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FINAL SCIENTIFIC REPORT

Research into the Adaptively Controlled Instruction of Compensatory Tracking Skills.

by

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The Adaptively Controlled Instruction of a Tracking Skill

1. Introduction

This report describes a number of experiments designed to compare the acquisition of a compensatory tracking skill in adaptively controlled and open loop conditions. Previous work has been carried out in the area of adaptively controlled tracking by Gaines, 1968, 1969, Hudson, 1964, Kelly, 1968, and Pask et al, 1964, 1967. The present investigations cover one dimensional tracking and two dimensional tracking, the latter in a relatively superficial manner. Several one dimensional tasks were employed in order to control the degree of subskill interference and memory load (which Gaines, 1968, 1969, found to be important). These tasks are outlined below:

1.1. One Dimensional Tasks

Task A consisted in straightforward tracking; the subject has on/off acceleration control of a vehicle which is perturbed (acceleration wise) by a quasi-random forcing input. In open loop training conditions, the mean amplitude of the forcing input is constant; in adaptively controlled conditions it is adjusted as a function of the subject's tracking error. For this task, there is no significant difference between the number, T, of trial blocks which are required to reach criterion performance in the adaptive and the open loop conditions of the experiment[ø].

[ø] FOOTNOTE: A trial block is defined in Section 2.4. For the moment, T is a reasonable measure of how long it takes to learn the skill.

Task B consisted in tracking (as in Task A) but in the presence of an alternation rule which alters the sense of the on/off acceleration input. Clearly, in this case, there is interference between the acquisition of an alternation subskill and the basic tracking subskill. Two versions of Task B were used; in B_1 the subject is given information (through signal lamps) about the prevailing sense of the on/off input; in B_2 this information is not provided and a load is thus imposed upon the student's memory. In both cases a significantly lower value of T is obtained in the adaptive condition and it may be concluded that the adaptive system aids learning in either case. If anything, the advantage of the adaptive system is greater for task B_2 than for task B_1. Finally, $T(B_2) > T(B_1) > T(A)$ either for adaptive or open loop training.

Task C resembles Task B except that the simple alternation rule is replaced by a complex rule. Once again there are two subconditions (with and without knowledge of state information) in each case the degree of interference is greater than in Task B and in Task C_2 the memory loading imposed on the subject is very much greater than it is in Task B_2. For both tasks, the adaptive T value is less than the open loop T value and $T(C_2) > T(C_1) > T(B_2) > T(B_1) > T(A)$ for either adaptive or open loop training. The trouble is that all C_2 (no lights) subjects failed to reach a criterion level of performance during a reasonable training interval. Consequently, the vehicle characteristics were modified to yield an "easy" vehicle (Task C^*_1 and Task C^*_2). With an "easy" vehicle the rate of learning is unequivocally increased by an adaptive routine so that $T(C^*_2)$ open loop > (TC^*_2) adaptive.

1.2. <u>The Two Dimensional Task</u>

Two dimensional tracking has only been studied in unperturbed conditions (no sense changing rule in the task). Adaptive two dimensional T values are less than open loop two dimensional T values, but the difference is only marginally significant. By hypothesis, the difference that does exist is due to residual interference between tracking along the two co-ordinates of the task. As expected, T (Two Dimensional) > T(One Dimensional) either for adaptive or open loop training.

2. Description of the Experimental Setup

The experimental equipment finally used is very similar to that described in the status reports. It differs insofar as certain of the timing devices had to be discarded and replaced by less ingenious but more reliable circuitry. At the same time the oscilloscope display was replaced by a rapid response meter display (single pointer for one dimensional tracking and crossover pointers for two dimensional tracking). Subjects who experienced both displays (not members of the experimental groups) preferred the meter display and it was more readily instrumented.

2.1. Overall System

Fig.1 is a block schematic of the entire system. In open loop conditions the mean amplitude of the forcing input is set at its maximum value. In the adaptive conditions the mean amplitude is controlled by the adaptive variable, η. The interfering rule operates as a parameter of the control input (Button Pressing) and its influence is nullified by turning a switch.

2.2. Rule Operation

The rule generator is shown in Fig.2 and three rules, based upon a cycle of six input (Button Pressing) operations, are available. If R is the output of the rule generator and if the relation is written by considering successive button pressing operations (either button) the rules are those indicated below.

			1st	2nd	3rd	4th	5th	6th	1st...	
Simple Altenation	Rule α	R =	1	0	1	0	1	0	1	0
Complex	Rule β	R =	1	1	1	0	0	0	1	1
Complex	Rule γ	R =	1	0	1	1	0	0	1	0

Cycle Length

R, as later transforms the sense of the button pressing responses.

At the end of each cycle of six operations, the subject is provided with an auditory signal to synchronise his activity (so that he does not get completely lost through miscounting or the like). The auditory signal is delivered whether or not knowledge of state information is provided. Finally, knowledge of state information can be given or withheld by turning a switch (shown in Fig.2).

2.3. Stimulus Production

The 8-channel tape reader in Fig.1 is fed with a paper tape on which six channels of each code are used in the present experiments. Channels (holes) 1 and 2 are used to determine the sense (+ or -) of the 1st acceleration disturbance; no holes (i.e. 0,0) indicating no disturbance. Channel 3 determines the duration of the disturbance (0 = 250 msecs., 1 = 350 msecs.) Channels 4 and 5 (unused in the one dimensional case) determine the sense of the 2nd acceleration disturbance and channel 6 its duration (0 = 200 msecs. and 1 = 350 msecs., as before).

2.4. Timing Arrangements

The quasi-random forcing input (Fig.1) is derived from a tape decoder (Fig.3), which is fed from a tape reader. This tape reader is driven by the master oscillator of the system (some code positions on the tape may, of course, be blank; indicating no disturbance). The master oscillator also feeds a 24 way selector (Fig.4) which counts over a "block" of 16 possible (forcing input) disturbances or "trials". At the end of the block (position 17) timing control is transferred to a fast oscillator for 8 positions; these 8 positions in the timing sequence are used for recording purposes (Fig.4).

During the recording routine (1) the subject receives a "rest" signal and (2) (1 sec . before the end of the routine, i.e. 1 sec. before the start of the next block) a "ready" signal. (3) The adaptive system operates. (4) The error integrator is zeroed. (5) The vehicle position is zeroed. At position 16 + 8 = 24, timing control is transferred to the master oscillator unless a sequence of 10 blocks have been completed. In this case, the process is halted and is restarted by the experimenter.

The entire sequence of events is summarised in Fig.5 and for the present experiments the time parameters were chosen as :

Time per impulse from master oscillator	= 3 secs.
Time per sequence of 16 impulses	= 48 secs.
Time per 8 recording impulses	= 2 secs.
Time per complete block	= 60 secs.
Time per sequence of blocks	=500 secs.

2.5. Vehicle Simulator and Error Integrator

The vehicle simulator and error integrator are made up on a standard analogue computer using the block circuitry of Fig.6 for the one dimensional system ("normal vehicle" and "easy vehicle" parameters as indicated) or of Fig.7 for the two dimensional system.

2.6. Adaptive Mechanism

The error integrator output is sampled towards the end of each sequence during the recording routine and before the vehicle integrators and the error integrators are zeroed; specifically, the sampling takes place at selection position 17. The sample, ρ, is presented to a comparator with a pair of thresholds, ρ_1 and ρ_2 and the comparator output is, for ρ_1 = 15v., ρ_2 = 20v. (Full ρ = 50v.):

$$\Delta\eta = +1 \text{ if } \rho_1 > \rho$$
$$\Delta\eta = 0 \text{ if } \rho_2 > \rho > \rho_1$$
$$\Delta\eta = -1 \text{ if } \rho > \rho_2$$

It will be noted that ρ in Fig.6 is a function of one variable and in Fig.7 it is a function of two variables.

At selector position 18 the value of $\Delta\eta$ determines the incrementation or decrementation of a 16 way η counter so that at the n + 1th sequence:

$$\eta(n+1) = \eta(n) + \Delta\eta(n)$$

unless it happens that $\eta = 0$ (when no decrease can occur) or $\eta = 15$ (when no increase can occur).

If the adaptive system is engaged the potential at point p in Fig.6 or Fig.7 assumes the value of η x U.

2.7. Display and R sponse Arrangements

Fig.8 shows the display and response board for the one dimensional task; for the two dimensional task the single pointer meter of Fig. 8b is replaced by a double pointer crossover type meter and the single pair of buttons (accelerate positive or negative)) is replaced by two pairs (one pair for the left hand and one pair for the right hand). Fig. 8c

Consider, first, the one dimensional system. The button output passes to the delay circuit of Fig.9, which is so constrained that (1) a single button depression produces a single 200 m.secs. output impulse (contact closure, gating a potential, V, to the acceleration control input). (2) Depression of both buttons leads to an alternation of 200 m.secs. impulses spaced 300 m.secs. apart (pressing both buttons at once is forbidden by the instructions but this behaviour does occasionally occur by accident or in a fit of frustration). The button relays of Fig.9 also feed the rule circuitry of Fig.2 and the binary output of this circuit, R = 1 or 0, determines the sense of the acceleration control input. Thus the input in question is:

200 m.secs.	+ V	if R = 1	and right button
200 m.secs.	- V	if R = 0	and right button
200 m.secs.	+ V	if R = 1	and left button
200 m.secs.	- V	if R = 0	and left button
	0		if no button is pressed.

For Task A only the value of R is set constant at R = 1 so that the sense of the acceleration control input is determined uniquely by the button that is pressed.

With respect to vehicle controllability, we note that the forcing input impulses may have durations of either 200 m.secs. or 350 m.secs. (as in Fig. 1 and Fig.3) and that these may be delivered in either a positive or a negative sense to point p (Fig.6). The maximum amplitude of the forcing input is $\pm$ 15 x U and the system is operated with $|15 \times U| = |V|$.

Still restricting our attention to the one dimensional task, the subject receives certain ancillary information, over and above the pointer position. This information is summarised below with respect to the tasks outlined in Section 1.1.
(using "1" to indicate "present" and "0" to signify "absent")

	Visual Ready Signal	Visual Rest Signal	Auditory signal from start of cycle counter	Knowledge of state lamps
Task A	1	1	0	0
Task B_1	1	1	1	1
Task B_2	1	1	1	0
Task C_1	1	1	1	1
Task C_2	1	1	1	0

2.8. <u>Arrangements for Double Tracking Skill</u>

For the two dimensional task the response circuitry is duplicated but no outputs are delivered to the rule unit (which is now functionless with R = 1 perpetually). Consequently, the sense of the input on either dimension is solely determined by the button pressed (just as it is, for the one dimensional case, in Task A). For two dimensional tracking, the subject presses a pair of buttons with the 1st and 2nd fingers indicating "up" and "down" accelerations on the crossover meter; the right hand button pair refers to the right hand crossover pointer and the left hand pair to the left hand pointer. Rest and ready signals are delivered as in performing the one dimensional task but the remaining auxiliary information is irrelevant and this part of the display is unused.

3. Experimental Details

3.1. Subjects.

The 64 subjects were males and females obtained from a population of students and coffee bar inhabitants. Their ages ranged between 18 and 27 years. They were assigned to conditions on an arbitrary basis, without discrimination. 8 subjects failed to complete the experiment and their results have been discarded. Subjects were paid 10s.0d. per hour.

3.2. Instructions

A subject is introduced to the equipment and the purpose of the experiment. He is allowed to manipulate the system and is told that training will extend over several days but not more than a couple of weeks. If he agrees to participate, he is accepted and assigned to a condition. For Task A (one dimensional) and for all two dimensional runs, the instructions are straightforward:

> "Try to keep the pointer (or pointers) in the centre region (the crossover or the centre area) by pressing the acceleration buttons. You are controlling an idealised simulation of a space vehicle".

For tasks B_1, B_2, C_1 and C_2 (or C^*_2) the instructions are more elaborate. In addition to the material given above,

> "Your acceleration control has a sense which depends upon your previous actions (demonstrate by switching on the knowledge of state display lamps and showing how the state depends on the button pressing operations). This dependence is given by a rule (exhibit rule and make certain the subject knows it). You will find the task

difficult but do not get disheartened".

For all conditions, the subject is asked to consider how he learns to perform the task and so far as possible to discuss his strategies.

3.3. Procedure

Training is carried out in daily sessions, which are scheduled as shown in Fig.10, following the technique adopted in previously reported experiments (Final Scientific Report, Contract No. AF 61(052)-964). A sequence consists in 10 trial blocks (Section 2.4.). These are followed by 2 trial blocks designated "test blocks" during which the system is run in the open loop condition and before which the subject is informed that his proficiency is to be tested. If the experimental condition is open loop in any case, the test blocks only differ from the training blocks insofar as the test instruction is delivered before they begin.

Call the sequence of 10 training blocks and the 2 test blocks an augmented sequence. The session consists in 5 augmented sequences between which the subject is allowed about 5 mins. rest, to avoid fatigue. The sequence proper (training sequence) occupies 500 secs. and the 2 test blocks occupy 100 secs. between them so that an augmented sequence is 600 secs. or 10 mins. in length. Hence a session, including the rest periods, lasts about 70 mins. At the end of each session, the subject is questioned about the strategies he adopted.

Training continues, day by day, until either the subject reaches a criterion of $\rho_1 > \rho$ for 2 consecutive blocks at maximum difficulty (open loop) or $T > 700$ (14 days or 2 weeks' training). The latter criterion was only used for O_2 subjects who showed no signs of learning.

3.4. Data Recorded

Data is recorded from electromechanical summary counters and from a meter reading the value of ρ at the end of each trial block. This consists in:

1. Number of impulses from 1st button (Right hand or pair)
2. Number of impulses from 2nd button (Right hand or pair)
3. Number of impulses from 1st button (Left hand, two dimensional only)
4. Number of impulses from 2nd button (Left hand, two dimensional only)
5. Number of blocks of trials
6. Value of variable η (adaptive condition only)
7. Value of variable ρ

For a few experiments, inkwriter records were obtained of

8. Sequence of one dimensional button depressions

In an adaptively controlled experiment, the data from the training sequence (Fig.10) is recorded as training data and that from the test sequence is recorded as:

Test data (η set at $\eta_{max} = 15$ for these trial blocks)

4. Experimental Design.

The design, already outlined in Section 1, is shown in Table 1, together with the number of subjects assigned to each condition in the experiment.

5. Results.

Typical learning curves for the principal conditions are shown in Fig.11 (condition A, non adaptive), Fig.12 (condition A adaptive), Fig.13 (condition B_1 non adaptive), Fig.14 (condition B_1 adaptive), Fig.15 (condition B_2 non adaptive). Fig.16 (condition B_2 adaptive), Fig.17 (condition C_1 non adaptive), Fig.18 (condition C_1 adaptive), Fig.19 (condition C^*_2 non adaptive easy vehicle) and Fig.20 (condition C^*_2 adaptive easy vehicle). The learning curves for the two dimensional task are shown in Fig.21 (two dimensional non adaptive) and in Fig.22 (two dimensional adaptive).

5.1 Gross Data.

Values of T (Trial Blocks to Criterial Proficiency) appear in Table 2 and of the mean incidence of button depressions in Table 3. The latter figures are of peripheral interest but indicate (1) Possible differences in strategy and (2) A rough guide to the fuel that would be used in navigating a real vehicle. It will be observed that subjects do not differ a great deal with respect to this variable.

5.2 Analysis of Data.

Analyses of the T value data are shown in Table 4 and Table 5 together with the significances attached to relevant differences.

5.3 Discussion.

As in Section 1, (and as expected), Task C is more difficult than Task B and Task B is more difficult than Task A; moreover, two dimensional tracking is more difficult than one dimensional tracking. Within the one dimensional conditions, the task without the knowledge of state information is more difficult than the task with it; thus, Task C_2 is much more difficult than task C_1

and T sk B_2 is more difficult than Task B_1, and (for the easy vehicle) Task C^*_2 is more difficult than Task C^*_1.

Comparing the adaptive and the non adaptive conditions, it is clear that the adaptive method enhances learning in all those one dimensional tasks (B, C, C*) that entail interference betwen subskills. This result is significant at the 0.1 % level. Individual results (T(B) Non Adaptive > T(B) Adaptive and T(C*) Non Adaptive > T(C*) Adaptive) are significant at the 2 % level. Statistical treatment of the C condition is hampered by the fact that none of the C_2 subjects achieved the criterial level of performance in the time allowed. However, making the (counter hypothetical) assumption that they would have reached criterion after quitting the task[ø], there is also a significant difference for this group.

It also happens that, on average, the adaptive technique is more effective in the absence of knowledge of state information. This result is predictable, since we should expect the partially cooperative influence of adaptation to be greater when the subject is working under a higher intermediate memory load than it would be otherwise. However, on closer scrutiny, the B condition subjects do not show a marked difference (though $T(B_2)$ Non Adaptive - $T(B_2)$ Adaptive) is greater than $T(B_1)$ Non Adaptive - $T(B_1)$ Adaptive, as predicted).

Finally, the adaptive system is of some benefit in two dimensional tracking (probably because of initial interference between the dimension specific subskills).

[ø]FOOTNOTE: We do not maintain that this task is <u>unlearnable</u> and we fully appreciate that our time limit, imposed for administration reasons, is arbitrary. The fact is, however, that only one of these subjects showed any sign of learning during the last few blocks of trials.

In contrast, for Condition A (no interference) the adaptively controlled group do not learn signficantly faster than the non adaptive group. This confirms our findings in an earlier, more extensive, study of simple compensatory tracking. (Contract No. AF 61 (052)-964).

5.4. Strategic Aspects of the Skill

5.4.1. Introductory Comments

The interviews and selected pen-recording protocols give a quite clear picture of the way subjects, in the various conditions, conceived and organised the skill. The skill is such that the proficient operator must have developed strategies and tactics for the control of his vehicle, i.e. he must have built up integrated sequences of responses and corresponding higher level controlling processes. The necessity in the matter is due to the temporal constraints imposed by the task; correction of disturbances and correction of corrections of disturbances have to be integrated. The vehicle, in its maximum difficulty (open loop) mode, goes out of control if the subject waits for feedback from his actions before making further responses. This is especially true of conditions B and C and C*, where the further task of remembering the sense of the buttons is introduced. A the overall results show, subjects trained in the open loop mode for conditions B and C*, need a long time to acquire the skill and for condition C find it virtually impossible.

5.4.2. Strategies Operating in Condition A

In condition A, two strategies for controlling the vehicle are reported and recorded (these are very similar to the strategies described by Pew (1966), though his task differs from the present one in several ways - notably that the subject has continually to correct his corrections, rather than correct for external disturbances).

The two strategies are found for both open and closed loop conditions. The only difference is seen by inspection; on the whole, the open loop group show the beginnings of a particular strategy earlier than the closed loop groups but take more time to consolidate it as an integrated piece of behaviour. This is probably due to the fact that the form of the strategies required is not obvious to a naive subject, when operating at the lowest difficulty levels of the closed loop condition, and that, when they are obvious (usually in the middle ranges of the difficulty levels), the vehicle dynamics are such that the strategies can be sustained for longer periods, before the vehicle goes out of control, than in the open loop condition.

The two strategies are as follows:

1. "Oscillation with feedback correction"

In this form, the subject is seen to correct for a disturbance, to quickly correct for overshoot of the first correction, to correct for overshoot of the second correction and so on. Eventually, he reaches a state where his button pressing is causing the needle to oscillate around the centre point.

Given a large disturbance, the oscillation cycle is broken and a separate set of responses is used to return the needle to the centre region of the scale, where it is captured and oscillation is continued, as in the following typical pattern of actions.

	Oscillation	Correction	Oscillation
Sense:	LR LR LR LR	RR RL	LR LR LR
Buttons:	AB AB AB AB	BB BA	AB AB AB

↑ Disturbance to left.

The main difficulty for the subject is judging the size of the disturbance and the corresponding frequency of correcting pulses. An overestimation may send the vehicle out of control.

2. "Oscillation with modulated correction"

This strategy is similar to the first in so far as an oscillating control is exerted to maintain the needle in its central position, though it is less overtly a manouvre designed to maintain a slight motion. The aim is more clearly that of centring the needle and button presses subside when this goal is reached. Similarly, correction of disturbances tends to be achieved by the extension of one swing of the oscillation, i.e. by the interpolation of extra thrusts on one side, until the needle is captured, at which point a modulated oscillation is used to guide it back to the centre, as in the following typical sequence.

	Oscillation	Correction	Modulated Oscillation
Sense:	LR LR LR	RRL RRL	RL RR LR LR
Buttons:	AB AB AB	BBA BBA	BA BB AB AB

↑ Disturbance to the left.

The main difficulty for the subject here is that the centring operation of the correction procedure, when applied to large disturbances, can take time, which means that error is being accumulated and that a second large disturbance can wreak havoc.

Both strategies are successful in that the proficient operator can apply them accurately and smoothly enough to avoid the difficulties mentioned.

5.4.3. Strategies Operating in condition B

The strategic operations found in condition B are analogous to those for condition A, but are complicated by the reversal in the sense of the buttons and a higher order organisation is required. In general, the two forms of oscillation are used but have a flexible organisation which can be applied by either button operating alone. Higher level organisation is needed to integrate the oscillation modes with the changing sense of the buttons. This is necessitated as the components of the skill interfere; subjects report difficulty in applying the oscillation strategies whilst remembering the sense of the buttons. Even where the present state of the buttons is indicated by lights, subjects do not have time to attend to this information continually, as well as control the dynamics of the vehicle. Typically, naive subjects attempt to control the vehicle.by attending to the light information continually; finding this unsuccessful, they then develop patterns of response pressing guided by occasional, confirmatory reference to the state lamps, especially when in difficulties. At this stage, the skill is conceived as the integration and maintenance of whole patterned groups of responses.

The form of the organisation is as follows: oscillation is achieved by continual pressing of one button; correction of a disturbance requires an extra pulse in a particular direction and is carried out by pressing the other button; oscillation is then continued on that button. In the most difficult conditions, more than one extra pulse may be required; thus, the subject has to switch from button to button and enter the oscillation mode on the final button in the sequence. as, for example, in the following typical sequence:

	Oscillation		Single Pulse Correction	Oscillation		Double Pulse Correction	Oscillation
Sense:	LR LR LR LR		R	LR LR L		LL	RL RL
Buttons:	AA AA AA AA	↑	B	BB BB B	↑	AB	BB BB
		Disturbance to the left.			Disturbance to the right.		

At maximum difficulty (open loop), the need for correcting pulses is more frequent and double or treble pulses may be required, thus, the periods of oscillation on a single button become brief. The proficient subject by now has a well-integrated, smooth control of his vehicle and reports that he is no longer consciously aware of the state of the buttons.

5.4.4. <u>Strategies Operating in Conditions C and C*</u>

In conditions C and C*, a similar need for higher level integration of response patterns is found (though the nature of the patterns acquired is difficult to discern for condition C as the majority of subjects failed to control the vehicle in its maximum difficulty conditions for more than part of a single trial).

Oscillation, again, is the basic mode of the strategies. This is not so easily achieved as in conditions A and B; in condition A, the two buttons are pressed alternately to achieve oscillation; in B, one button only is used. In condition C, two basic oscillation patterns are found, as follows:

(1)

	Rule Cycle
Sense:	LR LR LR LR
Buttons:	AB AA BA AB

(2)

	Rule Cycle
Sense:	LR LR LR LR
	BA BB AB BA

Their structures are isomorphic and seen as consisting of sets of three presses (e.g. 'xyz' or 'xxy' or 'yxx') by the subject.

Correction of a disturbance, by a single extra pulse to right or left, switches control tactic from, say, pattern 1 to pattern 2. A correction requiring two extra pulses will return to previous control tactic; a three pulse correction switches patterns and so on, for example:

Cycle Start ↓	Oscillation	Single Pulse Correction	Oscillation	Double Pulse Correction	Oscillation
Sense:	LR LR LR	R	LR LR L	LL	RL RL
Buttons:	AB AA BA	B	AB BA B	AA	BB AB
	Pattern 1	↑ Disturbance to left.	Pattern 2	↑ Disturbance to right.	Pattern 2

Thus, in this condition, a quite complex control strategy is required, whose structure is not immediately obvious. The adaptive conditions are most efficient, presumably because, without excessive disturbances, the subject can construct and maintain the basic oscillation patterns easily and has opportunity to integrate them without frequently losing control of his vehicle.

5.5. Mean Number of Button Presses and Strategies

Inspection of the records of the number of button presses made by subjects in each of the conditions, show no significant differences. In fact, the records are remarkably similar, especially over the final stages of training, which is consistent with the conclusions drawn above, about the strategies operating: the general form of all the strategies is very similar (an oscillatory mode integrated with specific correction operations) and should give rise to similar amounts of button pressing.

Two exceptions are seen, both of which are to be expected; (1) C* subjects, with "easy vehicle" dynamics tend to make fewer presses, and, (2) all closed loop conditions show an overall increase in the mean number of presses per trial as training proceeds. Both trends are presumably due to the fact that fewer rapid corrections are required when the disturbances are not at the maximum.

TABLE 1.

		Adaptive	Non-Adaptive
Normal Mode (A)		4	4
Reversal rule	Lights (B_1)	4	4
	No Lights (B_2)	4	4
Complex rule (difficult vehicle.)	Lights (C_1)	4	4
	No Lights (C_2)	4	4
Complex rule (easy vehicle)	Lights (C^*_1)	4	4
	No Lights (C^*_2)	4	4
Two dimensional task.		4	4

Table 1. Layout of Design showing number of subjects per condition.

TABLE 2.

Condition	A	B_1	B_2	C_1	C_2	C^*_1	C^*_2	Two Dimensional Task
	One Dimensional Task							
Non-Adaptive	95	260	297	430	f	388	575	200
	90	240	275	402	f	362	542	240
	86	230	256	372	f	331	534	247
	78	225	259	347	f	330	470	306
Adaptive	96	164	252	320	f	257	406	150
	90	161	222	292	f	302	378	195
	87	150	208	285	f	218	332	220
	71	137	200	250	f	231	320	234

Table 2. Values of T (trials to criterion) for each subject.
(f = failed to attain criterion after 700 trials).

TABLE 3.

Non-adaptive.	22.1	24.1	23.8	26.1	23.1	21.0	23.2
	24.6	23.2	23.6	23.2	20.8	20.0	19.6
	25.2	24.6	25.4	22.8	24.6	21.9	20.3
	23.2	23.8	22.1	24.1	25.1	19.8	20.5
Adaptive.	19.2	23.5	22.1	24.5	25.2	19.2	20.5
	30.1	22.8	20.3	21.9	20.0	17.6	18.4
	22.2	21.3	19.6	21.8	21.2	20.8	19.6
	22.8	22.4	24.2	23.1	20.9	20.0	21.2
	A	B_1	B_2	C_1	C_2	C^*_1	C^*_2

Table 3. Mean number of button presses per trial for each subject.

TABLE 4.

Mean T (C_2) > mean $T(C_1)$ > mean $T(B_2)$ > mean $T(B_1)$ > mean T(A)

Jonckheere's (1954) Trend Test shows trend significant at 0.1% level ($p < 0.001$)

Mean $R(B_1, B_2, C_1, C^*_1, C^*_2)$ adaptive > mean $R(B_1, B_2, C_1, C^*_1, C^*_2)$ non-adaptive.

Mann Whitney u-test shows difference is significant at 0.1% level ($p < 0.001$)

(where value of R for ith subject of jth group = $\frac{T_i \times 100}{\text{mean } T_j}$ % and

T = trials to criterion.

Table 4. Summary of overall differences between conditions.

TABLE 5.

All comparisons by Mann-Whitney u-test.

Condition A:	Mean T(adaptive versus Mean T(non-adaptive) No significant difference.
Condition B_1:	Mean T(adaptive $<$ mean T(non-adaptive) Significant at 2% level ($p < 0.02$)
Condition B_2:	Mean T(adaptive) $<$ mean T(non-adaptive) Significant at 2% level ($p < 0.02$)
Condition C_1:	Mean T(adaptive $<$ mean T(non-adaptive) Significant at 2% level ($p < 0.02$)
Condition C^*_1:	Mean T(adaptive $<$ mean T(non-adaptive) Significant at 2% level ($p < 0.002$)
Condition C^*_2:	Mean T(adaptive) $<$ mean T(non-adaptive) Significant at 2% level ($p < 0.02$)
Two dimensional task:	Mean T(Adaptive mean T(non-adaptive) Significant at 5% level (p 0.05)

Table 5. Summary of detailed differences between conditions.

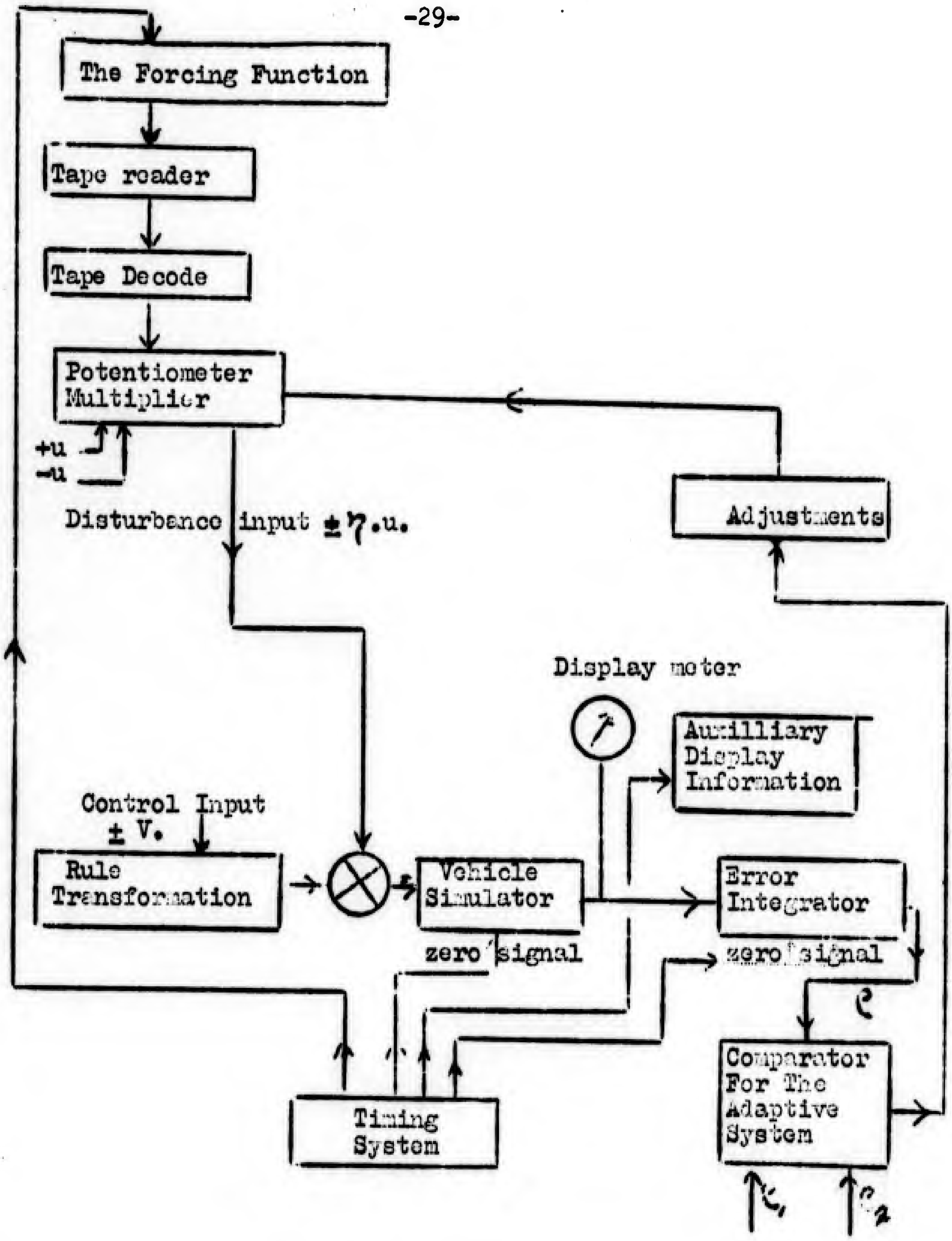


Figure 1. Overall picture of the system

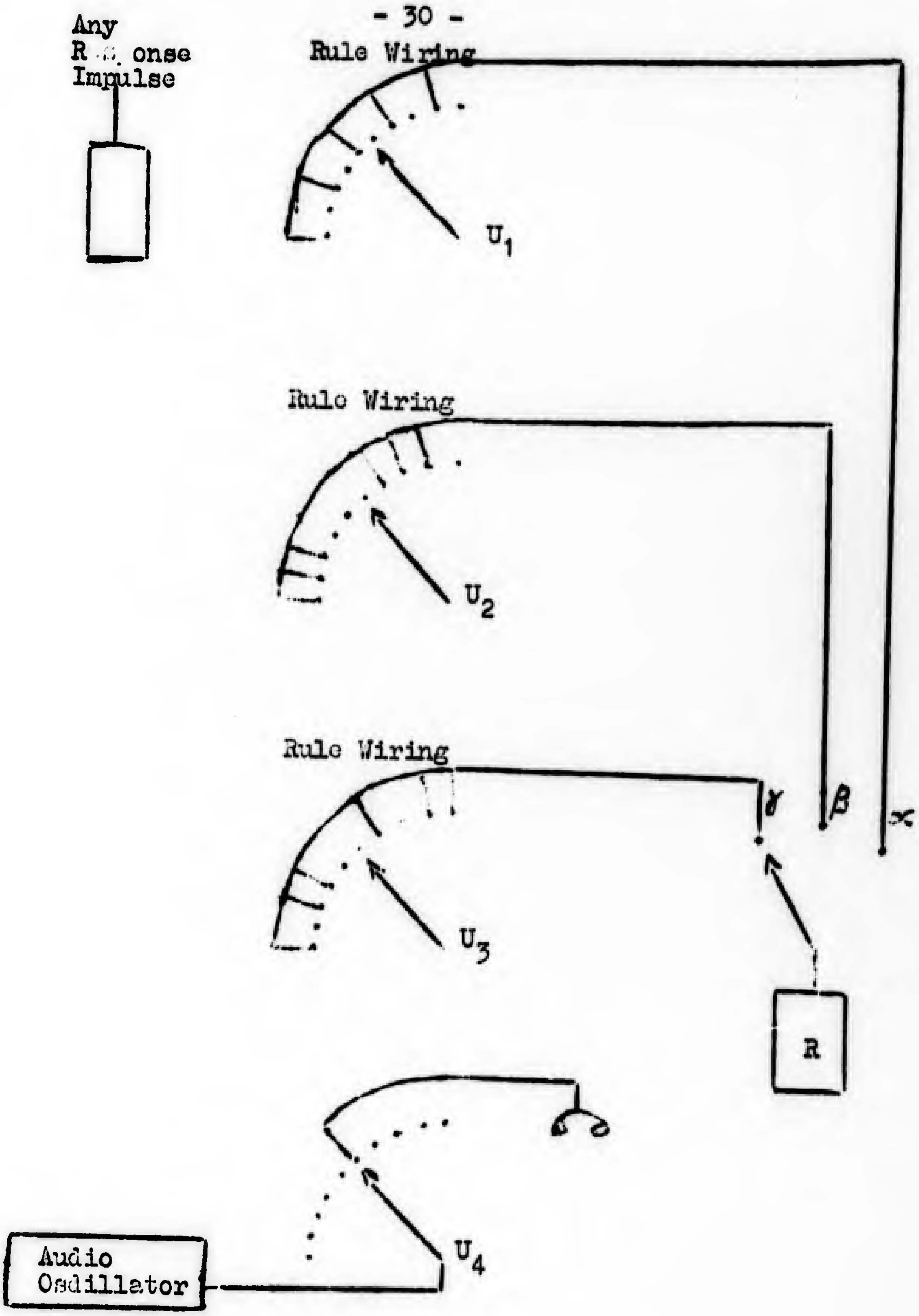


Figure 2. Rule Generator.

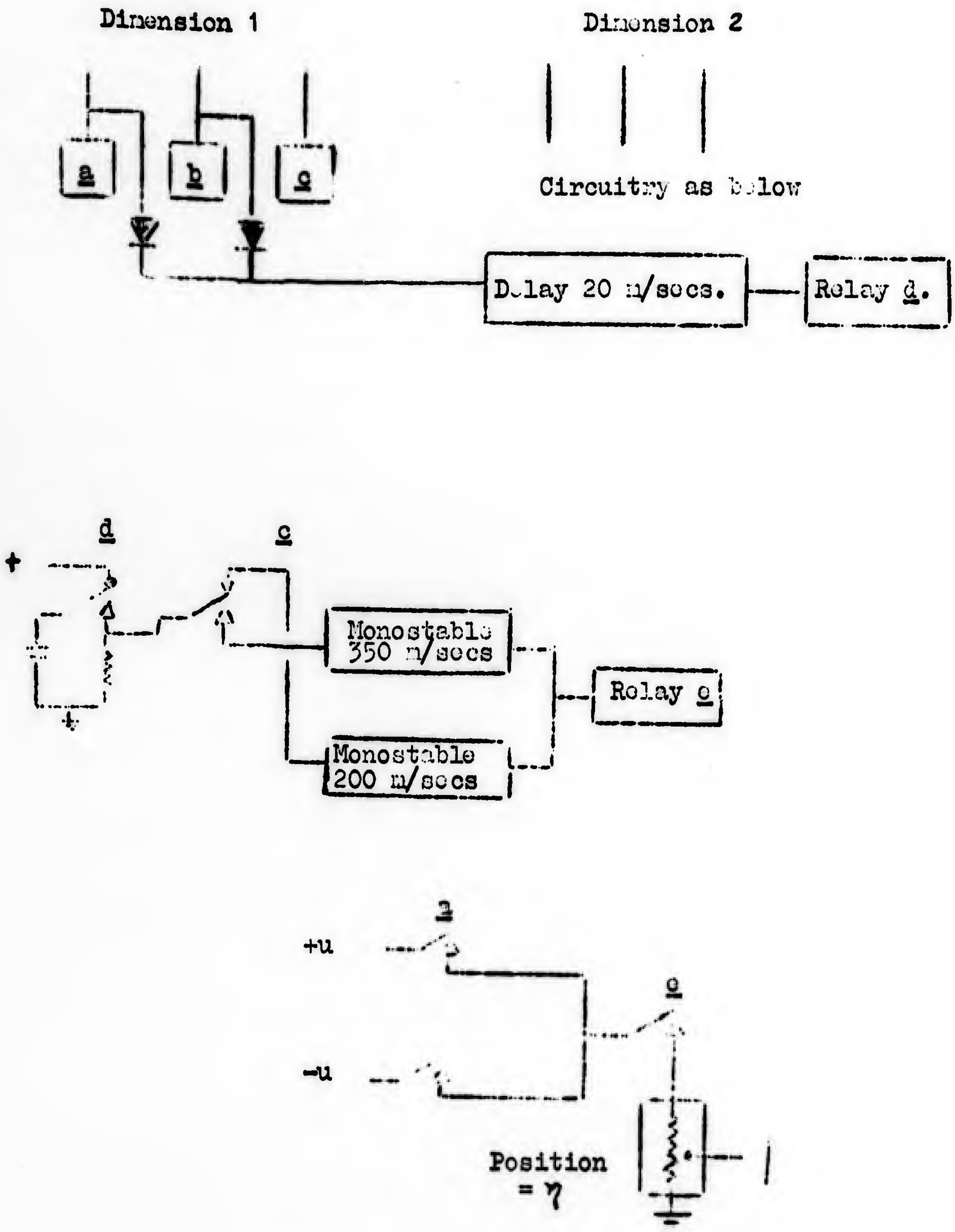


Figure 3. Stimulus Production

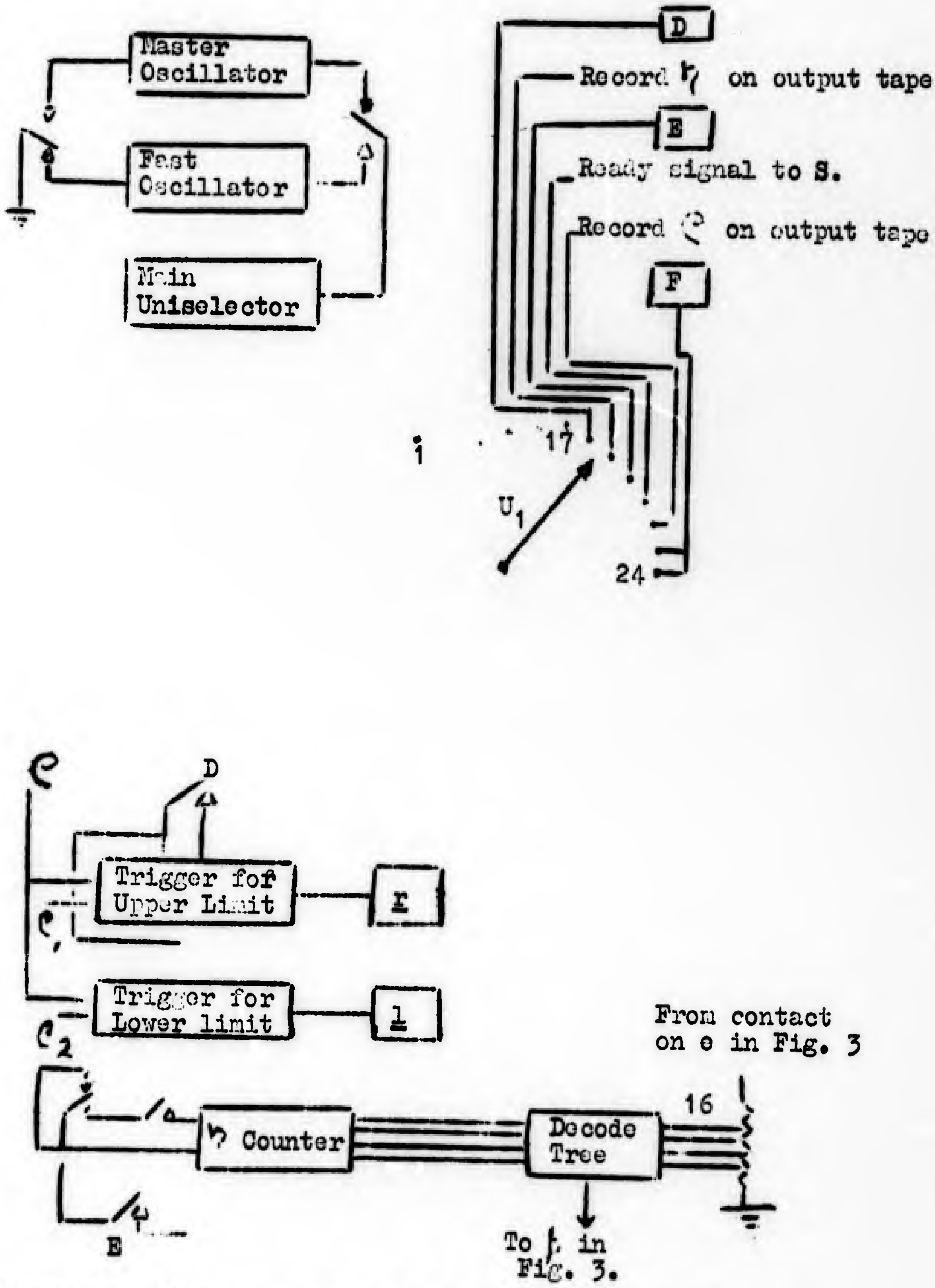


Figure 4. Timing arrangements and adaptive system.

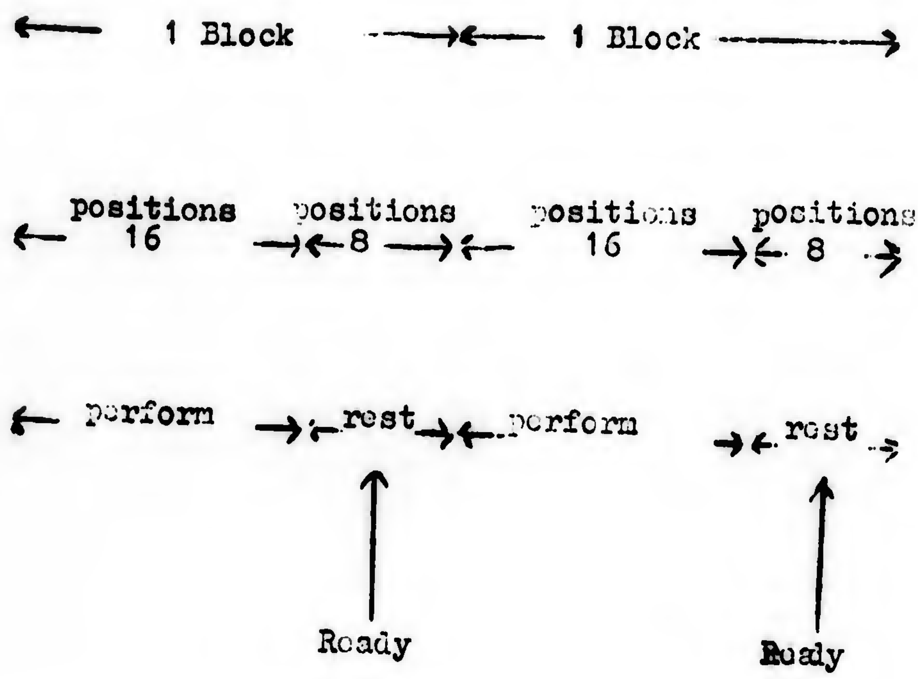


Figure 5. The organisation of trial blocks.

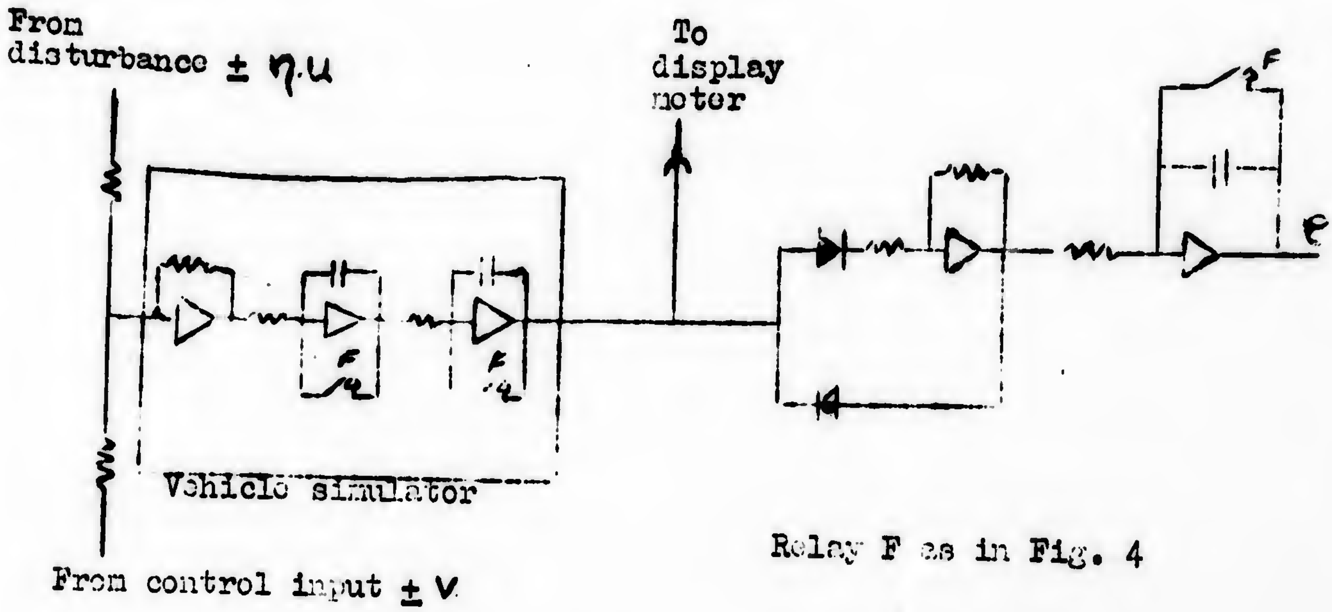


Figure 6. Detail of one dimensional system.

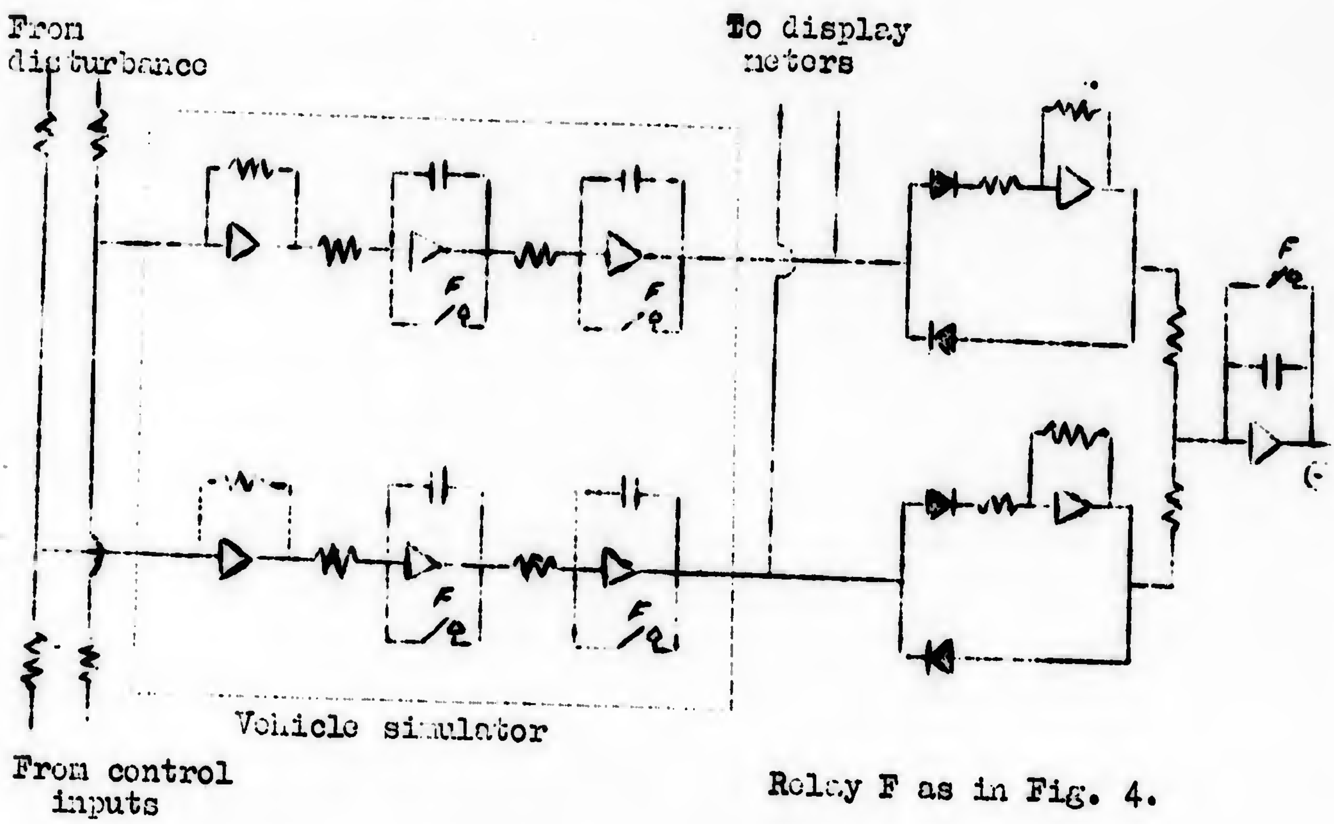
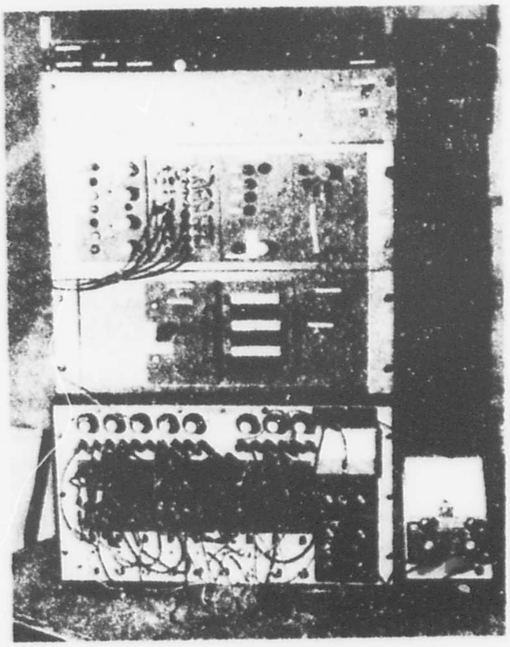
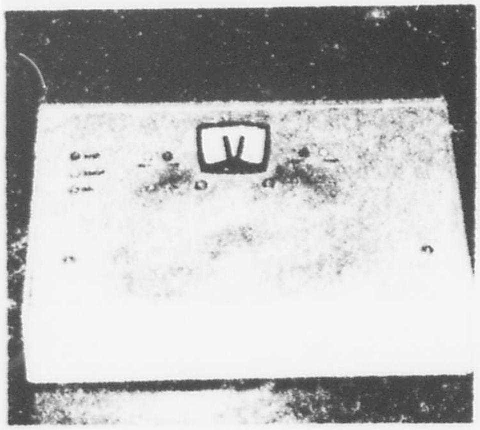


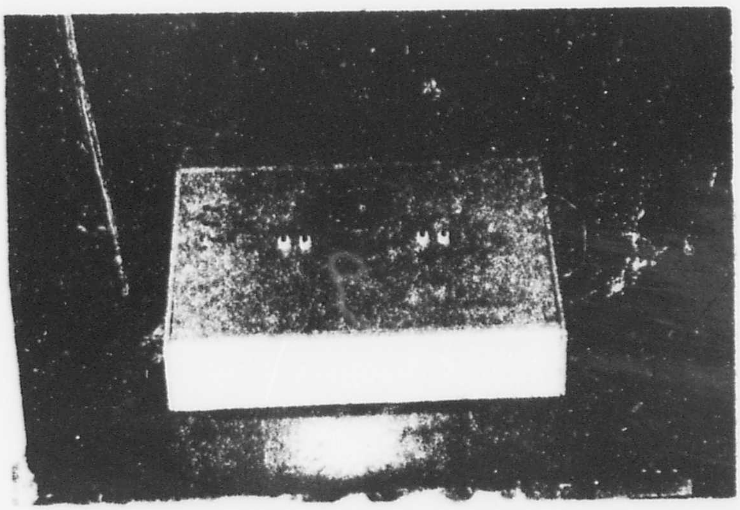
Figure 7. Detail of two dimensional system.



a. Analogue computer with Adaptive Device.



b. One dimensional subject's console.



c. Two dimensional subject's console.

Figure 8. Display and response boards.

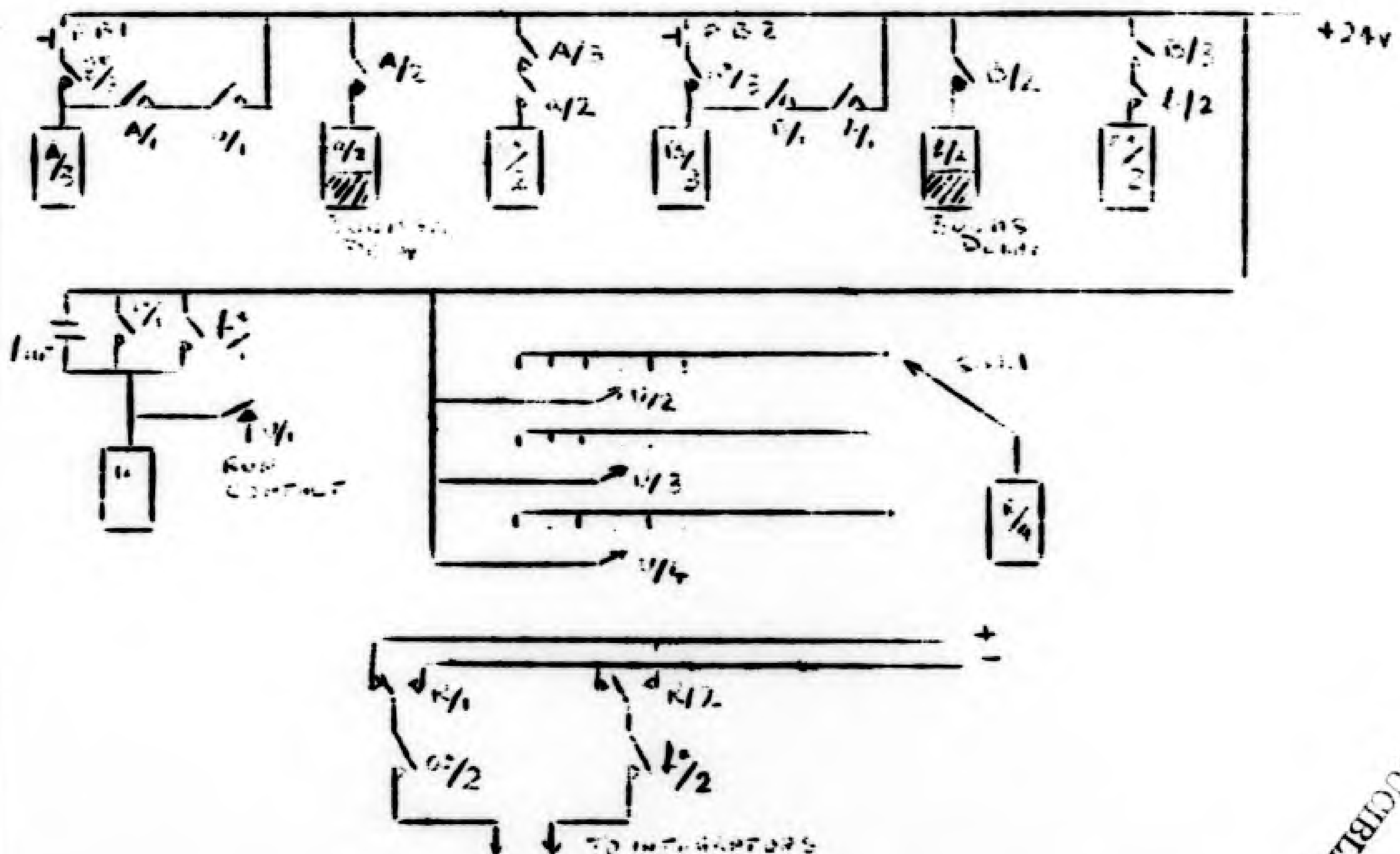


Fig. 9. Response Circuits for the One Dimensional Tracking. Duplicated for the Two Dimensional.

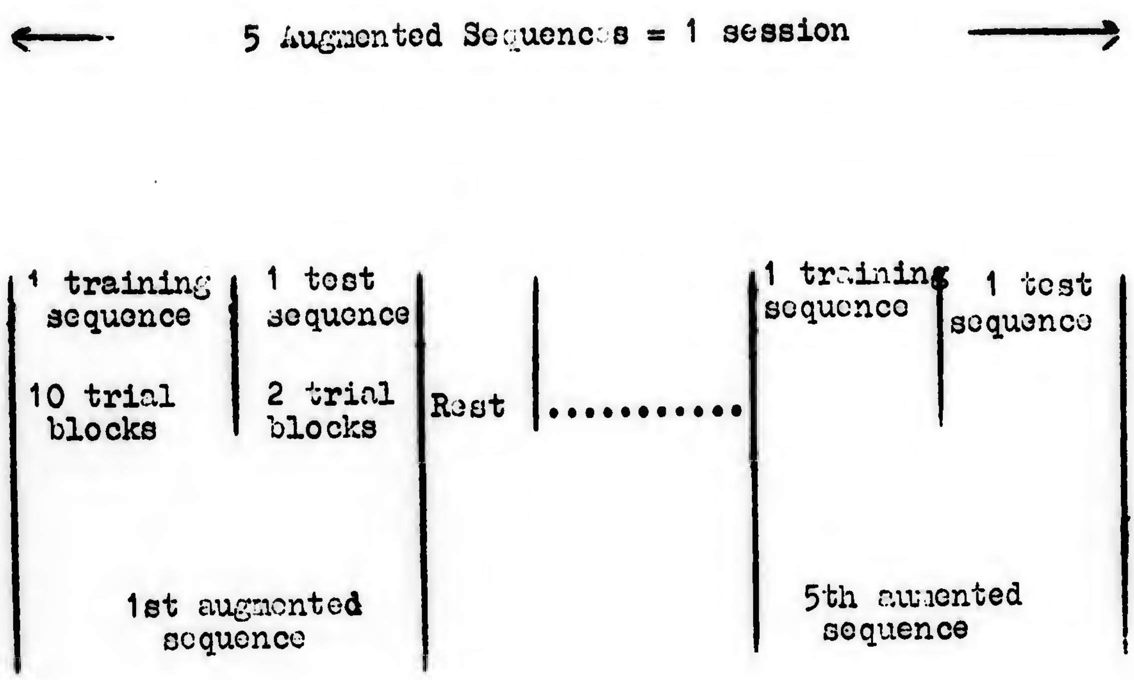


Figure 10. Experimental Procedure used for tracking.

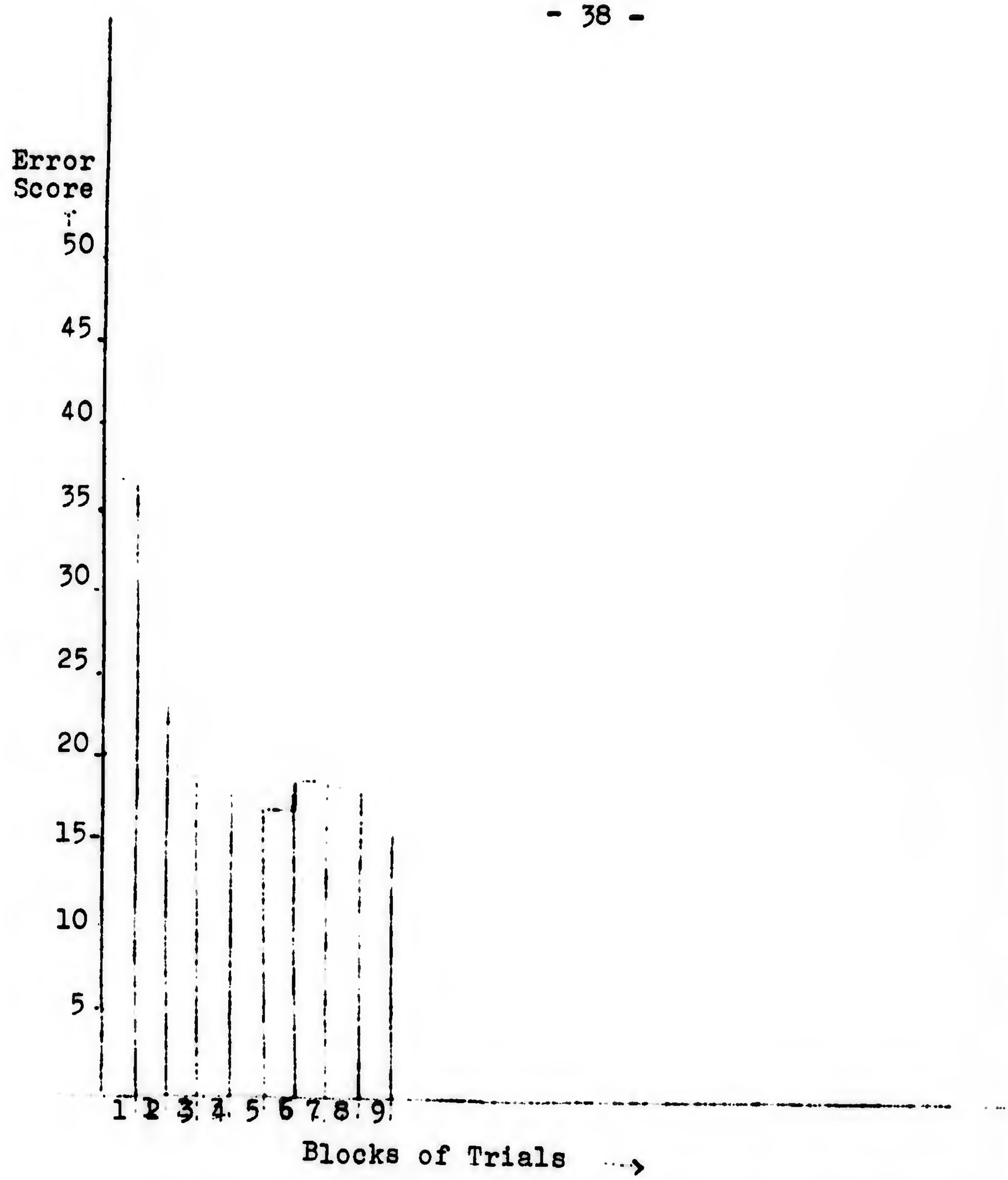


Fig. 11 (i) Typical Learning Curve for Condition A

(Non Adaptive)

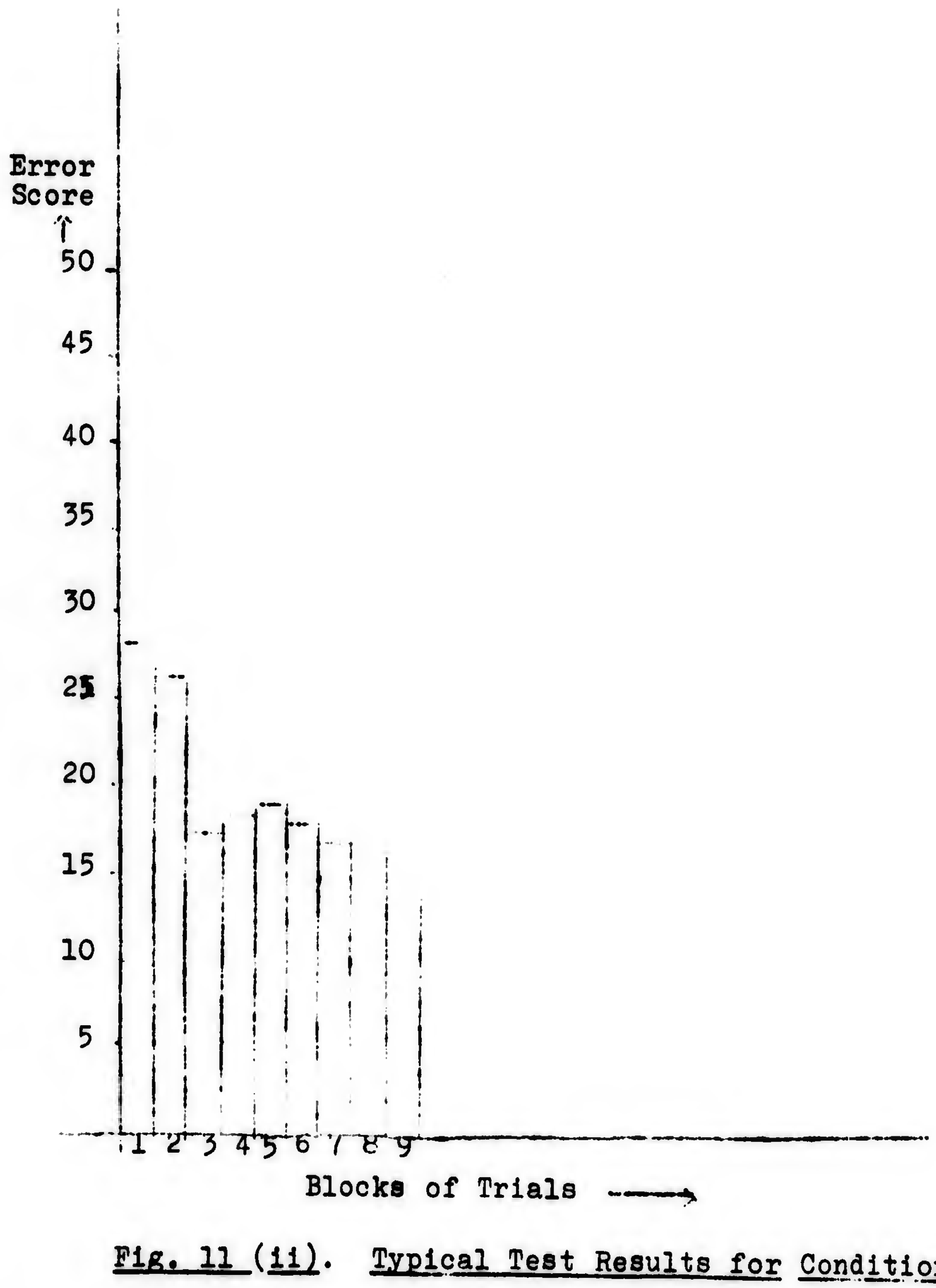


Fig. 11 (ii). Typical Test Results for Condition A.
(Non Adaptive)

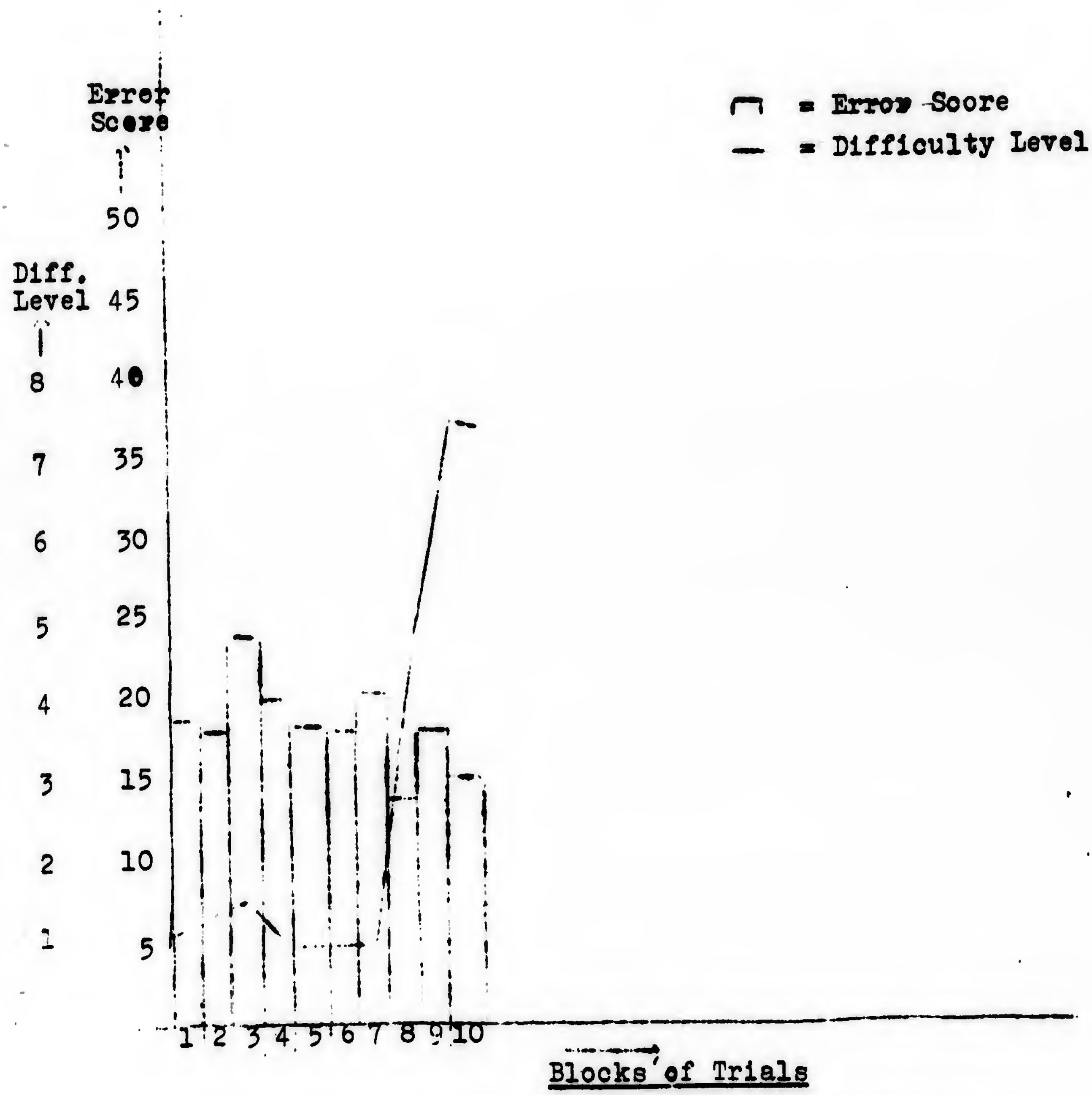


Fig. 12 (i). Typical Learning Curve for Condition A. (Adaptive)

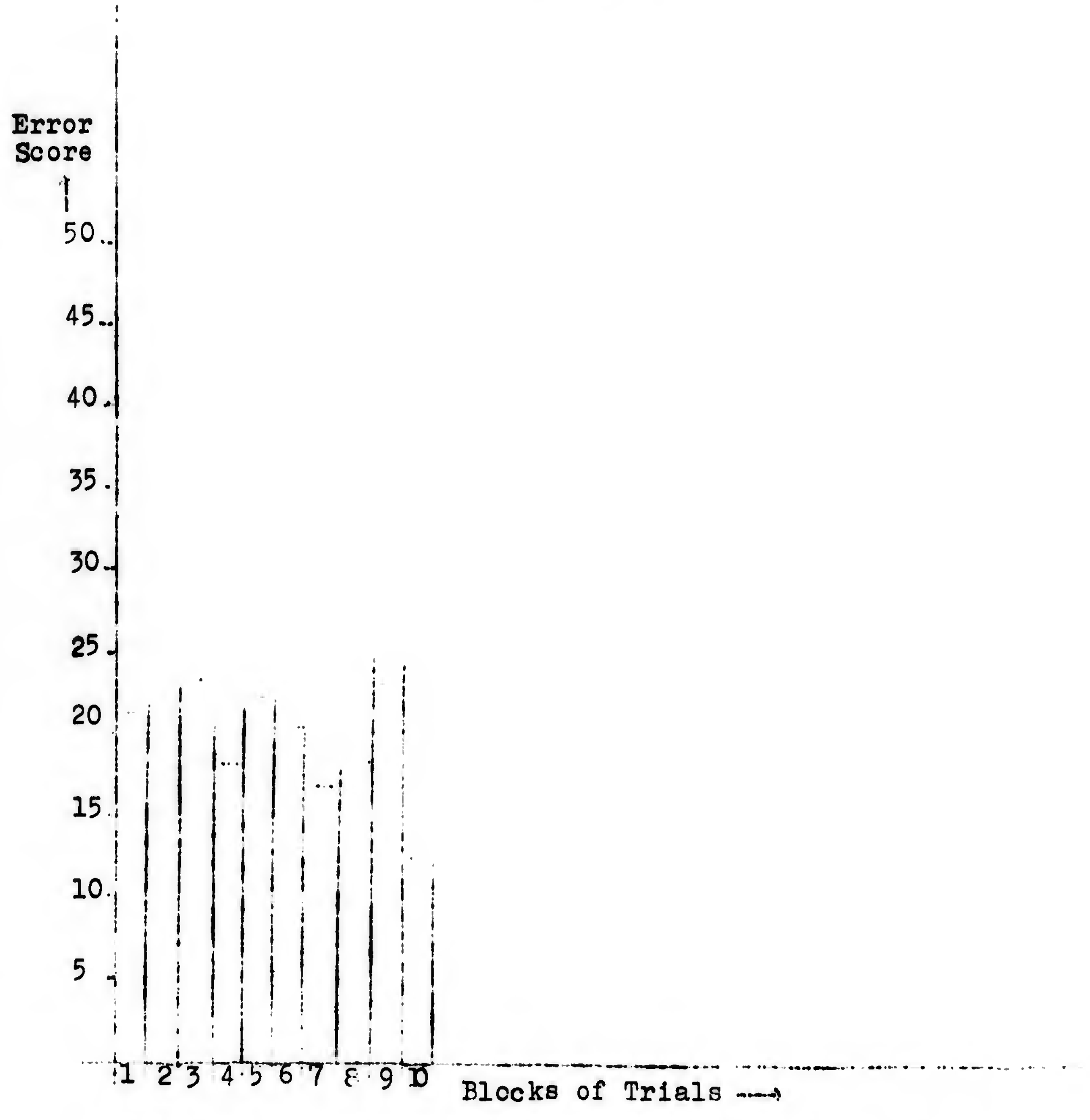


Fig. 12 (ii) Typical Test Results for Condition A (Adaptive)

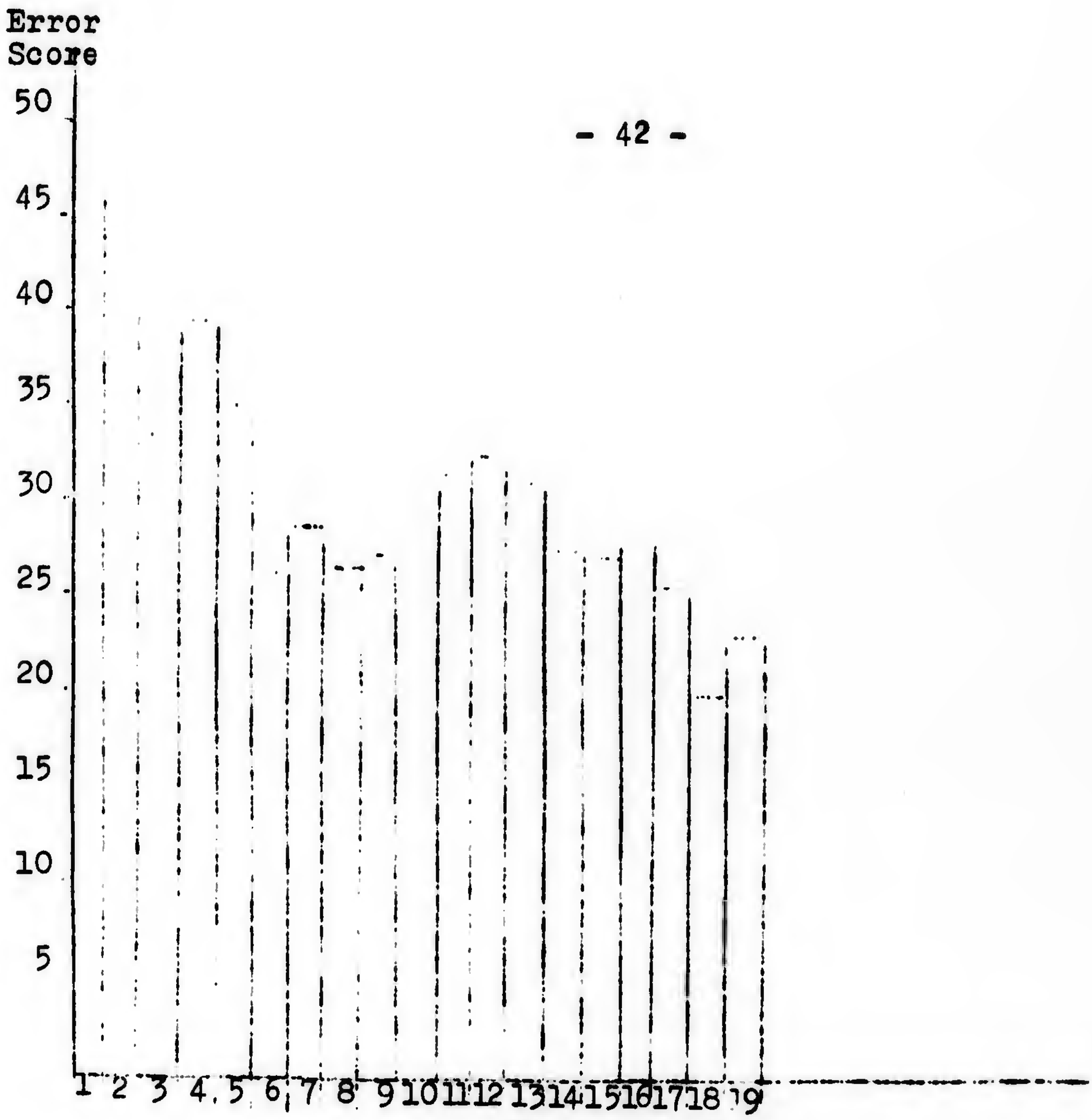


Fig. 13 (i) Typical Learning Curve for Condition B_1

(Non Adaptive)

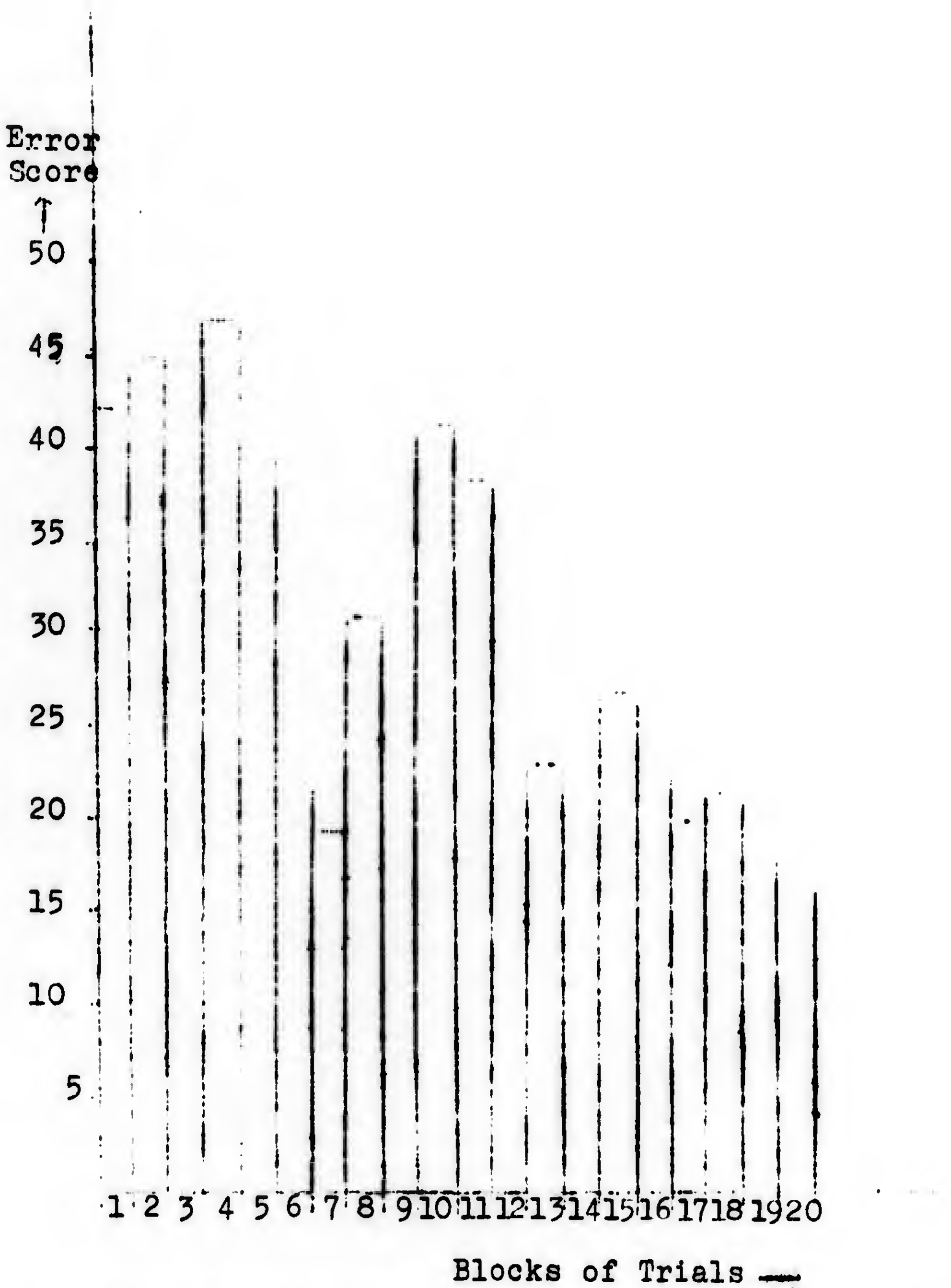


Fig. 13 (ii) Typical Test Results for Condition B_1

(Non Adaptive)

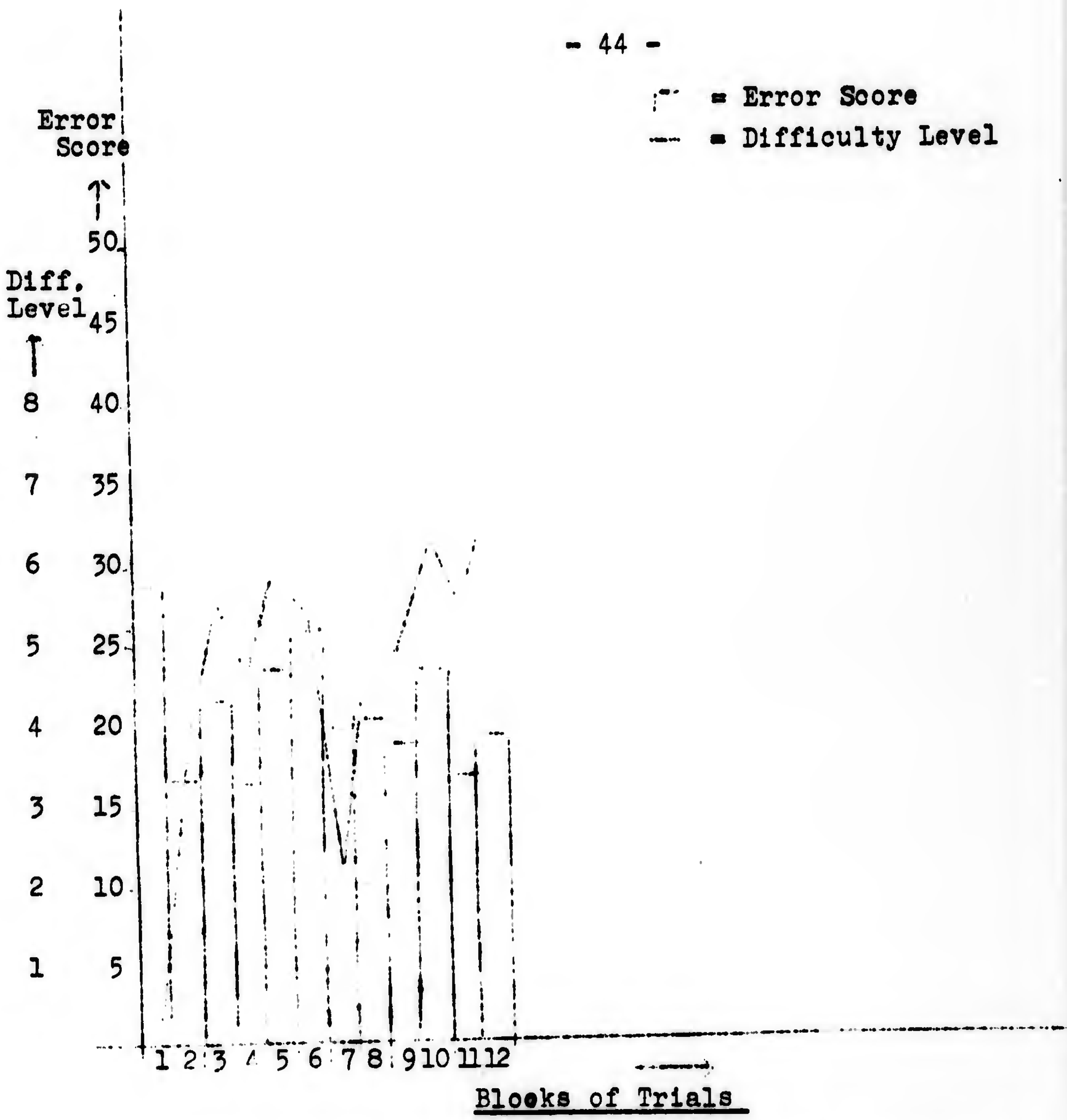


Fig. 14(i) Typical Learning Curve for Condition B_1

(Adaptive)

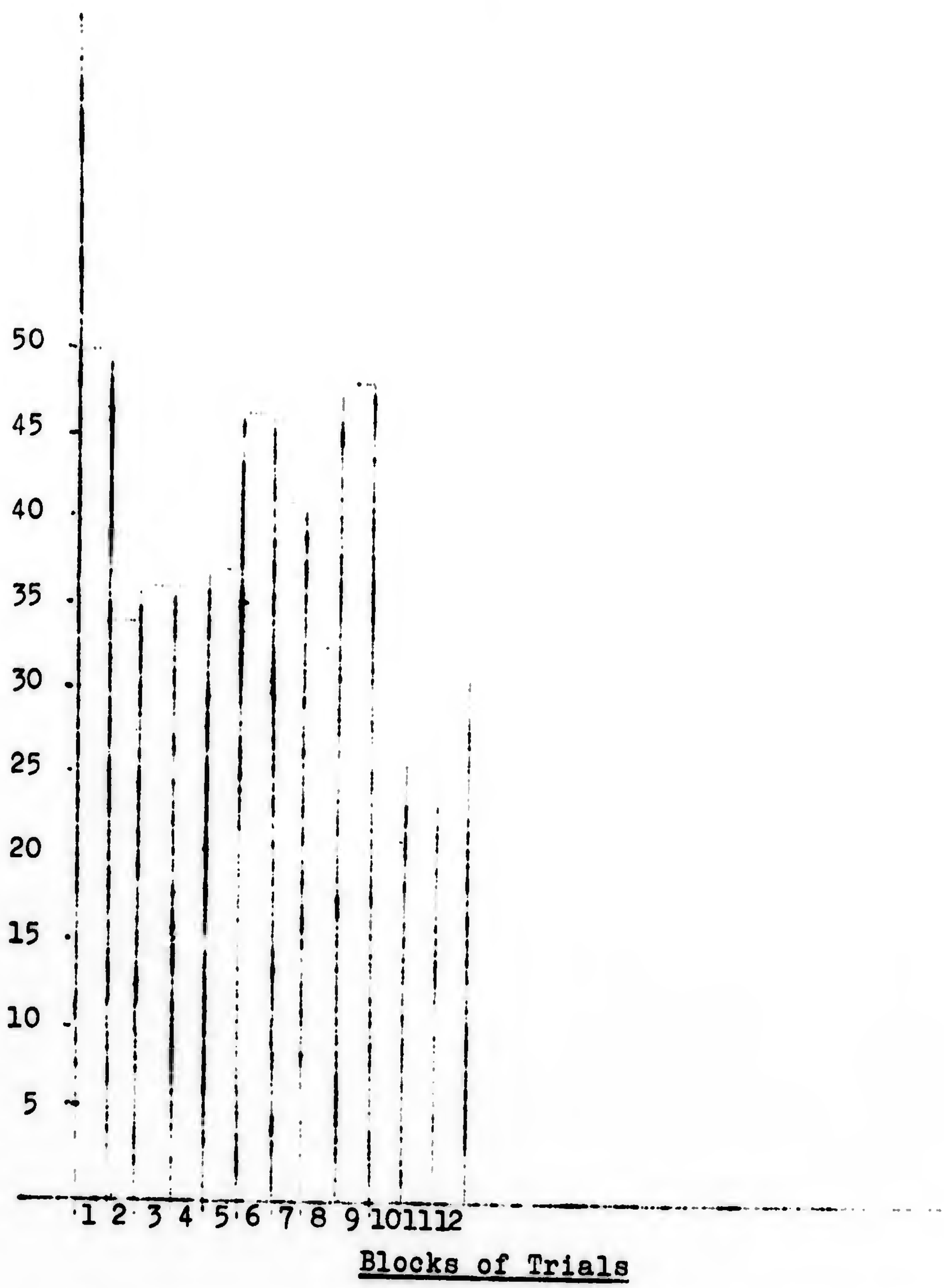


Fig. 14(ii). Typical Test Results for Condition B_1 (Adaptive)

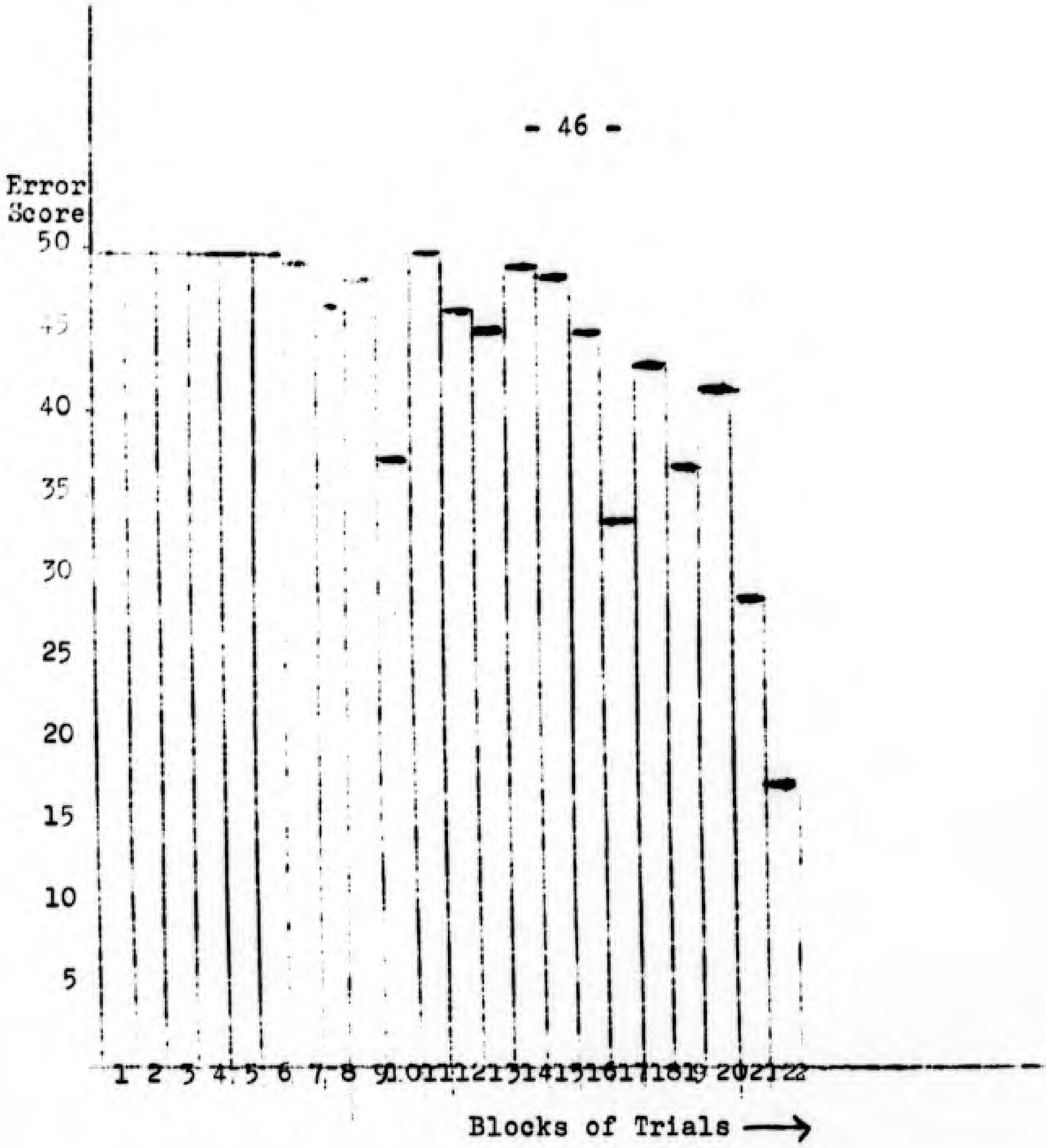


Fig. 15(i) Typical Learning Curve for Condition B_2 (Non Adaptive)

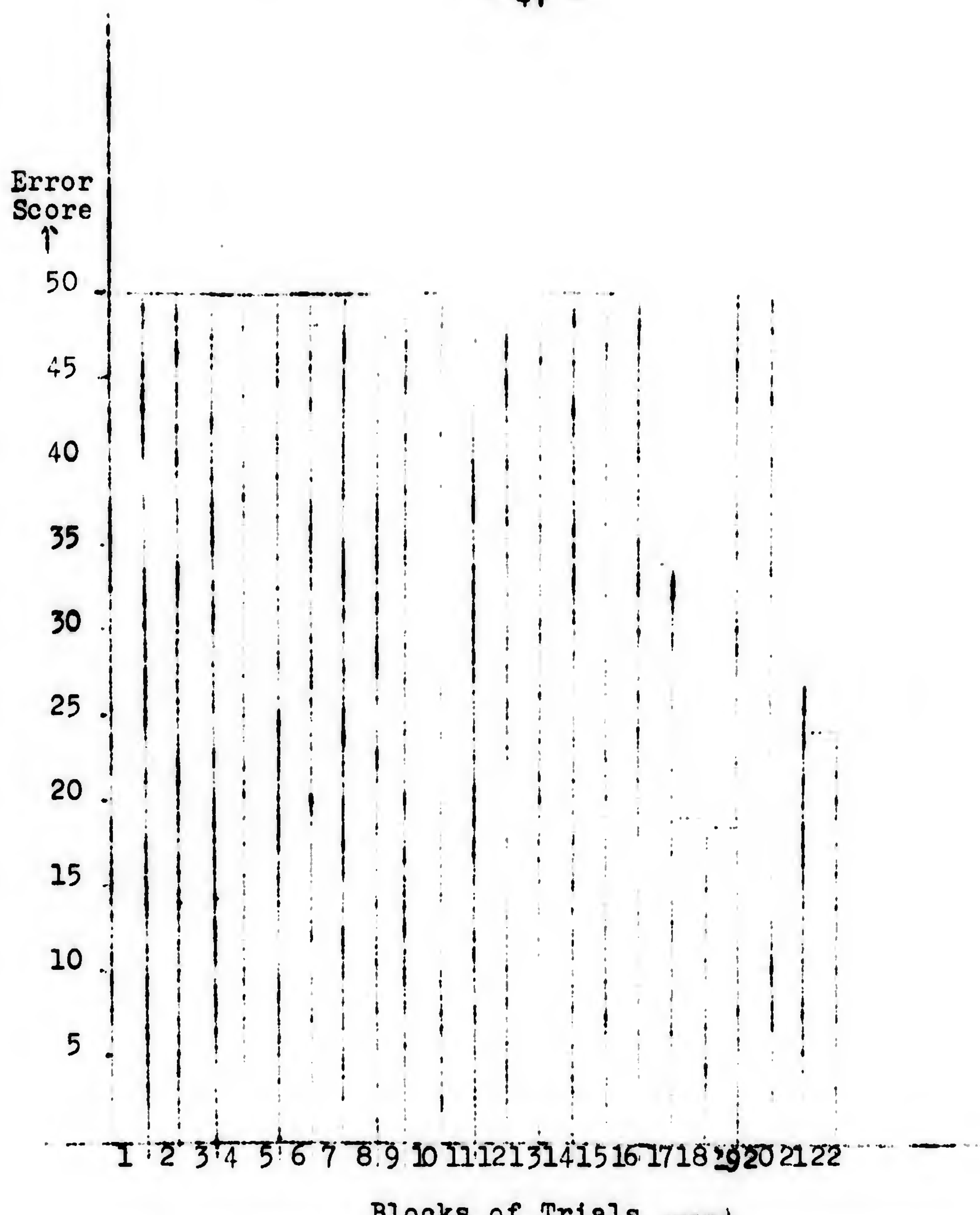
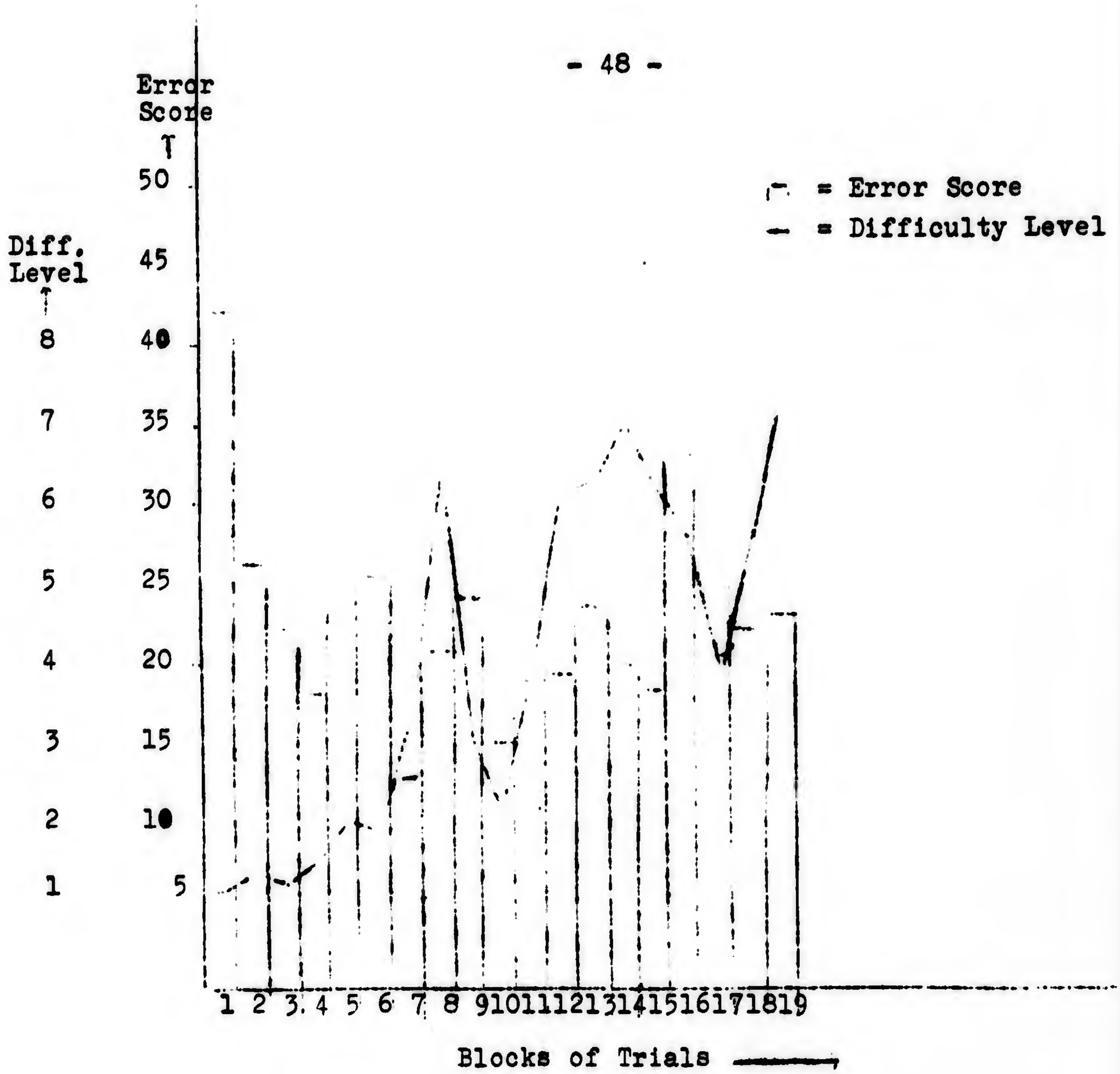


Fig. 15(ii) Typical Test Results for Condition B_2

(Non Adaptive)



<u>Fig. 16(i) Typical Learning Curve for Condition B_2</u>

(<u>Adaptive</u>)

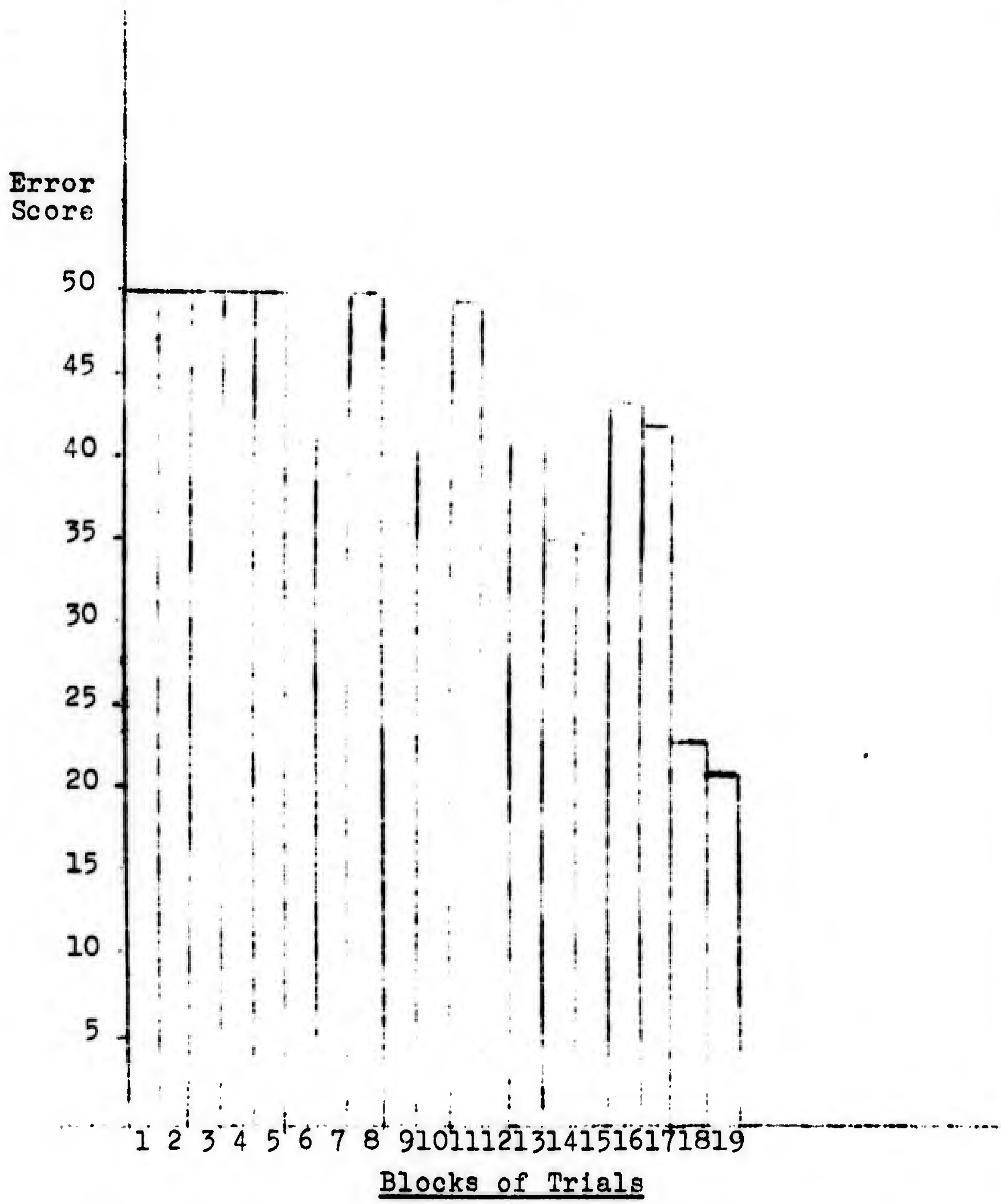


Fig. 16(ii) Typical Test Results for Condition B_2

(Adaptive)

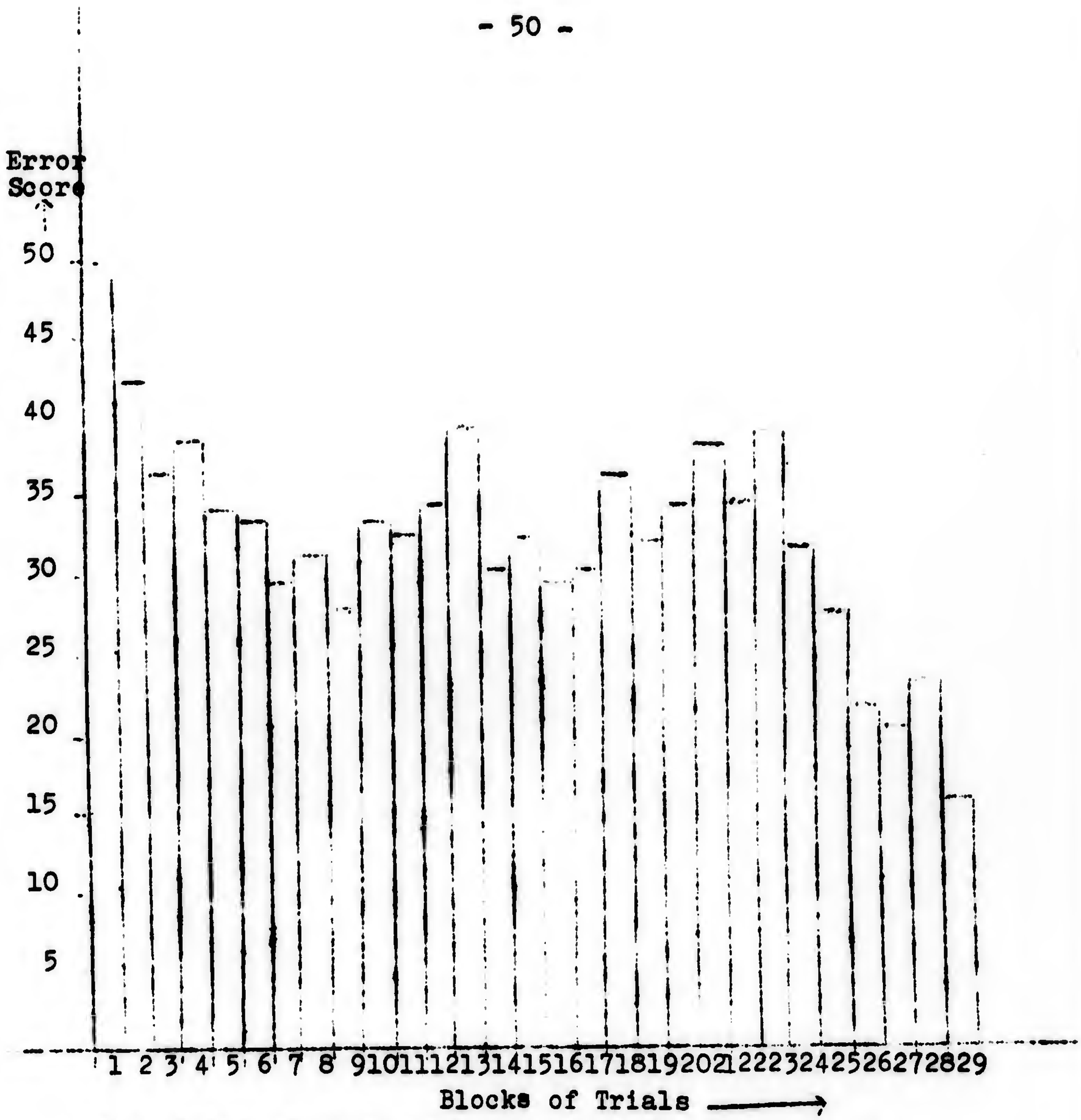


Fig. 17(i) Typical Learning Curve for Condition C_1

(Non Adaptive)

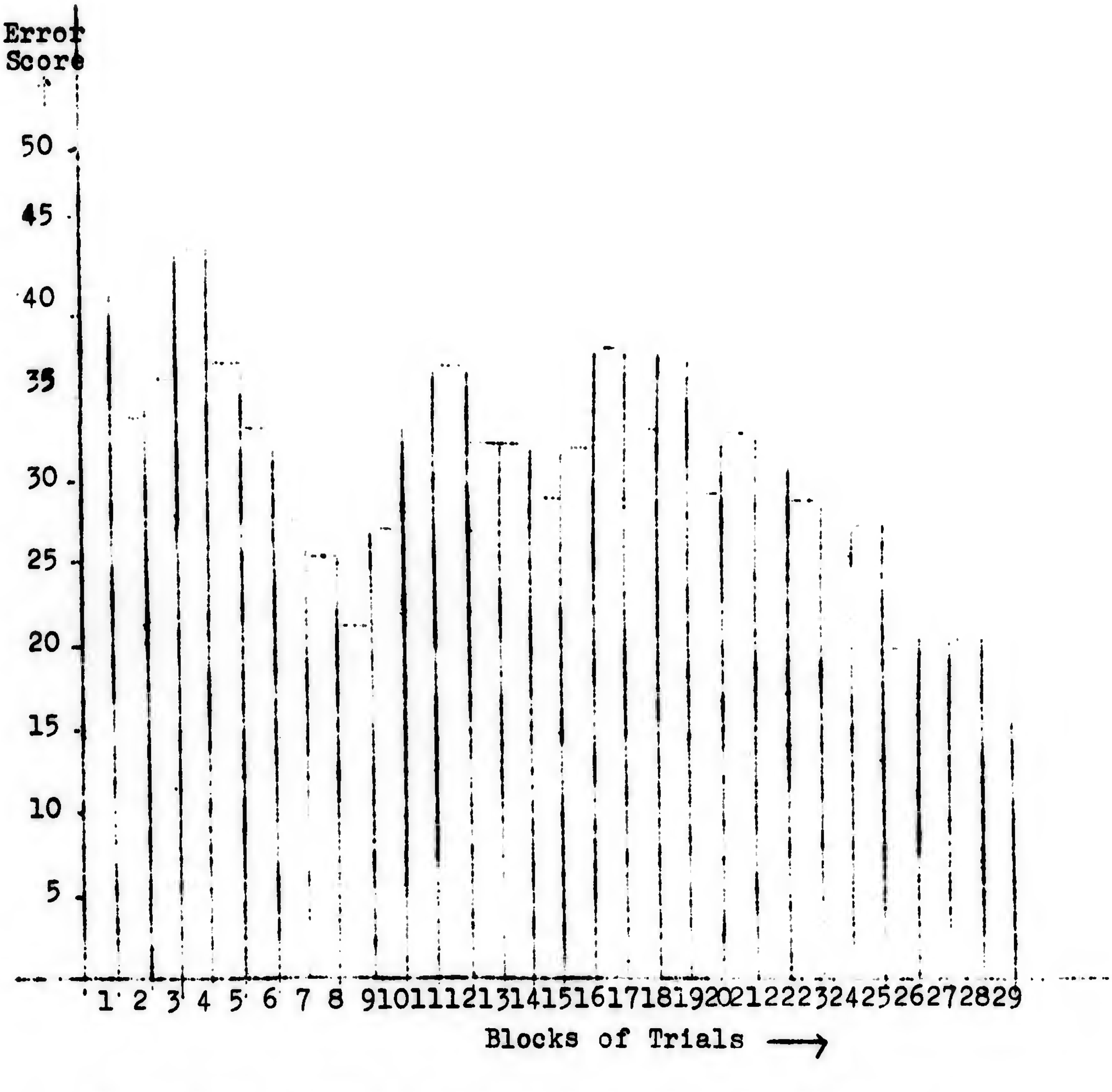


Fig. 17(ii) Typical Test Results for Condition C_1

(Non Adaptive)

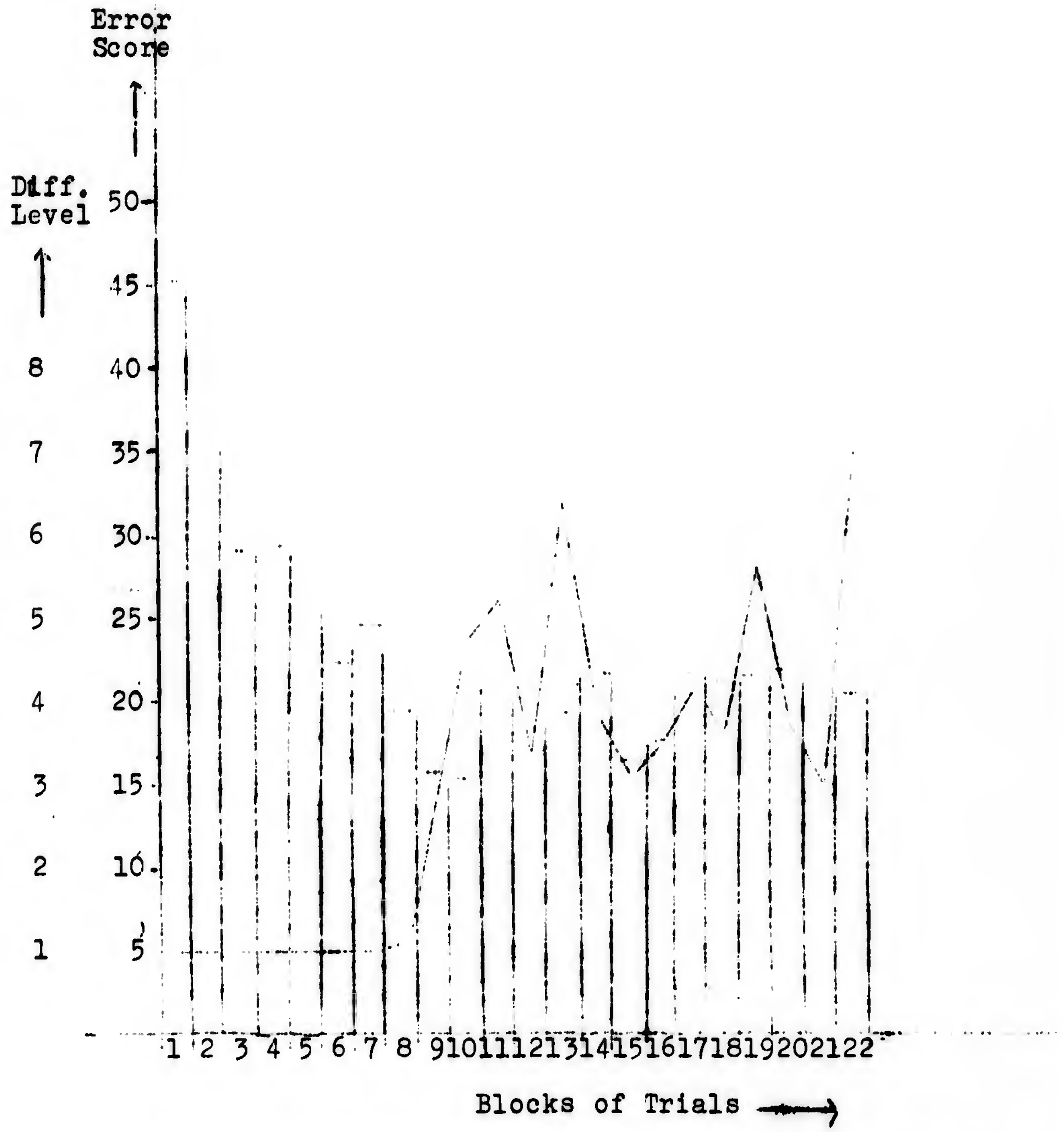


Fig. 18(i) Typical Learning Curve for Condition C_1 (Adaptive)

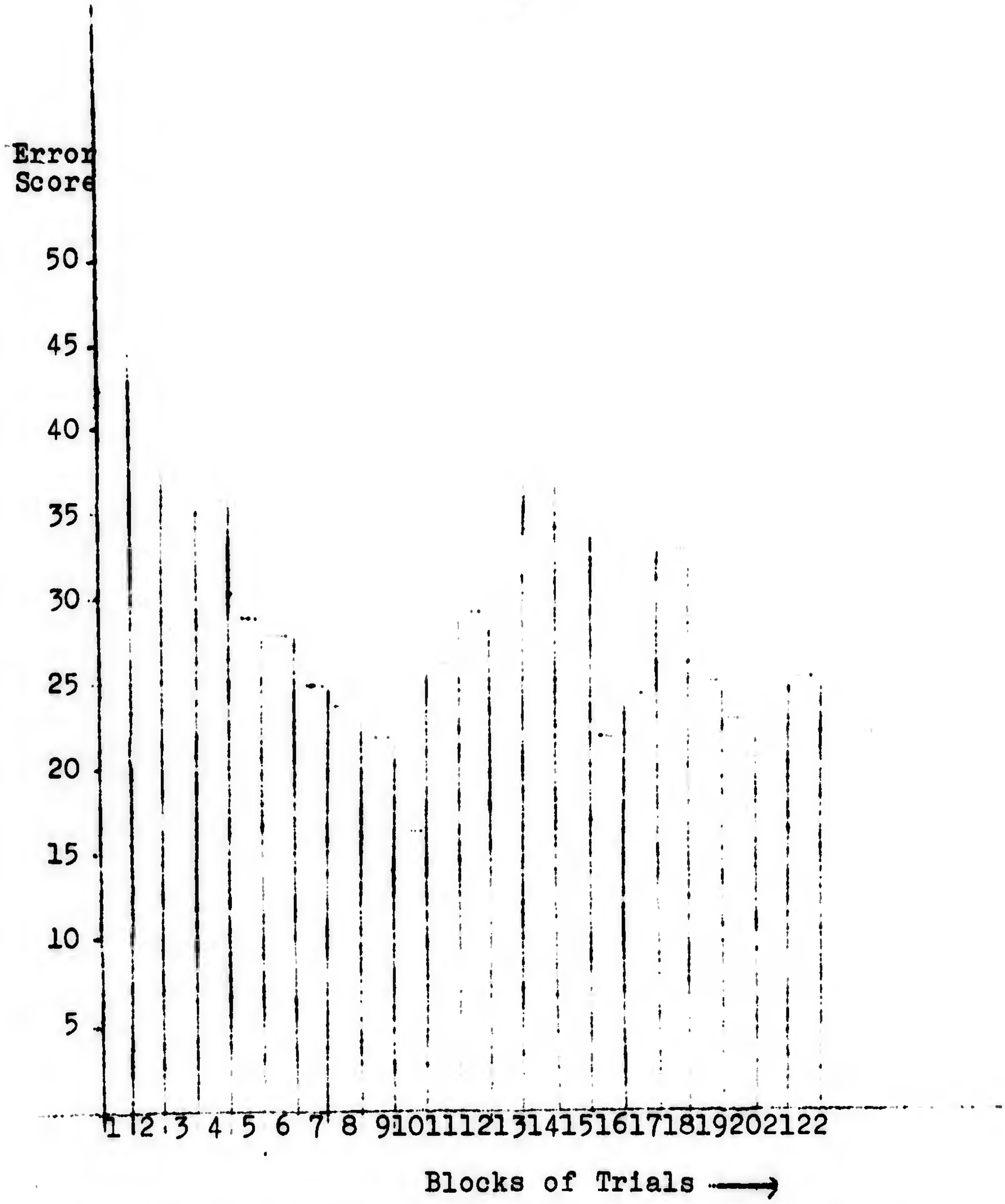


Fig. 18(ii) Typical Test Results for Condition C_1 (Adaptive)

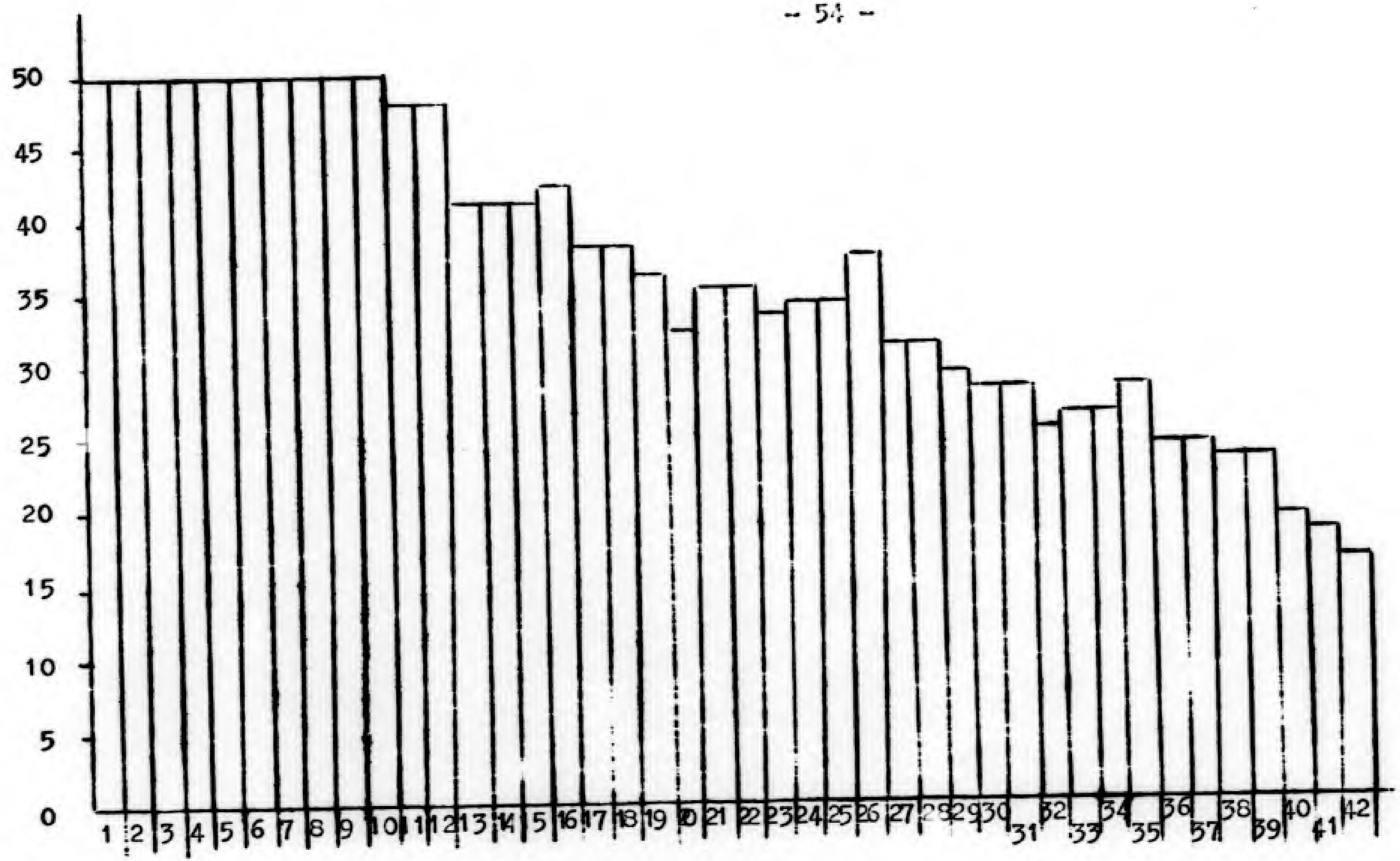


Figure 19(i) Typical learning curve for condition C^*_2 (non-adaptive)

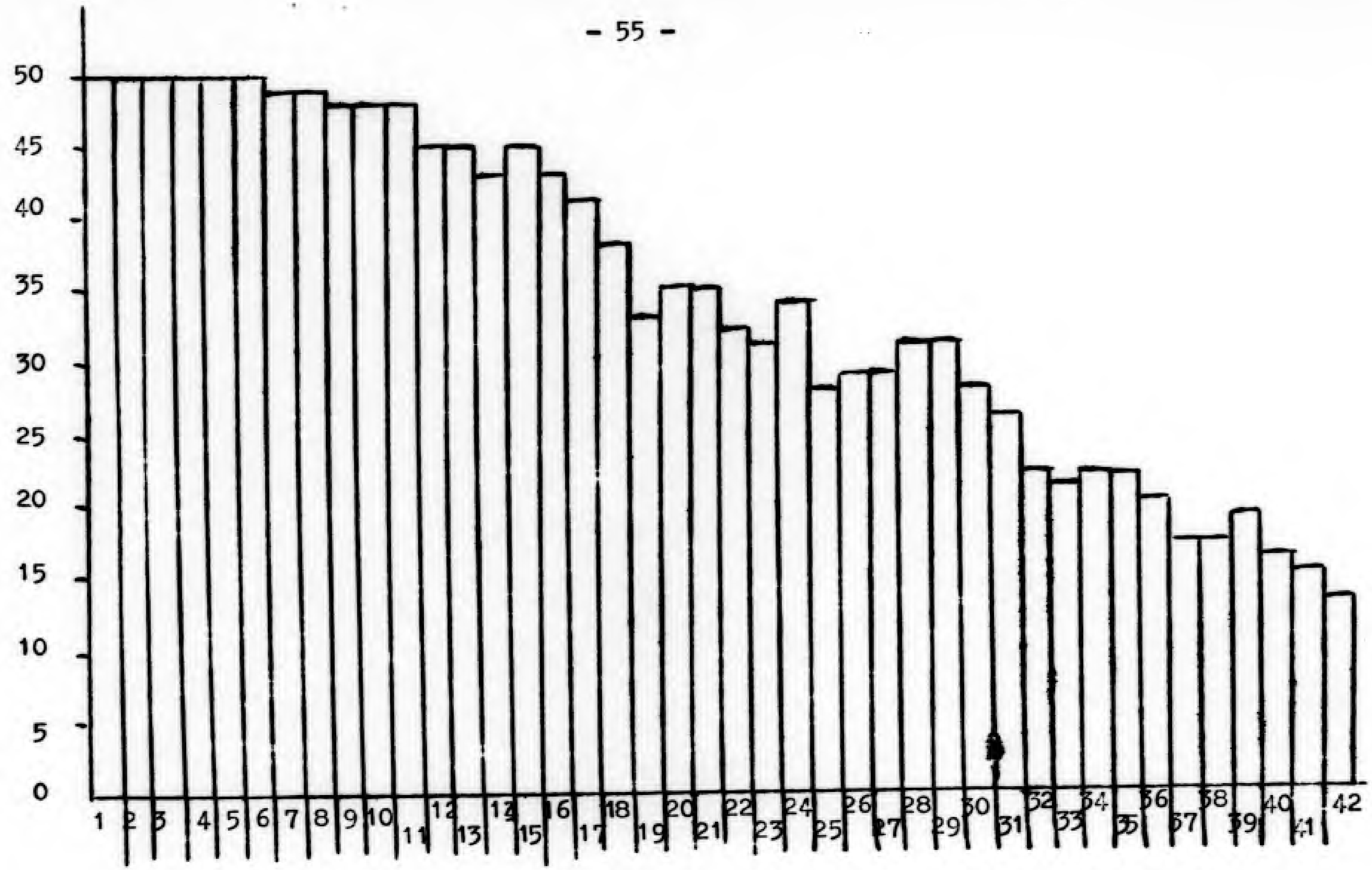


Figure 19(ii) Typical test results for condition C^*_2 (nonadaptive)

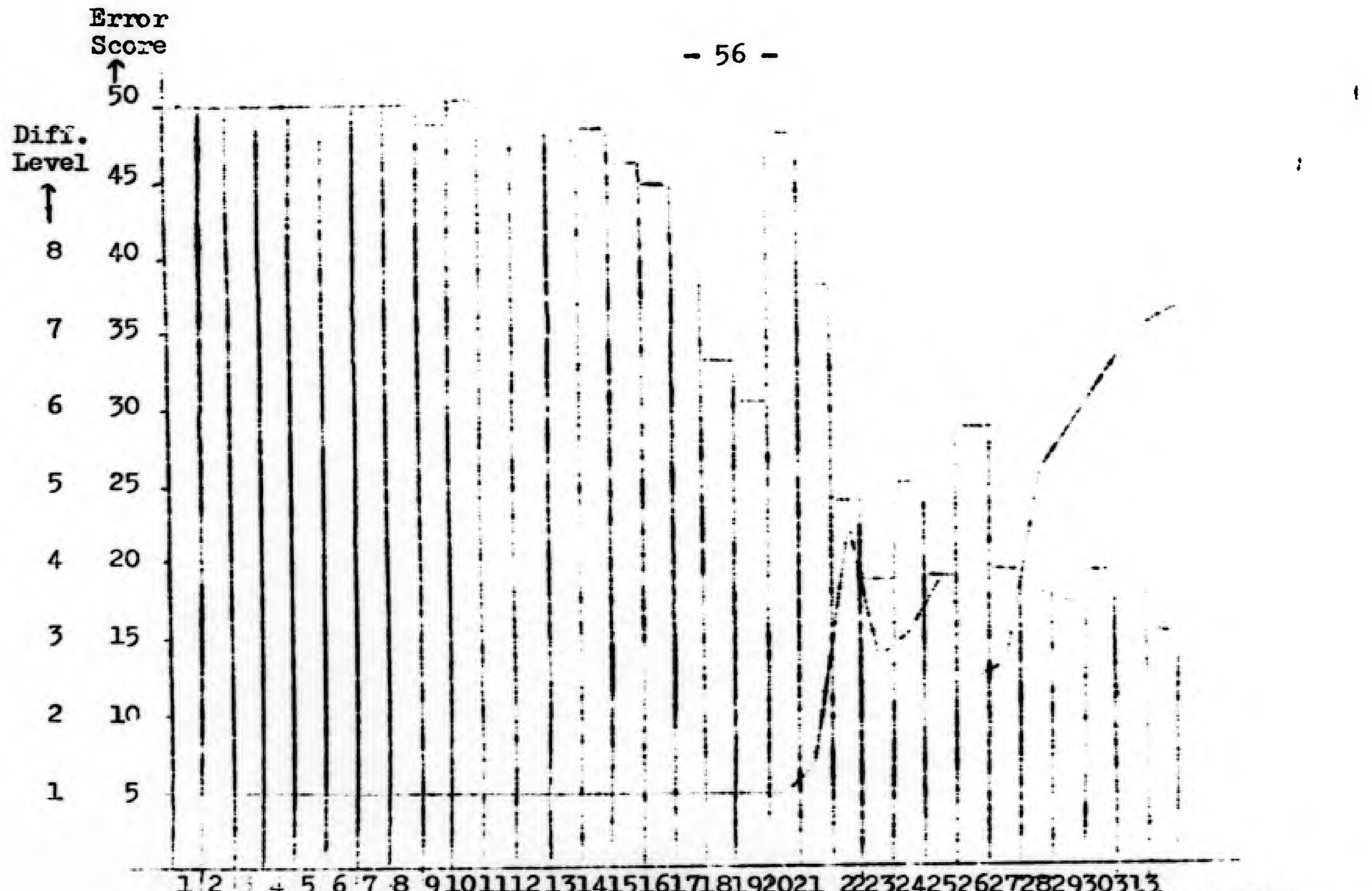


Fig. 20(i) Typical Learning Curve For Condition C^*_2

(Adaptive Easy Vehicle)

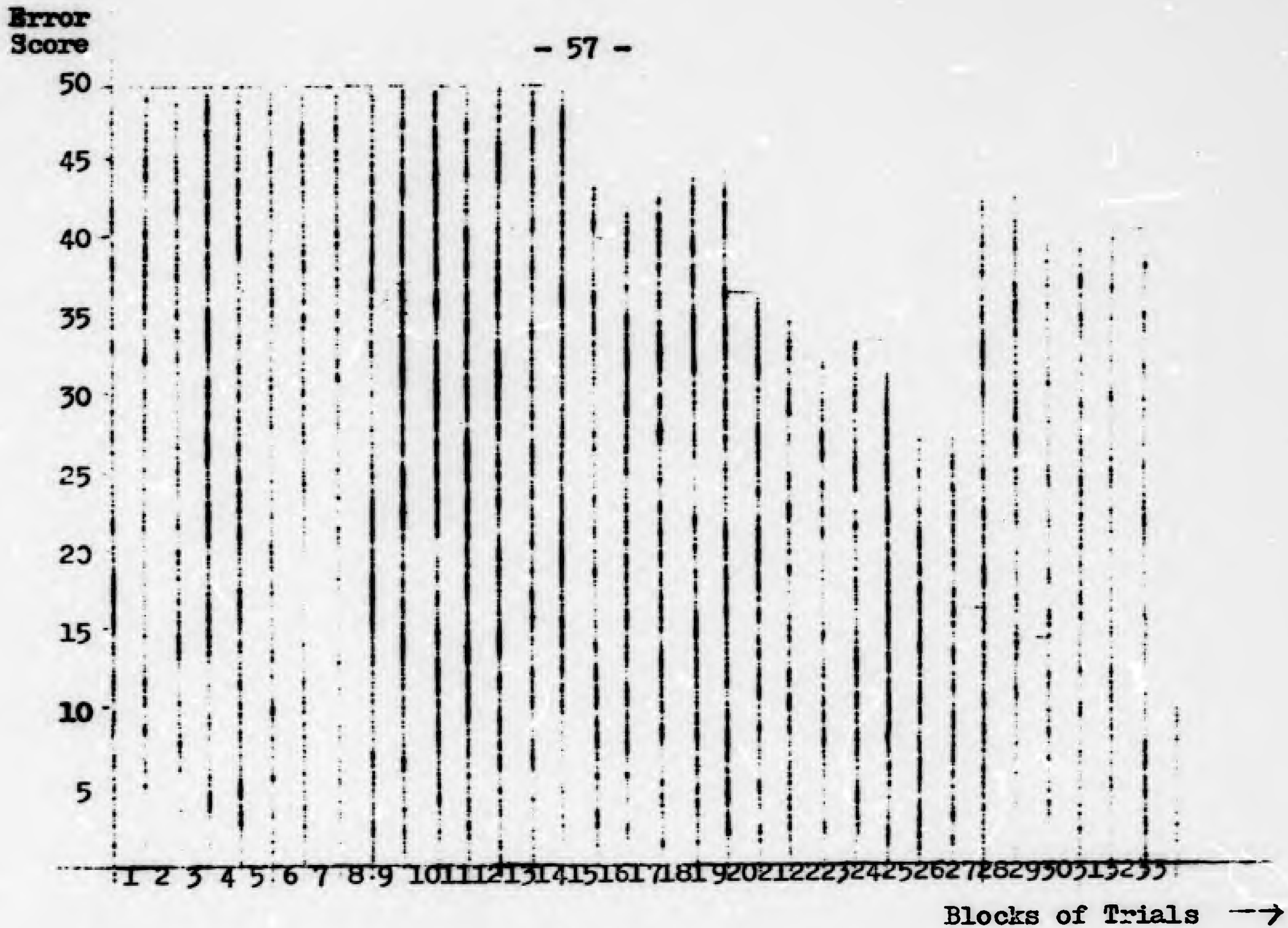


Fig. 20(ii) Typical Test Result for Condition C^*_2

(Easy Vehicle)

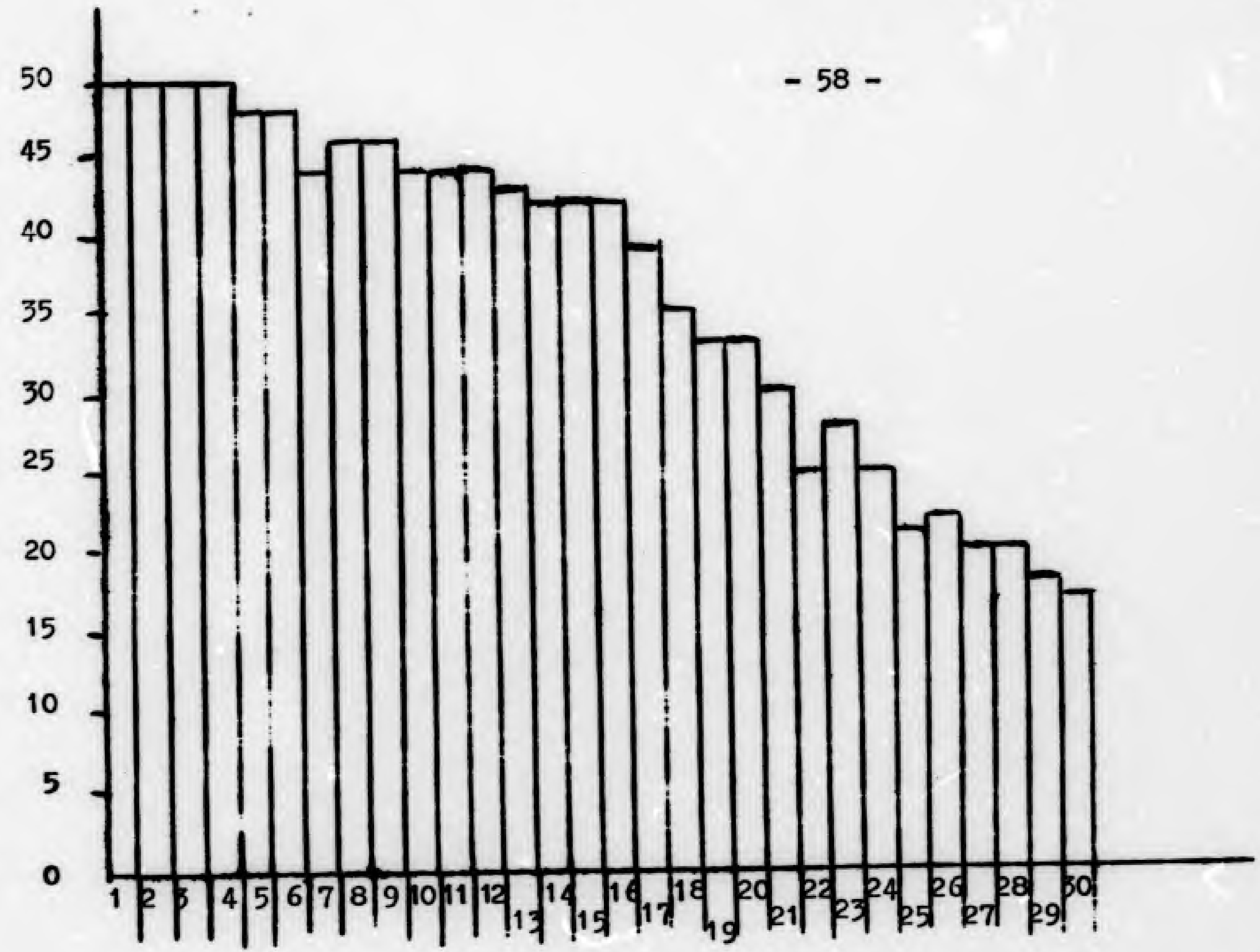


Figure 21(i) Typical learning curve for two dimensional task (nonadaptive)

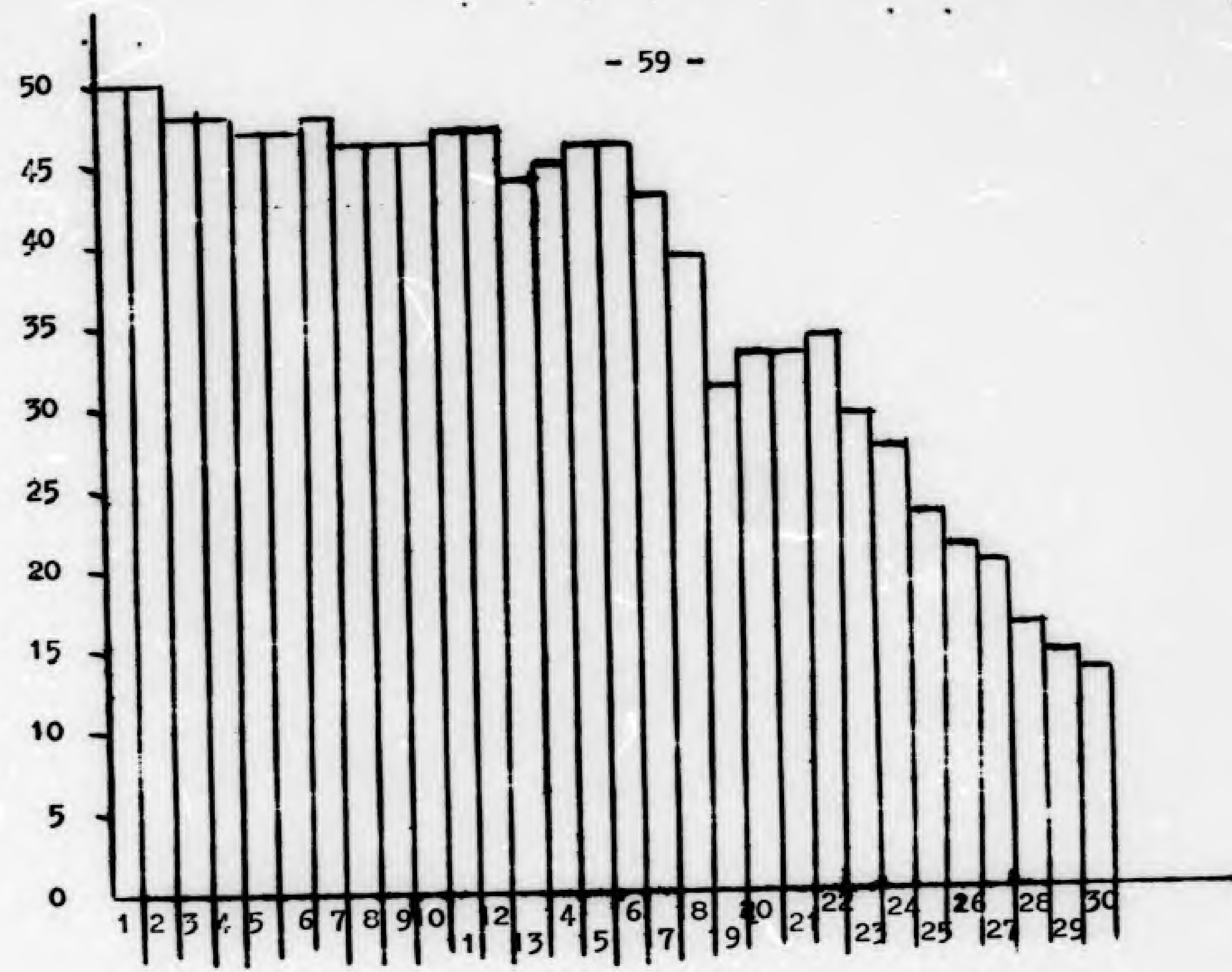


Figure 21(ii) Typical test results for two dimensional task (nonadaptive)

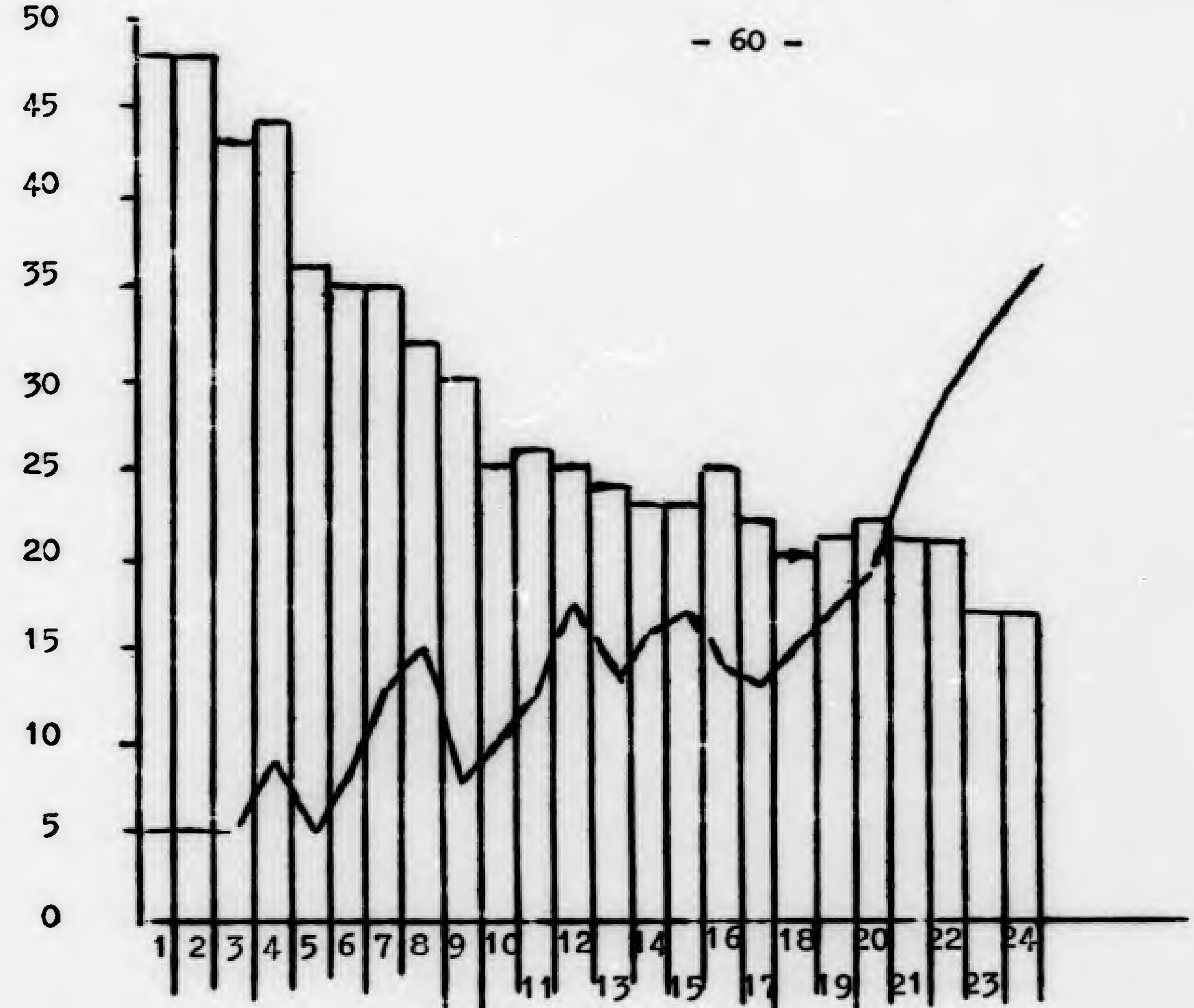


Figure 22 (i) Typical learning curve for two dimensional task (adaptive)

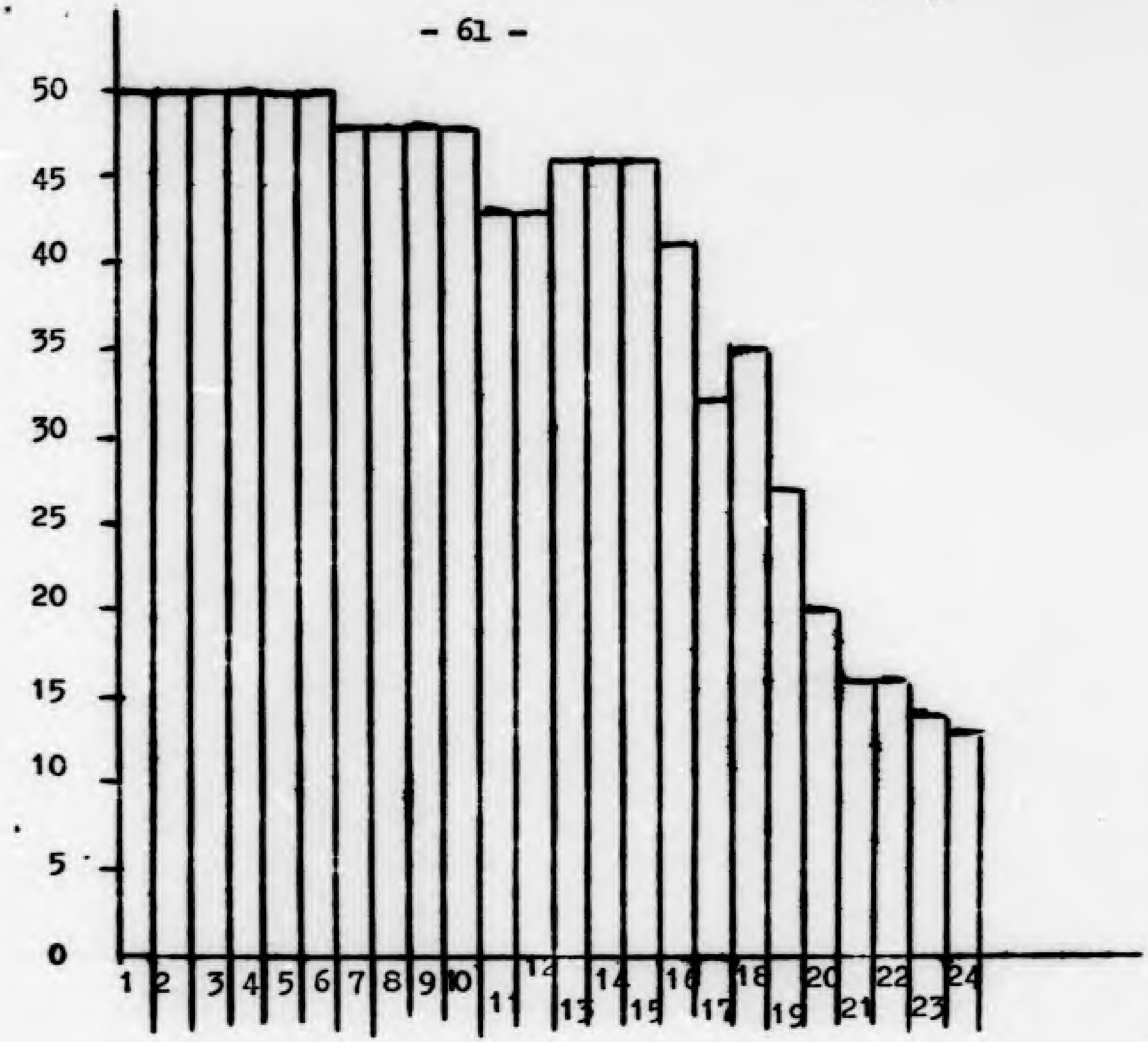


Figure 22(ii) Typical test results for two dimensional task (adaptive)

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13. ABSTRACT

This report describes a number of experiments designed to compare the acquisition of a compensatory tracking skill in adaptively controlled and open loop conditions. It covers one dimensional tracking and two dimensional tracking. Several one dimensional tasks were employed in order to control the degree of subskill interference and memory load. Typical learning curves for the principal conditions are presented.

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