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AUTHOR	Chechile, Richard A.; Gordon, Tracey
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ABSTRACT

A study was performed to investigate the storage and retrieval dynamics that occur during paired-associate acquisition by means of the storage-retrieval separation technique discussed recently by Chechile & Meyer (1976). Thirty subjects learned an 18-item paired-associate list to a criterion of three perfect trials. In the test phase of each trial, the pairs were randomly tested with either a recall, old or distractor recognition test cue. Analyses of the storage and retrieval functions for both the forward and backward learning curves indicated that paired-associate acquisition is characterized by statistically independent improvements in both storage and retrieval. (Author)

Paper read at APA Conference in Washington, D.C., 1976

Storage-Retrieval Analysis of Paired-Associate Acquisition

Richard A. Chechile and Tracey Gordon

Tufts University

A well-known fact of paired-associate (PA) learning is that repetition of pairs results in a gradual, negatively-accelerated acquisition curve in regard to the probability of correct recall, θ_c. There, of course, exists a number of differing theories as to what psychological processes and stages that occur in PA acquisition (eg. Underwood & Schultz, 1960; Martin, 1967; Greeno, 1970). The current research set out to investigate the underlying storage and retrieval changes that occur with PA acquisition. The current research thus involves a generalization of the storage-retrieval separation technique recently developed for the Brown-Peterson task (Chechile, 1973; Chechile & Butler, 1975; Chechile & Meyer, 1976). The separation procedure enables the probability of correct recall, θ_c, to be uniquely factored into two other components for a modified PA task. One component, θ_s, is identified with the probability of sufficient storage of the list, and the other component, θ_r, is identified with the probability of successful retrieval when the information is stored sufficiently. In essence, the procedure provides for standardized and previously validated measures of storage and retrieval that apply for each subject and for each trial.

In terms of the task, the data structure illustrated in figure 1 is required for each subject in order to apply the separation technique. The randominter-

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Insert figure 1 about here

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mixing of the recall and recognition test cues is a necessary step in order to assure the homogeneous processing for both test cues.

Insert figure 2 about here

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.

The probabilistic task analysis of the old recognition test trials is illustrated in Figure 3 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 3.

The task analysis for distractor recognition is illustrated in Figure 4. Because guessing processes should be different for distractor as compared to old recognition, a different guessing parameter, θ_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.

Lastly, in order to check for retrieval difficulties in recognition, another task analysis for distractor recognition can be examined. This probabilistic task analysis is shown in figure 5 and involves a recognition-retrieval parameter, θ_{dr}.

Insert figures 3 - 5 about here

The tree diagram shown in figure 5 is the most general case since when $\theta_{dr} = 1$ is the case shown in figure 4. The resulting estimation equations for this general case are shown in figure 6. Finally, an example of a typical separation for a subject investigated by Chechile (1973) is shown in figure 7.

Insert figures 6 and 7 about here

The data, n_1, n_2; n_{11} . . . n_{16}; n_{21} . . . n_{26}, for which these distributions were based are respectively 53,27; 0,2,76,0,1,1; 1,3,0,0,1,75. Notice that each distribution is a separate unimodal function. Also the standard deviations of θ_s and θ_r are respectively .027 and .061. Thus, for the above example, the correct recall measure of 53/80 or .66 is uniquely factorable into $\theta_s = .93$ and $\theta_r = .71$ such that $\theta_s \cdot \theta_r = .66$.

One important result concerning the validity issue has been the data on the independence of the storage and retrieval components of recall. For example, Gerrein (1976) has found that some independent variables only affect the retrieval measure. Also, Chechile (1973), Chechile & Meyer (1976), Chechile & Butler (1975), and Gerrein (1976) have typically found that even when both storage and retrieval measures significantly change in the same direction, these changes are statistically uncorrelated. These studies resulted in low, insignificant correlations between storage changes and retrieval changes indicating, of course, that knowledge of a particular subject's storage change results in virtually no predictability in regard to that subject's retrieval change. Consequently, correct recall is obviously decomposed into two independent processes, indicating that the resulting storage and retrieval measures are orthogonal and uncontaminated components of recall.

Another indication of validity comes from manipulations of memory search time. When the subject is permitted more time to retrieve the target information at the time of test, (with total time of the trial held constant), recall performance is improved (Chechile & Meyer, 1976). In addition, the storage parameter was invariant with respect to this manipulation and only the retrieval parameter changed. Obviously, the greater retrieval time resulted in a more extensive memory search and hence improved the probability of successful retrieval. The finding that search time affects only retrieval is particularly important because that is the only *a priori* reasonable outcome that one should expect if the measures of storage and retrieval are valid. Thus, taken together the separation procedure is a valid and powerful tool for investigating the underlying processes that occur during the acquisition of a PA list.

Method

Thirty subjects in this experiment learned to criterion an 18 item PA list by a modified study-recall method. The stimuli were randomly CVC's ranging 12-15% in meaningfulness from Archer (1960) and the responses were random AA words from Thorndike-Lorge (1944). The randomized pairs were auditorily presented by means of a Sony 105 tape recorder and Superex ST-Pro headphones at a 2 second rate in the study phase and with a 1 second pause between pairs. In the test phase of each trial, a random 1/3 of the responses were tested with a recall cue, and a random 2/3 of the responses were tested equally with either an old or a distractor recognition cue. Distractor pairs consisted of a random reordering of the stimulus with one of the other list responses. The randomization as to type of test trial was restricted such that across a block of three trials each test cue was used for each stimulus. During test phase, each test item was followed by a 2½ second response interval. The end of the response period was marked by a buzzer which was sounded for ½ second and then followed by the next test item. Additionally, 3-point confidence ratings were obtained in the case of recognition testing where instructions stressed that the 3 rating was to be the most confident case that involves no guessing whatsoever. Finally, criterion for mastery of the list was defined as 3 consecutive perfeet trials (6 correct recalls, and 12 correct and 3-rated recognitions) plus a final recall of all 18 items. Thirty of 45 subjects reached criterion within 21 trials. The 15 non-criterion subjects were stopped at that point and were not included in the subsequent data analysis.

Results and Discussion

The mean across subjects of the storage, retrieval and overall correct recall measures are graphed in figure 8 as a function of trials. Retrieval reaches a stable 90% or better performance level.slightly faster than storage

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Insert Figure 8 about here

(trial 8 versus 10). The backwards-learning curves plotted separately for the storage, retrieval and overall recall measures are displayed in figure 9. The pre-criterion performance indicates that both storage and retrieval undergo

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Insert figure 9 about here

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gradual improvement prior to criterion.

Inspection of Figure 8 indicates that most of the improvement as a result of repetition occurs by trial 8. Nevertheless the improvement in the storage and retrieval measures between trials 1 and 8 are statistically independent across subjects, $r = .34$, $df = 28$, $p > .05$. This low correlation also attests to the validity of separation procedure since it indicates that the measures are uncontaminated.

There are at least three note-worthy features for the present research. First, the storage-retrieval separation procedure has been successfully generalized to the PA task, providing an important methodological improvement to the PA paradigm. Second, the observed independence between the storage and retrieval processes in PA acquisition is consistent with the previously reported indepenedence in the retention function in the Brown-Peterson task (Chechile, 1973; Chechile & Meyer, 1976; Chechile & Butler, 1975; and Gerrein, 1976). Third, taken as a whole, the PA list does not appear to undergo identifiable changes or stages that correspond to storage and retrieval processes. In fact, apart from a slightly more gradual acquisition function for storage as compared to retrieval, all levels of learning are characterized by both storage and retrieval changes. Of course, however, individual pairs may have undergone stage-like changes.

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(a) RECOGNITION TRIALS

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

(b) RECALL TRIALS

Correct	Incorrect
n_1	n_2

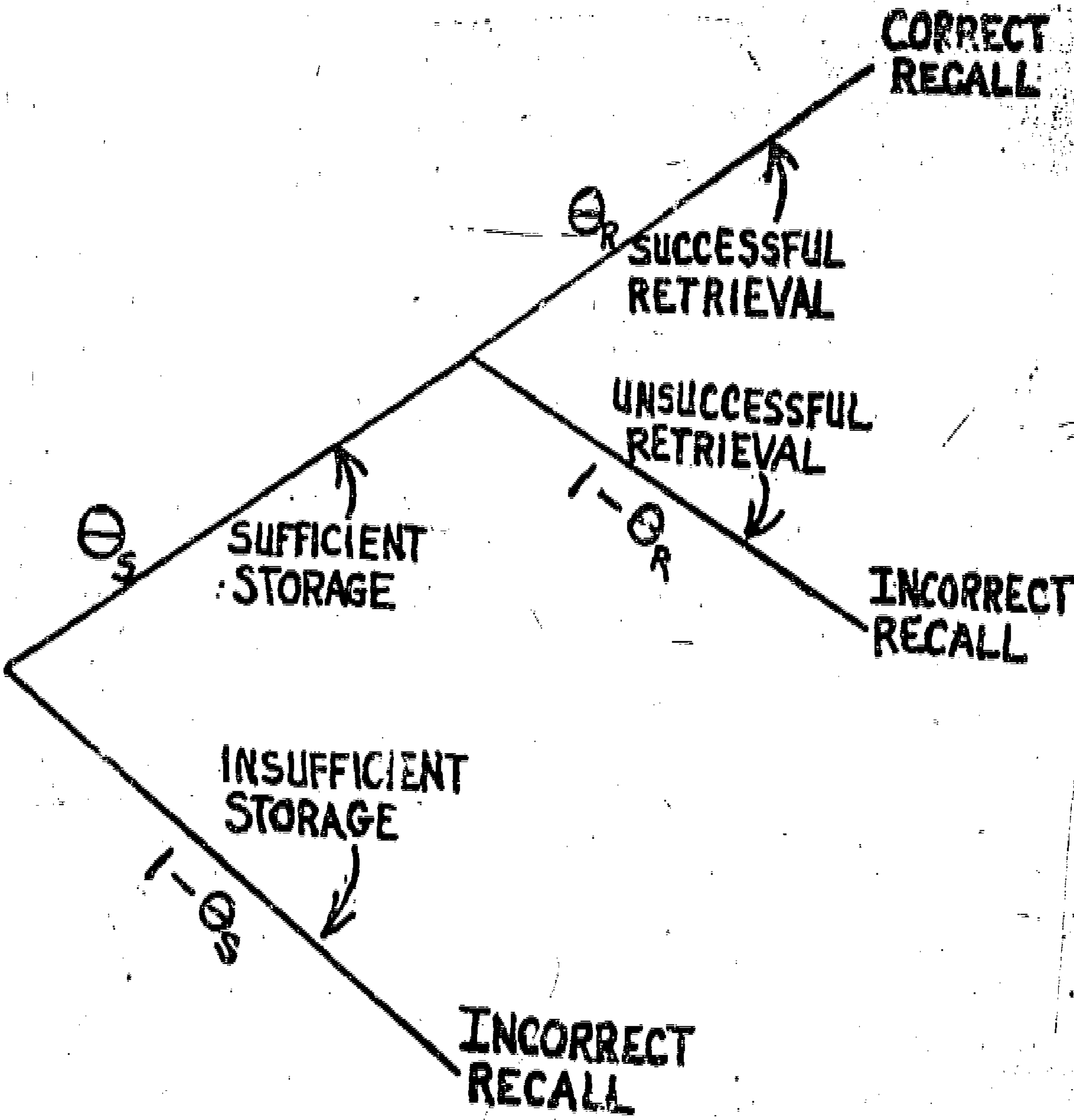
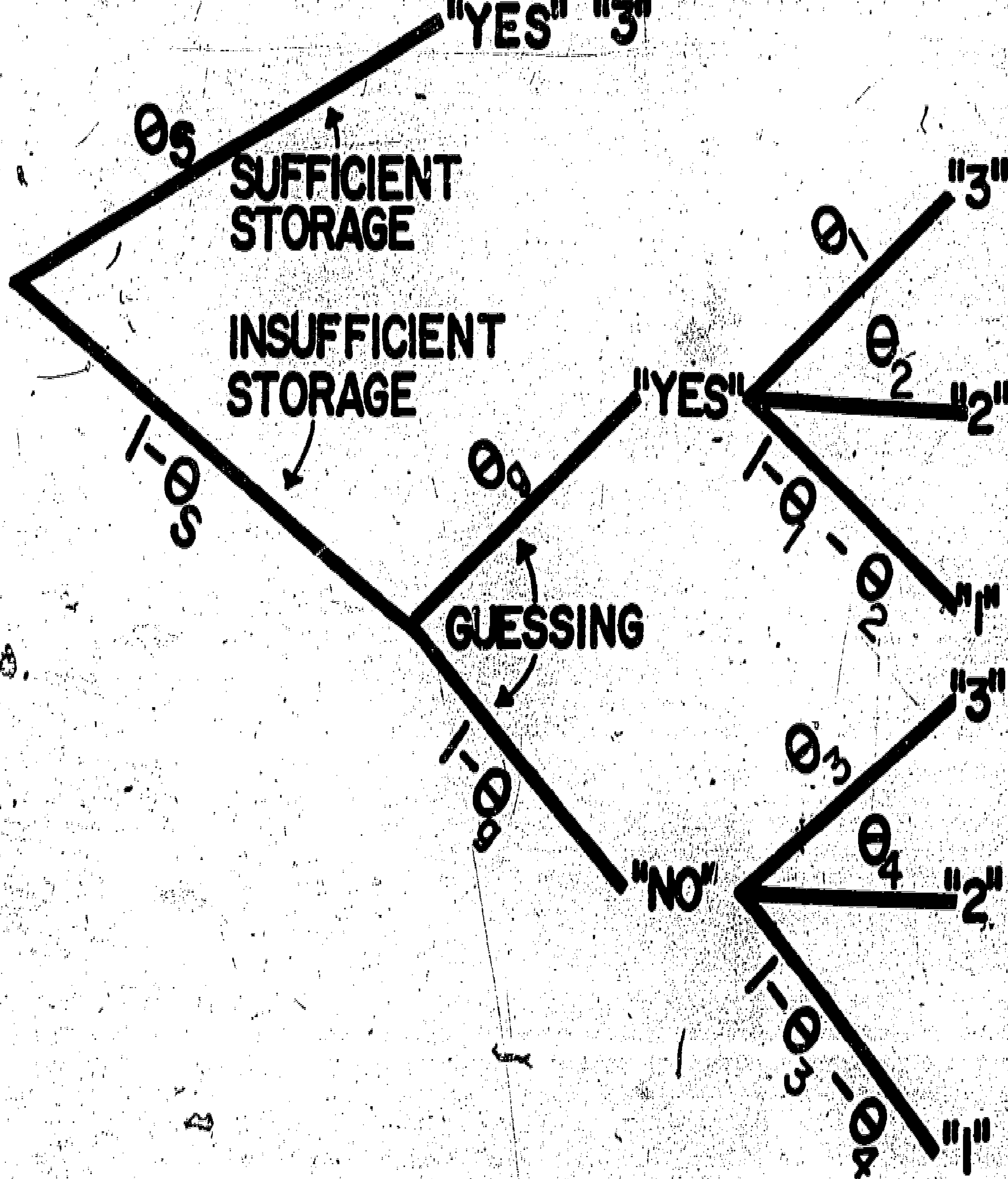
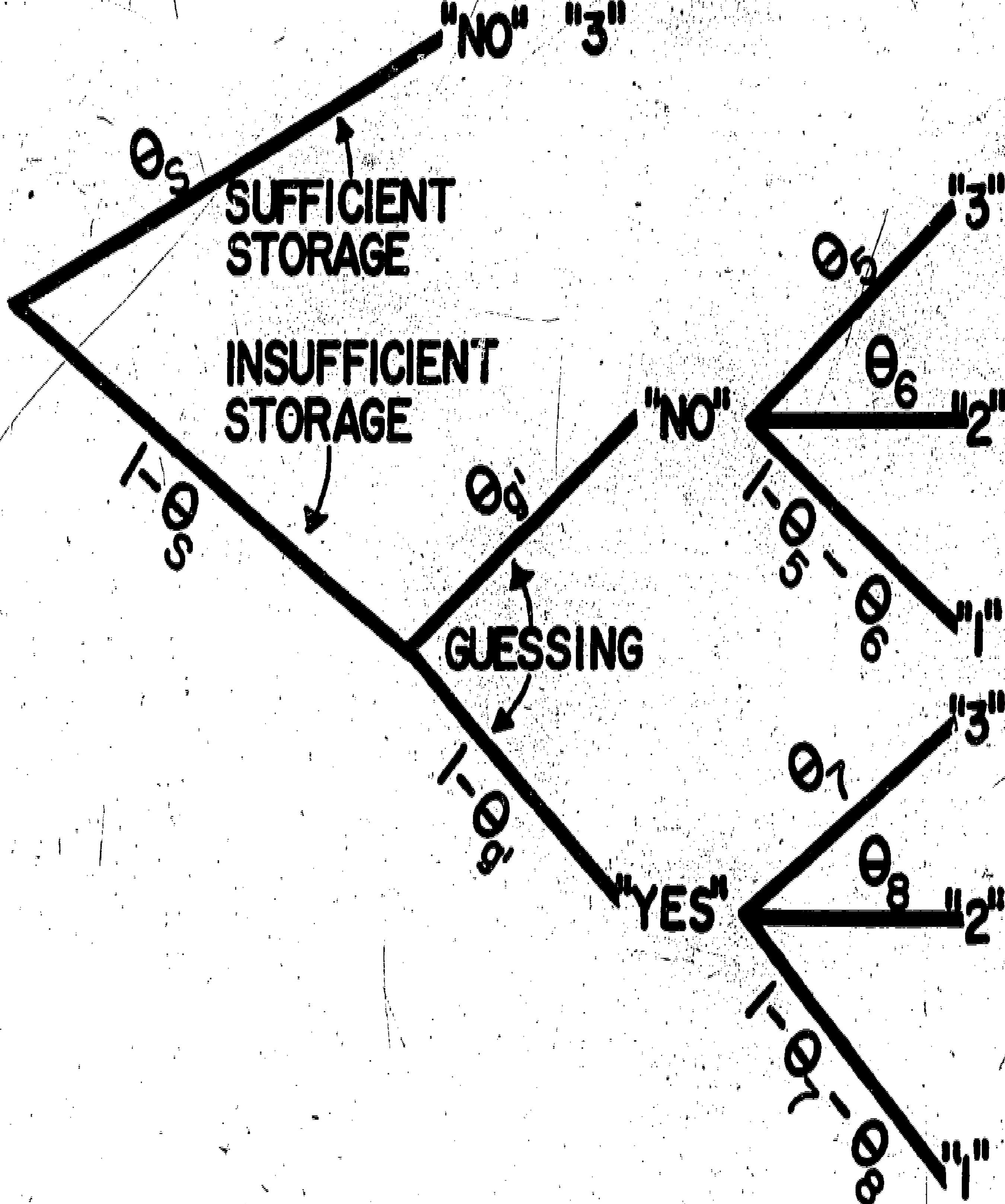
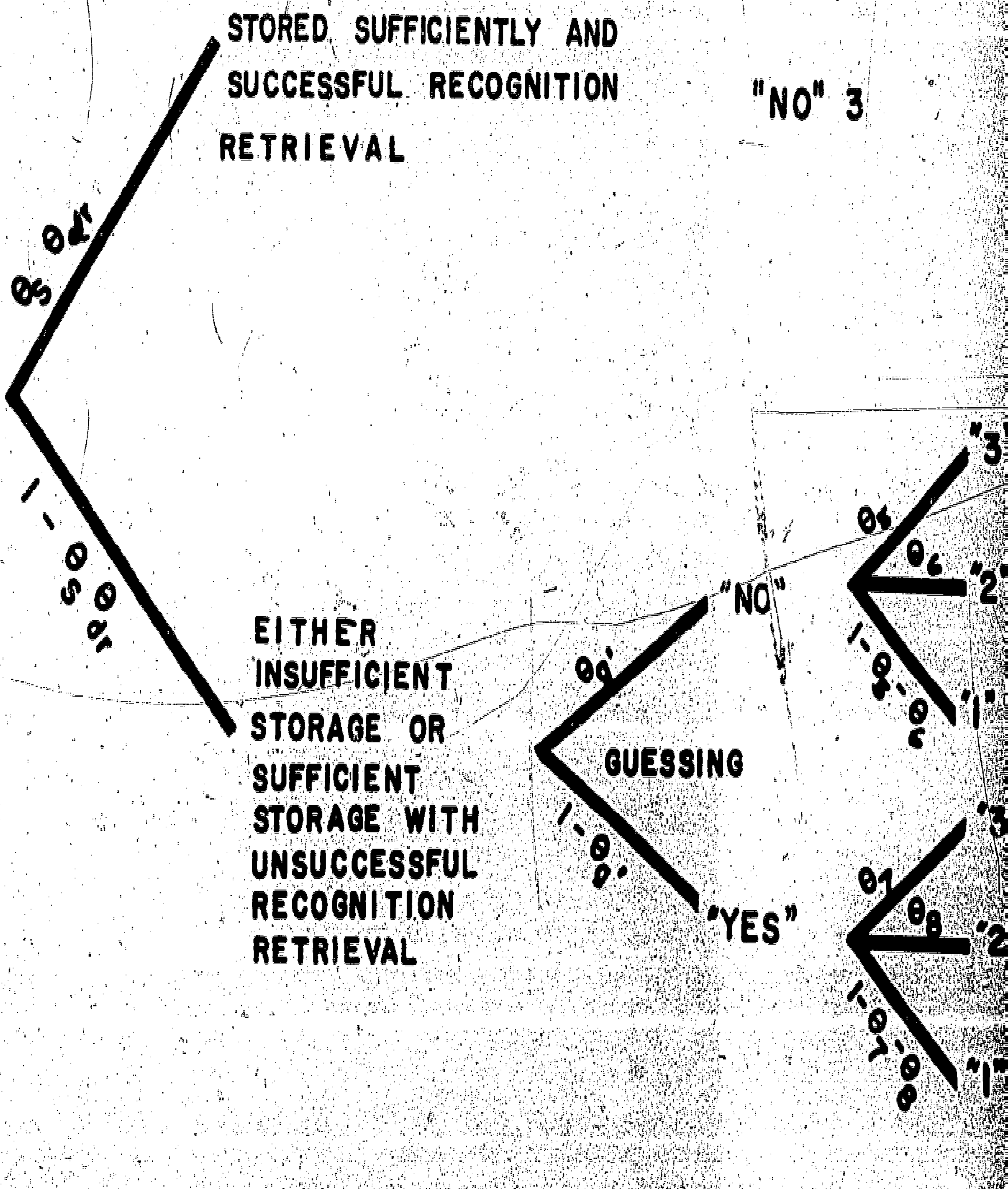

CORRECT RECALL
Θ_R
SUCCESSFUL RETRIEVAL
UNSUCCESSFUL RETRIEVAL
$1-\Theta_R$
INCORRECT RECALL
Θ_S
SUFFICIENT STORAGE
INSUFFICIENT STORAGE
$1-\Theta_S$
INCORRECT RECALL

Fig 2


"YES" "3"
Θ5
SUFFICIENT STORAGE
INSUFFICIENT STORAGE
1-Θ5
Θ9
GUESSING
1-Θ9
"YES"
"NO"
Θ1
Θ2
1-Θ1-Θ2
"3"
"2"
"1"
Θ3
Θ4
1-Θ3-Θ4
"3"
"2"
"1"


"NO" "3"
SUFFICIENT STORAGE
INSUFFICIENT STORAGE
GUESSING
"NO"
"YES"
"3"
"2"
"1"
"3"
"2"
"1"


STORED SUFFICIENTLY AND SUCCESSFUL RECOGNITION RETRIEVAL
"NO" 3
EITHER INSUFFICIENT STORAGE OR SUFFICIENT STORAGE WITH UNSUCCESSFUL RECOGNITION RETRIEVAL
GUESSING
"NO"
"YES"
"3"
"2"
"1"
"3"
"2"
"1"

$$\hat{\theta}_s = \text{MAX.}\, P(\theta_s | D)$$

$$\hat{\theta}_r = \text{MAX.}\, P(\theta_{dr} | D) \times \text{MAX.}\, P(\theta_{rr} | D)$$

$$P(\theta_s | D) = K_1 P_2 \int_0^1 P_1 P_3 \, d\theta_{dr} \,,$$

$$P(\theta_{rr} | D) = K_2 \int_0^1 \int_0^1 (\theta_s \theta_{dr} \theta_{rr})^{n_1} (1 - \theta_s \theta_{dr} \theta_{rr})^{n_2} P_2 P_3 \, d\theta_{dr} \, d\theta_s \,,$$

$$P(\theta_{dr} | D) = K_3 \int_0^1 P_1 P_2 P_3 \, d\theta_s \,, \quad \text{WHERE}$$

$$P_1 = (\theta_s \theta_{dr})^{-1} \int_0^{\theta_s \theta_{dr}} \alpha^{n_1} (1 - \alpha)^{n_2} \, d\alpha \,,$$

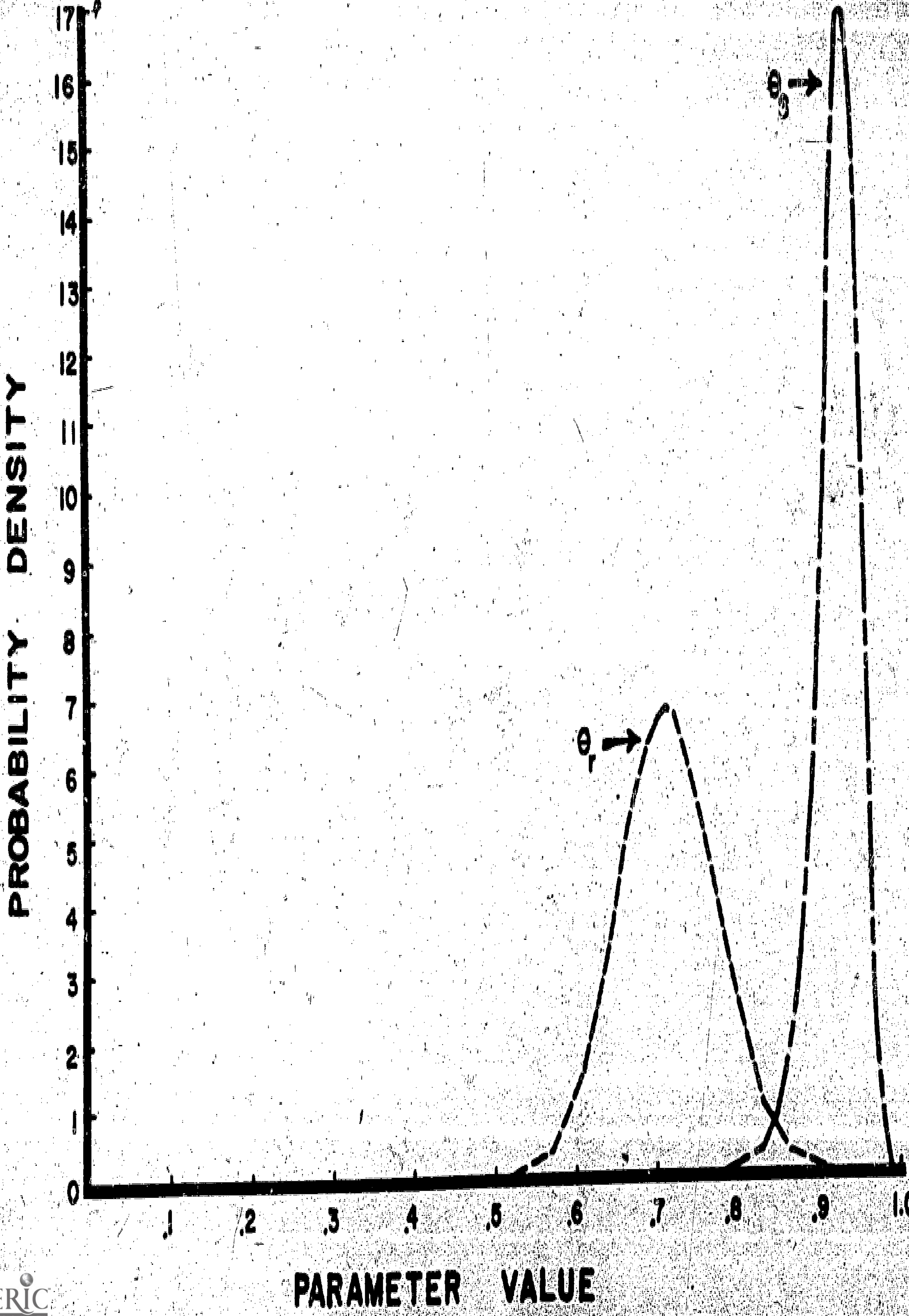
$$P_2 = \theta_s^{n_{13}} (1 - \theta_s)^{n_0 - n_{13}} \sum_{i=0}^{n_{13}} \frac{\binom{n_0 + 1}{n_{13} - i} \left(\frac{1 - \theta_s}{\theta_s} \right)^i}{\binom{n_{14} + n_{15} + i + 2}{2}} \,,$$

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

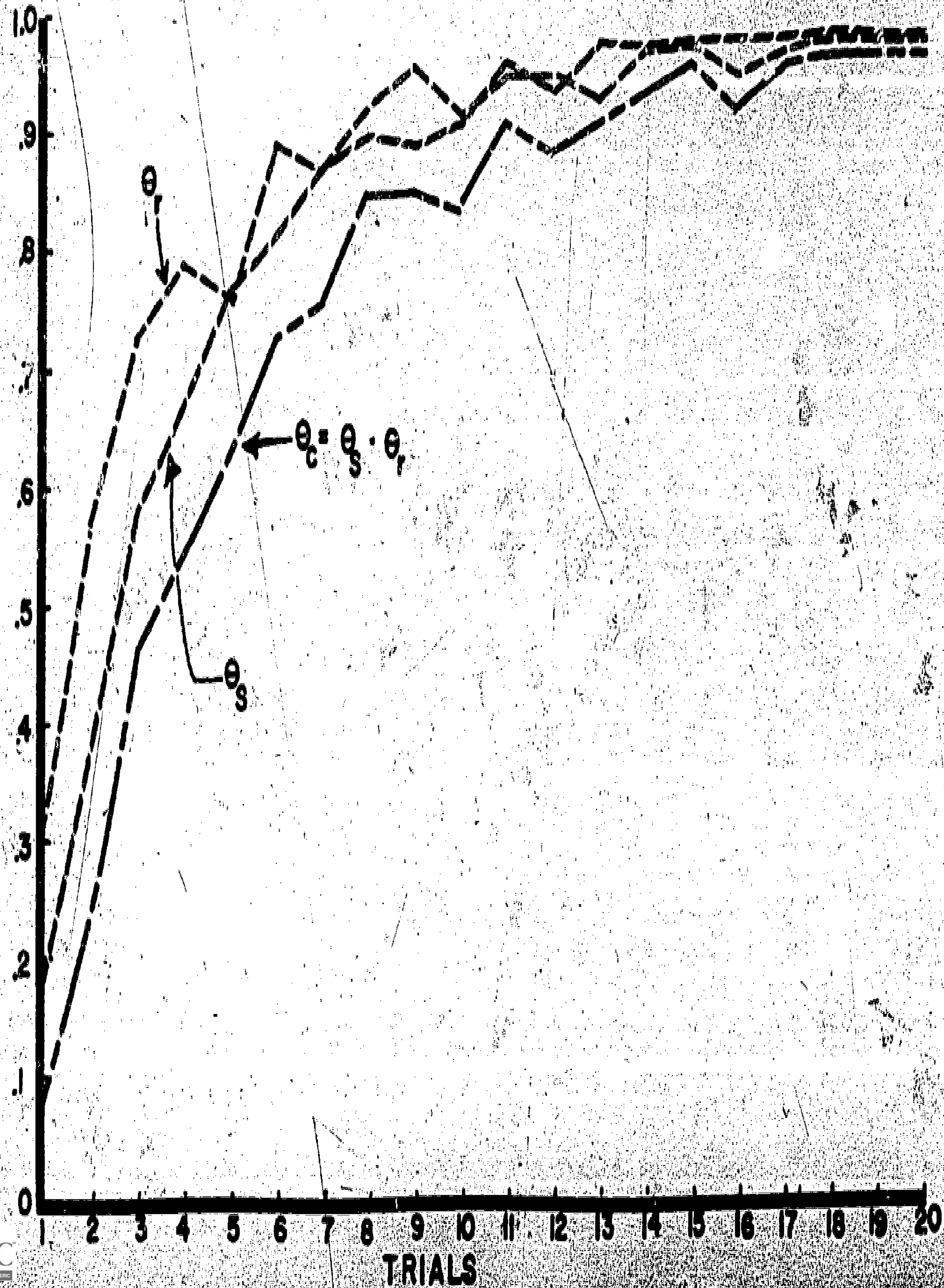
	"YES" RATING 1	"YES" RATING 2	"YES" RATING 3	"NO" RATING 1	"NO" RATING 2	"NO" RATING 3
OLD RECOGNITION	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
DISTRACTOR RECOGNITION	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}	n_{26}

	CORRECT	INCORRECT
RECALL	n_1	n_2

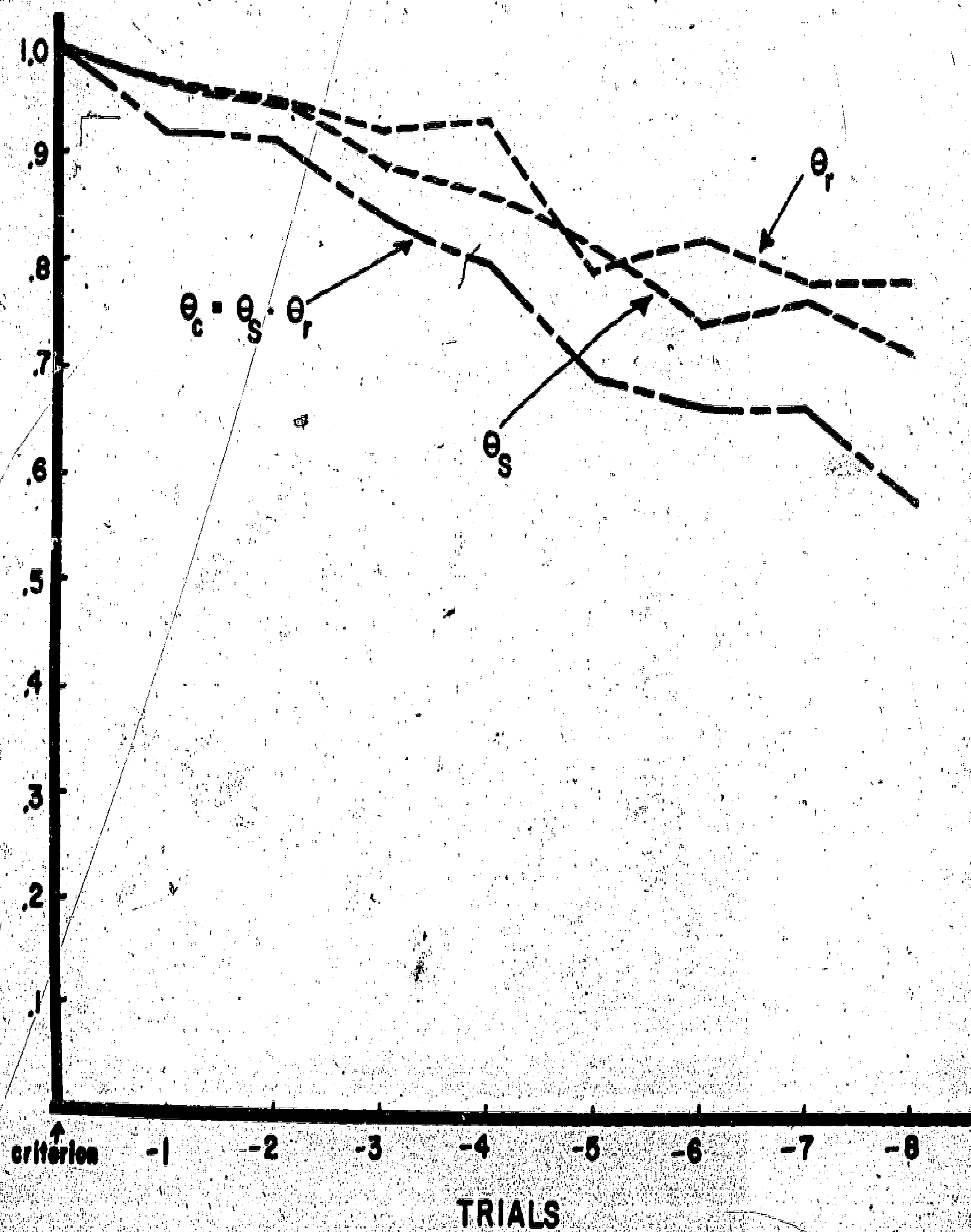
WHERE $\sum_{i=1}^{6} n_{1i} = n_0$, $\sum_{i=1}^{6} n_{2i} = n_d$



PROBABILITY DENSITY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PARAMETER VALUE



1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
θ_r
$\theta_c = \theta_s \cdot \theta_r$
θ_s
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TRIALS


1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
θ_r
$\theta_c = \theta_S \cdot \theta_r$
θ_S
criterion
-1
-2
-3
-4
-5
-6
-7
-8
TRIALS