JOURNAL OF VERBAL LEARNING AND VERBAL BEHAVIOR **14**, 430–437 (1975)

Storage and Retrieval Changes that Occur in the Development and Release of PI

RICHARD CHECHILE AND KEITH BUTLER

Tufts University

A Bayesian statistical procedure that separates storage from retrieval as discussed previously by Chechile (1973) and Chechile and Meyer (1975) was employed to study the development and release of proactive interference in the Brown–Peterson paradigm. Both the storage and retrieval components showed a reliable build-up and release of PI, but the storage and retrieval changes were found to be uncorrelated A two factor theory of PI is developed that stresses both the concept of response competition at the time of test to explain the retrieval changes as well as the concept of interference in the transfer process between short- and long-term memory to explain the storage changes.

Despite the importance of proactive interference in short-term memory, it is still an open question as to the processes that underlie this phenomenon. Initially, Keppel and Underwood (1962) proposed that proactive interference in the Brown–Peterson paradigm was attributable to response competition from items learned on previous trials. According to their explanation, these previous items were extinguished during the learning of a subsequent item, but then spontaneously recovered in strength as an increasing function of retention interval and interfered with the recall of the current target item. Thus the locus of the interference process, according to Keppel and Underwood, is a retrieval difficulty at the time of test. Furthermore the phenomenon of release from proactive interference, recently reviewed by Wickens (1972), also can be easily interpreted as a retrieval phenomenon in that a shift to a new encoding differentiates the memory traces and reduces the response competition at the time of test

Conrad (1967) has demonstrated that intrusion errors decreased in frequency as a function of retention interval, and he interpreted those data as contrary to the expectations of Keppel and Underwood's hypothesized spontaneous recovery notion. Conrad further argued for a memory decay explanation for his data. Thus the locus of the interference process, according to Conrad, is a storage difficulty like the failure to transfer the target item from a short-term to a long-term memory (e.g., Atkinson & Shiffrin, 1968) and hence the target item is lost because of its decay from the short-term store. Proactive interference, according to this theoretical position, is due to the decreased efficiency in the transfer process between memory stores because of the continuing presence in short-term memory of items from previous trials that are similar to the target item. If there is any change in the nature of the current target item to make it more dissimilar than previous items then there would be less competition between memory traces in the short-term store. Consequently, the target item would then have better transfer to long-term memory. Thus, a storage explanation could also account for both the development and release of proactive interference.

The important experimental and theoretical question now is: Which of the above theories is correct or are both theories correct? Gardiner, Craik, and Birtwistle (1972) have provided evidence that supposedly demonstrates that the build-up and release of proactive interference is due to retrieval alone. However, the design of the Gardiner *et al.*

study does not seem to be adequate to rule out a storage interpretation of proactive interference. In the Gardiner *et al.* experiment, the Brown–Peterson paradigm was used to investigate the release of proactive interference as a function of the availability of a subcategory cue. The subcategory cue was available (1) at input only; (2) at output only; or (3) neither at input nor output. There was release from proactive interference for both Groups 1 and 2, but not for Group 3. Certainly the difference between Group 2 (output only) and Group 3 (neither input nor output) attests to the role of retrieval in the build-up and release from proactive interference. However, the release from proactive interference found for Group 1 (input only) could have been due to storage changes. The input cue could have helped differentiate the target item from the other items in short-term memory so there may have been a facilitated transfer process. Furthermore, since a retrieval cue was not available after the interpolated activity for Group 1 (input only) then the release from proactive interference for that group might largely be due to storage changes. Furthermore, if an additional group had been run which had the cues both at input and output then it is likely that the relative role of storage and retrieval still could not be assessed For example, if the additional group (cue at both input and output) showed the most release from proactive interference, a result that seems likely, then it is impossible to interpret the mechanism for the additional release. It could be due to an additional retrieval facilitation on top of a storage facilitation, or it could be due to even greater retrieval facilitation because of the match between the output cue and the input cue as would be predicted by the encoding specificity hypothesis (Tulving & Thomson, 1973).

Clearly, then, a significant clarification of proactive interference would result if storage and retrieval could be quantified and analytically separated. Recently, Chechile (1973) and Chechile and Meyer (1975) have developed a Bayesian statistical procedure that analytically separates storage and retrieval components. In general, the separation procedure involves constructing a probabilistic task analysis for a task where the recall trials are randomly supplemented with forced-choice recognition trials followed by a 3-point confidence judgment. The task analysis includes storage and retrieval probabilities that when estimated then provide a means to study the underlying changes that occur in the build-up and release of proactive interference.

Definition of Storage and Retrieval

While it seems reasonable that both storage and retrieval can continuously vary in strength or effectiveness, it is convenient to dichotomize both factors. Storage will be dichotomized as either sufficient or insufficient. Fractional storage or no information will be grouped and characterized as insufficient, since in both cases the subjects would not have recalled the entire target item. Thus on any trial, the subject either has sufficient or insufficient storage concerning the target information. Now across many trials the proportion of times that the subject sufficiently stores the target information will be defined as θ_s, the probability of storage. Notice that the question of what is stored is not being addressed here, but just the question, "how frequently was something sufficiently stored?"

Given that sufficient storage has occurred on a trial, then retrieval can be dichotomized into successful retrieval of all of the stored information and unsuccessful or incomplete retrieval. Across the trials where there is sufficient storage the proportion of times that the subject successfully retrieves the information will be defined as θ_r, the probability of retrieval. Obviously the probability of correct recall θ_C, is just $\theta_s\theta_r$ since correct recall requires both sufficient storage and successful retrieval.

Task Analysis for Recognition Trials

The probabilistic task analysis of the old recognition test trials is illustrated in Figure 1 as a tree diagram. It is assumed that when the subject has sufficient storage, at the time of test, then the subject will give the "yes 3" response where the "3" rating denotes highest confidence. When there is insufficient storage then there may be guessing processes involved. The proportion of trials that the subject correctly gives the "yes" response when there is insufficient storage is defined as θ_g, the guessing probability for old recognition. The parameters θ_1, θ_2, θ_3 and θ_4 correspond to the rating responses as shown in Figure 1.

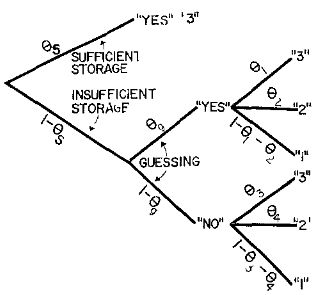

FIG. 1. Tree diagram for the old recognition task.

The task analysis for distractor recognition is illustrated in Figure 2. Because guessing processes should be different for distractor as compared to old recognition, a different guessing parameter, $\theta_{g'}$ is employed. Also, since there could be different rating processes θ_5, θ_6, θ_7 and θ_8 are introduced. Finally, it should be pointed out that the same storage parameter θ_s appears on recall, old recognition, and distractor recognition trials. This assumption is reasonable since the recall and recognition test trials are to be randomized throughout the experimental session so as to insure that the subjects will have no clue prior to the testing time as to the type of test procedure that will be used on that trial.

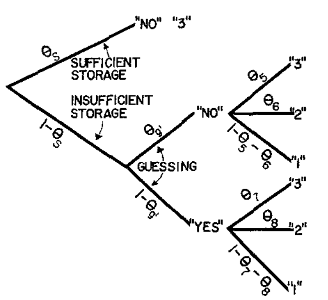

FIG. 2. Tree diagram for the distractor recognition task.

Chechile (1973) and Chechile and Meyer (1975) discuss in detail how point estimates for θ_s, θ_r, θ_g, and $\theta_{g'}$ can be obtained for each subject by means of a Bayesian analysis. These studies also provide several experiments to demonstrate the separation procedure as well as to provide evidence for the validity of the estimates. The resulting estimation equations are presented in the appendix of this paper. Furthermore the point estimates of θ_s and θ_r were found to also be uncorrelated across subjects (cf. Chechile, 1973) so there is obviously no difficulty in the storage measure detecting retrieval or vice versa. One might, of course, question the identification of θ_s to storage and θ_r to retrieval. However, Experiment II in the Chechile and Meyer (1975) study shows rather convincing evidence that the identification is appropriate. In that experiment the subjects in one condition of a Brown–Peterson type experiment were given greater time to recall the target information than subjects in another condition, but the total time for a trial was identical between the two groups. This manipulation ought to only affect search and retrieval processes and that is precisely the outcome of that experiment. Consequently, the separation procedure should be a valid and useful tool for the investigation of the underlying processes of proactive interference.

METHOD

Subjects

Thirty undergraduates at Tufts University volunteered to participate in the experiment.

All had normal hearing and spoke English as their native language.

Design

The experiment consisted of 33 blocks of four trials each. Within each block, the memory word items for the first three trials were all selected from the same taxonomic category (Battig & Montigue, 1969). The items for the fourth trial position were selected from previously unused categories. The 33 trials at each within-block position were randomly assigned to test memory using old recognition, distractor recognition, and recall measures in equal proportions.

Apparatus and Procedure

The tape-recorded instructions and experimental trials were played on a Sony TC 366 stereo tape deck and delivered over Koss Pro-4A headphones. Each trial consisted of three stages: the presentation of the word item, an 8-sec interpolated interval, and a test cue followed by the subject's response and confidence rating. A high-pitched ready tone preceded the male voice presentation of the memory item from the right headphone. Immediately after item presentation, a randomly selected three-digit number was presented in a female voice on the left headphone. The subject was required to repeat the item and the number and begin counting backwards by threes. After 8 sec of counting aloud, one of two types of test cues was spoken in the male voice on the right headphone. If the cue was the word "recall," the subject was allowed 1.5 seconds to verbally report the memory item. If, however, there was any other word presented, the subject had to identify whether or not that word was the memory item for that trial. The subject's "yes" or "no" response was followed by a confidence rating for that response. The rating was given as a number from 1 to 3, with 3 being most certain. The subject was not informed which type of cue would be used before the test.

Within each block, trials were separated by a 4-sec intertrial interval. A 20-sec rest interval was allowed between blocks. Subjects were given one practice trial with each type of test cue before the experimental session.

RESULTS

Using a standard Bayesian analysis of a normal model with uniform priors for both the group mean of the N point estimates, μ_m, and the log of the standard deviation of the point estimates, log σ, the posterior marginal distribution for $t=(\mu-\bar{X})\sqrt{N}/S$ is distributed as a Student-t distribution with N-1 degrees of freedom (cf. Box & Tiao, 1973, pp. 92–101). This Bayesian technique will be used in the subsequent data analysis to obtain probability statements concerning the group means. Only the more highly probable effects (i.e., $p > .95$) will be reported; so this Bayesian procedure, while logically different from traditional sampling-theory, results in absolutely equivalent conclusions. Finally, in order to better assure the assumptions concerning normality, all individual point estimates, θ, were transformed to 2 $\sin^{-1}\sqrt{\theta}$ for purposes of the data analysis.

The group means of the untransformed point estimates for the probability of correct recall, θ_C, the probability of sufficient storage, θ_s, and the probability of retrieval, θ_r, are displayed in Figure 3 as a function of within-block trials. It is highly probable that there is a build-up of proactive interference from Trials 1 to 3 for not only correct recall, $p > .99999$, but also for the storage parameter, $p > .99999$ and the retrieval parameter, $p = .995$. The proportion change in storage between Trials 1 to 3 is 2.4 times greater than the proportion change for retrieval. Despite the fact that there is a reliable change for storage and retrieval between Trials 1 and 3, there is only a −.01 correlation across subjects between the proportion change in storage and the proportion change in retrieval. Additionally, it is highly likely that there is a release from proactive interference from Trials 3 to 4 not only for correct recall, $p > .99999$, but also for the storage parameter, $p > .99999$, and retrieval parameter, $p = .977$. The change in storage is 3 times greater than the change in retrieval between Trials 3 to 4. Furthermore there is a – 06 correlation across subjects between the proportion storage change and the proportion retrieval change between Trials 3 and 4. Consequently, these data demonstrate a build-up and release of proactive interference for both storage and retrieval; and these data further indicate that the storage and retrieval changes are uncorrelated, denoting the presence of two separate factors, both susceptible to proactive effects.

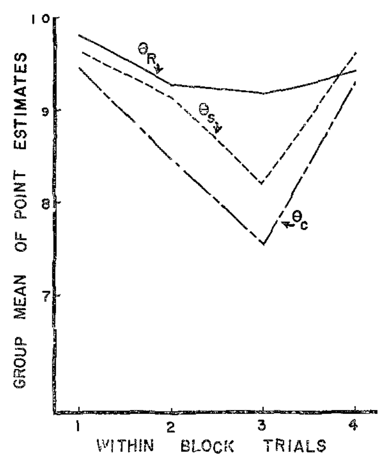

FIG. 3. The group means of the point estimates for the probability of correct recall, θ_C, the probability of storage, θ_s, and the probability of the retrieval, θ_r, as a function of within-block trials.

The group means for the probabilities of guessing incorrectly on recognition testing when there is insufficient information are displayed in Table 1 along with the group totals of recognition errors. There are no highly reliable differences as a function of within block trials for either the false alarms or the distractor incorrect guesses, $1\text{-}\theta_{g'}$. However, it is probable, $p > .975$, that there is an increase in both misses and, $1\text{-}\theta_g$ from Trials 1 to 3 followed by a reliable decrease in both measures for Trial 4. In addition, the correlation across trials between $1\text{-}\theta_g$ and total misses is .982, attesting to the covariation of the observed miss rate with the estimated old recognition incorrect guesses.

TABLE 1

COMPARISON BETWEEN RECOGNITION ERRORS AND MODEL ESTIMATES FOR INCORRECT GUESSING

Within block trials	$1-\theta_g$	Total misses	$1-\theta_{g'}$	Total false alarms
1	0 009	0	0.070	0
2	0.147	11	0 068	2
3	0 245	23	0 024	3
4	0.080	3	0 007	0

DISCUSSION

The important finding of this experiment is that proactive interference is not attributable to a single factor Clearly both storage and retrieval processes change and these changes are uncorrelated, which of course demonstrates the independence of the two factors. While storage was found to contribute more in this particular experiment, the relative contribution of storage and retrieval could easily change as a function of the experimental conditions so the most general result is that the build-up and release of proactive interference is due to both storage and retrieval. Consequently, the data of the present study contradict the conclusions of both the Gardiner *et al.* (1972) and the Loftus and Patterson (1975) studies which argue that proactive interference is due to retrieval alone. Further, the present study also contradicts the conclusions of Dillon (1973), and Petrusic and Dillon (1972) who argue that proactive interference is due to storage alone. These previous experiments, however, have not used a procedure that separates storage and retrieval on an individual subject basis and hence these previous studies cannot demonstrate simultaneously the role of both storage and retrieval in proactive interference.

A plausible two factor theory for proactive interference is a theory that stresses the role of competition both in making the transfer process between short- and long-term memory more difficult and also in making the retrieval process at the time of test difficult. The transfer process between memory stores becomes more difficult because of the continuing presence of previous trial items in short-term memory. If these previous items are similar to the current target item, for example if they come from the same taxonomic category, then these items constitute a noisy background and the noisy background decreases the efficiency of the transfer process to long-term memory. If, however, there is a shift to another taxonomic category then the current target item is easily differentiated from other previously presented items thus increasing the signal-to-noise ratio and also increasing the efficiency of the transfer process. Given, however, the times when there is sufficient information storage, then the retrieval process at the time of test will be less efficient if there are other members of the same taxonomic category recently stored. A shift to a new taxonomic category facilitates retrieval because there is only a single instance of the new category to retrieve.

Appendix

A Bayesian estimation procedure can be used to estimate the parameters discussed previously in this paper. The Bayesian procedure involves constructing prior probability distributions for each of the 12 parameters and then transforming the prior probability to posterior probability by means of Bayes' theorem. A symbolic representation of the data is depicted in Figure 4. The total number of old and distractor recognition trials are respectively n_o and n_d.

In this analysis the prior distribution for each of the parameters is taken to be independent and uniform distributions over the interval of 0 to 1 with the restrictions that $\theta_1+\theta_2 \leqslant 1$, $\theta_3+\theta_4 \leqslant 1$, $\theta_5+\theta_6 \leqslant 1$, and $\theta_7+\theta_8 \leqslant 1$. The prior distribution used here denotes initial indifference or ignorance on all parameters. The posterior probability concerning θ_s, θ_r, θ_g, and $\theta_{g'}$ can be summarized by four separate posterior marginal probability distributions, namely, $P(\theta_s|\text{data})$, $P(\theta_r|\text{data})$, $P(\theta_g|\text{data})$ and $P(\theta_{g'}|\text{data})$. Chechile (1973), and Chechile and Meyer (1975) showed that

(a) RECOGNITION TRIALS

	Yes Responses: Ratings 1	2	3	No Responses: Ratings 1	2	3
Old Recognition	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
Distractor Recognition	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}

(b) RECALL TRIALS

Correct	Incorrect
n_1	n_2

FIG 4. A representation of (a) recognition data and (b) recall data.

$$P(\theta_s|\text{data}) = K_1 P_1 P_2 P_3, \tag{1}$$

$$P(\theta_r|\text{data}) = K_2 \int_0^1 P_2 P_3 (\theta_s\theta_r)^{n_1} (l-\theta_s\theta_r)^{n_2} d\theta_s, \tag{2}$$

$$P(\theta_g|\text{data}) = K_3 \theta_g^{n_{11}+n_{12}} (1-\theta_g)^{n_{14}+n_{15}+n_{16}} \int_0^1 P_1 P_3 \theta_s^{n_{13}} (1-\theta_s)^{n_o-n_{13}} G\, d\theta_s, \tag{3}$$

$$P(\theta_{g'}|\text{data}) = K_4 \theta_{g'}^{n_{24}+n_{25}} (1-\theta_{g'})^{n_{21}+n_{22}+n_{23}} \int_0^1 P_1 P_2 \theta_s^{n_{26}} (1-\theta_s)^{n_d-n_{26}} G'\, d\theta_s, \tag{4}$$

where K_1, K_2, K_3, and K_4 are normalization constants and where

$$P_1 = \frac{1}{\theta_s} \int_0^{\theta_s} \alpha^{n_1} (1-\alpha)^{n_2} d\alpha, \tag{5}$$

$$P_2 = \theta_s^{n_{13}} (1-\theta_s)^{n_o-n_{13}} \sum_{i=0}^{n_{13}} \frac{\binom{n_o+1}{n_{13}-i}\left(\frac{1-\theta_s}{\theta_s}\right)^i}{\binom{n_{11}+n_{12}+i+2}{2}}, \tag{6}$$

$$P_3 = \theta_s^{n_{26}} (1-\theta_s)^{n_d - n_{26}} \sum_{j=0}^{n_{26}} \frac{\binom{n_d+1}{n_{26}-j}\left(\frac{1-\theta_s}{\theta_s}\right)^j}{\binom{n_{24}+n_{25}+j+2}{2}}, \tag{7}$$

$$G = \sum_{i=0}^{n_{13}} \frac{\left(\frac{1-\theta_s}{\theta_s}\right)^i \theta_g{}^i}{(n_{13}-i)!\,(n_{11}+n_{12}+i+2)!}, \tag{8}$$

$$G' = \sum_{i=0}^{n_{26}} \frac{\left(\frac{1-\theta_s}{\theta_s}\right)^i \theta_{g'}{}^i}{(n_{26}-i)!\,(n_{24}+n_{25}+i+2)!}. \tag{9}$$

The integrals in equations (2), (3), (4), and (5) can be numerically computed.

A typical set of posterior marginal distributions for a particular subject reported in Chechile and Meyer (1975) is illustrated in Figure 5. The posterior probability density for each parameter in Figure 5 was computed for the points .01 to .99 in steps of .02. The data n_1, n_2; $n_{11} \ldots n_{16}$; $n_{21} \ldots n_{26}$ for which these distributions are based are respectively 9, 71; 4, 26, 19, 22, 5, 4; 0, 6, 0, 17, 30, 27. The distribution for each parameter is a separate unimodal function so it is convenient to use the mode of the posterior marginal distribution as the point estimate for the parameter.

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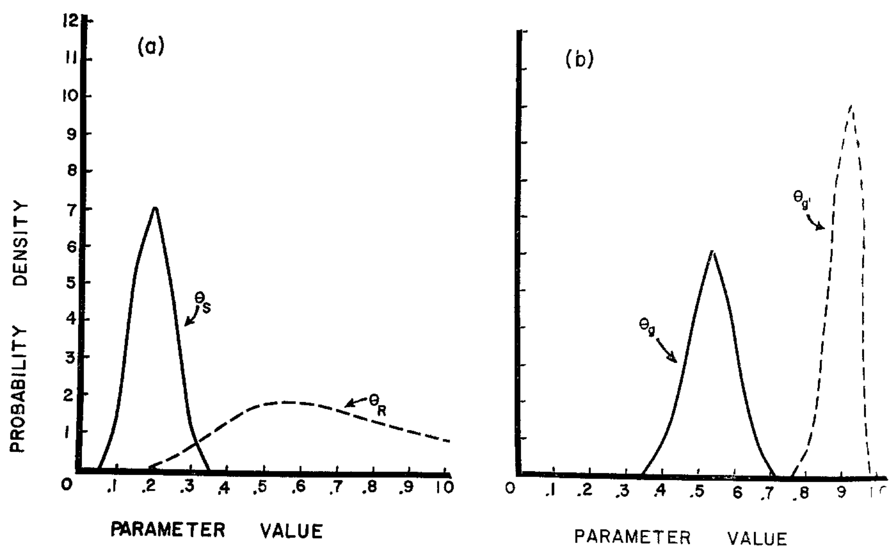

Fig. 5. Posterior marginal distributions for θ_s, θ_r, θ_g, and $\theta_{g'}$ on a subject whose data, n_1, n_2, $n_{11} \ldots n_{16}$; $n_{21} \ldots n_{26}$, are 9, 71; 4, 26, 19, 22, 5, 4; 0, 6, 0, 17, 30, 27, respectively.

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(Received March 21, 1975)