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One-trial versus incremental learning : a re-evaluation employing signal detection theory

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ONE-TRIAL VERSUS INCREMENTAL LEARNING: A RE-EVALUATION EMPLOYING SIGNAL DETECTION THEORY

BY

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Abstract

The purpose of the present study was to lend support to either the one-trial or incremental theory of learning by examining the probability of correct responses as a function of prior stimulus exposure. Signal detection theory was employed as the method of analysis. Two experiments tested the theories in a verbal learning task and a psychomotor task. On each of three trials a list of 6 AB pairs or 6 AB distances was presented once, then one of these 6 pairs or distances was tested for recognition. On the recognition test either AB (a previously viewed pair or distance) or AX (a novel pair or distance) was presented; S had to make a binary decision plus a confidence rating. Pairs and distances were the same for all three trials. From these data ROC curves were plotted which suggested support for both theories; however, no conclusive evidence appeared in either direction.

The original application of the tools of one research area to the controversies of a distinctly different research field can often open the door to new possibilities for experimental analysis. Familiar examples of successful combinations are the application of learning theory to clinical practice as evidenced in behavior modification or the application of theories of motivation in industry.

TSD, the theory of signal detectability, was originally introduced by psychophysical psychologists during World War II for the purpose of selecting code operators. The procedure involved a series of trials on which the prospective code operator was required to make judgments as to the presence, a signal-noise trial, or absence, a noise trial, of a signal or code in a static noise field. In addition to a binary decision, a procedure was evolved which required confidence ratings and thus allowed for a more sensitive measure of code presence identification. Only two possible answer combinations are of interest to the TSD psychologist; first, the proper identification of the code when it is present called the hit rate and second, the identification of the code when, in fact, it was not present in the noise field, called the false alarm rate. The resultant data are converted to probability scores with hit rate plotted on the ordinate as a function of false alarm rate on the abscissa. The obtained curve, labeled a receiver operator curve or ROC curve, is an indication of Ss performance. d', the difference between the means of the two normal distributions of signal noise and noise trials divided by their common standard deviation, is the index of the detectability of a signal in noise.

The issue in this study concerns the adaptation of TSD and procedures to the study of one-trial vs. incremental learning. This controversy involves the question of whether subjects learn in steps across trials until recognition threshold is reached or learn all or nothing on any given trial. This question has been the subject of long and vigorous debate. A variety of methodological approaches have been employed in an attempt to resolve the controversy. However, none has been effective in offering conclusive support of either theory. The one-trial theory has been espoused by such researchers as Guthrie (1952), Rock (1957), Rock and Heimer (1959), Clark, Lansford, and Dallenbach (1960), Voeks (1954) and Estes (1960). The incremental view has been supported by Hull (1943), Kristofferson (1961), Lockhead (1961), Underwood and Keppel (1962), Underwood, Rehula, and Keppel (1962), Postman (1962), and Williams (1962). The two theories make different predictions concerning the probability of learning a task based on prior exposure to the stimulus. One-trial adherents would predict no advantage as a result of prior exposure while the incrementalists would assert that some learning had occurred and a definite advantage existed for above-threshold identification. In terms of probabilities, incrementalists would predict increasing probability of learning across trials for all Ss who had not reached threshold on previous trials. Conversely one-trial theorists would predict constant probability across trials. It is these divergent probability theories that allow the application of TSD in this study.

From this analysis, one arrives at a testable prediction concerning the application of ROC curves for a learning task over trials. Assuming repeated exposure to an "as yet unlearned" stimulus one could expect either changing or constant probabilities, thus generating the two possible alternatives that might appear in an ROC plot. That is, over three trials one will either find three distinctly separate ROC curves with significantly different d' values or three ROC curves of essentially equal d' values. The former would indicate increased performance over trials with the latter representing unchanging probability of recognition. Clearly, the first would support incremental theory and the second would support one-trial theory. Two studies were devised to examine these possibilities in both a verbal and a psychomotor task.

TSD remained the tool of psychophysiology until the mid sixties when its other possible applications were discovered by various researchers. The reasoning behind the use of TSD in various types of studies is a desire to separate a process analagous to the Ss sensitivity from a response-criterion process. This in turn provides a far more sensitive measure of the performance quotient under study. To indicate the wide application of TSD one needs only to survey the literature of various experimental areas. Blough (1967) used TSD to deliniate stimulus generalization gradients in animals. Boneau and Cole (1967) employed TSD to study discrimination learning in pigeons. Price (1966) employed the method in personality and perception research.

The present idea was prompted by the recent application of TSD in recognition memory research. The concept of importance is that of response criterion. For example, a S may be required to decide if he "has" or "has not" previously been exposed to a stimulus. Clearly, the S is confronted with a decision making task. In many cases he may be quite sure that the stimulus is "old" and, in others, that it is "new." There will be cases, however, when he is not sure. It is at this point that the sensitive analysis of the decision process may be exploited by the use of confidence ratings possible in TSD. Without the confidence ratings, one must assume that the correct responses, that is, the hit rate, consist of learned responses and guesses. By applying a correction for guessing one can measure true learning. The TSD approach is different. It separates the learning process from the decision process. The latter is assumed to be continuous while the former may be either continuous or discrete. In either case, the method is applicable because of the process separations. In short, the theory corresponds perfectly to the methodology employed in the present experiment.

Murdock (1965), following the above reasoning, applied TSD to short-term memory. His purpose was to test the "high-threshold" concept proposed by Underwood and Keppel (1962). Basically, the "high-threshold" concept would predict an ROC plot with the data points lying along a straight line from the left hand vertical axis to the upper right hand corner of the graph. Murdock's data points did not fall on a straight line; thus his results cast some doubt on the "high-threshold" theory. It is, however, the methodology employed in the study which was most inspiring in the conception of the present study. The procedure described for Experiment I is basically the same as that employed by Murdock which suggested the theory taken herein and described earlier that allowed the distinction to be made between continuous and discrete learning.

Conceptually, previous exposure to a verbal pair or a psychomotor movement produces some degree of familiarity. This "performed task" is represented on a familiarity continuum with unperformed tasks. This is then the decision axis as opposed to the learning axis. Assuming both the exposed and unexposed task distributions are normal in regard to familiarity and of equal variance, the model is then identical to the basic TSD model. The "exposed" items correspond to the signal plus noise and the "unexposed" items correspond to the noise. Thus each item generates a "familiarity quotient" within S. S. consequently must adopt a criterian of familiarity, technically the likelihood ratio. If the item equals or exceeds the criterion the subject responds "yes," if not he responds "no." The confidence rating locates the proximity of the "familiarity quotient" to the criterion. The difference between the means of the two distributions is a measure of S's discriminability and is a function of learning and retention. The ROC curves can then be plotted and the distribution assumptions assessed; specifically, the change in learning over exposure trials.

In summary, the present experiment examined sets of ROC curves to determine whether prior exposure to a task facilitated the learning of that task. Thus support could be lent to either the one-trial or incremental theory of learning.

Experiment I

Method:

Subjects. Ss were 446 undergraduate students taken from several psychology courses at both the University of Richmond and Roanoke College.

Apparatus. Thirty 2 x 2 inch slides were prepared using radio mounts. The slides were pairs of nonsense trigrams rated above 40 on the Noble (1961) scale of associative value and above 40 on the Archer (1960) meaningfulness scale; that is, medium difficulty. The list of verbal pairs used is given in Appendix A. Slide presentation was with a Kodak Carousel projector; stimulus presentation being programmed by a Hunter timer with slides appearing at a .933 second rate. The size of the projected image was approximately 5 x 5 feet in all cases.

An answer sheet was also provided for Ss. A copy appears in Appendix B. It included the four confidence ratings, as well as blanks for Ss response on each of the three trials. In the upper right hand corner was a blank labeled form which was for the use of E.

Procedure. Ss were presented with six AB pairs followed by a recognition test for one of the six pairs. The recognition test consisted of presenting either an AB or an AX pair; Ss then deciding if the test pair "was" or "was not" among the original six pairs. Ss had to respond either "yes" or "no" and, in addition, give a confidence judgment. An AB pair would be a proper pair while an AX pair would be an improper pair; that is, trigrams which had and had not been paired during list presentation. The rating scale was an 8 point scale with an answer of "yes-3" or "yes-4" for AB trials and "no-3" or "no-4" for AX trials being considered correct. Ss were divided into two groups, half receiving AB test trials and half getting the AX pair. Serial position of the test pair in AB trials was varied over all Ss to equate its effect.

The Ss were shown the six original slides followed by a blank slide which in turn was followed by the test slide. The Ss were then given 15 seconds in which to respond on their answer sheet. The response was "yes" or "no" plus a confidence rating of 1 to 4. The rating chart appeared on the answer sheet; 1 being a pure guess, 2 was not very sure, 3 was relatively sure, and 4 was very sure.

For each S the task was repeated with both identical original pairs and test pair for two additional trials.

Results

The data obtained were analyzed to determine the probability of a correct response as a function of serial position in the AB test trials. Also an analysis of the probability of correct response on each of the three trials for AX pairs was performed. For AB pairs serial position was varied

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Insert Table 1 here

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over positions 2, 3, and 4. Positions 1, 5, and 6 were not used as AB tests because of the almost 100% recognition in these positions reported by Murdock (1965).

It was obviously easier to respond correctly to an AB test pair than to an AX pair. It should be remembered that the probabilities reported include all responses; that is, Ss giving a correct response on trial 1 or trial 2 were not omitted when arriving at the probabilities for trial 2 and trial 3, respectively.

ROC curves were constructed for each of the three trials. The data for trial 1 included all Ss. On trial 2 the data included only those Ss who had incorrectly identified the test pair on trial 1. The data for trial 3 included only those Ss who had incorrectly identified the test pair on both trials 1 and 2. The method used to construct the curves was that outlined by Pollack & Decker (1958). To indicate this method the

Table 1

Probability of a Correct Response for AB and AX

Tests in the Verbal Learning Task

	AX	AB	AB		
			SP 2	SP 3	SP 4
Trial 1	.1016	.3700	.3793	.3370	.4285
Trial 2	.1422	.5200	.6091	.4719	.3809
Trial 3	.2317	.6000	.6551	.5955	.4285

raw data for trial 1 are shown in Table 2. The first two rows

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Insert Table 2 here

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of the table show the distributions of S's responses over the 8 possible confidence judgments. The confidence judgments are ordered left to right from "No-4" to "Yes-4" to correspond to a criterion ordering from lax to strict respectively. The conditional probabilities, shown in the bottom two rows, are cumulative, the probability that a given confidence rating was assigned to category j or stricter. Thus, one starts from the right and moves to the left for AB and from left to right for AX.

The typical ROC curve shows hits on the ordinate as a function of false alarms on the abscissa. Here, the cumulative conditional probability of assignment to category j or stricter is shown for AB presentations on the ordinate as a function of AX presentations on the abscissa. The rationale behind the method has been given by Egan (1958), and others. Basically, S is capable of adapting multiple criteria, and a rating method provides more information about these criteria than one obtains from a binary (yes-no) judgment. For AB in the present case, a judgment of "Yes-4" represents the strictest criterion, "Yes-3" is next most strict, and any observation that exceeded the criterion in the former case would also do so in the latter. Then with 8 ratings, there are 7 criteria ranging, as indicated from strict to lax.

Table 2

Distribution of Confidence Judgments and Conditional Probabilities

for AB and AX Presentations on Trial 1

	NO				YES				TOTAL
	4	3	2	1	1	2	3	4	
AB	2	10	32	29	19	34	50	24	200
AX	4	21	26	21	33	49	67	25	246
$P(R_j \mid AB)$		.990	.940	.780	.635	.540	.370	.120	
$P(R_j \mid AX)$		.016	.102	.207	.293	.427	.626	.898	

Following this method the three ROC curves were generated. As can be seen, the curves are virtually overlapping.

Insert Figure 1 here

To further substantiate this overlap, the d' values for each curve were calculated from z-score conversions of the conditional probabilities. The obtained values were 1.023 for Trial 1, .924 for Trial 2, and 1.041 for Trial 3.

In the process of preparing the above ROC curves, it was observed that some Ss who responded correctly on trials 1 or 2 did not also respond correctly on trials 2 or 3, respectively. Since these Ss were omitted in the analysis of later trials, they were considered, statistically, to have learned the task. It was decided to perform an analysis of "true learners." These Ss were defined as those giving a correct response which was subsequently followed by correct responses on all remaining trials. Hence, only Ss who continually provided the correct answer were omitted on each trial. The use of the above procedure raises the question of what is to be done with Ss responding correctly on any given trial but not considered to be "true learners" as previously defined. These Ss were rejected from consideration on each trial; that is, they were not assigned to any response category. The Ss were then replaced for consideration on the next succeeding trial. It was assumed that by following this procedure only the "true

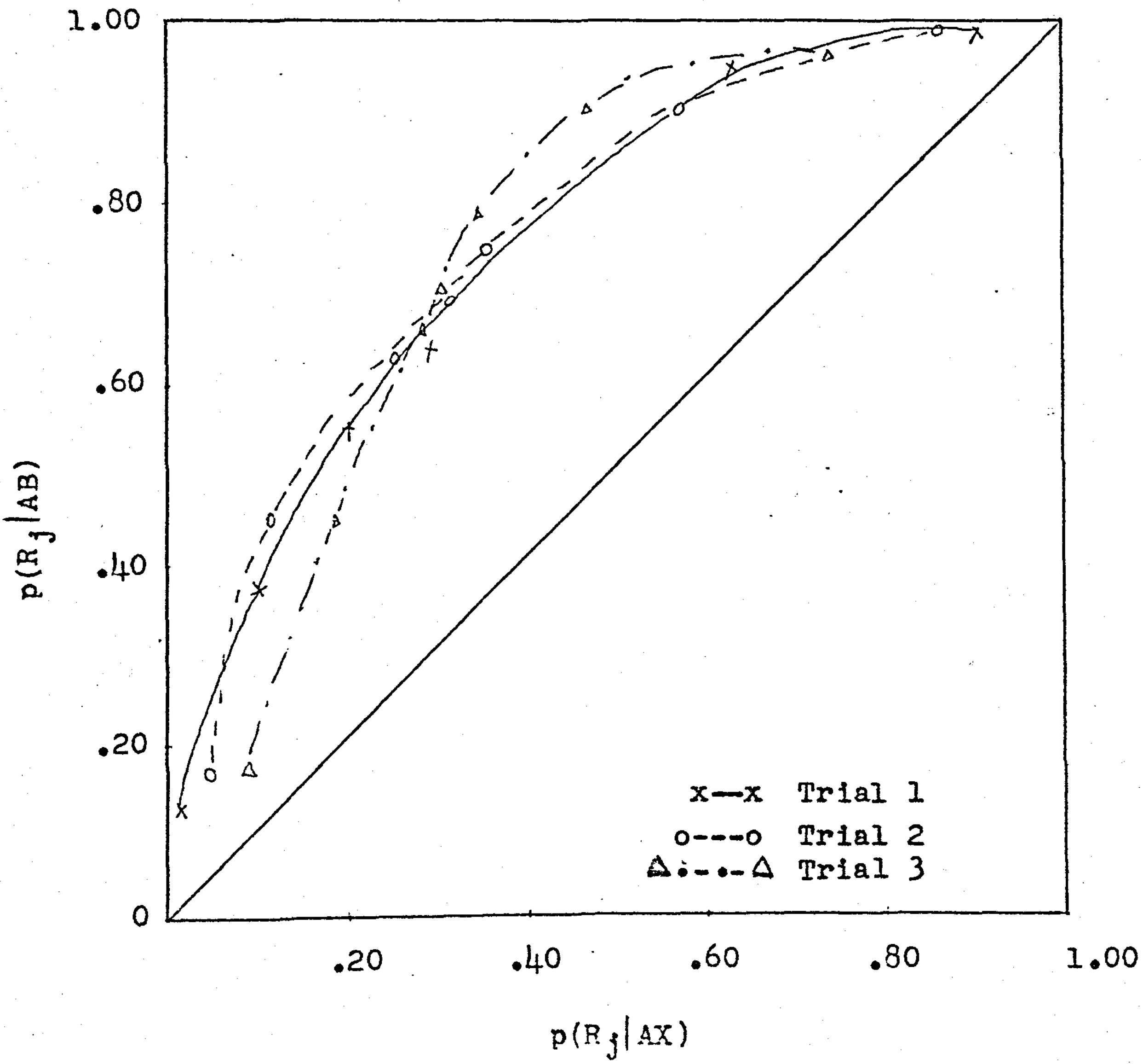

Figure 1

ROC Curves for Data Obtained in the

Verbal Learning Task

learners" were counted in the correct response categories; the rejected Ss not being added into the total for each trial. Since trial 3 is not followed by any other trials, it was not possible to validate correct responses; thus, all correct responses on trial 3 were counted as "true learners."

These data were also analyzed according to TSD and in the exact rationale presented earlier. ROC curves were plotted for each of the three trials.

Insert Figure 2 here

The results of this analysis support the results obtained by the prior method. However, there appears to be a definite separation of ROC's for the "true learners" that was not apparent in the earlier graph. Although the effect is small, it suggests differential performance across trials. The d' values obtained for the three curves were 1.070 for Trial 1, .806 for Trial 2, and .641 for Trial 3.

Experiment II

Method

Subjects. Ss were 120 graduate and undergraduate students obtained from psychology courses being conducted at the 1972 University of Richmond summer session.

Apparatus. A linear positioning response apparatus such as that described in a short term retention study conducted by Southall and Blick (1971) was employed.

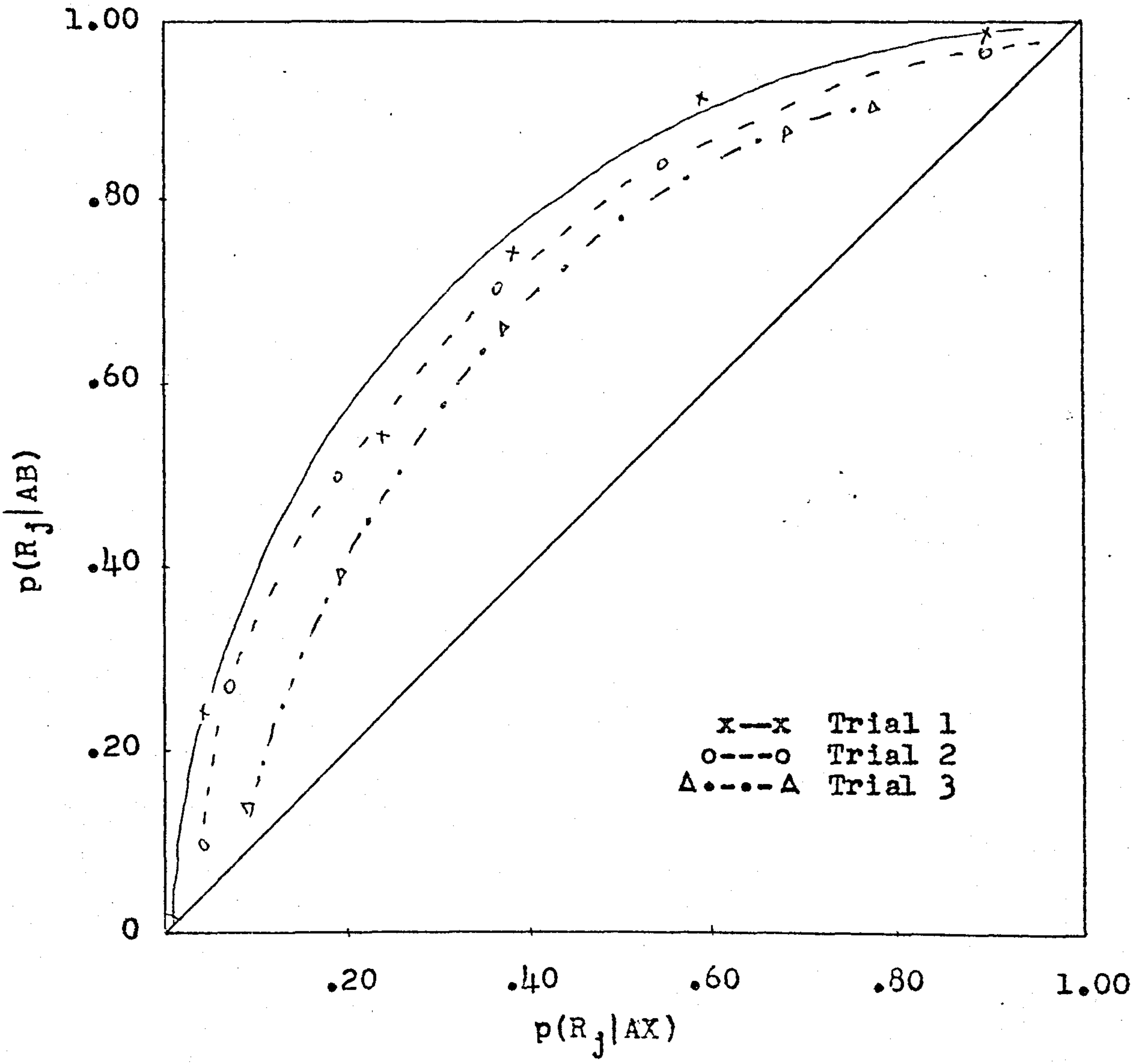

Figure 2

ROC Curves for Data Obtained in the

Verbal Learning Task and Recast for "True Learners"

A card table was also used throughout the experiment to hold the block of wood. It was marked in order to permit the exact placement of the block on successive test days.

Procedure. Ss were instructed concerning the nature of the task and then blindfolded. All Ss sat at the card table with their left hand on the slide and their left arm touching the edge of the card table and were cautioned not to lift their left arm off the table, although sliding their arm down the table was permissible. This was done in an attempt to standardize S's approach to the task. Ss moved the slide until it hit a stop and then returned it immediately to the starting position, a permanent stop at the starting position making this possible. The movements were made at E's command of "move." Ss were allowed to move the slide at any speed although this was not mentioned in the instructions. There was no intratrial interval in the sense that E commanded Ss to move as soon as the slide was returned to the starting position. The intertrial interval amounted to the length of time it took E to record S's response.

Ss moved the slide six times for six different distances. The six distances used were 10, 14, 18, 22, 26, and 30 centimeters. These distances having been chosen because the retention difficulty for all are essentially equal (Southall and Blick, 1971). The distances were always presented in order as listed above. On the seventh move, E explained that the distance moved may or may not have been equal to one of the six previously moved distances. The S's task was to decide whether or not the seventh distance was or was not equal to one of the original six distances. Ss responded yes or no and, in addition, rated the confidence of their decision. The same 8 point rating scale employed in experiment I was used.

E kept a record of the Ss' responses on answer sheets that were the same as those reported in experiment I. The task was repeated three times for each subject.

The length of the seventh distance depended upon which group the S was assigned to. Sixty Ss got AB test distances; that is, distances equal to one of the original six. The other 60 Ss got AX test distances; that is, distances not equal to one of the original six. In the AB groups, 10 Ss were tested at each of the six original distances. In the AX group 20 Ss received each of the three different AX distances; these distances were 7, 20, and 34 centimeters.

In all cases, the six original distances and the test distance were exactly the same for all three trials.

Results

The data obtained in experiment II were analyzed in the same fashion as those obtained in experiment I. The rationale employed there also applies to the current data.

The first consideration was probability of correct response for AB and AX trials and for the serial positions in the AB trials. It was obviously easier to identify AX

Insert Table 3 here

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distances than AB distances.

ROC curves were plotted for the distributions obtained in this experiment in exactly the same manner as that outlined in experiment I.

Insert Figure 3 here

The first plot revealed erratic data points which did not lend themselves to the smooth curves of TSD. d' values were calculated and were found to be negative for trials 1 and 2. The obtained values were -.4943 for trial 1, -.3342 for trial 2, and +.2229 for trial 3.

As before the data were reanalyzed with assignment categories determined for "true learners." The ROC curves

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Insert Figure 4 here

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for this data were also erratic and unable to be connected by smooth curves. The calculated d' values were -.5285 for trial 1, -.2856 for trial 2, and +.0114 for trial 3.

Discussion

The results of the present study pose several problems for interpretation. No concise conclusions concerning the validity of the one-trial versus incremental hypothesis can be

Table 3

Probability of a Correct Response for AB and AX

Tests in the Psychomotor Task

	AX	AB	AB					
			SP 1	SP 2	SP 3	SP 4	SP 5	SP 6
Trial 1	.5500	.3000	.3000	.3000	.2000	.2000	.4000	.4000
Trial 2	.4500	.2833	.3000	.5000	.3000	.0000	.2000	.4000
Trial 3	.3833	.2833	.0000	.4000	.4000	.1000	.1000	.7000

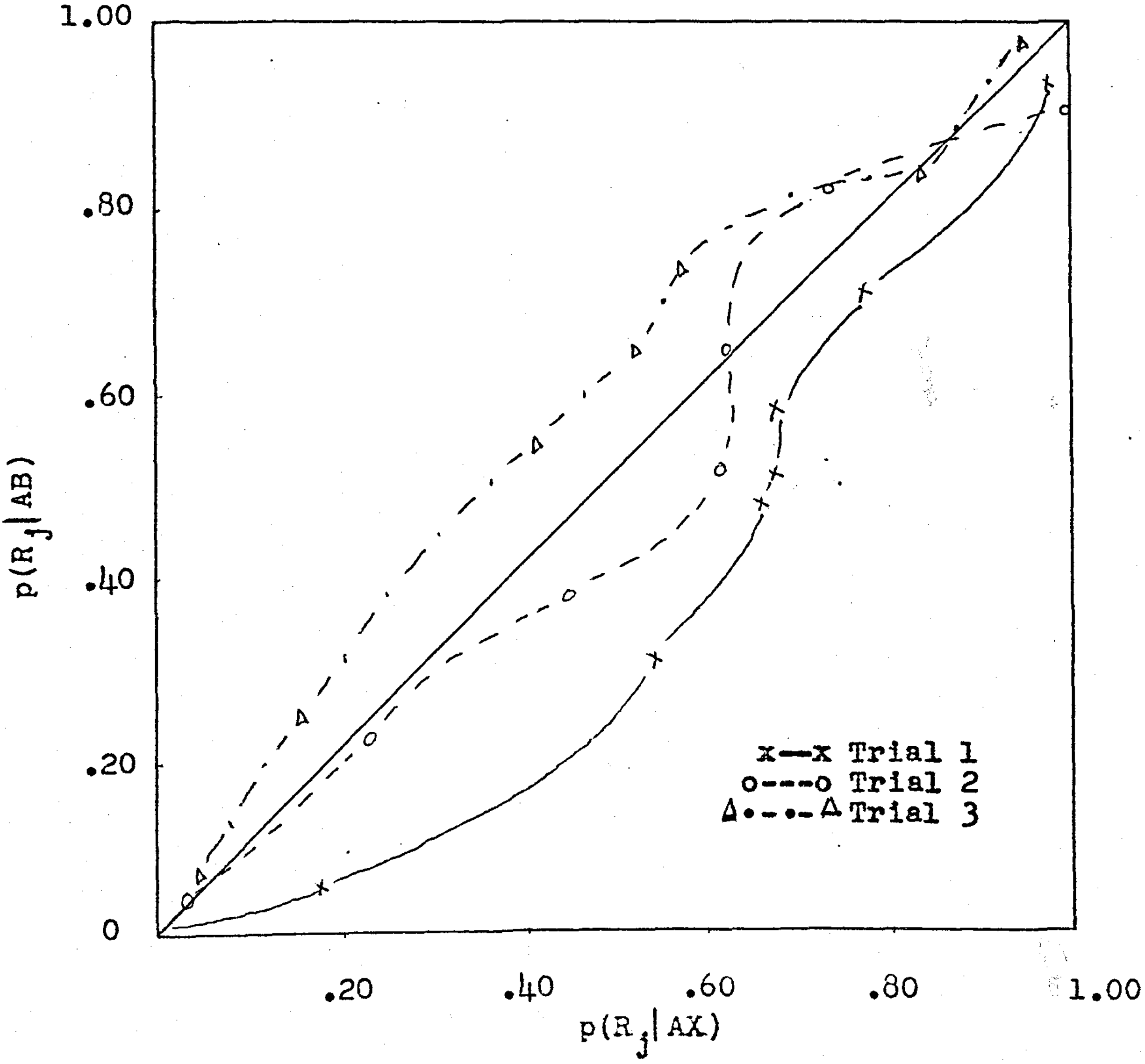

Figure 3

ROC Curves for Data Obtained in the

Psychomotor Task

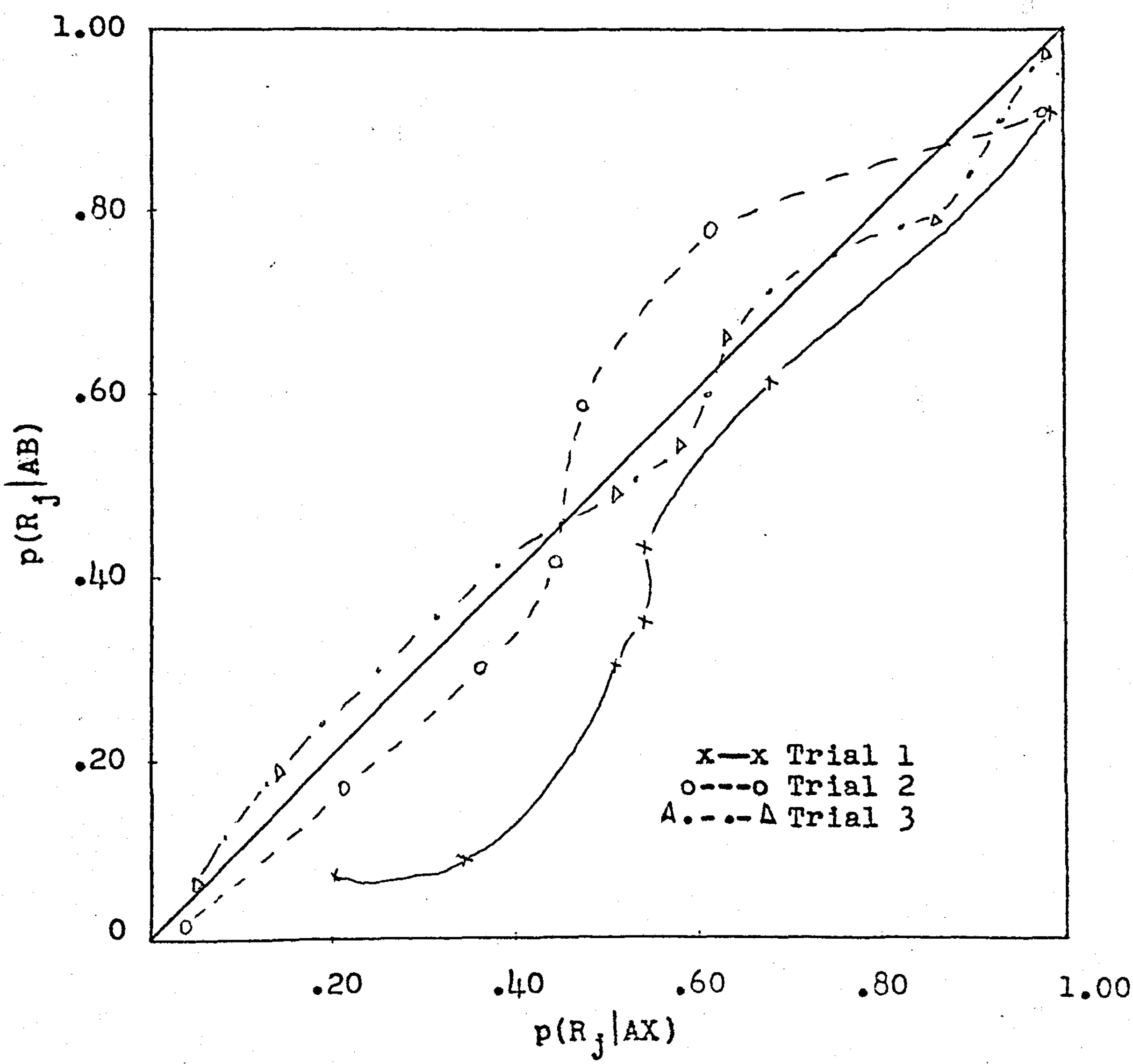

Figure 4

ROC Curves for Data Obtained in the

Psychomotor Task and Recast for "True Learners" easily drawn. Perhaps the clearest results are in the area of probability of correct response for AB and AX conditions, as well as serial position. In the verbal learning task, it was clearly easier to identify AB test pairs than AX pairs. A possible explanation for this finding lies in the similarity of the AX pairs to the original stimuli. Thus many Ss who are responding on the basis of partial recognition would respond affirmatively and be in error. A similar affirmative response based on partial recognition of the pair for AB tests would be a correct response. For the psychomotor task, the probability of a correct response for AX tests was greater. The placement of the AX test distances, two of the three preceding and following the first and last AB distances, may account for the greater likelihood of a correct response.

Serial position analysis for the psychomotor task proved inconclusive with only serial position six clearly easier to identify. This may be the result of the recency effect. For the verbal task, serial position effects were suggestive. Since position two exceeded three and three exceeded four, in probability of identification, one may conclude that initial positions were easier to learn and consequently recognize; a finding not consistent with that reported by Murdock (1965), who found that serial positions 2, 3, and 4 did not show any difference in ease of identification.

The results obtained concerning the original problem of one-trial vs. incremental learning were not easily interpreted. Examination of the initial graph for the verbal task revealed three overlapping ROC curves and strongly suggested that learning occurs in an all-or-none fashion. However, the recasting of the data for "true learners" yielded somewhat different results. Here the three ROC curves are not overlapping and at first examination would appear to support the incremental view. However, the curves were in reverse order from that anticipated; i.e., performance seemed to have declined over trials. Thus, this recasting supported neither theory and it was impossible from the present results to draw any final conclusions in the matter of one-trial versus incremental learning.

The ROC curves for the psychomotor task are even more ambiguous. The results suggest that Ss were not discriminating between the various linear movements which may be the result of a task which was simply too difficult. In both the original plot and the plot for "true learners," the curves seem to fluctuate about the chance line. However, there is a suggestion of improvement over trials. The first plot clearly illustrates this and the second tends toward a similar improvement. In summary, the present results do not allow any brazen conclusions to the long-standing learning theory controversy. There were suggestions toward improvement over trials, the incremental view, in the motor task. However, the verbal task plot tended to support the one-trial theory.

Perhaps more important is the invitation to apply TSD in a variety of research areas. Several different applications have already been mentioned; however, the reader is referred to D'Amato (1970) for further suggestions of novel approaches to various research through signal detection theory. For example, it would seem quite valid to use TSD in testing the assumption of Amsel's (1958) motivation theory which states that frustration can be conditioned and its avoidance serve as reinforcement for learning. ROC curves would indicate if, in fact, the reduction of conditioned frustration was enhancing learning.

It seems apparent that TSD may provide the answers to many unanswered questions and establish its importance outside the confines of psychophysics.

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Appendix A

Verbal Pairs Used in Both the AB and AX Conditions

AB Pairs	AX Pairs
SIQ-TOH	YOM-CEY
LUQ-DEH	
JIR-RAJ	
YOM-CIY	
BOH-NEF	
MOY-GEZ	

Appendix B

Answer Sheet Employed in Both Experiment I and II

FORM ____________

Rating Scale:

1 - a pure guess

2 - not very sure

3 - relatively sure

4 - very sure

TRIAL 1 _________

TRIAL 2 _________

TRIAL 3 _________

Vita

James W. Hyams was born September 26, 1946 in Clarksburg, West Virginia. In 1950 he moved with his family to Bluefield, West Virginia whereupon he completed his secondary education, graduating from Bluefield High School in 1964. In September 1964, he entered the University of Richmond. While at the University of Richmond, the author accepted membership in Phi Delta Theta social fraternity. In June, 1968, he was awarded a Bachelor of Arts degree in English. The author then taught in the public high schools in Roanoke County, Virginia until entering the graduate program in psychology at the University of Richmond in February, 1971. The author has been appointed as an instructor in psychology at Stratford College for the 1972-73 academic year. Following that appointment, he hopes to begin work on the doctoral degree in experimental psychology.