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KANSAS STATE UNIVERSITY

MANHATTAN

Second Semi-Annual Report
(First Annual Report)

on

NASA Grant NsG 606

by

Kansas State University
Manhattan, Kansas

To: National Aeronautics and Space Adminstration

On: Analytic Studies in the Learning and Memory of Skilled Performance

For the period: October 1, 1964 to March 30, 1965

Prepared By:

Merrill E. Noble
Co-Investigator

Don A. Trumbo
Co-Investigator

Date: April 20, 1965

Analytic Studies in the Learning and Memory of Skilled Performance

This is the second semiannual report (first year-end report) of progress in the research being conducted under NASA Grant NsG 606. This research is being technically monitored by the Biotechnical Division of the Ames Research Laboratory. Mr. Robert Randle of the Human Performance Section serves as Grant Monitor.

Report of Work

In the first semiannual report (dated November 6, 1964) the development of the research apparatus and equipment was described, and the research schedule for the first major study was outlined. At that time the apparatus was in the final stages of completion and we anticipated beginning data collection by mid-November.

Data collection was actually begun on November 30, 1964. Since that time over 120 experimental subjects have been trained and retention data collected on 60 of the subjects. Retention data will be collected on the remaining 60 subjects, beginning on May 10, 1965. This will complete approximately 550 hours of subject testing time. In addition we have completed data analysis of integrated error (performance) scores for the training phase of the study, obtained oscillographic records for analytic scoring of 360 individual trials, and arranged to have additional analysis performed by the Flight test Data Analysis Section of McDonnell Aircraft. The first major study is described, in detail, below.

Study I: Acquisition and Retention of Skilled Performance as a Function of Target Predictability and Sequence Length.

In a communication entitled: Addendum to: Analytic Studies in the Learning and Memory of Skilled Performance (dated October, 1964), we proposed to conduct studies in three major problem areas during the second year of the Grant (beginning April 1, 1965). The second study proposed (Item B) at that time was entitled: Acquisition of Skilled Performance as a Function of target Predictability and Sequence Length (similar to study 8 of the original proposal.)

However, in the Semiannual Report (November 6, 1964) we indicated that this study would be conducted during the second half or the first grant year, rather than during the second grant year.

Certain important design modifications were made in this study to provide additional information. First, two retention periods were scheduled. Second, a procedural variable-cueing the end of the sequence at each repetition-was included. Third, whereas our prior research had matched all subjects by giving them equal practice (time), half of the subjects in this study were matched to an equal repetitions (of the coherent sequence) criterion. A systematic review of study I follows.

Purpose

The major purpose of Study I was to evaluate the role of sequence length on the acquisition and retention of skill when the task involves coherent and partially coherent sequences. The implications of both sequence length and sequence coherency (or task predictability) for human performance situations should be apparent. Both variables represent dimensions of task complexity not unlike those found in a wide variety of human controller tasks in man-machine systems. Knowledge of the relation of these variables to skill learning rate, final performance levels, and performance levels after extended periods of no practice will provide basic information on the potentials and limitations of the human operator. Specifically, such information will aid in the description of the information processing capacities and limitations of the human operator, and his ability to retrieve and use such information after extended periods of disuse.

Method

Subjects: A total of 120 male University students, between 18 and 24 years of age, constituted the sample for this study. Subjects were selected who were right-hand dominant. They were paid for their services.

Apparatus: The components of the apparatus were described in the first semiannual report. Basically, the apparatus is a tracking system with certain limited analog scoring capabilities built in. The major subsystems are:

(A) the target programmer. This consists of a Digitronics model 3718 tape reader, with pre-punched paper tape programs, a digital to analog converter (computer control) and regulated power supplies. While the original proposal called for additional flip-flop circuits, purchase of the digitronics reader negated this requirement. Input tapes are punched on a university-owned Flexowriter. The output of the programmer drives the target signal on the subjects' CRT displays.

(B) Displays. Two tektronix Model 561A oscilloscopes and plugs in units, one in each of two 6' X 8' subject booths, constitute the display apparatus. The target which is driven by the programmer, appears as a 1/2" vertical hair line along the X-axis of the 5" CRT.

(C) Controls. Each subject booth is equiped with a steel chair on which has been mounted a right-hand lateral arm pivoted at the elbow. A potentiometer, attached to the lower end of the pivoted shaft, provides a linear voltage output corresponding to the position of the control. This output is displayed as a cursor blip, identical to the target blip, but located 3/8" lower on the CRT. The control is positional and linearly related to the cursor (controlled element) with a control-to-display ratio of 11.25° are to 1". A Schaevitz HG-2 accelerometer is attached to the underside of each control at 12" from the pivot.

(D) Data Scoring. The scoring unit consists of two Philbrick Model 6009 Manifolds with a total of 10 operational amplifiers and 10 stabilizers and power supplies. This capability allows us to obtain integrated absolute error for each subject. This is accomplished by obtaining the difference between the input (target) and output (cursor) voltages, without regard to sign, and integrating this difference over the fixed interval which constitutes a trial. Momentary error and momentary accumulated error may be obtained and recorded when desired.

In addition, by integrating the output from the arm control accelerometers a rate score, or an average rate score, may be obtained.

(E) Data Storage and Read out. Data is stored on 1/2" magnetic tape recorded with a Minneapolis-Honeywell Model 8100 F-M tape system. With four recording channels, output from both Subjects' controls can be recorded simultaneously with the common input (target) record. In addition such indices as momentary error or momentary acceleration can be recorded on a time-sharing basis on the remaining channel.

Integrated error is read out continuously for each subject on a voltmeter and recorded at the end of each run or trial. In addition, data are read out as desired on a Minneapolis-Honeywell Visicorder (Model 906C) for visual inspection and hand scoring of continuous response records. Finally, data stored on magnetic tapes can be read into analog or analog-to-digital electronic computers for additional analyses.

(F) Automatic controls. Durations of trials, durations of intertrial intervals, and durations of integration intervals are automatically controlled by Hunter Interval timers.

Tasks: All subjects received irregular step-function target inputs at one step per second. Targets could appear at any one of 15 equidistant positions within the middle 4" of the X-axis of the CRT. Trials were 48 seconds in duration with an intertrial interval of 15 seconds, the final two seconds of which were filled with a warning buzzer.

Experimental conditions: two levels of task predictability, five sequence lengths, two training criteria, and two retention intervals were employed in this study in a complete factorial design (2 X 2 X 2 X 5).

(A) task predictability, One half of the subjects received a completely predictable task in that a fixed sequence of target positions, N targets long, was repeated within and throughout all trials. Thus, for example, numbering the 15 equidistant positions on the X-axis of the CRT, the target sequence might appear as: 2, 12, 5, 11, 15, 7, 4, 12; 2, 12, 5, 11, 15, etc. for a sequence of eight targets. The remaining one-half of the subjects received a partially predictable sequence of N targets wherein three-fourths of the targets repeated, in order, within and throughout all trials, but where every fourth target was selected anew, and randomly, on each repetition. Thus, the sequence might appear as, 2, 12, 5, (11), 15, 7, 4, (12); 2, 12, 5, (1), 15, 7, 4, (8); etc. with the non-repeating, and therefore, unpredictable targets shown in parentheses for a basic sequence of eight targets. The sequences were drawn without replacement and without repetition of target positions for sequences of less than 15 targets. For the longer sequences, only the minimum number of repetitions was allowed (e.g. for a sequence of 24 targets, nine targets were repeated once within the sequence.) Random targets were drawn from the same population of target positions except that random targets could not duplicate target positions immediately preceding or succeeding in the sequence. Thus, in the above example Random targets would not appear at positions 5 and 15, or 4 and 2.

(B) sequence length. One fifth (6) of the subjects in each of the two task conditions was assigned to one of five sequence lengths: 8, 12, 16, 24, or 48 targets long.

(C) training criteria. One-half of the subjects in each of the ten task X sequence length conditions was assigned to an equal-practice training criterion. All these subjects received one-hundred 48-second trials distributed over five successive daily sessions of 1/2 hour each. The remaining one-half of the subjects received varying amounts of practice but were equated on <u>number of repetitions</u> of the basic sequence. All these subjects, except the group with the longest sequence (N=48), received 360 repetitions, which, for the sequences of 8 targets required 60 trials, for the sequence of 12 targets, 90 trials, etc. The subjects with the 48-long sequences were terminated after 180 repetitions.

(D) Retention intervals: One-half the subjects in each combination of the above conditions returned for 40 retention trials after 3 months of no practice. The remaining subjects are scheduled to return in May, 1965, after 5 months of no practice for 40 retention trials.

Procedures

Subjects were scheduled, two at a time, for identical experimental conditions. All testing sessions were 1/2 hour long with repeated sessions on successive days until the training level was reached. Subjects were given detailed instructions, including illustrations from oscillographic records of various sources of tracking error (slow rate of movement, poor timing, overshooting, etc.). They were told that different subjects were receiving different sequences but that the first target of each sequence was always located at the center of the scope. All subjects were given feedback after every second trial when their error scores were reported via an intercom system. After Day 1, subjects were told only that the task remained the same as on the previous day.

Performance Measures

Absolute error, integrated over the 48-second trial, was recorded after each trial and served as the primary performance criterion. In addition 3 trials for each subject, which were recorded on magnetic tape, are being scored for a number of temporal and spatial response indices. Present plans include additional scoring of recorded trials using the analog and digital computer facilities at McDonnell Aircraft, St. Louis, Missouri.

Results

We are in the process of analyzing the data from the training phase of the study. Since the retention phase is not yet completed we will present only the first analyses for error scores on the training data in this report.

Equal practice: Data were analyzed separately for the equal practice and equal repetitions conditions. Overall analyses of variance were performed and will be followed by a number of secondary analyses, including mean separation tests of differences at the end of training.

Figure 1 summarized the results for the predictable tasks (only) under conditions of an equal practice criterion. It will be seen that, with equal practice, length of the sequence has an appreciable effect on tracking performance. However, this effect does not appear to be linear; rather, as shown in Figure 3, it appears that error is an accelerated function of number of targets in the sequence.

Figure 2 presents the results for the equal practice condition with the intermediately predictable tasks. It may be noted, first, that the overall performance is considerably poorer on this than on the completely predictable task. Best performance on the intermediately predictable task is in excess of five volts error, whereas three of the five predictable-task groups reach a low of about four volts error. Thus, estimating the total gain from an initial error of 9.5 volts, the predictable tasks resulted in nearby 20% greater reduction in error than the intermediate tasks.

The relation of sequence length to integrated error under the intermediate task conditions is shown in Figure 3. When compared with the fixed task conditions, it appears that the introduction of random elements has a particularly adverse effect on the shortest (N=8) sequence. Why this should be the case is not immediately apparent. It also appears that the remainder of the function for

Figure 1

PREDICTABLE

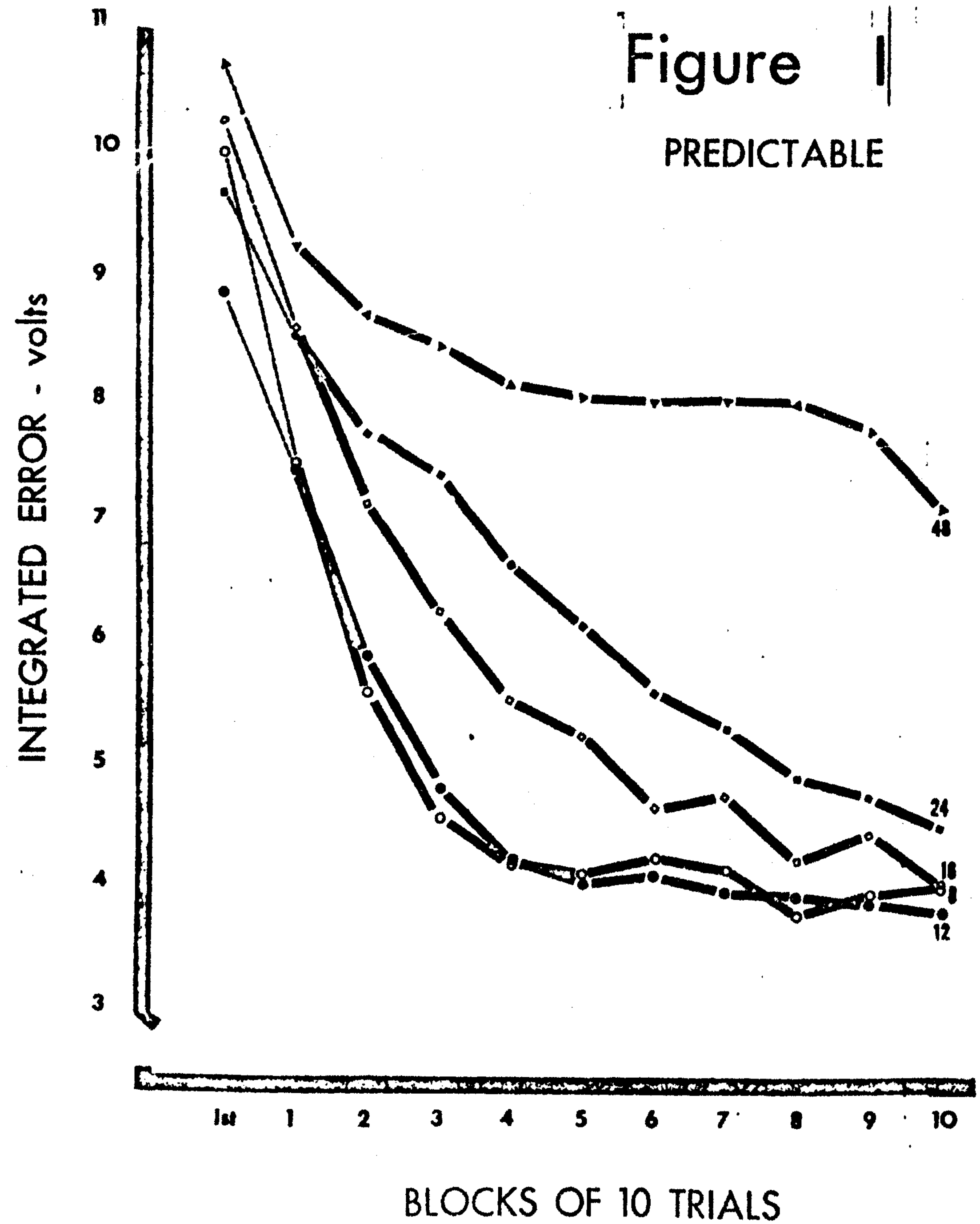
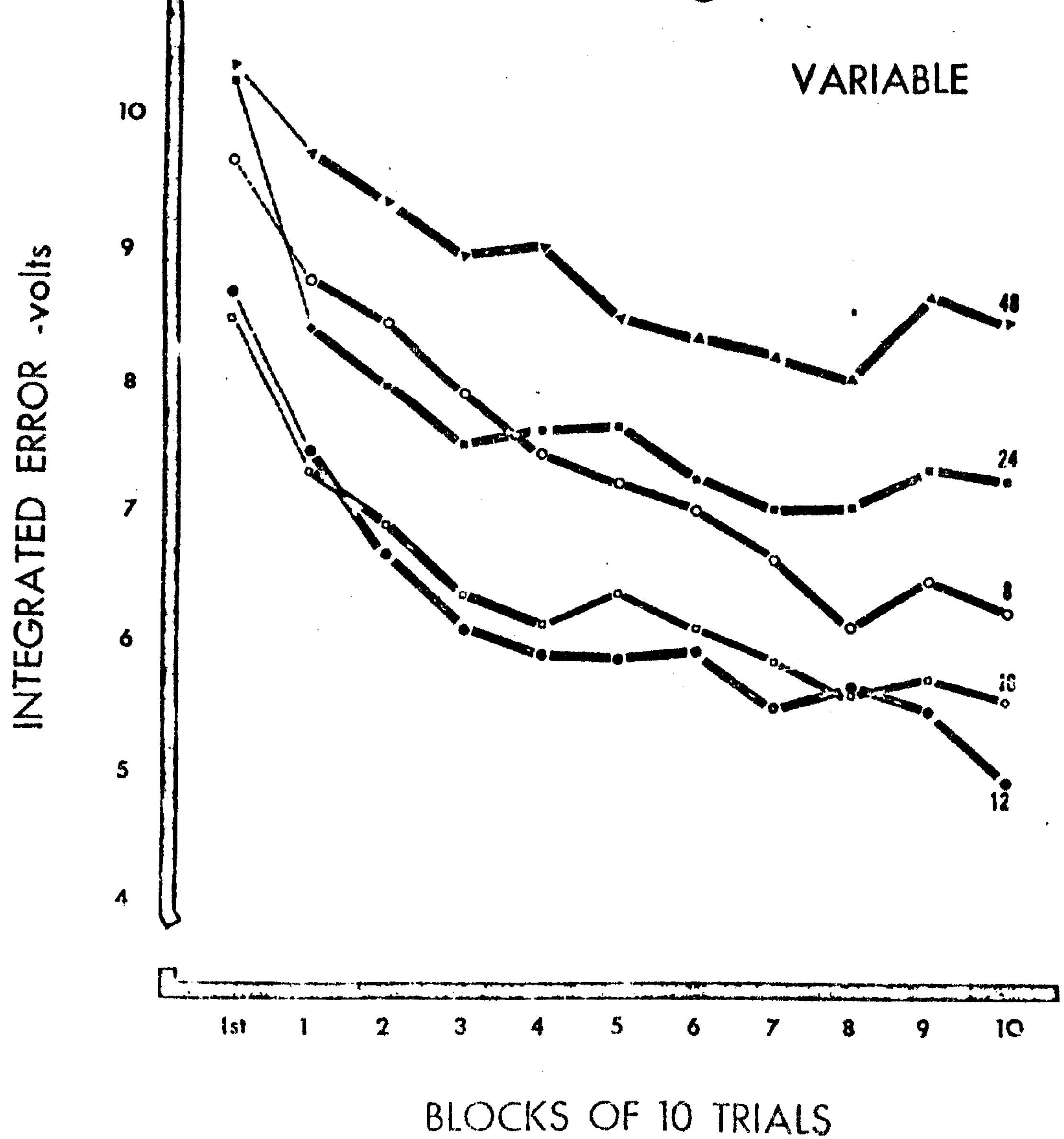


Figure 2


VARIABLE
INTEGRATED ERROR -volts
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BLOCKS OF 10 TRIALS

Figure 3
(Equal Practice Time: 100 Trials)

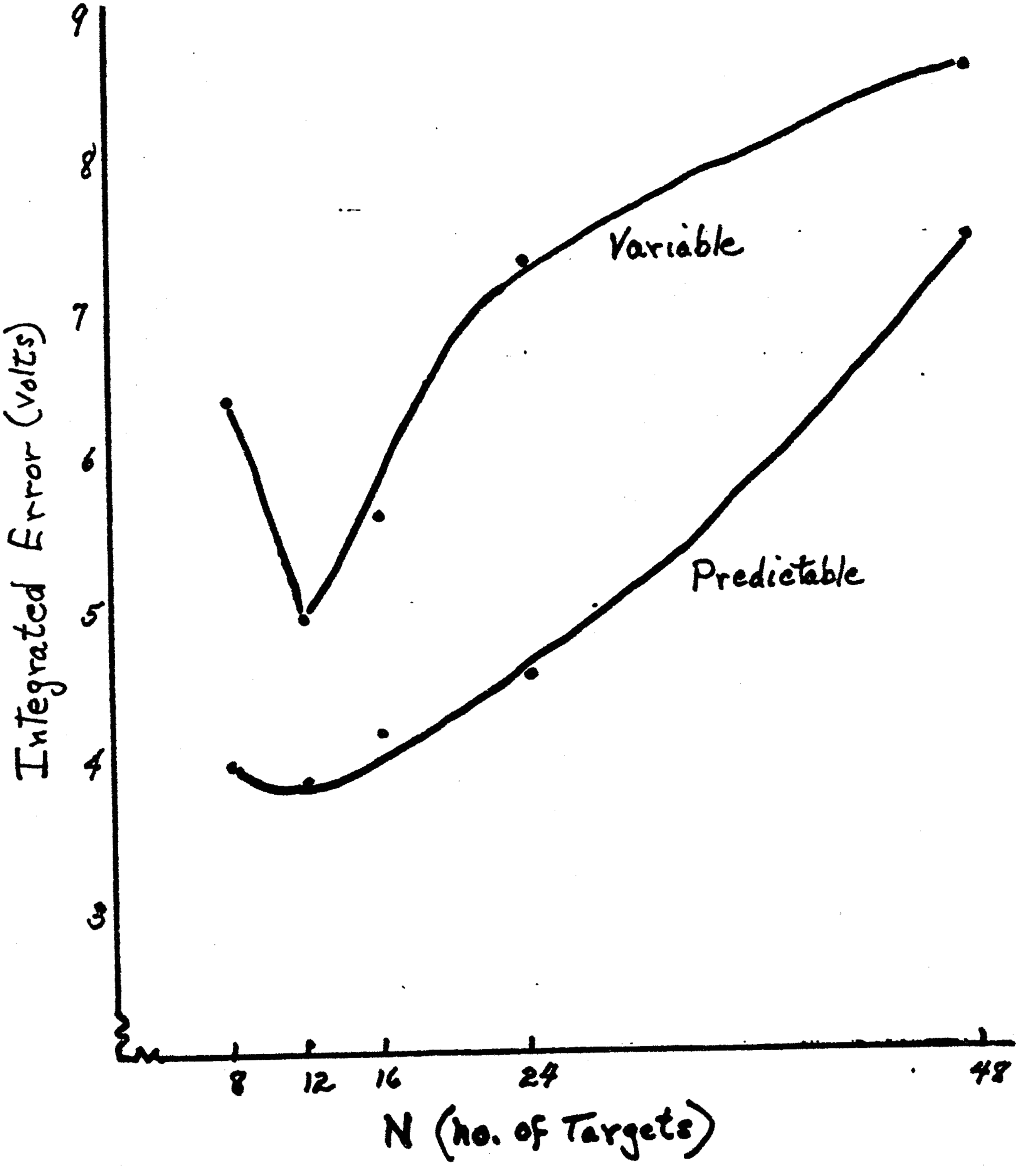


Table 1

Summary of

Analysis of Variance for all Equal

Practice Conditions

Source	df	SS	MS	F
Predictability	1	138.3803	138.3803	22.74**
Sequences	4	374.0684	93.5171	15.37**
Pred. X Seq.	4	38.9089	9.7272	1.60 NS
Subj W/I	50	304.2289	6.0846	
Blocks (20 trial)	4	184.0959	46.0240	146.34**
Blocks X Pred.	4	15.7751	3.9438	12.54**
Blocks X Seq.	16	11.2743	.7046	2.24**
Blocks X Pred. X Seq.	16	16.6987	1.0437	3.32**
Blocks X Subj	200	62.8965	.3145	
Total	299	1146.3271		

the intermediately predictable tasks is more nearly linear than that for the fixed task.

The analysis of variance for all equal practice conditions is summarized in Table 1. Here the differences between conditions of sequence length and between fixed and intermediate task conditions are statistically confirmed. Both main effects are highly significant. However, the inter-action between these effects (Predictability X sequence length) fails to reach significance, Practice effects are highly significant as indicated by the F for Blocks of 20 trials. In addition, the interactions between practice blocks and predictability, practice blocks and sequence length, and the three-way interaction among these variables are all significant. These results support the evidence in figures 1 and 2 that both sequence length and task predictability affect the shapes of the performance curves, i.e., the rate of change of performance at different points in training.

<u>Equal repetitions</u>: Data for those conditions in which subjects were equated on an equal-repetition-of-sequences criterion were analyzed separately. The results are shown in figures 4 and 5 for the predictable and intermediate task conditions, respectively. It will be noted, in Figure 4, that the overall shape and slopes of the curves for the various sequence lengths are highly similar. Furthermore, the absolute level of performance is highly similar by the fifth block of 36 repetitions.

The data for the intermediate groups (Figure 5) show more variable performance, but no evidence that length of sequence is predictive of tracking performance when equal repetitions is used as the criterion.

Figure 4

PREDICTABLE

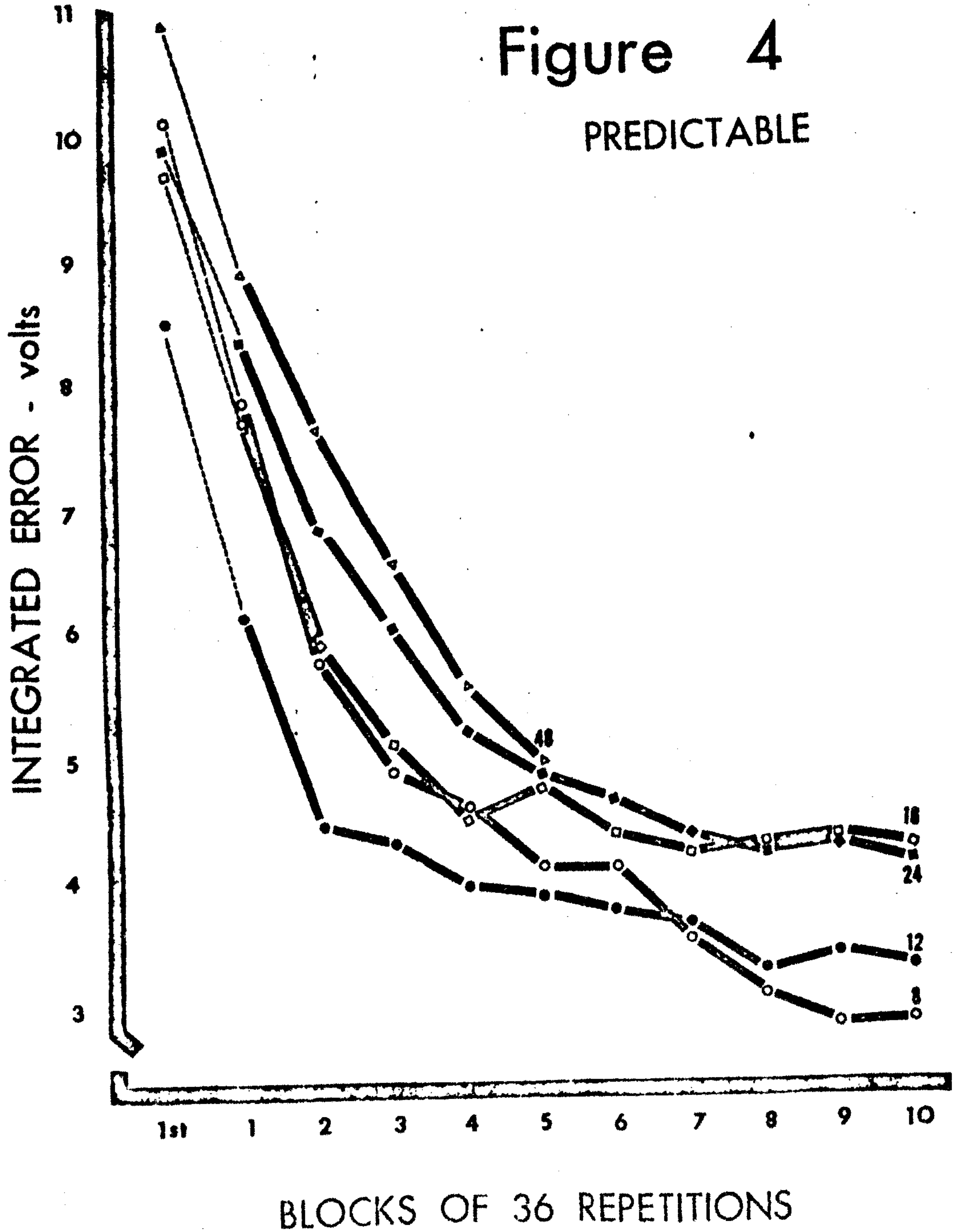
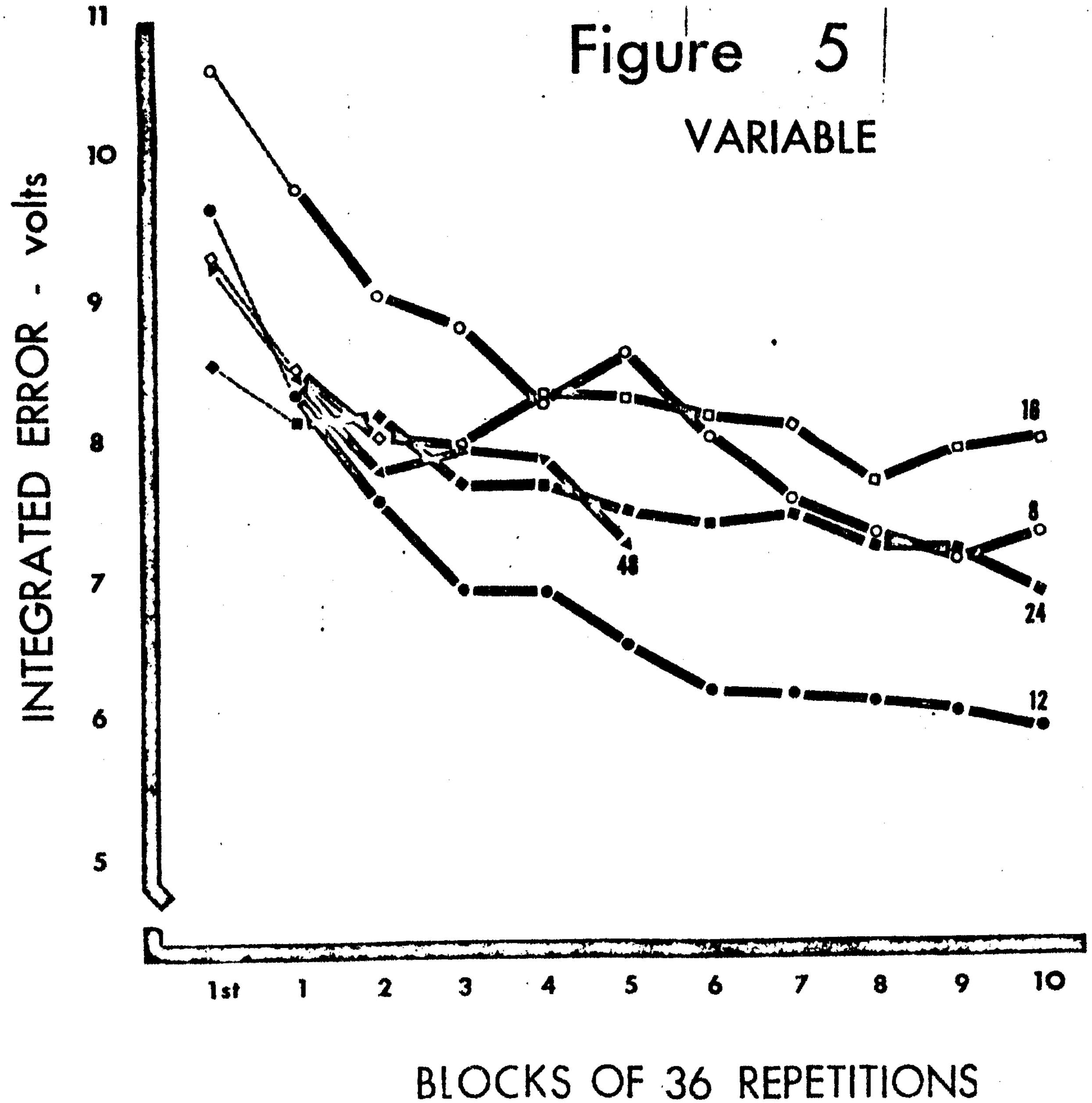


Figure 5



VARIABLE
INTEGRATED ERROR - volts
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BLOCKS OF 36 REPETITIONS

Figure 6
(Equal Repetitions: 180 repetitions)

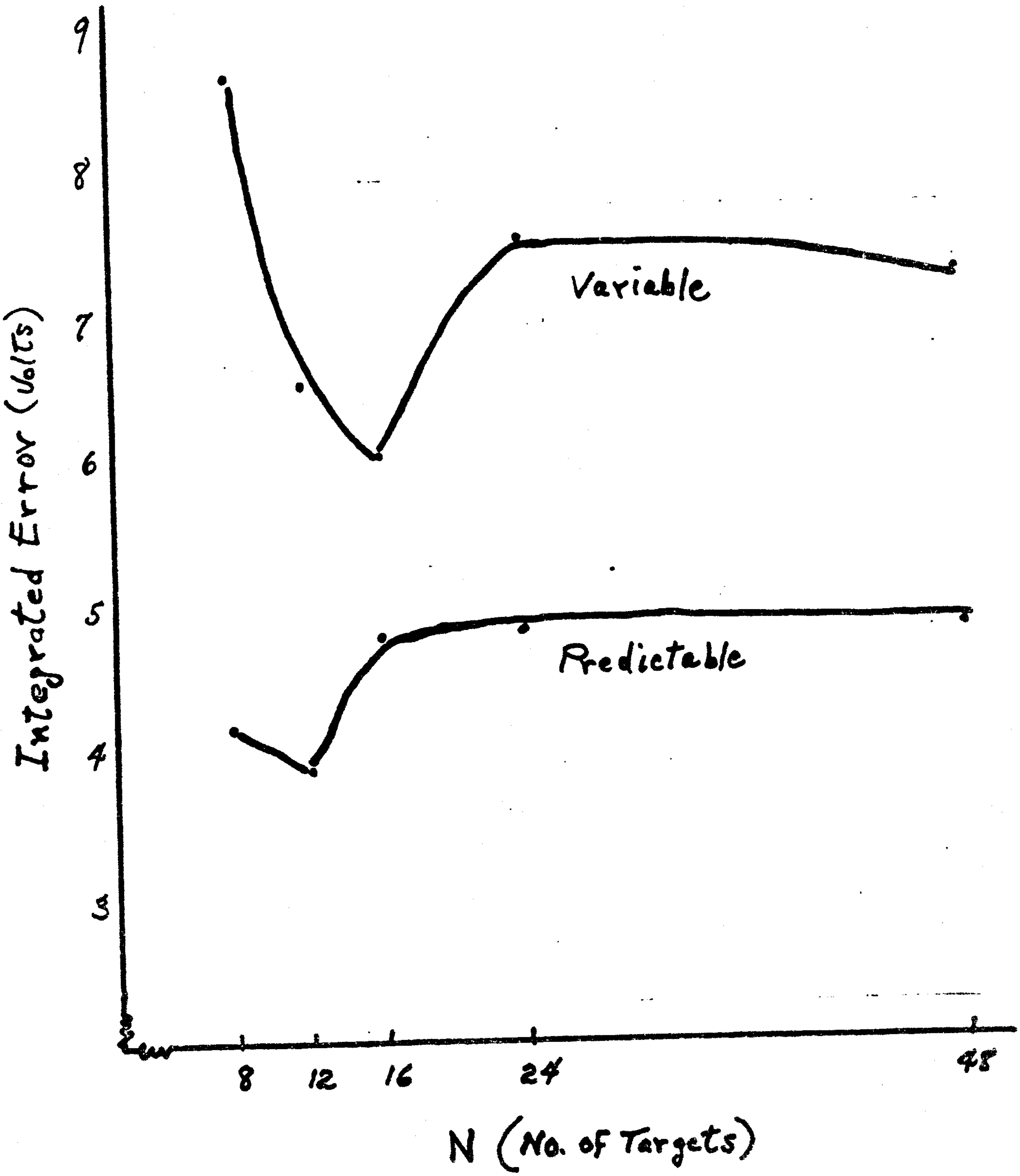

Table 2 summarizes the analyses of variance for all groups after 180 repetitions (2-A) and for all groups, except with N=48, after 360 repetitions (2-B). The results provide statistical confirmation of the difference between fixed and intermediate task conditions (Fs for predictability; $p < .01$) and of the apparent lack of differences among sequence lengths. In addition, the interactions with practice (Blocks of repetitions) are again significant indicating that, while sequence length is not a significant main effect-that is, it does not affect the overall mean level of performance--it does interact with practice blocks to affect the overall shapes of the curves. The nature of these interaction effects is apparent from Figure 4 in that early blocks of repetitions differentially favor the shorter sequence-length tasks more than do later blocks of repetitions.

The group with a sequence 16 targets long, under conditions of intermediate predictability and equal repetitions, appeared to be an abberant group, as is evident from Figure 5. This interpretation was supported when an additional group of six subjects was run to 180 repetitions under identical task conditions. Data for this group are shown in Figure 6, together with functions relating number of targets in the sequence to error scores after 180 repetitions. A second group, run on the fixed sequence of 16 targets, was run as a control group. The results indicated that the new 16-intermediate group corresponded almost perfectly in error scores with the original 16-intermediate equal practice group and the control group corresponded almost exactly to the original group with the same task conditions. Thus, it was con-

Table 2 (A)

Summary of Analysis of variance for all Equal Repetition Conditions (180 repetitions)

Source	df	SS	MS	F
Predictability	1	398.2003	398.2003	44.93**
Sequences	4	73.4989	18.3747	2.07 NS
Pred. X Seq.	4	53.9139	13.4785	1.52
Subj. W/m	50	443.1376	8.8628	
Blocks (36 Reps)	4	176.0466	44.0116	155.74**
Blocks X Pred.	4	50.9249	12.7312	45.05**
Blocks X Seq.	16	9.9941	.6246	2.21**
Blocks X Pred. X Seq.	16	13.1224	.8206	2.90**
Blocks X Subj.	200	56.5178	.2826	
Total	299	1275.3565		

Table 2 (B)

Summary of Analysis of variance for all (except N=48 Condition) Equal repetition conditions (360 repetitions)

Source	df	SS	MS	F
Predictability	1	1042.2655	1042.2655	68.58**
Sequences	3	103.4117	34.4706	2.27 NS
Pred. X Seq.	3	40.9722	13.6574	.90 NS
Subj. W/m	40	607.8732	15.1968	
Blocks (36 Reps.)	9	318.0082	35.3342	95.09**
Blocks X Pred.	9	50.5242	5.6138	15.11**
Blocks X Seq.	27	25.7010	.9519	2.56**
Blocks X Pred. X Seq.	27	19.1626	.7097	1.91**
Blocks X Subj.	360	133.7750	.3716	
Total	379	2341.6936		

cluded that the original group with the 16-target variable sequence under equal repetitions practice was an atypical group and that the second group's data is probably more indicative of performance under these task conditions.

Discussion

While any summary of the study as a whole is premature, certain significant findings from the training phase merit comment. First, with the completely predictable task, and equal practice time, the function relating sequence length to error scores appear to be a positively accelerated curve. However, when subjects are trained to the same number of repetitions of the sequence, regardless of sequence length, then it appears that equal repetitions gives essentially equal criterion performance, at least within the sequence lengths and specific task conditions used in this study. In other words, it appears that a task involving a fixed sequence of discrete input events (with continuous adjustment of response output) which is six times as long as a second task may be expected to take about six times as much <u>practice time</u> as the shorter task, but approximately the same number of <u>repetitions</u> as the shorter task requires.

With equal repetitions and predictable sequences there is a sharp increase in error between sequences of 12 and 16 targets. This is also noticeable, though somewhat less so, with the equal practice conditions. This finding replicates that of an earlier study in our laboratory using sequence of 5, 10, and 15 targets. In that study, the sharp increase occurred between sequences of 10 and 15 targets. Thus it appears that the nature of the information processing aspects of the task may change in the region of 13 or 14 target sequences and that "short" and "long" sequence tasks may be dichotomized at about these values. If this proves to be the case, it may have a number of implications for the training and maintenance of skill on tasks involving sequences of discrete input events. On the intermediately predictable tasks, the function relating sequence length to error is more complex with first decreasing then increasing error with increased sequence length. The sharp increase occurs between 16 and 24 targets, rather than between 12 and 16 targets. However, if one considers only the predictable elements of the sequence, the 16 target sequence contains only 12 fixed targets. Thus, the data from the two tasks can be seen as indicating the <u>same</u> dichotomy between short and long sequences, namely, a break occurring somewhere between 12 and 16 <u>predictable</u> target events. Further interpretation and discussion will no doubt follow from additional analyses of the acquisition data and from the results of the retention data.