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REHEARSAL PROCESSES AND THE RETENTION OF PAIRED-ASSOCIATES

by

Donald S. Ciccone

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INTRODUCTION

Rehearsal, defined as vocal or subvocal item repetition, is one example of the many control processes available to the human information processor (Atkinson & Shiffrin, 1971). These control processes or learning strategies may be thought of as the software or computer programs governing the flow of information through the hardware of a computer. They determine what sort of information is encoded, stored, and subsequently retrieved. In addition to rehearsal, subjects typically have at their disposal strategies which include visual imagery, mnemonics, and the use of rules to organize or categorize stimuli. In contrast to these subject-determined processes are the structural mechanisms or hardware of the system. These consist of such things as: an attentional device; short- and long-term storage units; and transfer mechanisms. These structural mechanisms are the physiologically wired-in features of the system that set the boundaries within which the control processes can operate. Viewed within this perspective, the use of rehearsal as a learning strategy is one of the simplest and hence least sophisticated means of acquiring verbal information.

Despite its apparent lack of uniqueness as an encoding process, the rehearsal concept has been relied upon extensively in a number of theoretical accounts of verbal learning. Atkinson and Shiffrin (1968), for example, suggest that rehearsals serve a dual function in information processing by maintaining an item in the short-term store (STS) and transferring information to the long-term store (LTS). They view the STS as an executive monitor which governs the flow of information in the processing system. It is here that control processes execute their control of the subject's encoding and retrieval operations. Short-term memory is described as a limited capacity storage unit from which information may be retrieved with unfailing accuracy. Long-term memory, on the other hand, is a larger capacity store with information retrieval on a probabilistic basis. Within this general theoretical framework, Atkinson and Shiffrin (1968) have formalized a model which places primary emphasis upon the rehearsal concept. According to this model the STS is conceptualized as a rehearsal buffer of fixed size analogous to a push-down stack in which entering items displace older items already residing in the buffer. In terms of this particular model the length of time spent in STS is a critical factor determining the probability of retrieval from LTS. This assumption derives from the notion that a constant proportion of information is transmitted to LTS on every trial in which the item resides in the rehearsal buffer.

The bowed serial position curve obtained in free recall experiments is easily explained within the context of this rehearsal model. The primacy effect results when items occurring at the beginning of the list are rehearsed more frequently owing to a relatively empty rehearsal buffer. As the buffer fills up, items are accorded a more or less constant number of rehearsals. Finally, items at the end of a list are often recalled correctly because the subjects adopts the strategy of emptying his rehearsal buffer before attempting long-term retrieval. This model has been able to account both qualitatively and quantitatively for the effects of a large number of independent variables known to influence the retention of verbal information (e.g., presentation rate, list length, number of repetitions, etc.). In addition, it has generated predictions concerning such subtle effects as the lag function in paired-associate learning (Brelsford, Shiffrin, & Atkinson, 1968). Interpresentation lag is manipulated by controlling the number of items intervening between successive repetitions of critical items. When tested after a constant long-term retention interval a nonmonotonic lag function is obtained which indicates the existance of some optimal lag value. Brelsford, et al. (1968) were able to accurately predict this rather non-intuitive finding using a modified version of the Atkinson and Shiffrin memory model.

Another model which places heavy emphasis upon the rehearsal concept has been suggested by Bernbach (1971). According to his "postperceptual" memory model, each rehearsal produces an internal representation called a "replica". The number of these replicas does not, however, increment retrieval probability, since a single copy is sufficient for the recall of an item. The number of copies is important only in so far as it serves to prevent forgetting induced by interfering items which intervene between study and test. There is some probability that a replica is lost with each succeeding interpolated item. Thus, the number of replicas which are stored determines the resistance of the item to forgetting.

In addition to these various theoretical developments, a significant methodological improvement in the study of rehearsal processes was introduced by Rundus and Atkinson (1970) in their use of an overt rehearsal technique. Using a standard free recall task, they instructed their subjects to freely and overtly rehearse each item on the list of words to be learned. The subject's rehearsal protocol was tape recorded and each item analyzed both in terms of recall probability and number of rehearsals. The direct observation of overt rehearsal provided evidence that recall probability was highly correlated with rehearsal frequency. The case for rehearsal as a critical factor in the retention of verbal stimuli was clear and convincing. In addition, these data provided further support for models which stressed the importance of the rehearsal concept (e.g., Atkinson & Shiffrin, 1968).

In a subsequent series of studies, Rundus (1971) was able to demonstrate the usefulness of the overt rehearsal technique in investigating a number of well established empirical relationships in free recall, including the spacing effect, the effect of categorized word lists, and the Von Restorff effect. In each case the mean number of rehearsals accorded an item closely paralleled its recall probability.

Using a similar overt rehearsal technique, Ciccone and Brelsford (1974b) conducted an empirical investigation of the lag effect in recognition memory. With three digit numbers serving as stimuli, and a continuous yes-no recognition procedure (cf., Shepard & Teghtsoonian, 1961) they found a substantial correlation between subjects' recognition performance and rehearsal frequency. In addition to a variable or free rehearsal condition in which subjects' rehearsal strategy was unconstrained, they also used a constant rehearsal condition. In this condition rehearsal strategy was controlled by having subjects rehearse an item exactly four times during each presentation. This altered the shape of the resulting lag function so that it assumed a flat, as opposed to the more typical interted U, shape. The fixed rehearsal condition provided strong evidence in favor of rehearsal frequency as a moderator of recognition performance. Previous manipulations had correlated rehearsal frequency with recall probability. Rather than demonstrating a correlational relationship, Ciccone and Brelsford were able to directly control the subjects' performance level by manipulating rehearsal frequency. This illustrated rather clearly that rehearsal was directly implicated in long-term recognition memory.

The studies reviewed above suggest that the length of time an item spends in short-term memory (i.e., the number of rehearsals it receives) determine the amount of information transmitted to long-term memory. In an early statement on the transfer of information from STS to LTS Atkinson and Shiffrin (1968) speculated that "any information in STS is transferred to LTS to some degree throughout its stay in the short-term store (p. 115)." They pointed out, however, that there is not necessarily a close correspondance between the length of an item's residence in STS and the subsequent amount of information transferred to LTS. They suggested that the amount and type of information transferred may vary in response to the demand characteristics of the task, the type of stimuli, or in general according to the control process adopted by the subject. The formal model which they developed within this theoretical framework has already been discussed. It places considerable emphasis upon the notion that rehearsals do increment strength in LTS. This assumption was confirmed in a number of experiments in which model predictions matched obtained data quite closely. Although Atkinson and Shiffrin's theoretical discussion permitted alternative conceptions of the rehearsal process, the model which was <u>formalized</u> assumed that rehearsal was a homogeneous activity which invariably served to increment trace strength in LTS. A more recent study by Shiffrin (1973) suggests that under certain experimental conditions, the amount of time spent in STS does not necessarily covary with the amount of information transferred to LTS (Experiment 111). This represents an empirical demonstration of Atkinson and Shiffrin's earlier theoretical speculation that given different demand characteristics of the experimental task, the amount of information transferred to LTS may be drastically altered. In the recent Shiffrin paper, it was demonstrated that when an item was in STS for only one second, subsequent recall was nearly identical to that of an item residing in STS for forty seconds. In other words, there seemed to be no constant build-up of information in LTS. It seems quite clear that under certain experimental conditions an item can remain in STS for a prolonged period without transferring an appreciable amount of information to LTS. It is equally apparent that in other experimental circumstances this transfer may be substantial.

Similarly, Craik and Watkins (1973) were able to demonstrate that the length of time an item resided in short-term memory did not predict subsequent long-term retention. The subjects in their study were instructed to maintain an item in short-term memory under the guise of a perceptual tracking task. An "unexpected" test of recall followed the tracking task. This test indicated that the number of items intervening between presentation and subsequent test, i.e., the amount of time spent in short-term memory, did not influence long-term recall.

The levels of processing approach of Craik and Lockhart (1972) offers a reasonable explanation for this finding in terms of two distinctively different types of rehearsal activity. Rehearsal can either maintain an item in STS or strengthen it in LTS depending upon the level of analysis achieved. If an attempt is made during rehearsal to encode the semantic-associative attributes of the stimulus it is said to be elaborative and therefore useful in a subsequent test of long-term retention. On the other hand, if the item is merely repeated passively or echoically the rehearsal only serves to maintain the item in short-term memory. Jacoby (1973) has reported results consistent with the notion that when a recall test is the dependent measure, overt or covert vocalizations do not necessarily transfer any useful information to long-term memory. The situation with respect to recognition memory may, however, be quite different. A study by Woodward, Bjork, and Jongeward (1973) indicated that both maintenance and elaborative forms of rehearsal improved subsequent recognition performance. It would appear that maintenance rehearsals transfer information to long-term memory at a rate significantly below that of elaborative rehearsals.

Maintenance rehearsals may well be an instance of a process which only occurs under certain experimental circumstances such as those described by Craik and Watkins (1973). On the other hand, it seems more likely that the phenomenon of maintenance rehearsal might occur with some regularity even under typical circumstances. It is suggested that during the course of any continuous learning task the subject can engage in qualitatively distinct forms of rehearsal activity on different trials. He may select an active or elaborative rehearsal mechanism which permits the encoding of semantic stimulus attributes or a passive (maintenance) mechanism which does not. While the distinction being drawn here is not isomorphic with that of Craik and Watkins it is certainly related. They have shown the feasibility of qualitatively different rehearsal processes operating under drastically altered experimental circumstances. The present suggestion is that perhaps qualitatively different rehearsal processes operate even under nominally identical experimental circumstances. In terms of an information processing approach (e.g., Atkinson & Shiffrin, 1971), the quality of the rehearsal activity, i.e., active or passive, is determined by the control process adopted in response to the demand characteristics of the task. The selection of an encoding mechanism is a decision which governs the flow of information in the processing system and thus ultimately determines which items become encoded and which do not.

It is interesting to note that Bjork (1971) touched, albeit indirectly, on this issue when he wrote "I think it is quite likely in continuous procedures that subjects choose on some trials not to make any real storage effort with the item presented (p. 320)." Translated into the language of Craik and Watkins, subjects rehearse passively (the maintenance mode) or actively (the elaborative mode) depending upon some, as yet unspecified, decisional process. Ciccone and Brelsford (1974b) have speculated that the pattern of rehearsals accorded a given item may be intimately tied to its accessibility which in turn fluctuates during the course of an experimental session. This suggests that one possible basis upon which a subject may make an encoding decision lies in the accessibility of the item. It seems reasonable that subjects should attempt to rehearse elaboratively only when presented with an item that is inaccessible. This is done to maximize the chances of success on a subsequent test. On the other hand, when an item is accessible, it is possible that subjects may adopt a passive rehearsal strategy, merely repeating items in an echoic fashion with no real attempt at encoding. There is little point in actively rehearsing a well learned item.

In summary, it would appear that the empirical effects of rehearsal upon retention have been rather well established, but that the decision making aspects of this process have been largely ignored. This being the case, any adequate model of rehearsal processes must first, specify a formal relationship between task characteristics and consequent rehearsal activity, and second, allow for the existance of both active and passive forms of rehearsal, each responsible for transferring information to long-term memory at a different rate.

The Model

The foregoing discussion suggests that a model of rehearsal processes should attempt to integrate the decision making aspects of the verbal learning task with the selection of encoding mechanisms. A schematic diagram of such a model is contained in Figure 1. The informational bases upon which the subject

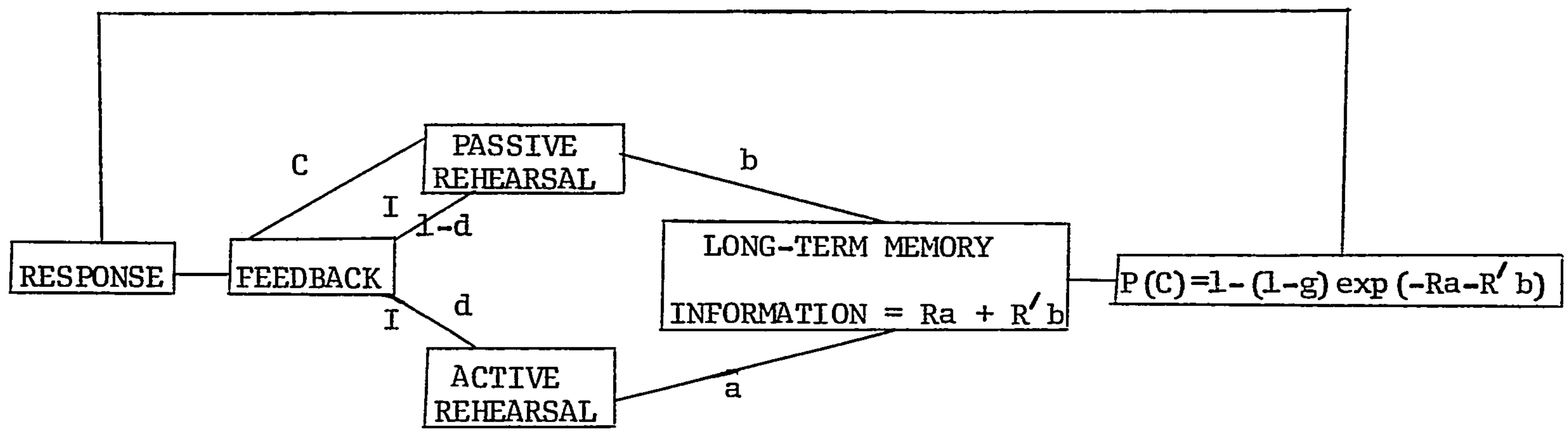

Figure 1. The role of passive and active rehearsal in transferring information to long-term memory. R and R' represent the number of rehearsals and a and b the rates of information transfer from the active and passive modes, respectively; g is the guessing probability; and d is the probability an item will be actively rehearsed given it was incorrect. C and I indicate the type of feedback, correct or incorrect.

makes his decisions include external feedback supplied by the experimenter and internal or subjective variables. The present model addresses itself to the role of external feedback in directing rehearsal activity and intentionally omits from consideration subjective factors such as motivational level, intelligence, and degree of task involvement. Although these variables certainly play a role in determining the absolute number of rehearsals generated, they are poorly defined and difficult to operationalize. The specific domain to which the present model claims to be applicable is that in which all subjects are of uniform intelligence and relatively well motivated to perform the task.

In order to evaluate the effects of external feedback, a paired-associate learning task was thought to be most appropriate. In a continuous paired-associate anticipation procedure (cf., Brelsford, Keller, Shiffrin, & Atkinson, 1966) the subject responds to the stimulus during the test phase of the trial and then receives feedback as to his accuracy during the study phase. In terms of the present model, the subject receives external information as to item accessibility during the study phase. This sort of objective feedback is critical in determining the type of encoding mechanism, either active or passive, selected for use on a given trial. The specific decision rule relating accessibility to rehearsal strategy is rather straightforward. Given that an item is responded to correctly (i.e., either guessed correctly or retrieved) the subject engages in passive rehearsal. This results from the assumption that subjects will not attempt to actively encode accessible items since they are already learned (cf., Brelsford, et al., 1968). On the other hand, when external feedback informs the subject that he has made an error, he will more likely engage in an active elaborative effort to encode. This relationship is not absolutely deterministic however, since limitations upon the subject's processing system may force him to use the passive rehearsal mode even when he is informed that the item is inaccessible. On the other hand, the effort required to engage in active rehearsal may preclude such an attempt upon every "incorrect" trial. Other on-going cognitive activity resulting from previous trials may simply prevent the elaboration of every stimulus presented.

For the purposes of the model, active rehearsal is specifically defined as an elaborative encoding process which accesses and stores semantic or associative stimulus attributes. Passive rehearsal consists of accessing the phonemic code or label of the stimulus without reference to semantic content. Ciccone and Brelsford (1975) have reported that subjects can in fact encode stimulus attributes with the specificity required by the preceding definitions. Each of these two rehearsal modes is associated with a differential rate of information transfer to long-term memory since semantic information is more useful than non-semantic in long-term recall (Ciccone & Brelsford, 1974a). This fact is represented in the model by assuming that the rate parameter which transfers information to long-term memory during each active rehearsal (a) is greater than the corresponding rate for each passive rehearsal (b). The amount of information stored in long-term memory then, is the sum obtained by multiplying each rehearsal by its appropriate rate parameter $(Ra + R'b)$.

The rule used to transform the amount of information stored in long-term memory into a response probability is given below:

$$P(C) = 1 - (1-g)\exp(-Ra - R'b).$$

This rule has the property of setting the probability of a correct response at the guessing rate (g) when the amount of information equals zero. As the amount of stored information approaches infinity, the probability of a correct response approaches one. This rule was chosen because it is the function of the typical linear learning model (cf., Atkinson & Shiffrin, 1968).

The continuous flow of information which this model suggests implies that subjects utilize an active form of rehearsal at the outset of the experimental session (with inaccessible items) and later shift to a passive form (as items become accessible).

The overall rate of information transfer to long-term memory is therefore a declining function over trials, since the rate associated with passive rehearsal is much less than the rate associated with active.

The particular model being proposed contains no provision for loss of information from long-term memory. It is assumed that with a relatively short interpresentation lag information loss from long-term memory is negligible.

Experiment 1

Parameter Estimation and Test of the Formal Structure of the Model

The previous discussion has suggested a formal relationship between item accessibility and the consequent selection of encoding mechanisms. A paradigm in which explicit accessibility feedback may interact with subsequent rehearsal activity is the continuous paired-associate procedure (cf., Brelsford, et al., 1966). A first step in ascertaining the validity of the proposed model lies in comparing simulated data generated by the model with experimental data generated by subjects. In order to determine whether or not the mathematical structure of the empirical data could be adequately described by the model under consideration the following experiment was undertaken.

Method.

Experimental design. A single experimental condition was employed in which subjects were administered two paired-associate lists a day for four consecutive days.

Materials and procedure. The stimuli were all common abstract adjectives varying in length from four to nine characters and were all either mono- or di-syllabic. A set of 50 two-digit numbers served as responses. The numbers ranged from 23 to 98, excluding numbers with consecutive digit repetitions and items containing zeros.

A continuous paired-associate anticipation procedure was used with a two-second test phase and a three-second study phase. A one-half-second intertrial interval separated the test and study phases of each trial, as well as the study and test phases of adjacent trials. The stimuli were presented visually on a television monitor attached to a PDP-8 computer. The computer controlled the temporal sequencing of the stimuli throughout the experiment. The subject was instructed to respond aloud with a two-digit number as soon as a single word appeared on the screen (the test phase) and then to rehearse aloud when the correct word-number pair appeared (the study phase). The number of rehearsals was determined entirely by the subject with the exception that he had to rehearse at least once. Only the pair on the screen could be rehearsed. A tape recorder was placed in each experimental cubicle and each session was recorded.

The instructions specifically precluded subjects from engaging in visual imagery or using mnemonic encoding strategies. Subjects were told that the objective of the experiment was to study rehearsal and for this reason they should limit their learning strategy to the use of rehearsal only. Nothing about the quality of the rehearsal was specified and subjects were free to generate as few (with a minimum of one) or as many rehearsals as they wanted during the study interval.

Each subject received two lists during each of four experimental sessions. This resulted in a total of eight lists per subject. There were, however, a total of 16 different experimental lists used across subjects, with each subject only receiving eight (the remaining eight lists were to be used in Experiment 11). Each list contained 243 test-study trials. A five minute break intervened between the two lists. All lists contained 13 critical items, each presented exactly seven times with seven items intervening between successive repetitions. Buffer items were used to fulfill the requirements of this sequence. Each list began with 20 buffer items and, in addition, the two lists used on the first day were treated as practice lists and not used in the data analysis. While each list contained different words, the same set of 50 numbers served as a common set of stimuli. A given number was not used more than once during any single experimental session (which consisted of two lists).

<u>Subjects</u>. A total of 15 Rice undergraduates served as subjects. All were paid for their participation. They were run individually or concurrently (up to four at one time), with each subject seated in a separate cubicle. Each subject received

a total of six experimental lists (not counting the two practice lists) with 13 critical items per list, so that each subject received a total of 78 critical items (this procedure was designed to produce a total of 1170 critical items across subjects).

Data analysis. The number of rehearsals per item and the accuracy of the subject's response were recorded for each of the seven learning trials for each critical item for all subjects. A computer program was used to analyze the data. In addition to calculating the learning curve, probability distributions were calculated for each of the following random variables: total number of errors; number of errors before the first success; number of errors between adjacent successes; and number of successes between adjacent errors. In addition, there were 32 possible sequences of correct and incorrect responses from trial one through trial five and the frequency of occurrence of each of these categories was also obtained.

Simulation procedure. The model shown in Figure 1 contains three parameters: d, a, and b. In order to determine the best-fitting set of these values for the present data, a parameter estimation program called Stepit (Chandler, 1965) was used. This program searches for parameters which minimize some arbitrary goodness-of-fit criterion. In the present instance, this criterion was based upon the sum of the squared deviations between expected and obtained data for each of the following distributions: total number of errors; number of errors before the first success; number of errors between adjacent successes; and number of successes between adjacent errors. In addition, the learning curve and the proportion of cases falling at each of the 32 possible sequences of corrects and incorrects (as described above) were also used.

The formal structure of the model specifies that the number of rehearsals in each rehearsal mode is a critical factor determining the overall amount of information stored. Rather than treating each of the seven trials as a single opportunity for the transfer of information, the simulation procedure employed the actual number of rehearsals that an item received on a given trial. For example, if an item was rehearsed three times on some trial, the appropriate rate of transfer (for either the active or passive mode) was multiplied by three and stored. The total amount of information stored about an item was then converted into a correct or incorrect response using the response rule given in Figure 1. The total amount of information about each item was stored separately and was cumulated across trials. For example, the amount of information on trial seven for a given item was the sum of the information stored on its six previous trials.

In order to produce stable simulated data, each subject-generated rehearsal sequence was used ten times in the parameter estimation procedure. This had the effect of producing a number of simulated items equal to ten times the actual number of experimental items.

<u>Results and Discussion</u>.

Due to the inaudibility of some subject responses and occasional mechanical failures the total number of data points collected at each point along the learning curve was 986 (instead of the projected 1170). These data were analyzed in the manner described above and the three best-fitting parameter values were obtained using the Stepit program. The information transfer parameters for active (a) and passive (b) rehearsal were .91 and .05, respectively. The rehearsal mode selection parameter (d) was estimated to be .44. Since there were a total of 986 empirical observations, there were 9,860 simulated data sequences (in accordance with the simulation procedure described above).

The predicted learning curve along with the observed data points are shown in Figure 2. As in all subsequent figures, the continuous function represents model predictions, while the circles indicate obtained data. The goodness-of-fit is indicated by the fact that the predicted values closely approximate observed data. The mean number of correct responses across trials for the obtained data was 4.26.

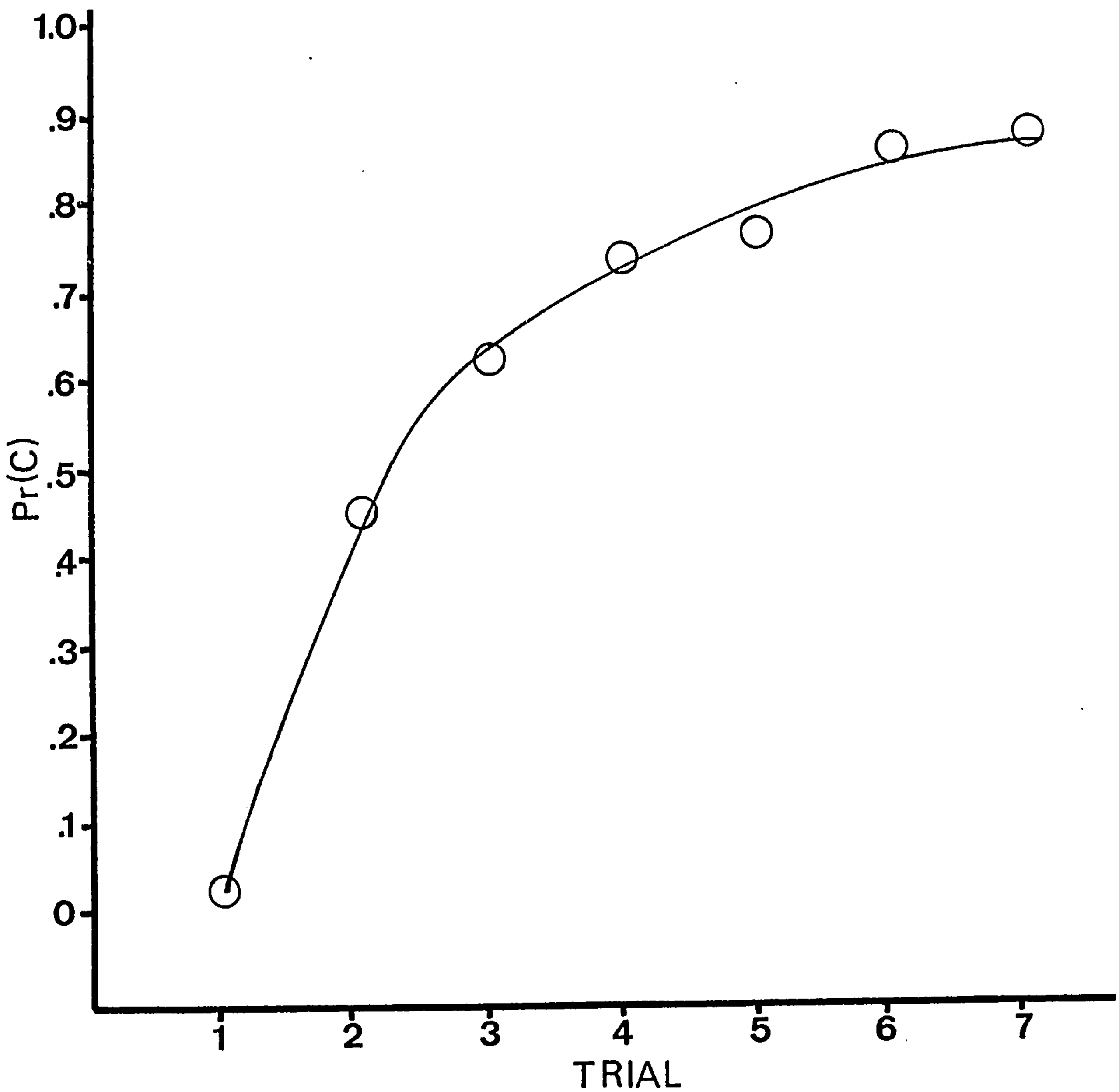

Figure 2. Predicted learning curve and obtained data points.

In addition to the learning curve it is of interest to examine how well the formal structure of the model was able to approximate the probability distributions of the four random variables mentioned previously: total number or errors; number of errors before the first success; number of errors between adjacent successes; number of successes between adjacent errors. The predicted probability distribution for the first of these random variables, total number of errors (T), is presented in Figure 3 along with the obtained data. In order to test the goodness-of-fit of the model a Kolmogorov-Smirnov one-sample D statistic was computed (Siegel, 1956). The statistic D is the maximum deviation between the cumulated predicted probability distribution and the cumulated observed distribution. For a given number of degrees of freedom, the higher the value of D the greater the probability that the obtained distribution is not a random sample from the predicted distribution. The D value between the predicted and obtained cumulated probability distributions of total errors is given in Figure 3. On the basis of this test it is clear that the model predictions are in reasonable agreement with obtained data.

The predicted and obtained probability distributions for the number of errors before the first success (J), the number of errors between adjacent successes (E), and the number of successes between adjacent errors (S) are presented in Figures

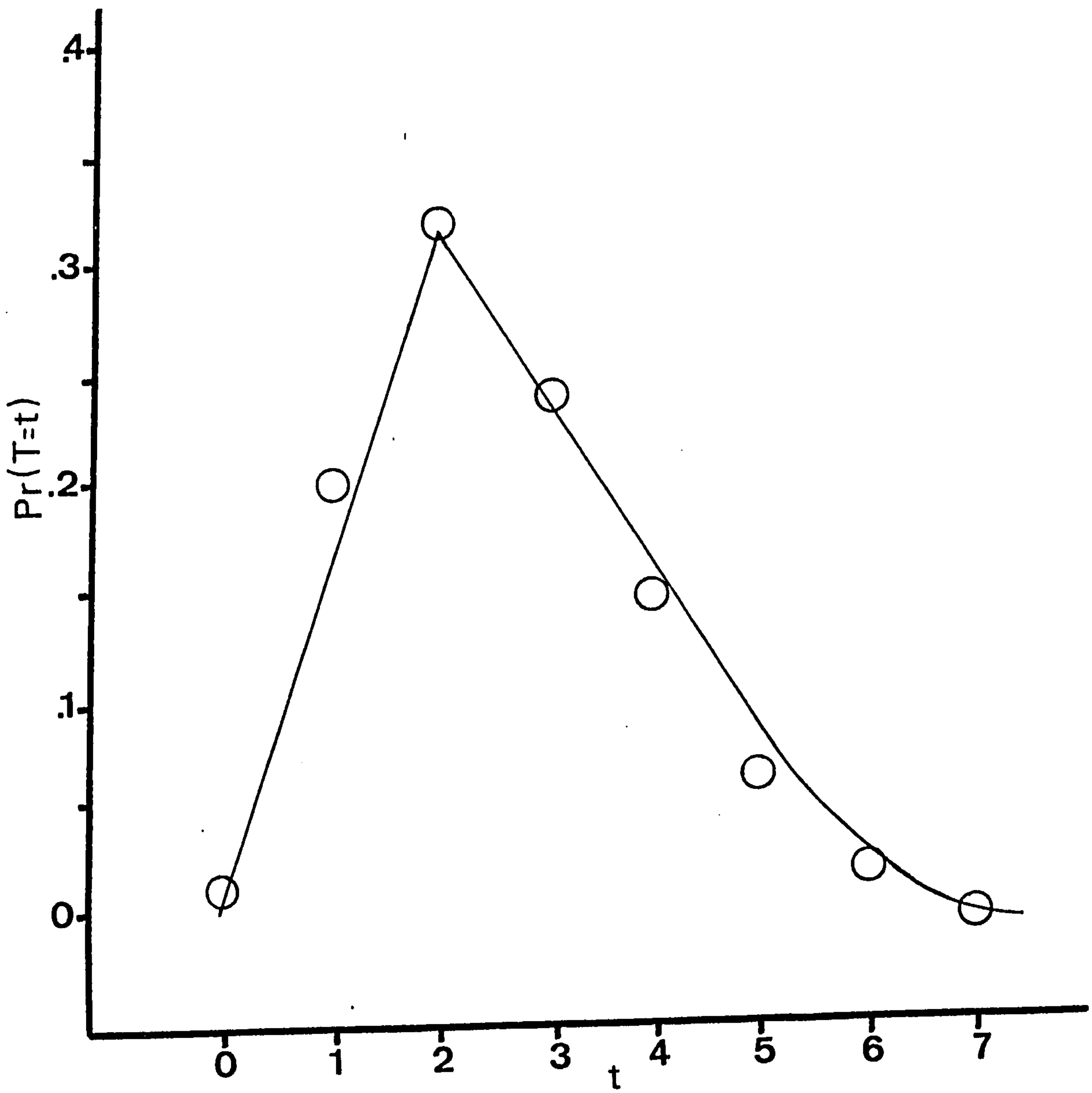

Figure 3. Predicted and obtained probability distributions of total errors, T. D = .03, $\underline{p} > .20$.

4, 5, and 6, respectively. The value of the D statistic, as an index of the goodness-of-fit, is given in each figure and all are in accord with the notion that the obtained distributions are random samples drawn from the various predicted probability distributions.

It was mentioned previously that the 32 possible sequences of corrects and incorrects on trials one through five were recorded and used in the parameter estimation procedure. The obtained frequencies of cases falling into each category for both the observed and predicted data are given in Table 1. All of those cases in which the expected frequency was five or less were lumped together. The goodness-of-fit between obtained and predicted data was evaluated using a test of chi-square. The value of χ^2 (given in Table 1) indicates that the obtained frequencies are not significantly different from the predicted.

In summary, the formal structure of the model has been shown to provide an adequate description of the empirical data. Numerous goodness-of-fit tests support this conclusion. While the parameter estimates obtained seem reasonable and the model fits the obtained data quite well, no inference can be drawn as to the psychological validity of the model. Having demonstrated the formal adequacy of the model as a descriptive device, the next experiment was designed to test its psychological implications.

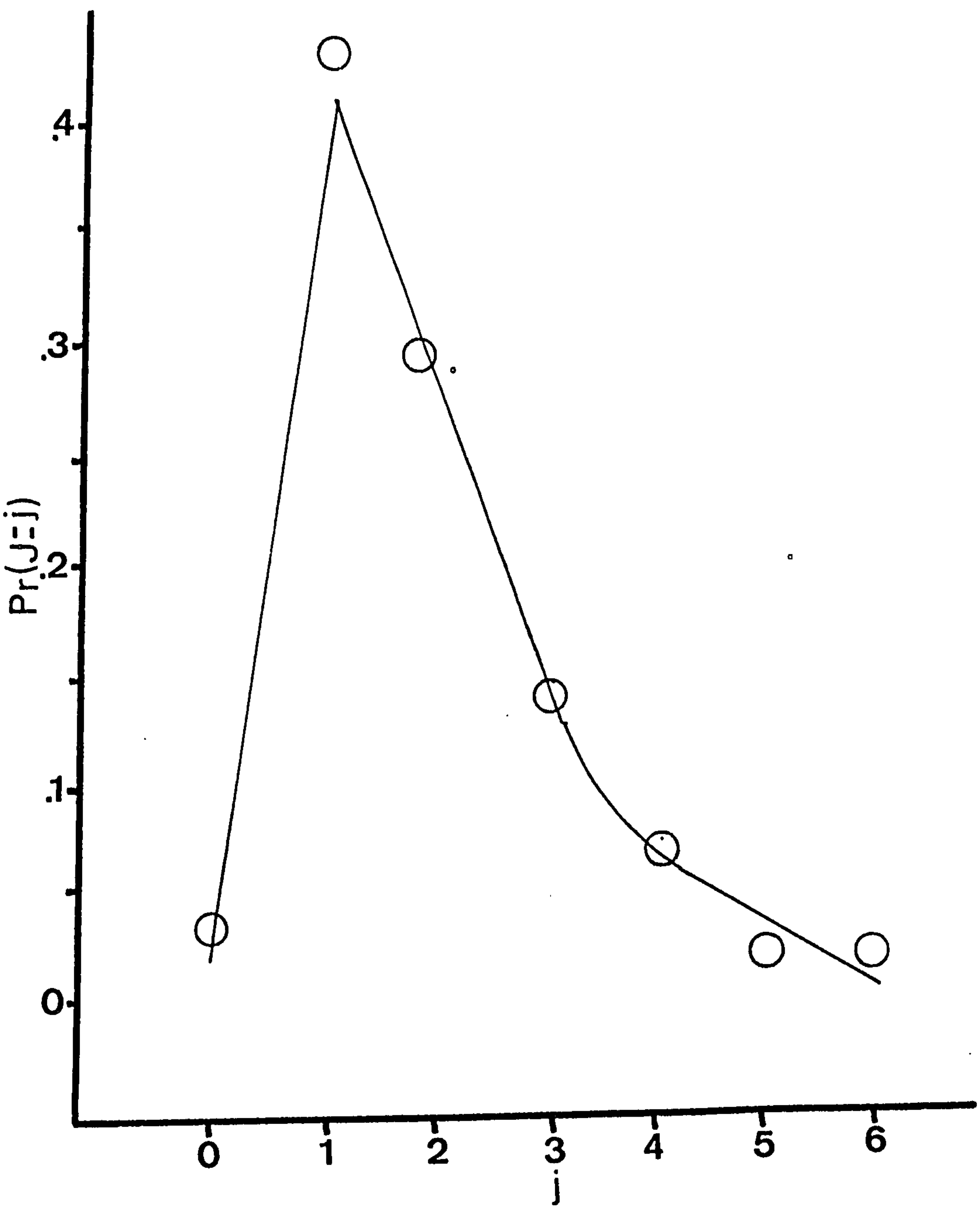

Figure 4. Predicted and obtained probability distributions of the number of errors before the first success, J. D = .01, p > .20.

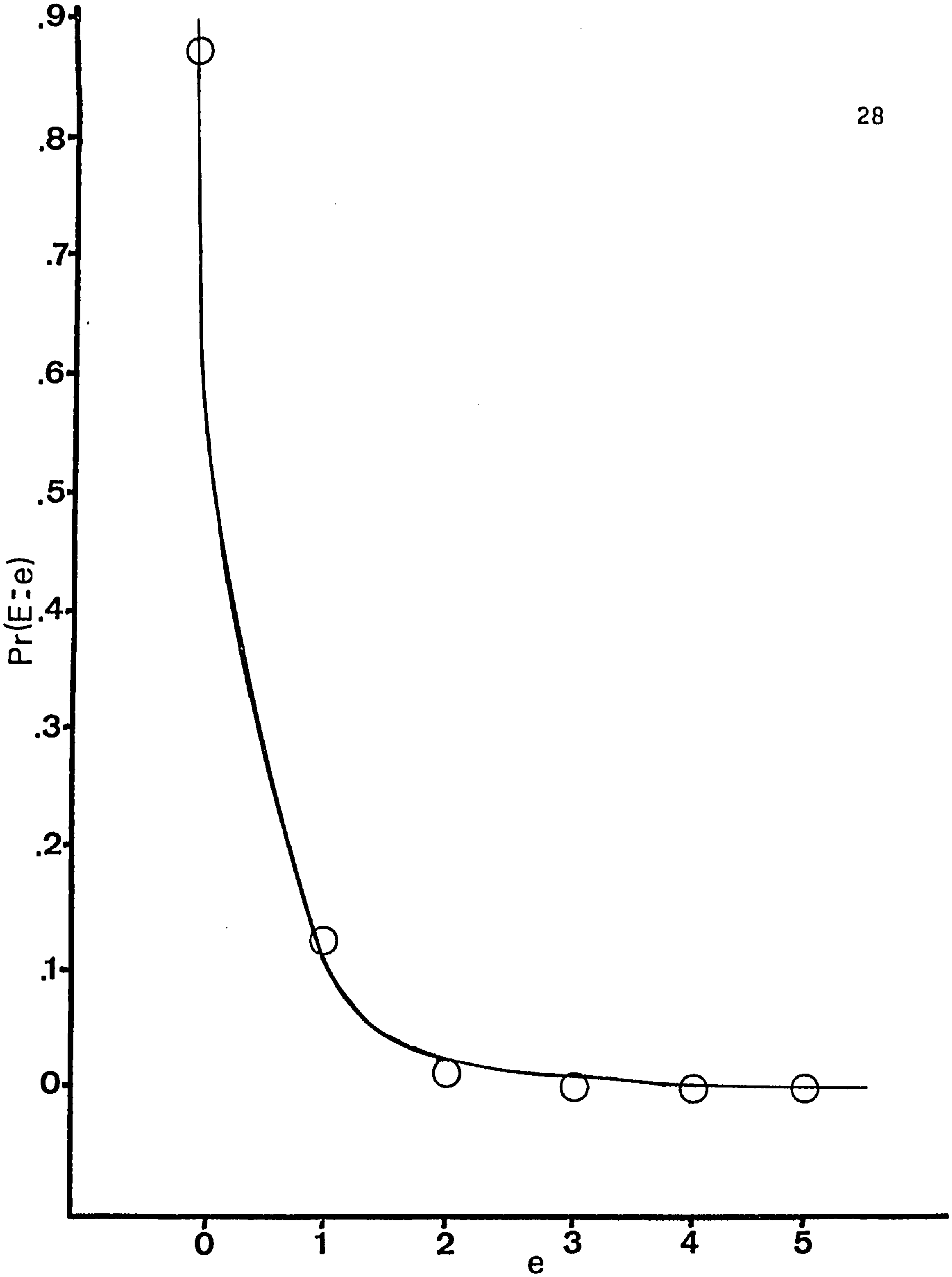

Figure 5. Predicted and obtained probability distributions of the number of errors between adjacent successes, E. D = .02, p >.20.

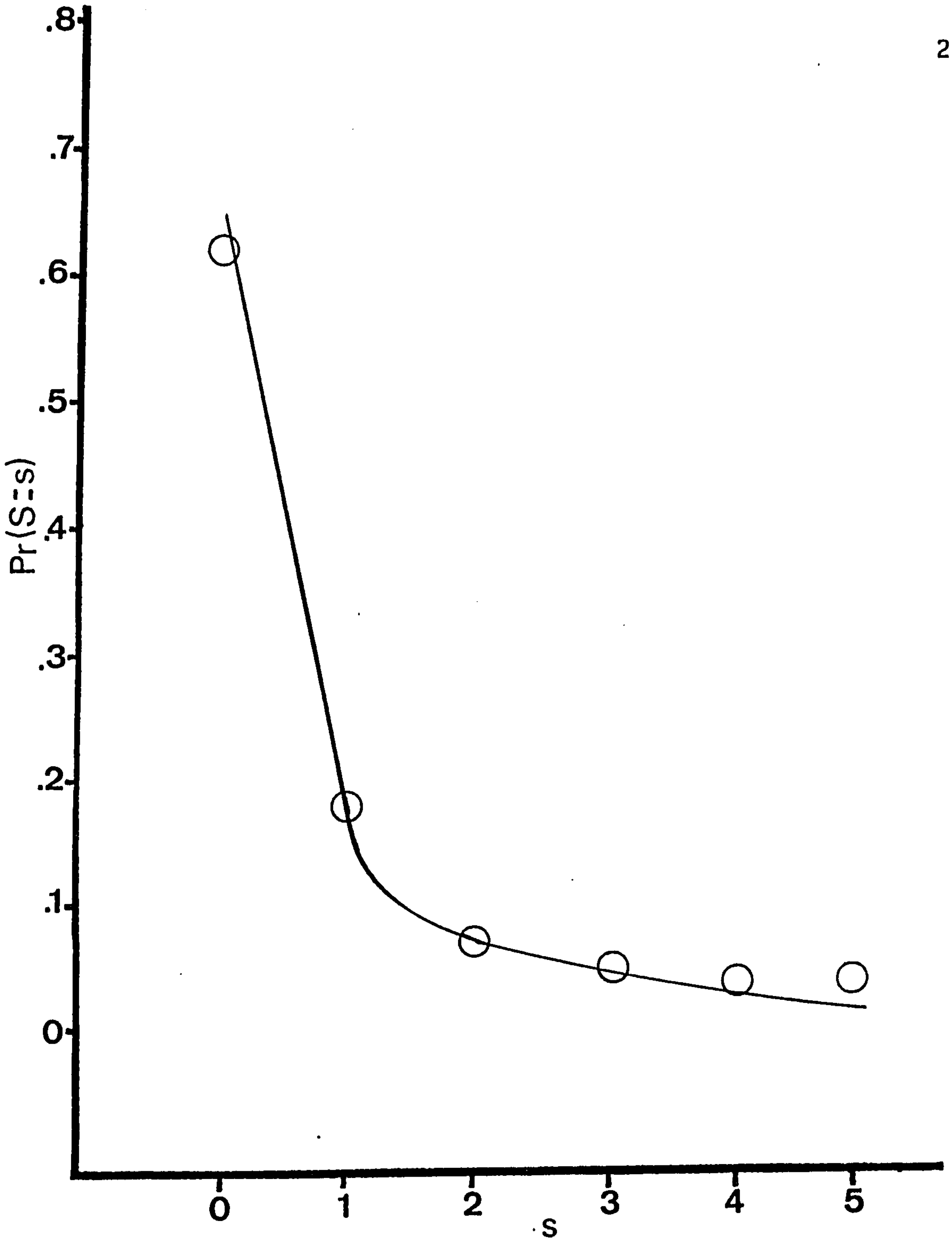

Figure 6. Predicted and obtained probability distributions of the number of successes between adjacent errors, S. D = .03, $\underline{p} > .20$.

Table 1

Frequency of Response Sequences on First Five Trials

Sequence (12345)	Predicted Frequency	Obtained Frequency
00000	0*	0
00001	0*	0
00010	0*	0
00011	0*	0
00100	3*	2
00101	0*	0
00110	1*	0
00111	0*	2
01000	3*	4
01001	1*	3
01010	1*	2
01011	2*	2
01100	4*	5
01101	1*	3
01110	3*	3
01111	2*	1
10000	230	221
10001	34	40
10010	33	30
10011	14	12
10100	50	48
10101	16	20
10110	22	24
10111	9	10
11000	189	180
11001	29	35
11010	57	55
11011	27	30
11100	112	108
11101	38	37
11110	55	62
11111	50	47
	986	986

χ^2 = 8.37, df = 13, p > .70
0 = correct 1 = incorrect
*These cells were pooled.

Experiment 11

Experimental Manipulation of Rehearsal Mode Selection

The results of the previous experiment indicate that the model under consideration is capable of accurately describing various quantitative characteristics of the obtained data. The present experiment was designed to test the psychological theory underlying the formal model structure. Specifically, the model states that following an incorrect response an item will be actively rehearsed with some probability d. This presumed relationship between item accessibility and encoding strategy is strictly applicable only to an experimental circumstance which permits the subject some latitude in his selection of encoding mechanisms (as in Experiment 1). When this latitude is absent, the subject may be more likely to use a particular rehearsal mode irrespective of feedback. It should, for example, be possible to induce the subject to engage in passive rehearsal more often following an error if certain constraints were placed upon his rehearsal strategy. Theoretically, this manipulation of d should have no effect upon the rate parameters a and b. The present study used the same subjects and the same general procedure as in the previous experiment but controlled the number of overt rehearsals during the study phase of each trial. Specifically, subjects were instructed to rehearse once in the one rehearsal condition, and three times in the three rehearsal condition. The rationale behind this manipulation was suggested by the work of Schulman (1970) who reported that subjects recognize homonyms faster than they recognize synonyms. This suggests that it takes longer to access semantic or associative stimulus attributes than it does to access phonemic features. Therefore, if subjects were constrained to rehearse three times in a short time interval they might find it necessary to employ a passive mode more often even in the case of incorrect feedback. On the other hand, if a subject were constrained to rehearse only once given this same time interval, one might expect him to actively rehearse more often than he would otherwise. A manipulation of this sort should tend to produce passive rehearsals in the case of the three rehearsal condition and active rehearsals in the case of the one rehearsal condition. Nominally, the total number of overt rehearsals would favor the three rehearsal condition by a wide margin. However, since the model suggests that the passive mode is associated with a lower informational transfer rate, one might expect the single rehearsal condition to be superior. In a formal sense, the model specifys that the number of rehearsals in each mode is multiplied by its corresponding rate parameter to determine the amount of information stored on each trial. It is suggested that, given the transfer rates obtained in Experiment 1, the benefit of rehearsing three times (most likely in a passive mode) as compared to only once (most likely in an active mode) would not outweigh the low amount of information associated with the passive type of rehearsal. Theoretically, controlling the number of rehearsals should only alter the selection parameter d and not the rate parameters a and b. For this reason, and to test the predictiveness of the model, only the value of d was estimated in the present experiment. In the case of the one rehearsal condition, the value of d should be quite high while in the case of the three rehearsal condition its value should be correspondingly low.

Method.

Experimental design. A within-subjects design was employed in which each subject received each of two experimental conditions. Each subject received both conditions on each of five consecutive days and the order in which they were administered was counterbalanced.

Materials and procedure. All the details of the previous experiment apply to the present one as well, with the exception of the experimental instructions. The present experiment employed a one rehearsal and a three rehearsal condition. In the one rehearsal condition subjects were instructed to rehearse the word-number pair exactly one time aloud in such a manner as to completely fill the three second study phase of each trial. In the three rehearsal condition, subjects were instructed to rehearse exactly three times during each study phase of each trial.

Each subject received two lists during each experimental session (as in Experiment 1) with one list serving as the one rehearsal condition and the other as the three rehearsal condition. The order of the conditions was counterbalanced for each subject. As in the previous experiment, the first experimental session was devoted to practice and no data from it were analyzed. Since there was a total of 16 experimental lists used in Experiment 1 and each subject received only eight, a total of eight lists remained that each had never seen. These were the eight lists that each subject received in the present experiment. This procedure ensured that all 16 experimental lists used in Experiment 1 were also used in Experiment 11.

Subjects. The same 15 Rice undergraduates used in Experiment 1 also served in the present experiment and were paid for their participation. Since each subject received a total of eight experimental lists (the first of the five sessions was a practice session with a list from Experiment 1), four were given in each rehearsal condition. Thus, there were a total of 52 critical items per subject (this procedure was designed to produce a total of 780 critical items across subjects).

Data analysis. The same data analysis procedure described in Experiment 1 was followed in the present experiment. This resulted in two sets of data, for the one and three rehearsal conditions.

Simulation procedure. The parameter searching program (Stepit) used in Experiment 1 was also employed in the present procedure. In addition, the same criterion for the goodness-of-fit test used in the previous experiment was used to fit the model to each condition in the second experiment. The important distinction to be drawn between the estimation procedures of Experiments 1 and 11 is that in the case of 11 only the value of d was estimated. The values of a and b obtained previously (.91 and .05, for active and passive rehearsal, respectively) were held constant. In all other respects the simulation procedure operated exactly as in the previous experiment. For example, the amount of information transferred on each trial, whether active or passive, was multiplied by three in the three rehearsal condition and one in the one rehearsal condition.

Results and Discussion.

As in the previous study, occasional lapses on the part of the subject and mechanical failures reduced the number of observations collected. In the one rehearsal condition the number of observations at each point on the learning curve was 706, while in the three rehearsal condition this value was 713. The data were analyzed in the same manner as described in Experiment 1 and the Stepit program was used to obtain the best fitting estimates of d in each rehearsal condition. Following incorrect feedback, the probability of selecting an active rehearsal mode was .96 in the case of the one rehearsal condition and .15 in the case of the three rehearsal condition. This set of values is in the direction specified by the psychological theory underlying the formal model. In the case of the one rehearsal condition, a total of 7,060 simulated data sequences were generated, and in the three rehearsal condition, there were 7,130 sequences generated.

The predicted learning curves for the one and three rehearsal conditions along with the obtained data points are presented in Figure 7. The predicted curves closely approximate the obtained data in both conditions. The mean number of obtained correct responses across trials was 4.59 in the one rehearsal condition and 3.50 in the three rehearsal condition. In Experiment 1, in which rehearsal strategy was unconstrained,

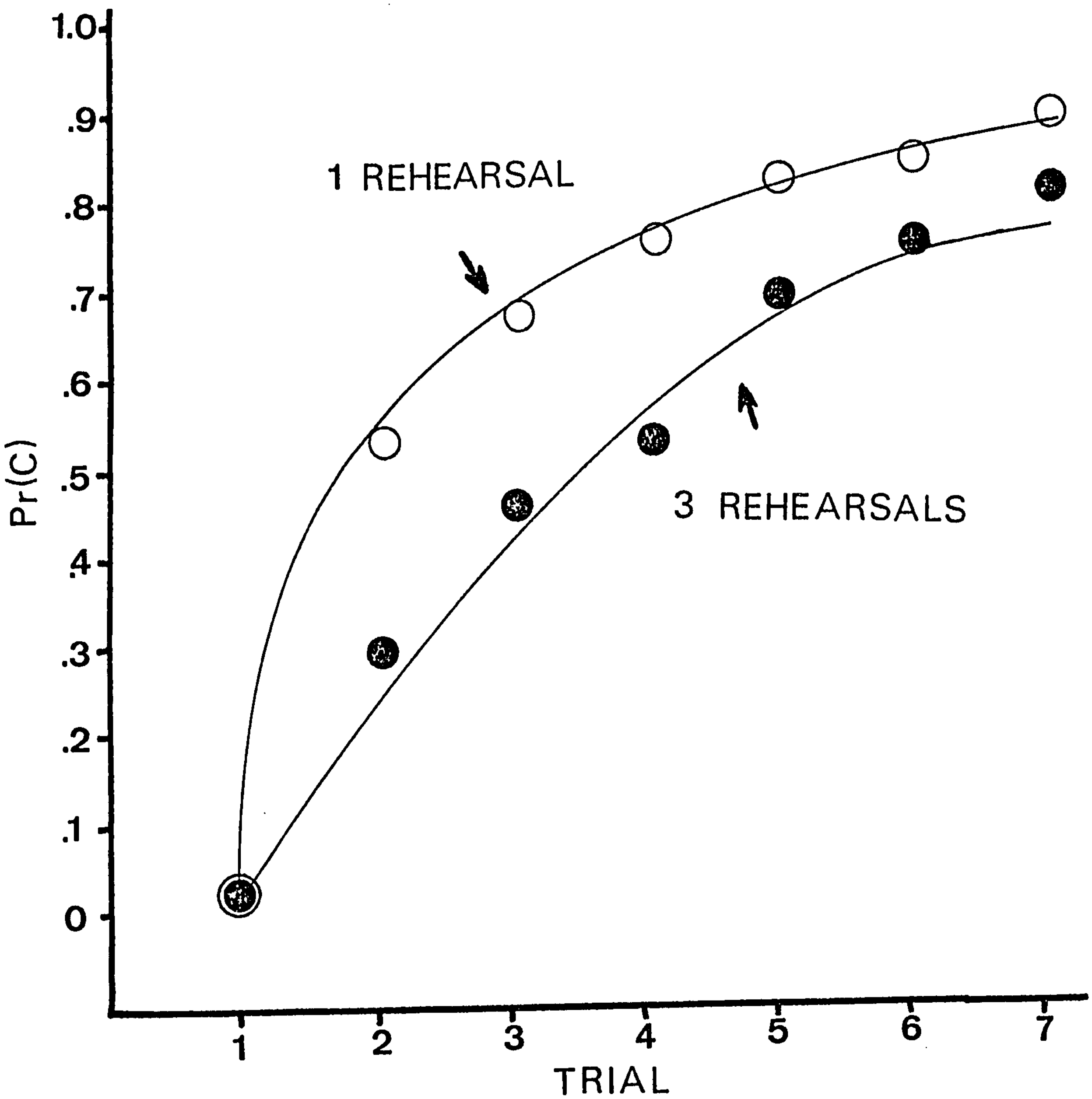

Figure 7. Predicted learning curves and obtained data points for one and three rehearsal conditions.

the mean number of correct responses was 4.26.

The same distributions examined in Experiment 1 are presented in the present experiment for both rehearsal conditions. The probability distributions associated with the total number of errors (T), the number of errors before the first success (J), the number of errors between adjacent successes (E), and the number of successes between adjacent errors (S) are presented for both predicted and obtained data for the one and three rehearsal conditions. Figures 8, 9, 10, and 11 summarize the data for the one rehearsal condition, and Figures 12, 13, 14, and 15 summarize the corresponding set of data for the three rehearsal condition. Each figure gives the value of the goodness-of-fit measure (the D statistic) and its probability under the assumption that the model generated the data. In addition, the sequences of corrects and incorrects over the first five trials are presented in Tables 2 and 3, for the one and three rehearsal conditions, respectively. Each table contains the value of the χ^2 computed on the predicted and obtained frequencies of data.

An examination of the figures and tables described above indicate that the single estimated parameter utilized in the present experiment was sufficient to accurately describe the obtained data in both rehearsal conditions. The size of the D statistic obtained in each case indicated that the observed

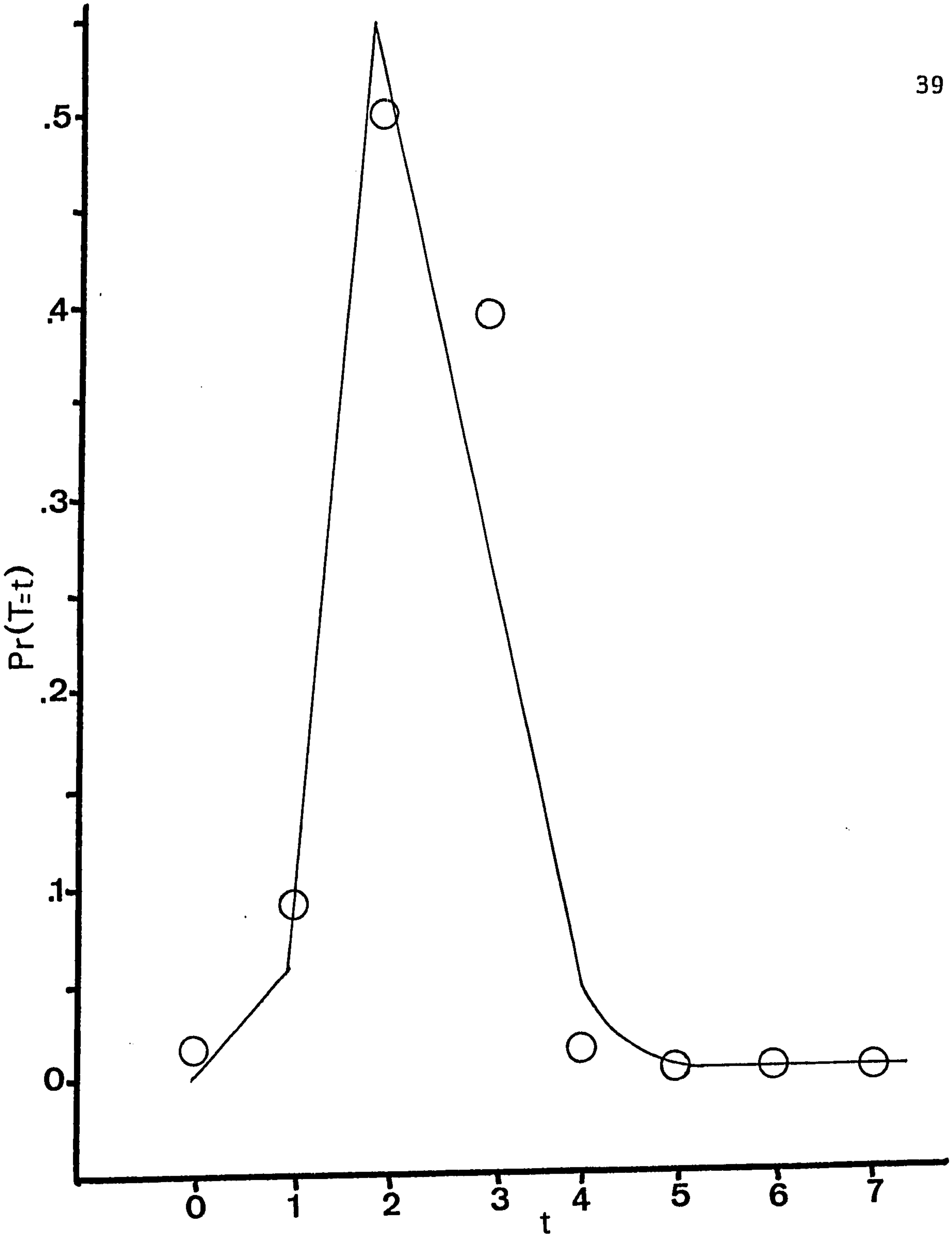

Figure 8. Predicted and obtained probability distributions of total errors, T, for one rehearsal condition. D = .04, p ⟩.20.

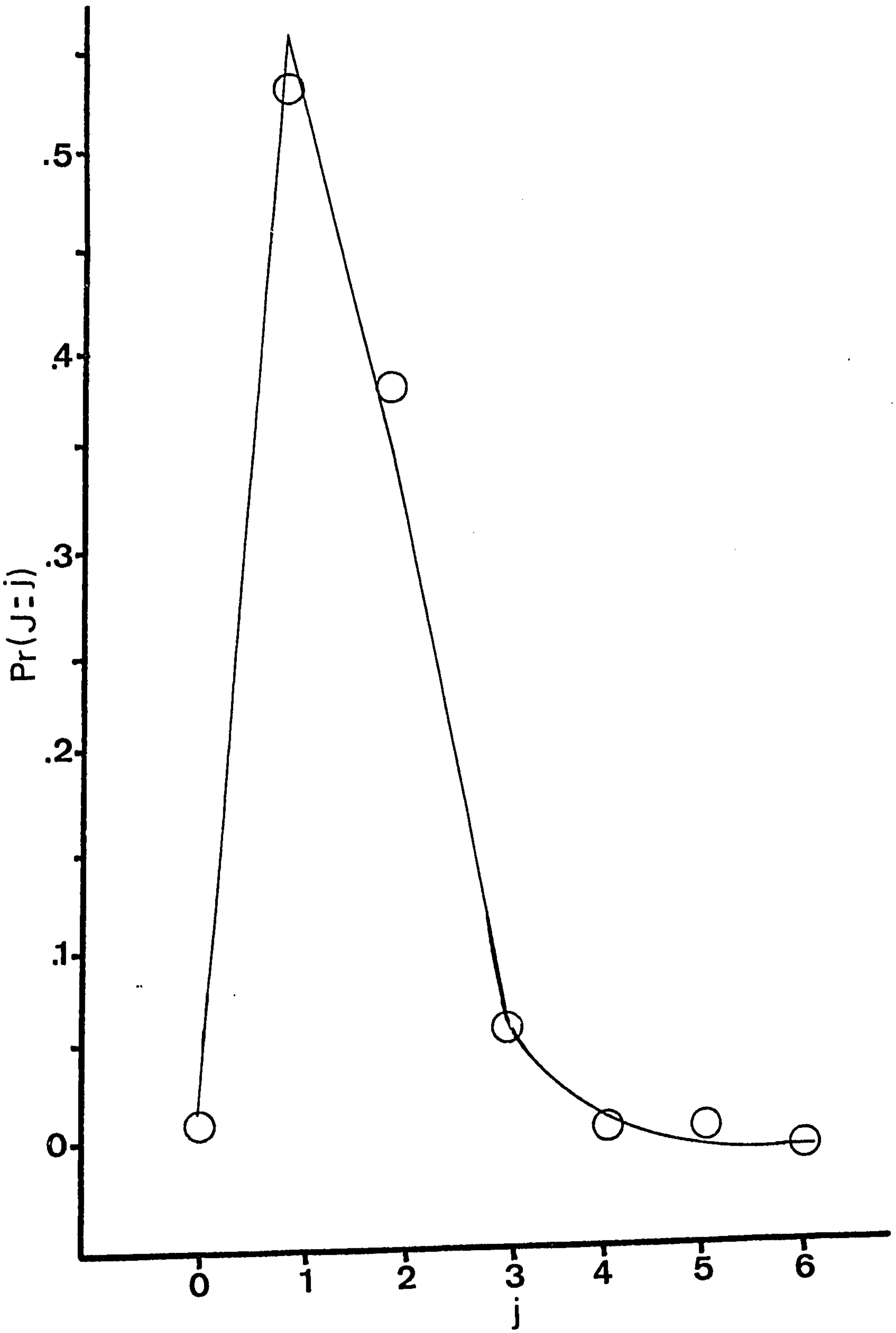

Figure 9. Predicted and obtained probability distributions of the number of errors before the first success, J, for one rehearsal condition. D = .03, $\underline{p} > .20$.

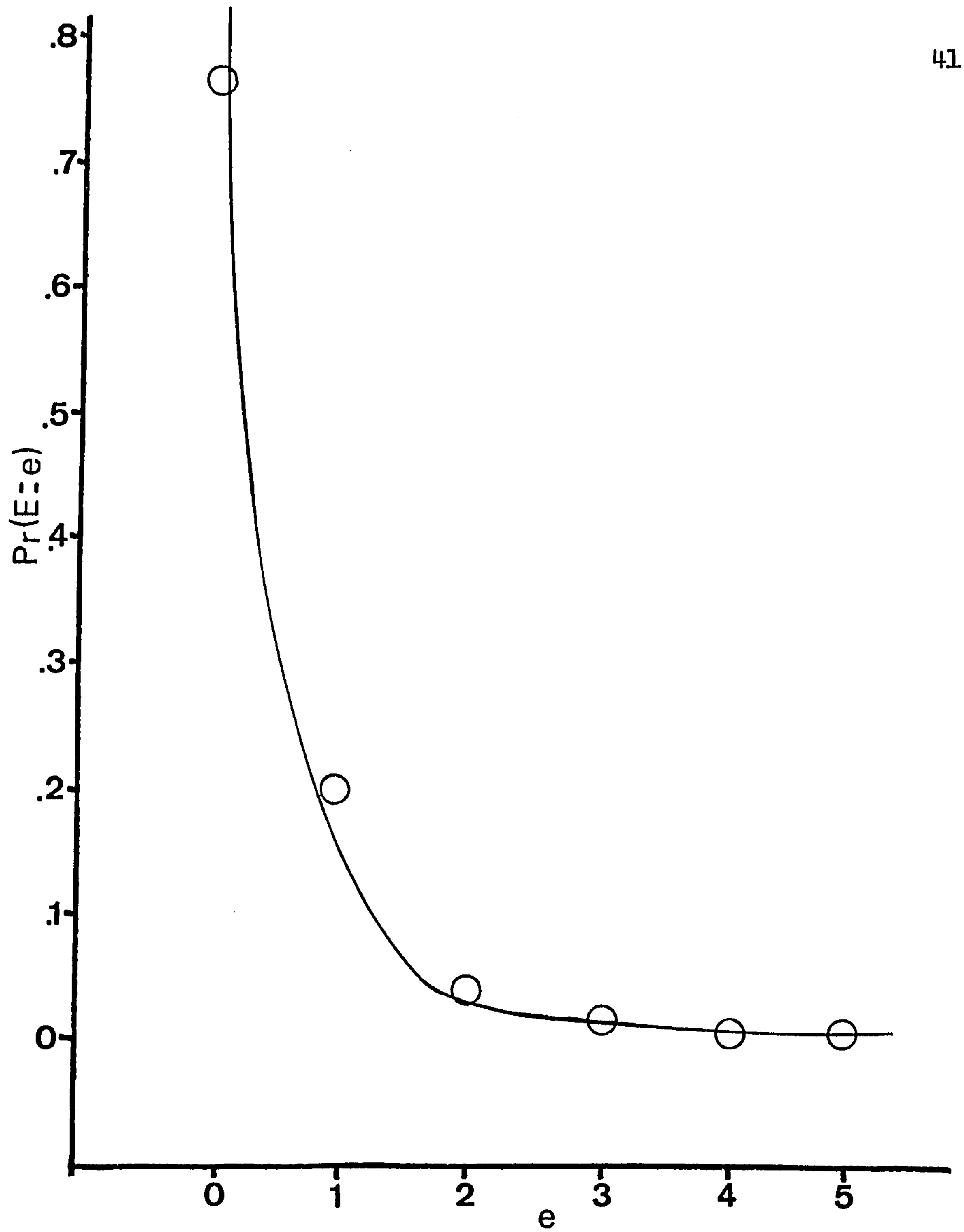

Figure 10. Predicted and obtained probability distributions for the number of errors between adjacent successes, E, for one rehearsal condition. D = .03, p > .20.

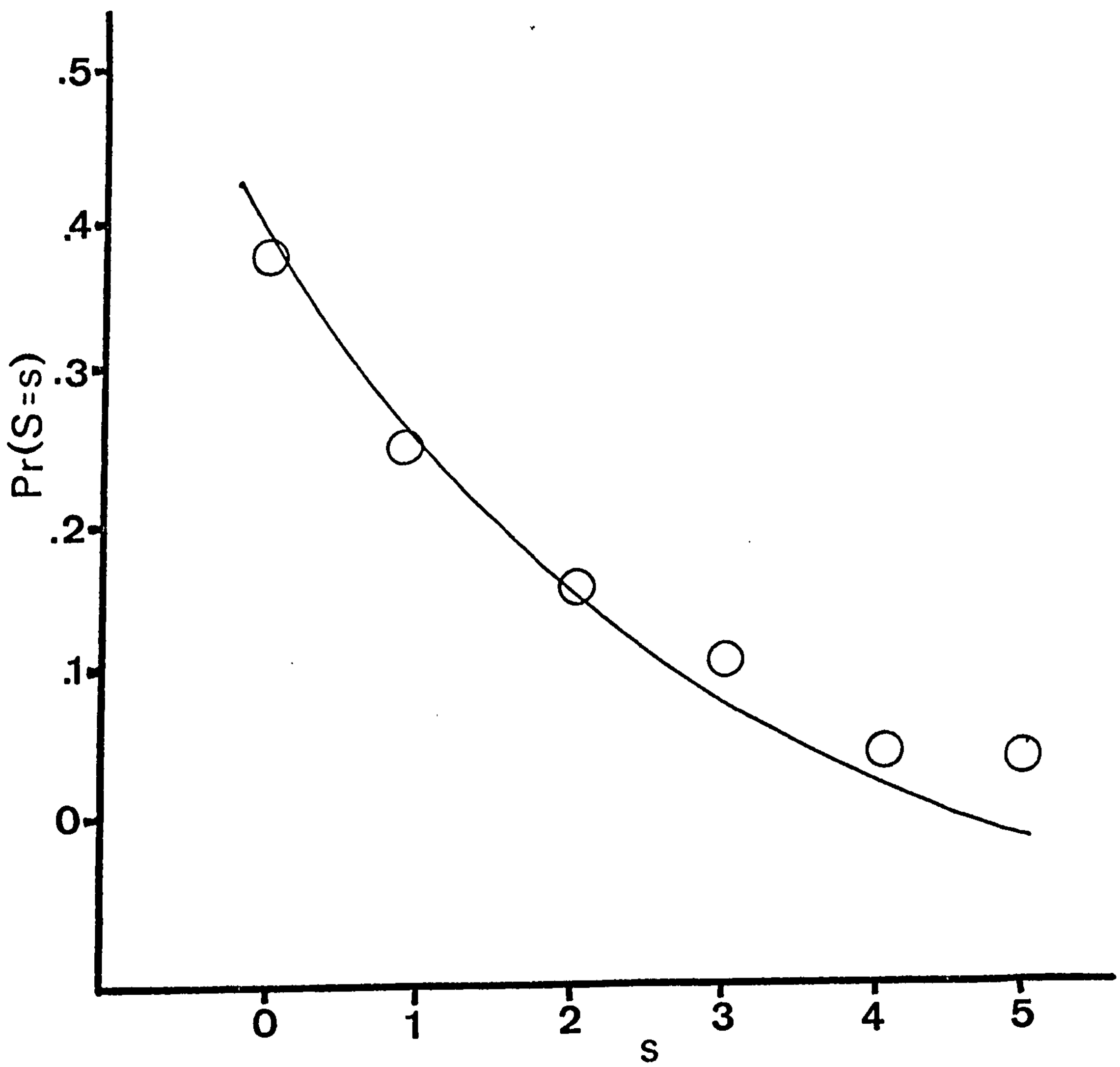

Figure 11. Predicted and obtained probability distributions for the number of successes between adjacent errors, S, for one rehearsal condition. D = .06, p > .15.

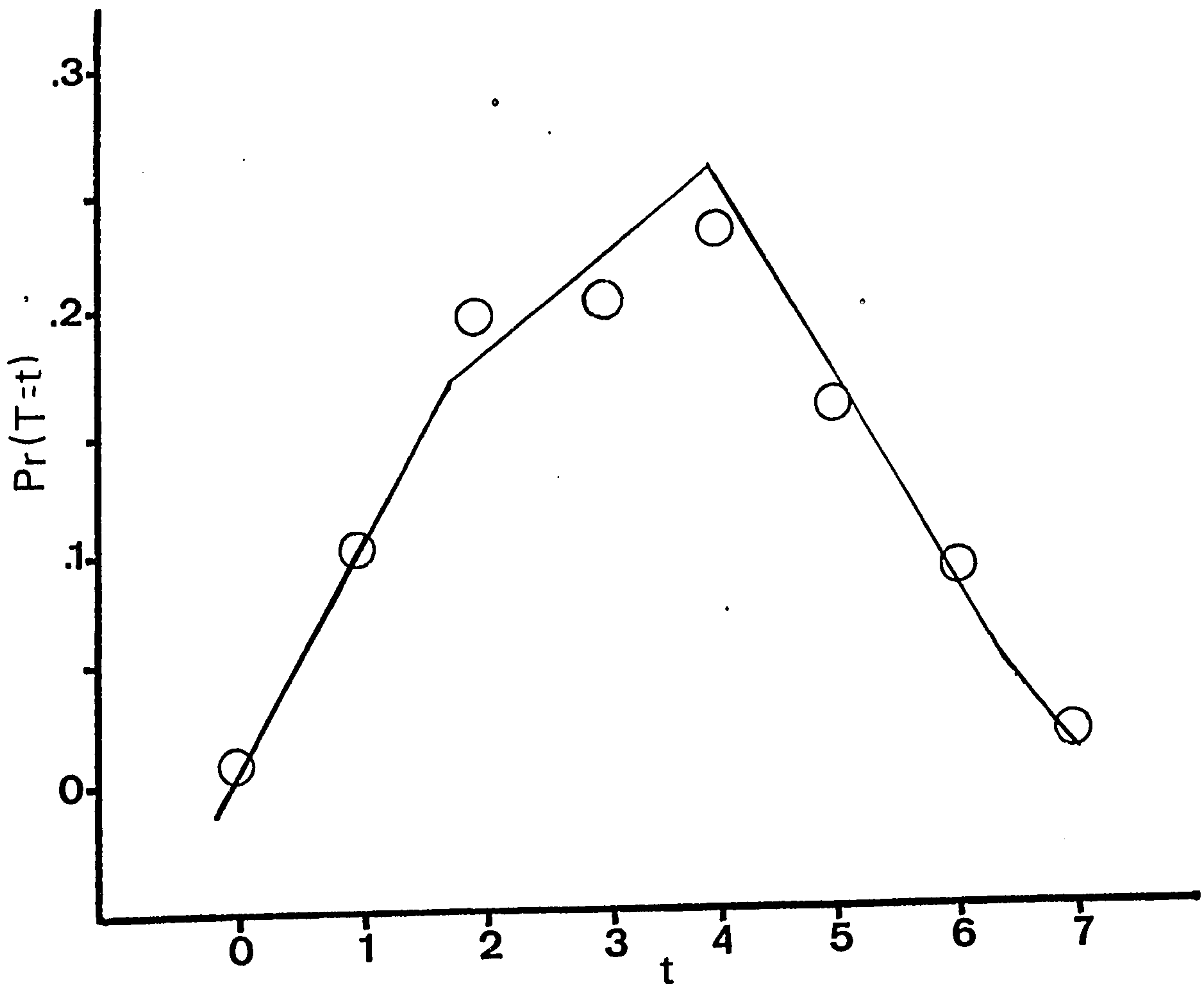

Figure 12. Predicted and obtained probability distributions of the total number of errors, T, for three rehearsal condition. D = .03, p ⟩ .20.

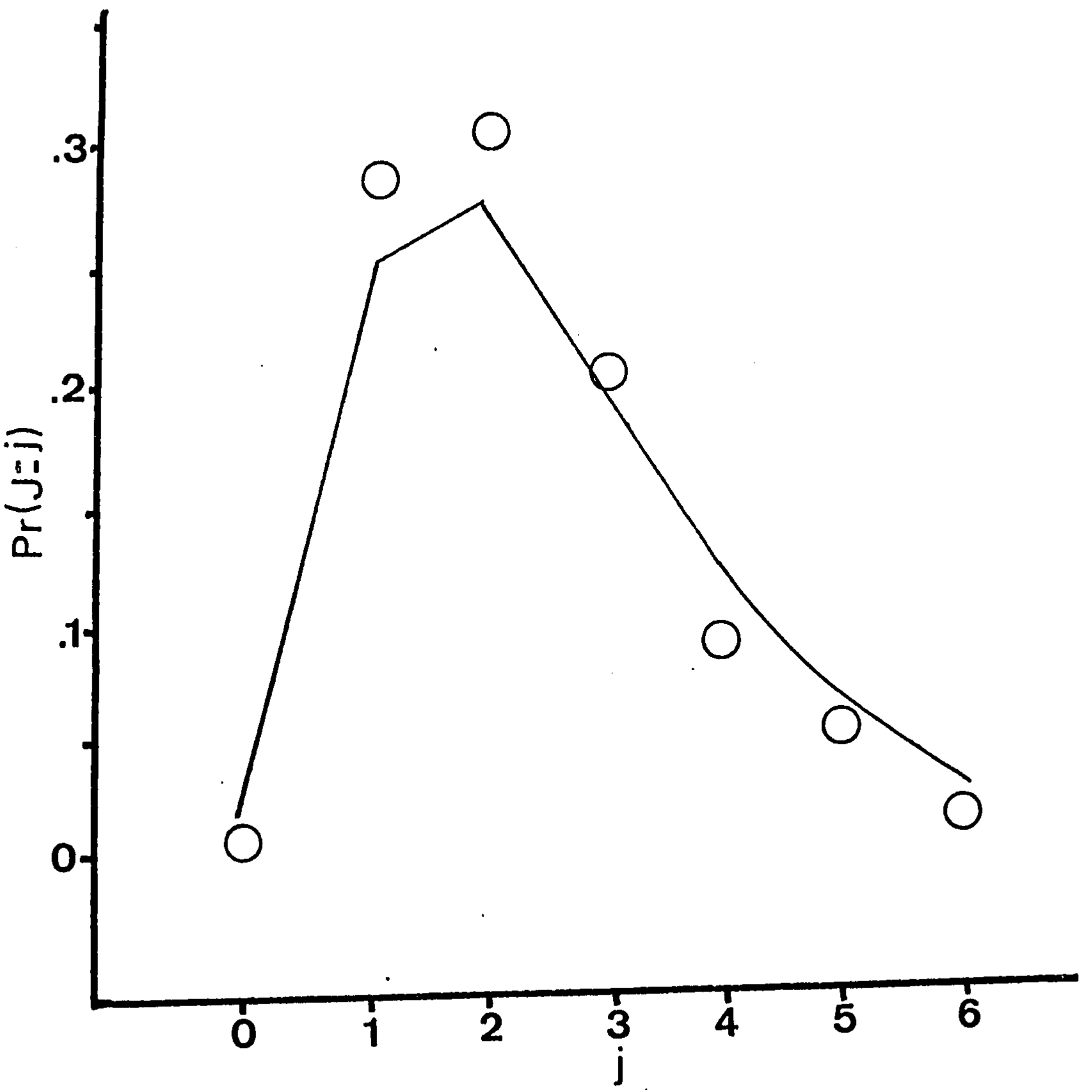

Figure 13. Predicted and obtained probability distributions of the number of errors before the first success, J, for three rehearsal condition. D = .03, p >.20.

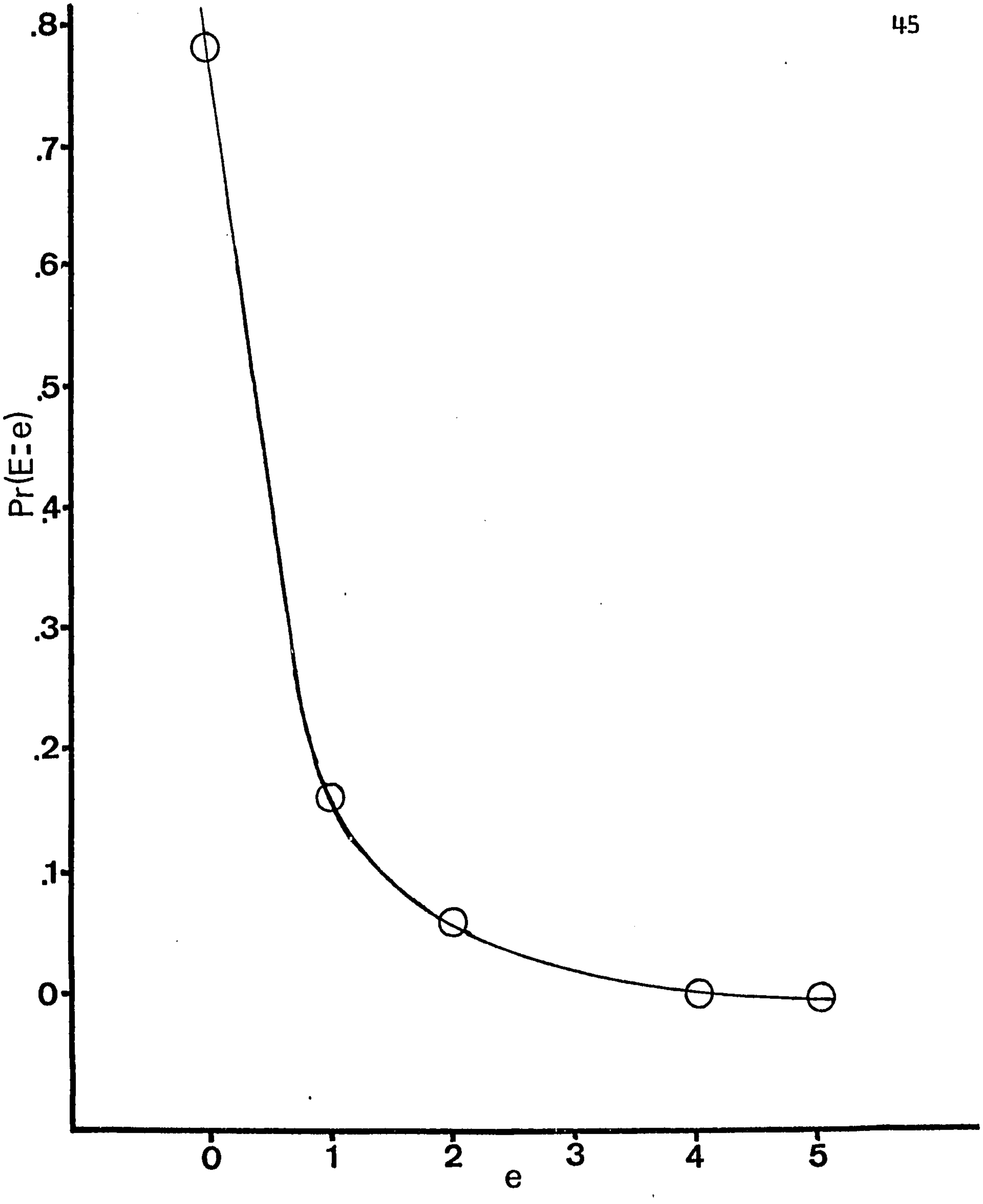

Figure 14. Predicted and obtained probability distributions of the number of errors between adjacent successes, E, for three rehearsal condition. D = .04, $\underline{p} > .20$.

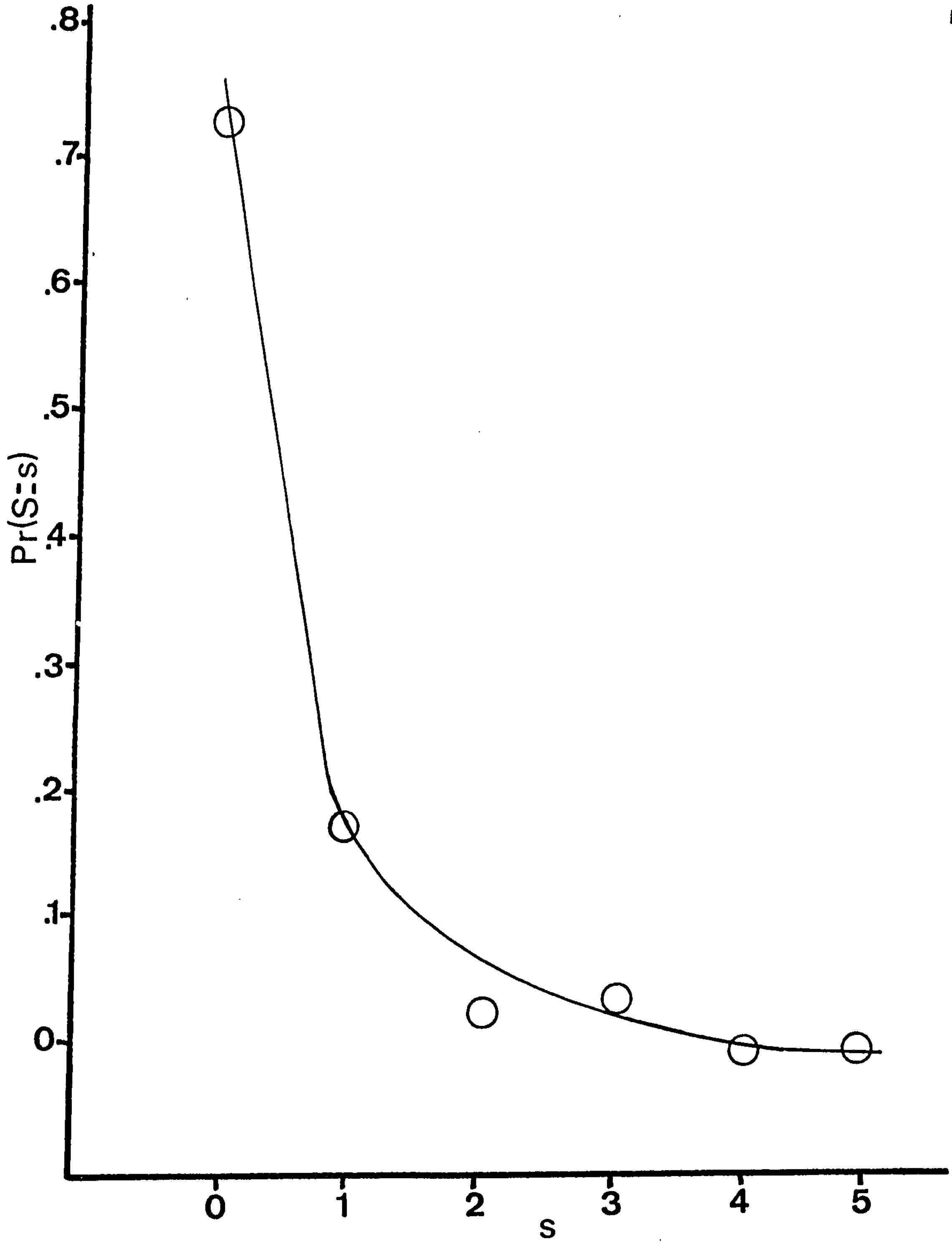

Figure 15. Predicted and obtained probability distributions of the number of successes between adjacent errors, S, for three rehearsal condition. D = .03, p >.20.

Table 2

Frequency of Response Sequences on First Five Trials

One Rehearsal Condition

Sequence (12345)	Predicted Frequency	Obtained Frequency
00000	0*	0
00001	0*	0
00010	0*	0
00011	0*	0
00100	1*	0
00101	0*	0
00110	0*	0
00111	0*	0
01000	2*	0
01001	1*	3
01010	3*	4
01011	1*	2
01100	4*	2
01101	0*	0
01110	2*	0
01111	0*	1
10000	79	62
10001	68	59
10010	77	71
10011	9	9
10100	118	127
10101	26	34
10110	17	16
10111	1*	5
11000	175	183
11001	34	39
11010	36	44
10111	3*	2
11100	42	33
11101	2*	5
11110	5*	4
11111	0*	1
	706	706

$\chi^2 = 13.97$, df = 10, $p > .15$
0 = correct 1 = incorrect
*These cells were pooled.

Table 3

Frequency of Response Sequences on First Five Trials

Three Rehearsal Condition

Sequence (12345)	Predicted Frequency	Obtained Frequency
00000	0*	0
00001	0*	0
00010	0*	0
00011	0*	1
00100	0*	0
00101	0*	2
00110	0*	0
00111	1*	1
01000	0*	0
01001	0*	2
01010	3*	5
01011	0*	1
01100	5*	2
01101	2*	2
01110	2*	1
01111	2*	0
10000	83	92
10001	14	10
10010	24	29
10011	12	9
10100	15	13
10101	9	7
10110	17	24
10111	16	20
11000	99	107
11001	28	33
11010	48	39
11011	18	15
11100	87	95
11101	58	51
11110	95	85
11111	75	67
	713	713

$\chi^2 = 15.98$, df = 15, $p > .50$
0 = correct 1 = incorrect
*These cells were pooled.

data was probably a random sample from the predicted probability distribution. This conclusion is further supported by the χ^2 tests between the predicted and obtained frequencies of each data sequence.

In summary, the model has been shown to adequately describe the empirical data in both rehearsal conditions. It should be emphasized that the present test of the model, while not conclusive in any sense, was specifically directed at testing some of the psychological assumptions of the model. To the extent that these assumptions are reasonable, one might expect some correspondance between the predicted and obtained data. Clearly, this study has shown that the psychological theory underlying the formal model structure is at the very least a reasonable one.

General Discussion

The concept of rehearsal has been relied upon extensively in numerous theoretical models of human verbal learning (e.g., Atkinson & Shiffrin, 1968; Bernbach, 1971). The formal, if not the conceptual, structures underlying these various theories of memory are built upon the notion of an automatic strengthening of trace strength as a function of rehearsal frequency. These theories have been given additional credence by studies employing overt rehearsal procedures (e.g., Rundus, 1971), since such studies have shown that performance is highly correlated with rehearsal frequency. Recently, however, it has been demonstrated that, under certain experimental circumstances, it is possible for subjects to engage in a rehearsal process which transmits little or no information to long-term memory (e.g., Craik & Watkins, 1973). The rationale adopted in the present research was that this passive form of rehearsal may sometimes be used by subjects even in typical laboratory learning situations. This suggests that on some trials subjects actively rehearse, while on others they merely echo the stimulus which is presented. The use of more than one encoding mechanism implys that subjects are engaging in a selection process of some sort to determine which items will be actively encoded and which will not. The adoption of a particular "control process" is at issue since the proposed model attempts to specify the basis upon which subjects make these encoding decisions in the case of paired-associate learning. Specifically, the criterion which the model assumes is item accessibility. Given that an item is correct it will be passively rehearsed, on the other hand, if it is incorrect it has some probability d of being actively rehearsed. The model makes the implicit assumption that decision processes of this sort, since they govern the selection of encoding mechanisms, are ultimately responsible for determining the amount of learning and the rate at which it takes place.

The first step in evaluating the proposed model was to determine whether or not its formal structure is consistent with empirical paired-associate data (Experiment 1). The results of the analysis indicated that obtained and predicted data agreed quite closely in many respects. This demonstration does not by itself lend any special credence to the model since a large number of models might be constructed that could handle the data equally well. The value of the model lies in its psychological implications and not in its formal structure. In order to test the psychological theory which gave rise to the model, a second experiment was performed. This study (Experiment 11) attempted to alter the subject's selection process (thus manipulating the value of d) by inducing him to use first one type of rehearsal and then another. The consequences of shifting from one rehearsal mode to the other were demonstrated empirically (i.e., there were differences between the one and three rehearsal conditions) and the model was able to accurately predict what these consequences would be. In addition, since the same subjects and the same general procedure were used, it was possible to hold two parameters invariant across experiments (a and b, the rates of information transfer following an active or passive rehearsal, respectively). It was only necessary to estimate one parameter (the rehearsal selection parameter d) to describe the data from the second experiment. If the coordinating definitions between real world events and hypothesized model events specified in the second experiment were entirely specious it would be unlikely that the data could have been predicted as accurately as it was. The goodness of the model fit in Experiment 11 provides considerable evidence in favor of the proposed psychological model.

There are, of course, other possible interpretations of the data which do not rely upon differential encoding mechanisms. For example, it might be possible that the requirement of counting to three in the three rehearsal condition (Experiment 11) might have interfered with the subject's attempt to encode.

However, it remains unclear why counting to one and attempting to fill the entire study interval with only one rehearsal did not produce a similar extraneous influence upon the encoding process in the one rehearsal condition.

Another possible weakness of the psychological model lies in its assumption that subjects transfer very little information into long-term memory following a correct response. It is possible to speculate that, in fact, this is not necessarily true. Subjects may perhaps be "consolidating" information that has just been stored. The only point to be made here, is that this speculation, while plausible, has not been tested. On the other hand, the assumption of little or no transfer to long-term memory following a correct response has been shown to produce an accurate fit to the data. At present the most parsimonious explanation of the findings is in terms of a selection between two different kinds of encoding mechanisms, rather than a parallel processing interpretation in which the subject echoically rehearses while simultaneously consolidating recently stored information.

It should be noted that, the formal structure of the model was derived from its underlying psychological theory and not vice versa. For this reason, any attempt to modify the formal model must be made on psychological as well as mathematical grounds. It is quite clear that a fourth estimated parameter, for example, would provide an even closer fit to the observed data. Its psychological justification, however, would be difficult. Given the limited applicability of the model, any further complication of its formal structure seems unnecessary. This is especially true in view of the fact that following the estimation of d for both conditions in Experiment 11, an additional unconstrained parameter search was made. This procedure yielded parameter values of a and b in each condition which did not differ by more than .05 from those obtained in Experiment 1.

It seems appropriate at this point to specify the boundary conditions within which the present model is applicable. Specifically, a task which provides external feedback as to item accessibility (as in a paired-associate anticipation procedure) seems to be one possible restriction. The extent to which the subject may rely on internal accessibility feedback is not known. Another restriction lies in the lack of any provision in the model for forgetting. It is clear that with a sufficiently long interval between presentation and test, performance declines (Atkinson & Shiffrin, 1968). The present experimental paradigm specified an interpresentation lag of seven items during which it was assumed that no information was lost from long-term memory. Clearly, if this lag is increased, forgetting or inaccessibility will occur. In order for the model to handle such lag effects some specific assumption(s) about loss of information from long-term memory would be necessary.

Aside from the restrictiveness of the assumptions just noted, the model does have some specific as well as general implications which should be discussed. On an empirical level, the rehearsal manipulation discussed in Experiment 11, lends further support to the distinction between qualitatively different kinds of rehearsal processes. It showed quite clearly that sheer number of overt rehearsals is not necessarily a good predictor of retention (i.e., one rehearsal was clearly better than three). In this respect, the present findings are entirely consistent with those of Craik and Watkins (1973) and others cited previously. The present model suggests that not only do active rehearsals transfer more information to long-term memory than do passive rehearsals, but that this ratio is of the order of 18:1 (since the active rate was estimated to be .91 per rehearsal while the passive rate was .05 per rehearsal). This ratio is useful only in indicating the magnitude of the difference between the two modes of rehearsal found in the present study and would not be expected to remain invariant across situations.

Traditionally, the active nature of the human information processing system has been neglected, with the result that research emphases in the field of memory have typically focused on structural mechanisms (e.g., the nature of short-term memory). The role of decision making processes in the selection and control of learning strategies, for example, has been acknowledged (Atkinson & Shiffrin, 1971) but never given a formal or systematic structure. The present model has suggested an explicit framework for the operation of one control process, rehearsal, and shown that it is possible to speculate about the formal relationships involved in the selection of encoding mechanisms. The feasibility of this approach in other learning situations and for other control processes remains to be investigated.

REFERENCES

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: Advances in research and theory. Vol. 2. New York: Academic Press, 1968.

Atkinson, R. C., & Shiffrin, R. M. The control of short-term memory. Scientific American, 1971, 225, 82-90.

Bernbach, H. A. A multiple-copy model for postperceptual memory. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press, 1971.

Bjork, R. A. Repetition and rehearsal mechanisms in models for short-term memory. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press, 1971.

Brelsford, J. W., Keller, L., Shiffrin, R. M., & Atkinson, R. C. Short-term recall of paired-associates as a function of the number of interpolated pairs. Psychonomic Science, 1966, 4, 73-74.

Brelsford, J. W., Shiffrin, R. M., & Atkinson, R. C. Multiple reinforcement effects in short-term memory. British Journal of Mathematical and Statistical Psychology, 1968, 21(1), 1-19.

Chandler, J. P. Subroutine Stepit. Program QCPE 66. Quantum Chemistry Program Exchange, Indiana University, 1965.

Ciccone, D. S., & Brelsford, J. W. Semantic and phonemic encoding in recall and recognition. Department of Psychology Technical Report No. 74-3, Rice University, 1974(a).

Ciccone, D. S., & Brelsford, J. W. Interpresentation lag and rehearsal mode in recognition memory. Journal of Experimental Psychology, 1974(b), 103, 900-906.

Ciccone, D. S., & Brelsford, J. W. Encoding specificity: The processing of stimulus attributes. Journal of Experimental Psychology: Human Learning and Memory, 1975, 104, 60-64.

Craik, F. I. M., & Lockhart, R. S. Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 671-684.

Craik, F. I. M., & Watkins, M. J. The role of rehearsal in short-term memory. Journal of Verbal Learning and Verbal Behavior, 1973, 12, 599-607.

Jacoby, L. L. Encoding processes, rehearsal, and recall requirements. Journal of Verbal Learning and Verbal Behavior, 1973, 12, 302-310.

Rundus, D. Analysis of 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.

Shepard, R. N., & Teghtsoonian, M. Retention of information under conditions approaching a steady state. Journal of Experimental Psychology, 1961, 62, 302-309.

Shiffrin, R. M. Information persistence in short-term memory. Journal of Experimental Psychology, 1973, 100, 39-49.

Shulman, H. G. Encoding and retention of semantic and phonemic information in short-term memory. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 499-508.

Siegel, S. Nonparametric statistics. McGraw-Hill Book Company: New York, 1956.

Woodward, A. E., Bjork, R. A., & Jongeward, R. H. Recall and recognition as a function of primary rehearsal. Journal of Verbal Learning and Verbal Behavior, 1973, 12, 608-617.