9	$(1,94) = 2.89$
	Expt. III	.655	.729	.711	$(2,94) = 3.17^*$	16.8	$(1,94) = 1.07$
	Average	.626	.673	.714			$\chi^2(6) = .692^*$ and $z = 2.23^*$

for words correctly recalled in short term. These two dependent variables are designated $p(FR|C)$ and $p(CR|C)$, respectively. The two sections labeled "intrusions subtracted" bear some discussion. As noted above, the rationale for having no-recall trials was to eliminate the problem of having final recall probabilities based partly on words recalled in short-term and partly on words not recalled in short-term. However, despite this precaution, subjects did, from time to time, output words from no-recall trials as intrusions in subsequent recall trials. Hence, some words from no-recall trials were recalled in short-term. A partial solution to this problem is to eliminate such intruding words from consideration in computing final recall probabilities which is what has been done in the two sections labeled "intrusions subtracted". Note, however, that this leads to an item selection problem as discussed above. Hence, the "true results" are probably not observable. They are, however, bracketed by the results with and without intrusions subtracted.

For each dependent variable, Table 2 shows the value of the dependent variable as a function of short-term trial number for each experiment (Columns 1–3 of each section). The row labeled "average" simply shows the arithmetic means of the values from the three experiments. Column 4 shows the degrees of freedom and F values for the effect of trials in each experiment. The Fs result from repeated measures analyses of variance using blocks and trials as fixed factors and subject pairs as a random factor. Column 5 shows the percent of variance accounted for by the planned comparison corresponding to a monotonic increase/decrease of performance over trials (see Abelson & Tukey (1970) for a more detailed description of this procedure). Column 6 shows the F value corresponding to this planned comparison. At the intersection of Column 6 and each row labeled "Average" are the χ^2 and z values from the two combining probabilities tests described above. It is worth emphasizing that these tests are performed on the F values corresponding to the monotonic increase/decrease, not on the average values themselves.

An asterisk is placed next to all test statistics which are significant beyond the .05 level.

Short-term recall. The probability of short-term recall was computed taking into account item information only. In all three experiments, $p(STR)$ declines substantially over the three trials; the average drop from Trial 1 to Trial 3 is .267 over the three experiments. In all three experiments, the variance accounted for by the planned comparison corresponding to a monotonic decrease exceeds 80% and is, in all cases, statistically significant. This finding replicates numerous past experiments (see Wickens (1970)).

Final recall. It seems reasonably safe to conclude that there is virtually no effect of short-term trial number on final free recall. When intrusions are not subtracted, $p(FR|NR)$ drops an average of only .015 from Trial 1 to Trial 3. This difference switches sign to $-.009$ when the results are recomputed with intrusions

subtracted. In no case, either for any individual experiment or when probabilities are combined, does the planned comparison corresponding to a monotonic increase/decrease even approach statistical significance.

The situation is slightly more equivocal for cued recall. When intrusions are not subtracted, $p(CR|NR)$ drops from Trial 1 to Trial 3 for two out of the three experiments, and the average drop over the three experiments is (a modest) .041. For two out of the three experiments, the planned comparison of a monotonic increase/decrease is significant, and the combining probabilities tests are significant. However, when intrusions are subtracted, the average drop from Trial 1 to Trial 3 is reduced to .013, and all traces of statistical significance disappear, both for individual experiments and for the combining probabilities tests. Note that both with and without intrusions subtracted, $p(CR|NR)$ is generally higher for Trial 2 than for either Trial 1 or Trial 3. All in all, there is very little support for the hypothesis that $p(CR|NR)$ is reflecting a decrease over trials in the amount of stored long-term information.

Final recall of words correctly recalled in short-term memory. For both $p(FR|C)$ and $p(CR|C)$ there is a small but reasonably consistent increase over trials. This increase is not statistically significant for any individual experiment, but the combining probabilities tests are significant for both dependent variables. These increases confirm the item-selection hypothesis discussed earlier.

Short-Term Conditional Data

As discussed above, the use of no-recall trials was included primarily to solve a methodological problem. However, this aspect of the design permits an examination of how short-term performance on Trials 2 and 3 within a block is affected by the number of acts of retrieval carried out on Trials 1 and 2.

Error probability. Table 3 shows the probability of an error, $p(STE) = 1 - p(STR)$, for Trials 2 and 3 conditionalized on whether

TABLE 3

SHORT-TERM ERROR PROBABILITIES CONDITIONALIZED ON RECALL VERSUS
NO-RECALL PREVIOUS TRIALS

| | | | Trial 3 | | | |
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment I	Trial 1 recall	.326	.427	.365	.396	$(1,31) = 3.78$
	Trial 1 no-recall	.292	.318	.359	.339	
	Average		.372	.362		
	F values	$(1,31) = 2.52$	$(1,31) = .30$			

| | | | Trial 3 | | | |
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment II	Trial 1 recall	.316	.389	.451	.406	$(1,47) = 1.39$
	Trial 1 no-recall	.243	.375	.361	.368	
	Average		.382	.406		
	F values	$(1,47) = 2.72$	$(1,47) = .22$			

| | | | Trial 3 | | | |
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment III	Trial 1 recall	.290	.385	.486	.435	$(1,47) = 3.76$
	Trial 1 no-recall	.365	.351	.399	.375	
	Average		.368	.443		
	F values	$(1,47) = 4.18*$	$(1,47) = 3.57$			

| | | | Trial 3 | | | |
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	χ^2, z values
Average	Trial 1 recall	.311	.400	.434	.417	$\chi^2(6) = .34*$ $z = 2.91*$
	Trial 1 no-recall	.297	.348	.373	.369	
	Average		.374	.403		
	χ^2, z values	$\chi^2(6) = 9.96$ $z = 0.69$	$\chi^2(6) = 3.29$ $z = 1.04$			

Trials 1 and 2 were recall or no-recall trials. Table 3 is organized as follows. Each section shows data from a given experiment and the last section shows average data over the three experiments. For each experiment, Column 1 shows p(STE) on Trial 2 conditional on whether Trial 1 was a recall trial (Row 1) or a no-recall trial (Row 2). Columns 2–4 show p(STE) for Trial 3. A given Trial 3 can be viewed as falling into one cell of a 2 × 2 factorial design with Trials 1 and 2 as factors and recall versus no-recall as levels of each factor. The values of each of the four cells along with the row and column marginals are shown. For each experiment, three F values are reported. The F value corresponding to the effect of Trial 1 on Trial 2 is shown in Column 1, Row 4. The F value corresponding to the main effect of Trial 1 on Trial 3 is shown in Column 5, and the F value corresponding to the main effect of Trial 2 on Trial 3 is shown in Columns 2 and 3, Row 4. The F values corresponding to the Trial 1 × Trial 2 interactions are not shown.[5] The corresponding test statistics for the section labeled "average" are the χ^2 and z values resulting from the two combining probabilities tests.

The most striking aspect of Table 3 is the lack of consistency both across and within experiments. Consider first Trial 2. For Experiments I and II, p(STE) is greater if Trial 1 was a recall as opposed to a no-recall Trial. Although this effect is not statistically significant in either experiment, it is in a direction which replicates the findings of Ellis and Montague (1973). However, in Experiment III (the most powerful and well-controlled of the three experiments) this effect reverses and

is statistically significant. Turning to the Trial 3 data, it appears that in all experiments, if Trial 1 is a no-recall as opposed to a recall trial, performance on Trial 3 is improved. This effect is not statistically significant in any given experiment, but it is significant for the combining probabilities tests. Finally, there is no significant effect of Trial 2 on Trial 3 for any single experiment or for the combining probabilities tests. However, the tendency is in a direction opposite to the effect of Trial 1.

Omissions and intrusions. To clarify this somewhat muddy picture, the error probabilities from Table 3 were broken into two classes: the probability of an omission and the probability of an intrusion from a previous trial within the block. Omission and intrusion probabilities are defined as follows: On a given trial, a subject can name up to three words. Omission probability is defined as $1 - $ [(number of words named)/3] and intrusion probability is defined as (number of prior-trial intrusions)/3, for that particular trial. Thus, correct responses, omissions, and intrusions are mutually exclusive events. Additionally, they are almost mutually exhaustive, constituting approximately 99 % of all responses in each experiment.

Table 4 shows omission probabilities and is organized in exactly the same way as Table 3. The data from Table 4 are very consistent across experiments; hence the section labeled "average" may be viewed as presenting typical data. Omission probability on Trial 2 is considerably higher if Trial 1 is a recall as opposed to a no-recall trial. Omission probabilities on Trial 3 show an analogous effect: They are higher if either Trial 1 or Trial 2 is a recall versus a no-recall trial. Trials 1 and 2 have approximately equal and (loosely speaking) additive effects on Trial 3 omission probabilities.

Table 5 shows intrusion probabilities. Table 5 is organized in a similar manner to Tables 3 and 4 with the exception that Trial 3 intrusions have been further broken down according to whether they came from Trial 1 or

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[5] The interactions are not reported for two reasons. First, if analyses of variance were performed on raw probabilities, an interaction would be meaningful only for a class of models involving some measure (for example of "memory strength") which is linearly related to response probability. To the best of the authors' knowledge, no such class of models exists. Second, even if such a class of models did exist, the analyses were carried out on arcsine transformations which, of course, are nonlinearly related to response probability.

TABLE 4

SHORT-TERM OMISSION PROBABILITIES CONDITIONALIZED ON RECALL VERSUS
NO-RECALL PREVIOUS TRIALS

			Trial 3			
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment I	Trial 1 recall	.216	.328	.167	.247	(1,31) = 14.4*
	Trial 1 no-recall	.130	.177	.109	.143	
	Average		.253	.138		
	F values	(1,31) = 9.20*	(1,31) = 12.2*			

			Trial 3			
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment II	Trial 1 recall	.212	.284	.264	.274	(1,47) = 2.98
	Trial 1 no-recall	.111	.270	.130	.200	
	Average		.277	.197		
	F values	(1,47) = 6.03*	(1,47) = 3.17			

			Trial 3			
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	F value
Experiment III	Trial 1 recall	.205	.323	.260	.291	(1,47) = 18.7*
	Trial 1 no-recall	.151	.194	.146	.170	
	Average		.259	.203		
	F values	(1,47) = 5.71*	(1,47) = 3.08			

			Trial 3			
		Trial 2	Trial 2 recall	Trial 2 no-recall	Average (Columns 2, 3)	χ^2, z values
Average	Trial 1 recall	.211	.312	.230	.271	$\chi^2(6) = .07^*$ $z = 5.69^*$
	Trial 1 no-recall	.131	.214	.128	.171	
	Average		.263	.179		
	χ^2, z values	$\chi^2(6) = .034^*$ $z = 4.56^*$	$\chi^2(6) = .16^*$ $z = 4.06^*$			

TABLE 5

SHORT-TERM INTRUSION PROBABILITIES CONDITIONALIZED ON RECALL VERSUS NO-RECALL PREVIOUS TRIALS; TRIAL 3 INTRUSIONS ARE FURTHER CONDITIONALIZED ON WHETHER THEY CAME FROM TRIAL 1 OR TRIAL 2

	Trial 2	Trial 3 from 1				Trial 3 from 2			
		Trial 2 recall	Trial 2 no-recall	Average Columns 2, 3	F value	Trial 2 recall	Trial 2 no-recall	Average Columns 6, 7	F value
Experiment I									
Trial 1 recall	.091	.021	.062	0.42		.073	.130	.101	
Trial 1 no-recall	.133	.068	.083	.076	(1,31) = 8.11*	.068	.141	.105	(1,31) = .01
Average		.045	.073			.071	.135		
F values	(1,31) = 4.82*	(1,31) = 1.57				(1,31) = 7.25*			
Experiment II									
Trial 1 recall	.083	.042	.042	.042		.063	.146	.105	
Trial 2 no-recall	.118	.035	.069	.057	(1,47) = .33	.063	.153	.108	(1,47) = .01
Average		.039	.056			.063	.149		
F values	(1,47) = 1.31	(1,47) = 1.32				(1,47) = 8.13*			

TABLE 5—continued

Experiment III

		Trial 3 from 1				Trial 3 from 2			
	Trial 2	Trial 2 recall	Trial 2 no-recall	Average Columns 2, 3	F value	Trial 2 recall	Trial 2 no-recall	Average Columns 6, 7	F value
Trial 1 recall	.070	.021	.049	.035		.038	.156	.097	
Trial 1 no-recall	.186	.083	.076	.079	$(1,47) = 8.62^*$	.069	.160	.115	$(1,47) = 1.45$
Average		.052	.063			.053	.158		
F values	$(1,47) = 35.6^*$	$(1,47) = 1.25$				$(1,47) = 23.1$			

Average

		Trial 3 from 1				Trial 3 from 2			
	Trial 2	Trial 2 recall	Trial 2 no-recall	Average Columns 2, 3	χ^2 and z values	Trial 2 recall	Trial 2 no-recall	Average Columns 6, 7	χ^2 and z values
Trial 1 recall	.081	.028	.051	.039		.058	.144	.101	
Trial 1 no-recall	.146	.062	.076	.069	$\chi^2(6) = .678^*$ $z = 3.77^*$	.067	.151	.109	$\chi^2(6) = 2.86$ $z = 1.28$
Average		.045	.063			.063	.147		
χ^2 and z values	$\chi^2(6) = .480^*$ $z = 5.37^*$	$\chi^2(6) = .774^*$ $z = 2.03^*$				$\chi^2(6) = .012^*$ $z = 5.98^*$			

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Trial 2. Hence, for each experiment, Trial 3 data are broken down into two sets of probabilities and test statistics.

The data in Table 5 are again very consistent across experiments and thus the section labeled "average" shows representative data. Intrusion probability on Trial 2 is considerably higher if Trial 1 is a no-recall as opposed to a recall trial. Consider now the probability of a Trial 3 intrusion from Trial 1 (Columns 2–5). Trials 1 and 2 have similar effects on this probability: If either is a no-recall as opposed to a recall trial, Trial 1–Trial 3 intrusion probability is higher. Finally, Columns 6–8 show the probabilities involving Trial 3 intrusions from Trial 2. If Trial 2 is a no-recall as opposed to a recall trial, this intrusion probability is raised considerably. However, intrusions from Trial 2 into Trial 3 appear to be completely unaffected by whether Trial 1 was a recall or a no-recall trial.

The general conclusion to be drawn from these data is that omission and intrusion probabilities are affected in opposite ways by the recall–no-recall manipulation. Relative to a recall trial, a no-recall trial lowers omission probability but raises intrusion probability on a subsequent trial. This situation permits the inconsistency over experiments in unconditional error probability demonstrated in Table 3.

DISCUSSION

The Locus of Short-Term Proactive Interference

The results of all three experiments strongly suggest that the declining memory performance across trials in the Brown–Peterson paradigm is not due to variation in the amount of information initially encoded into long-term store. If, as other investigators have suggested (Petrusic & Dillon, 1972; Gorfein & Jacobson, 1973; Dillon, 1973), proactive interference were a manifestation of decremental storage across trials, then final recall per-

formance should also have declined. In fact, final recall probability for no-recall trials showed little or no effect of trial position. Final recall probability conditionalized on correct recall in short-term memory showed an actual increase over trials. Even though these conditional probabilities are confounded with item-selection effects as noted earlier, they offer no support for the notion that short-term proactive interference is a storage phenomenon.

Proactive interference as retrieval failure. A number of recent studies have suggested that short-term proactive interference results from long-term retrieval failure (Turvey, Brick, & Osborn, 1970; Baddeley & Scott, 1971; Craik & Birtwistle, 1971; Ellis, 1973). Some of the most compelling support for this position comes from a proactive interference release experiment by Gardiner, Craik, and Birtwistle (1972). This study used words from a single taxonomic category which could be divided into two distinct subcategories (for example, flowers which could be divided into garden flowers and wild flowers). No release from proactive interference resulted from a shift from one subcategory to the other unless subjects were informed of the shift. The critical finding was that release was obtained when the shift cue came either at the time of presentation or at the time of recall. This result again mitigates against a storage notion, since cueing after the retention period could not have affected initial storage.

Implications of short-term conditional data. One aspect of the present results, the effects of no-recall trials on subsequent performance, may be useful in isolating the nature of the retrieval process. Other investigators (for example, Ellis & Montague (1973)) have found that no-recall trials facilitate later performance relative to recall trials. Ellis and Montague concluded that the act of recall must affect the rate of proactive interference buildup, possibly by increasing the strength of recalled items which would be directly related to their interfering effects. Experiments I and II of the

present study replicated Ellis and Montague's finding (albeit nonsignificantly) but the reverse effect was found in Experiment III; no-recall trials produced more errors on subsequent trials than recall trials. However, this apparent contradiction in results largely dissolves when the pattern of omissions and intrusions is examined. The consistent result in the present experiments is that fewer omissions but more intrusions occur following no-recall as opposed to recall trials.

Presumably a no-recall trial differs from a recall trial only in that there is no attempt to retrieve the trial items. But how does this difference change the pattern of errors rather than merely the number of errors? A strength interpretation as proposed by Ellis and Montague seems to predict only that no-recall trials should produce fewer errors but says nothing about the relative proportion of types of errors.

A Tentative Model

It seems likely that an explanation of these results demands a more complete account of the total information available on each trial. Let us assume that both presentation and recall periods provide the subject with an opportunity to encode information about items. Encoded information is probably quite extensive (Wickens, 1970), including, for example, modality, semantic, and contextual information. One aspect of this informational array which we would like to stress is that it must contain some measure of *recency* (Yntema & Trask, 1963). Differences in encoded information for items from no-recall as opposed to recall trials may now be characterized as follows. Items from no-recall trials are afforded less total processing time and therefore should have less complete item information encoded. Also, however, no-recall trial items have a longer time span between the termination of their processing and the processing of subsequent trial items which should, in accordance with the Yntema and Trask findings, increase their temporal discriminability relative to recall items.

Guided by this notion that no-recall trials offer less total information about items, but increased temporal discriminability, we outline here, the basic tenets of a model which seems capable of accounting for the present results and other major aspects of proactive interference in this paradigm. The model is basically a specific adaptation of a more elaborate model proposed by Anderson and Bower (1973) and can be described with three assumptions. The first two assumptions pertain to the structure of the informational array, whereas the third describes the retrieval process.

(1) During the presentation of a triad, a recency-structured list is created in memory. The list is a push-down stack in that as new words are presented, they are placed at the top of the list, since they are the most recent. Information encoded about each word (for example, modality, semantic associations, and contextual cues) is stored directly with the word.

(2) During the retention interval, the recency value of each word decays. The exact form of the decay function is not specified here, but we assume that the function is negatively accelerated and that the decay rate is variable over items (see Hinrichs (1970)). Since the recency value determines list position, this variability in decay rate allows items from the current trial to occasionally descend in the recency list below prior trial items.

(3) At the time of retrieval, the recency list is searched serially from top to bottom. A stop rule (Anderson & Bower, 1973, p. 467) terminates the search either after some stop time or after N responses have been made where N is the number of words in the stimulus item (typically three). Each retrieved word is initially assumed to be from the current trial (a plausible assumption since list position is a function of recency and items retrieved first have the greatest probability of being the correct response). This presumption is maintained unless the item information stored with the word reveals that it belongs to a previous trial (an "innocent until proven guilty" principle).

A word is output if it is retrieved and not identified as coming from a previous trial.

The basic findings handled by this model are as follows.

Types of responses. Errors occur due to variability in the recency decay rate which allows current trial words to descend below prior trial words. When order information is required, the most common type of error will be a transposition error as found by Murdock (1961). An omission will occur if N responses have not been made before a search is terminated and an intrusion will occur if a prior trial word is retrieved and not correctly rejected on the basis of its encoded information. Note that since increasing numbers of prior words will be examined over trials, latency of correct responses will increase over trials as found by Murdock (1961) and Gorfein and Jacobson (1973).

Proactive interference. The probability of an error is thus monotonically related to the function $1 - (1 - \alpha)^n$, where α is the probability that a current trial word will drop below a given prior trial word in the recency list and n is the number of prior-trial words there are in the recency list. Over trials, n and hence error probability increases, accounting for the basic proactive interference effect. Release from proactive interference may be accounted for in either of two ways: (1) A shift in stimulus category may lead the subject to create and process a completely new recency list or (2) the same recency list may be maintained but the information in a preshift word will invariably be sufficient to allow it to be rejected.

Final recall. Since the recency decay function is assumed to asymptote rapidly, the recency of all trial items will be virtually equal after relatively long retention intervals and should not affect final recall performance, as found in the present study.

Effects of recall and no-recall trials. The model also predicts that no-recall trials should produce more subsequent intrusions and fewer subsequent omissions than recall trials. Items from no-recall trials encounter a longer period of temporal decay, resulting in fewer items from a current trial descending in the list below prior trial items. Thus, there will be fewer subsequent omissions because more current-trial items will be accessible within the allotted search time. However, those items which *are* retrieved from prior no-recall trials will have less item information available on which to base the acceptance/rejection decision and thus will intrude more often.

There is still the problem of why these two error-producing factors, working in opposition, usually result in no-recall trials producing fewer errors (Ellis & Montague, 1973; Experiments I and II of the present study) whereas this effect reversed in Experiment III of the present study. We suggest that two seemingly minor procedural differences in Experiment III may be responsible for this. First, in Experiment III, subjects were not required to repeat words aloud at the time of study, which may have produced a critical difference in the nature of the information on which the acceptance/rejection decision was based. Item presentation in Experiment III was exclusively visual whereas the recall period was exclusively auditory. This meant that an item which was retrieved and found to have auditory information encoded could be immediately rejected as having come from a prior trial. Such was not the case, either in Experiments I and II or in the Ellis and Montague (1973) study. In all of these experiments, subjects repeated the words aloud at time of study; thus the stimuli had auditory codes established during presentation as well as during recall. The fact that there were, in general, fewer intrusions following recall trials in Experiment III suggests that modality information may have been critical for making the acceptance/rejection decision. However, the modality information would only aid discrimination of recall trial items. No-recall trials would have no encoded auditory information which would allow them to be rejected.

The second procedural alteration in Experiment III was that presentation rate was re-

duced from 2 to 1.5 sec per triad. The likely result of reduced study time is to decrease the amount of item information. This, in turn, should produce more intrusions, according to our model, since the acceptance/rejection decision will be based on less information. However, the reduction in item information should affect no-recall trials more than recall trials. This is because the recall trials still include a 10-second recall period during which item information may be encoded; hence the relative reduction in processing time is minimal. Conversely, the total processing time for no-recall trials has been reduced by 25%.

REFERENCES

ABELSON, R. P., & TUKEY, J. W. Efficient conversion of non-metric information into metric information. In E. R. Tufte (Ed.), *The quantitative analysis of social problems.* Reading, Mass: Addison–Wesley, 1970.

ANDERSON, J. A., & BOWER, G. H. *Human associative memory.* Washington: V. H. Winston, 1973.

ATKINSON, R. C., & SHIFFRIN, R. M. Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation,* Vol. 2. New York: Academic Press, 1968.

Battig, W. F., & Montague, W. E. Category norms for verbal items in 56 categories. *Journal of Experimental Psychology,* 1969, **80,** 1–46.

BADDELEY, A. D., & SCOTT, D. Short-term forgetting in the absence of proactive interference. *Quarterly Journal of Experimental Psychology,* 1971, **23,** 275–283.

BROWN, J. A. Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology,* 1958, **10,** 12–21.

CRAIK, F. I. M. The fate of primary memory items in free recall. *Journal of Verbal Learning and Verbal Behavior,* 1970, **9,** 143–148.

CRAIK, F. I. M., & BIRTWISTLE, J. Proactive inhibition in free recall. *Journal of Experimental Psychology,* 1971, **91,** 120–123.

DILLON, R. F. Locus of proactive interference effects in short-term memory. *Journal of Experimental Psychology,* 1973, **99,** 75–81.

ELLIS, J. A. Inability to transfer information from one level of memory to another as a source of forgetting in single presentation studies. Unpublished doctoral dissertation, University of Illinois, 1973.

ELLIS, J. A., & MONTAGUE, W. E. Effect of recalling on proactive interference in short-term memory. *Journal of Experimental Psychology,* 1973, **99,** 356–359.

GARDINER, J. M., CRAIK, F. I., & BIRTWISTLE, J. Retrieval cues and release from proactive inhibition. *Journal of Verbal Learning and Verbal Behavior,* 1972, **11,** 778–783.

GLANZER, M. Storage mechanism in recall. In G. H. Bower (Ed.), *The psychology of learning and motivation,* Vol. 5. New York: Academic Press, 1972.

GORFEIN, D. S., & JACOBSON, D. E. Memory search in a Brown–Peterson short-term memory paradigm. *Journal of Experimental Psychology,* 1973, **99,** 82–87.

HELLYER, S. Frequency of stimulus presentation and short-term decrement in recall. *Journal of Experimental Psychology,* 1962, **64,** 650.

HINRICHS, J. V. A two-process memory-strength theory for judgement of recency. *Psychological Review,* 1970, **77,** 223–233.

KEPPEL, G., & UNDERWOOD, B. J. Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behavior,* 1962, **1,** 153–161.

LOESS, H. Proactive inhibition in short-term memory. *Journal of Verbal Learning and Verbal Behavior,* 1964, **3,** 362–368.

MELTON, A. W. Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behavior,* 1963, **2,** 1–21.

MILLER, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review,* 1956, **63,** 81–97.

MURDOCK, B. B. JR. The retention of individual items. *Journal of Experimental Psychology,* 1961, **62,** 618–625.

PETERSON, L. R., & PETERSON, M. J. Short-term retention of individual items. *Journal of Experimental Psychology,* 1959, **58,** 193–198.

PETRUSIC, W. M., & DILLON, R. F. Proactive interference in short-term recognition and recall memory. *Journal of Experimental Psychology,* 1972, **95,** 412–418.

RUNDUS, D. Rehearsal processes in free recall. *Journal of Experimental Psychology,* 1971, **89,** 63–77.

RUNDUS, D., & ATKINSON, R. C. Rehearsal processes in free recall: A procedure for direct observation. *Journal of Verbal Learning and Verbal Behavior,* 1970, **9,** 99–105.

RUNDUS, D., LOFTUS, G. R., & ATKINSON, R. C. Immediate free recall and three-week delayed recognition. *Journal of Verbal Learning and Verbal Behavior,* 1970, **9,** 684–688.

TURVEY, M. T., BRICK, P., & OSBORN, J. Temporal course of proactive interference in short-term memory. *British Journal of Psychology*, 1970, **61**, 467–472.

WAUGH, N., & NORMAN, D. A. Primary memory. *Psychological Review*, 1965, **72**, 89–104.

WICKENS, D. D. Encoding categories of words: An empirical approach to meaning. *Psychological Review*, 1970, **77**, 1–15.

Wickens, D. D., Born, D. G., & Allen, C. K. Proactive inhibition and item similarity in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 1963, **2**, 440–445.

WINER, B. J. *Statistical principles in experimental design*. New York: McGraw–Hill, 1962.

WINER, B. J. *Statistical principles in experimental design*, 2nd ed. New York: McGraw–Hill, 1971.

YNTEMA, D. B., & TRASK, F. P. Recall as a search process. *Journal of Verbal Learning and Verbal Behavior*, 1963, **2**, 65–74.