34342

National Library of Canada
Bibliothèque nationale du Canada

CANADIAN THESES ON MICROFICHE
THÈSES CANADIENNES SUR MICROFICHE

NAME OF AUTHOR/*NOM DE L'AUTEUR* IAN MICHAEL FRANKS

TITLE OF THESIS/*TITRE DE LA THÈSE* THE ORGANIZATION OF A PATTERNED SEQUENCE OF MOVEMENTS

UNIVERSITY/*UNIVERSITÉ* UNIV OF ALBERTA EDMONTON ALTA

DEGREE FOR WHICH THESIS WAS PRESENTED/*GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* M. Sc.

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1977

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. R. B. WILBERG

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOTHÈQUE NATIONALE DU CANADA de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans l'autorisation écrite de l'auteur.

DATED/*DATÉ* 19th September 1977 SIGNED/*SIGNÉ* Ian M. Franks

PERMANENT ADDRESS/*RÉSIDENCE FIXÉ* 436 MICHENER PARK
EDMONTON
ALBERTA

NL-91 (3-74)

National Library of Canada

Cataloguing Branch
Canadian Theses Division

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED

Bibliothèque nationale du Canada

Direction du catalogage
Division des thèses canadiennes

AVIS

La qu[illegible] cette microfiche dépend grandement de la qua[illegible] se soumise au microfilmage. Nous avons tout [illegible] pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

NL-339 (3/77)

THE UNIVERSITY OF ALBERTA

The Organization of a Patterned Sequence of Movements

by

© Ian M. Franks

A THESIS

SUBMITTED TO ACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF M.Sc.

in

Motor Learning and Human Performance

Department of Physical Education

EDMONTON, ALBERTA
Fall, 1977

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Organization of a Patterned Sequence of Movements submitted by Ian M. Franks in partial fulfillment of the requirements for the degree of Master of Science. in Motor Learning and Human Performance.

Supervisor

Date July 26th 1977

Abstract

A series of four experiments were undertaken to investigate how subjects organize a sequence of movements. The perceptual-motor task used for these experiments was a pursuit tracking task that displayed step function characteristics. A P.D.P. 11/10 Computer controlled the signal output, data collection and subsequent analysis for these experiments. Location errors at the transition of the movements and tracking errors made during the movement were examined for both structured pattern and random pattern movement sequences. The dependent variables used were:

(a) percent recall
(b) root mean squared tracking error
(c) lag time difference plus reaction time
(d) constant position error
(e) directional errors (undershooting and overshooting)
(f) percent error ratio

Supportive evidence for Restle and Burnside's (1972) results was found in Experiments I and II. This suggested that the organizational subunit run, was being used by subjects during the pursuit tracking task.

Experiments III and IV investigated the movement attributes of the subunit run. It was found that a logarithmic increase in movement distance cannot be used to define the run. Evidence of an organizational subunit was found in Experiment IV, for both the structured pattern and random pattern subsequences. It was also found that movements made toward the midline of the body were less errorful than movements made away from the midline. The results are discussed in the light of the contemporary serial pattern learning literature.

Acknowledgements

My sincere appreciation goes to Dr. R.B. Wilberg, whose help and advice has been invaluable to me during my graduate program. My thanks goes to Dr. P. Runquist and Professor A.E. Wall for their guidance and knowledgeable suggestions, given to me during this series of studies.

A special note of thanks goes to Craig Hall, who supplied the electronic expertise for the apparatus used in these studies.

Table of Contents

Page

List of Tables

List of Figures

List of Figures (cont'd)

Serial learning is a highly familiar psychological task, both in daily life and in the research laboratory. This type of learning occurs whenever a person learns what item follows or is adjacent to another in a spatial or temporal array (Harcum 1975). The problem of serial order in behavior has been outlined by Lashley (1951). The main concern of Lashley's paper was the relationship between spatial and temporal order, and with those errors that reveal disturbances of serial ordering of responses. The question of how serial behavior can be integrated, is of primary importance to the study of serial pattern learning. Serial pattern learning has been defined as the integration of a sequence of responses that are organized in a meaningful way (Lashley, 1951; Miller & Chomsky, 1963). Serial patterns are evident in many forms of human behavior. They range from walking and speaking, to playing musical instruments. The resultant behavior is the smooth arrangement of serial elements. This behavior is said to have a meaningful and organized pattern (Restle, 1970).

The organization of a sequence of items and the learning process has been closely aligned by many authors. Tulving (1968) has argued that organization is a property of retrieval. His position is that the organization of material into coherent recall units occurs because of a retrieval plan established during learning. Johnson (1970) assumes that the organizational effects seen in a subject's behavior reflect not only the way the material was retrieved from memory, but also the way the material was stored in memory. Although these two views appear to differ, Johnson sees no inconsistencies. The term organization is used to refer to either the determination of output order or a scheme used for determining output order.

> "Regardless of how one defines the term organization, or how the content of a code is viewed, it is necessary to assume that the organization of a sequence is learned". (Johnson, 1970, p. 255).

In an earlier paper Tulving (1964) offers substantial empirical support to his suggestion, that an item is not stored in long term memory until it is organized with other items into a "chunk". Miller (1956) has defined a chunk as being any response set or sequence which is represented in memory by a single code. Studies undertaken by Tulving (1964; 1966; 1968), Bower and Winzenz (1969) and Johnson (1970; 1972; 1973) have suggested that a critical component of a response is the organization that a subject imposes on it. While this data has little to offer regarding how learning occurs, they do indicate that organization must be considered a part of what is learned.

Serial Pattern Learning: Data

Early studies examined how subjects mastered periodic sequences of binary events. Keller (cited in Restle & Brown, 1970c) using apparatus originally designed for probability learning, studied the rate at which subjects acquired various binary sequences. He found that the errors accumulated during learning to criterion were not dependent upon the length of the sequence repeated, but on its complexity. Complexity was defined in terms of "code length". For example, a binary sequence of (10111001) is recoded into run lengths, and becomes (1,1,3,2,1). Keller found that total errors to master a sequence was approximately 10 times the code length, for quite a variety of sequences.

Simple repeating patterns were used by Vitz and Todd (1967). These patterns were in the form of run lengths of the letters "a" and "b". Their definition of simple patterns excluded different run lengths of a single letter within one sequence. The patterns would include (aaabb) and (aaaab) but not (aabaaab). The last example has different run lengths of the letter "a". Vitz and Todd found that simple patterns lead to simple all-or-none learning.

The work of Garner and his colleagues has also investigated the learning and perception of simple, temporal patterns. The majority of his experiments involved the use of repeating temporal patterns. The patterns consisted of either visual or auditory stimulus elements presented at different rates but with the time between successive stimuli being uniform so that the pattern is formed by the arrangement of the elements and not by temporal variations.

Royer and Garner (1966) attempted to obtain a measure of psychological uncertainty of sequences of fixed length, and also a measure of difficulty of perceptual organization of the temporal auditory patterns. They hypothesized that these measures would be positively correlated. Two distinctly different tones were used to make up a pattern length of 8 events. Each tone was presented for 0.25 secs. in duration and they were presented at a rate of two per second. Twenty basically different patterns were used with a starting position that varied (e.g. 11111110 = pattern E; 11110111 = pattern E, 4th starting position). Each sequence of patterns was continuously presented to the subject, hence the two patterns shown above have the same basic pattern but only vary in their starting position. The subjects were divided into two conditions, (a) one group would watch the pattern and begin responding when they wished, (b) the second group were asked to respond to the onset of the first tone and continue throughout the experiment. The response required, was that the subject depress one of two telegraph keys. The keys were placed in compatible positions under the respective tones (to the left and right of the subject).

Royer and Garner (1966) found that when one of these patterns is heard initially, it appears as a rather rapid sequence of individual elements. With continued listening, however, the series of elements becomes an organized entity. The more simple the pattern the more rapidly it was organized. After this perceptual organization has occurred the pattern can be responded to in complete synchrony with little difficulty. Before this time, responding with any degree of accuracy was very difficult. The use of the delayed responding (condition a) became a necessity. The forced responding (condition b) lead to almost complete disorganization and interfered with the perceptual organization process.

The results pertaining to synchronized tracking are in agreement with Klemmer (1967). He found that with tone, subject could stay in phase at the presentation rate of two per second. Difficulty arose only at response rates of three per second. Further investigations into sequential complexity and motor response rates were undertaken by Royer (1967). Using the same sequence patterns as Royer and Garner (1966), his purpose was to investigate the difficulty of performing a series of repeated motoric sequences as a function of the complexity of the sequence. The difficulty was defined as the maximum rate of responding correctly. Royer's assumption was that sequences, regardless of their source, contain information which is processed similarly by the central nervous system. The subjects were presented with a card which had the repeating sequence pattern printed on it using the digits "0" and "1". Two telegraph keys were labelled "0" and "1". These were to be depressed by the subject in response to his printed sequence pattern. The keys were to be depressed in synchrony with an audible "click". The clicks began at a rate of one per second. Every eight clicks the rate was incremented by 0.2 pulses per second. The subject continued until he made an error or could not keep up with the click response.

The results of Royer's (1967) experiment showed that maximum rate is evident where the pattern provides long repetitions of a single response. Simple alternations (e.g. 0101) and symmetrical sequences (0011100) also facilitated performance. The negative correlation (- .91) of maximum rate of response with response uncertainty indicated that the complexity of the sequence has comparable effect on both perceptual and motor activities. Royer suggested that it is at the "juncture points" where the subjects organize their sequences. These juncture points are at the beginnings and ends of such patterns as runs and alternations (e.g. _000_1111_ the underline indicates these juncture points). The more juncture points in a pattern the more the performance decreases. This finding led Royer to equate perceptual units and response units with units of organization.

Further research by Garner and Gottwald (1967, 1968) used binary events (lights) to produce their varied patterns. The general conclusions reached in both experiments was that the learning of sequential patterns of binary events involves perceptual factors, which are similar to those found in pattern perception experiments. The distinguishing variable between learning and perception experiments is assumed to be the speed of stimulus presentation. Stimulus presentation of two elements per second or faster is considered by Garner to be an experiment in pattern perception. Although Garner and Gottwald (1967, 1968) found a great deal of commonality between learning and perception, they did find differences in the effect of the starting position of the pattern. The starting position had little effect at fast rates of presentation, but had significant effects on pattern organization at slow rates (i.e. one element per second or slower). The authors suggested that at fast presentation rates the sequence was less intellectualized by the subject. The perception is more immediate and directly available (i.e. perception of the "whole pattern"). The differences were probably related to the ability of faster patterns to provide an integrated percept.

While continuing to use a pattern composed of binary events (tones), Royer and Garner (1970) used a new technique which avoided the problems of confounding starting position with list organization. The pattern was started at a rate too fast to be perceived. The rate of presentation was reduced until the pattern of tones could be distinguished. It was reduced further until the subject could write down a description of the pattern. A further advantage of this technique is that the basic pattern could be presented just once (i.e. there was no need to go through all the permutations of starting position with one basic pattern). The major findings of this research was that the principles used by the subjects to organize the pattern were holistic in nature. It was not just the beginning a pattern with a long run that was important, it is the relationship of that run length to other run lengths in the pattern. Two principles were most evident, (a) temporal balance - the most preferred pattern organizations are those that provide the best possible balance (long runs of single events at both ends of the pattern), (b) Temporal progression - for example, run lengths of 5, 2, 1, 1. This sequence progresses from longest run of events to shortest in a rank order of run length.

All of the studies reviewed to this point have shown clearly that subjects encode binary sequences into run lengths but they have not answered the question of how subjects encode binary sequences into run lengths and how the subject used this coded information to reproduce the binary sequence. This question received some attention from Restle (1967). Using a binary sequence of events, Restle noted differential error accumulation at certain locations throughout the sequence. From the results of this experiment Restle formulated a simple "grammatical" theory. This theory was based on the subject operating on first-order rules. An example is given below.

"If the sequence is (10111100) then the first-order rules are: -

1 → 0 (1)[†]
1 → 11 (2)
11 → 11 (3)
111 → 1111 (4)
1111 → 0 (5)
0 → 1 (6)
0 → 00 (7)
00 → 1 (8)

Notice that Rules (1) and (2) have the same stem, 1, but different continuations. They are therefore not mandatory but optional rules". (Restle 1970c, pp. 252).

[†] Arrow (→) implies leads to.

Restle's (1967) results showed that there were more errors at the locations of optional rules than at the locations of mandatory rules. The binary sequences limited his investigations into how the subjects overcome this optional rule problem. He suspected the subjects were using higher-order rules.

Previous experiments outlined in this paper had used binary-events in their experiments. In these experiments there are two alternatives, one of which is correct. Although there may be several possible causes of error at a single point in the pattern, they all lead to one response. This makes it relatively difficult to examine the various sources of error in serial pattern learning. For this reason Restle undertook a series of experiments (Restle and Brown, 1970a, 1970b; Restle and Burnside, 1972; Restle, 1972, 1973) using several alternatives. This made it possible to identify different sources of error. For the majority of these studies Restle used the same apparatus. A relatively detailed outline of this apparatus follows. The subjects learned a repeating sequence of events. The events were six lights arranged in a row on a panel. The responses were six buttons, one beneath each event light. An amber ready light was centered above the six event lights. The ready lights and event lights were controlled by a process-control computer, and the responses were recorded by the same device. The computer was programmed to turn the event lights on in a particular pattern. The event lights were equidistantly spaced in front of the subject but did not have any label on them.

In the first of a series of studies Restle and Brown (1970a) attempted to evaluate several S-R interpretations of serial learning, particular emphasis being placed on the associative chain and serial position theories of serial learning. The subjects were divided into eight groups. Each group learned a repeating sequence of events by the method of anticipation. Two distinct patterns were used. Each pattern of events was given four different forms. These forms are shown in Table 1. The *initial* form used Events 1-5 (five leftmost lights); the *transposed* form was obtained by moving the initial form over, one place to the right; the *inverted* form was obtained by replacing Event N with Event 6-N; the *inverted and transposed* form was obtained by replacing Event N with Event 7-N. The dependent variables were the number of errors made at particular locations. The pattern was repeated for 20 times with no break between successive repetitions of the pattern. At each presentation the ready light was lit and the subject had three seconds to respond, the correct event light was then lit for one second. After a one second delay the procedure was repeated.

The mean errors at each location for each form of pattern 1 and pattern 2 are illustrated in Figures 1 and 2. A profile analysis verified that the (pooled) error profiles for pattern 1 and 2 were significantly ($p<.001$) non parallel. Based on their findings, Restle and Brown concluded that subjects could not have used any form of associative chaining. This is due to the high level of performance (performance on Trials 8-20 was better than 75% correct on every location) attained by the subjects, which precluded differential performance at locations where "branching" could occur (branching within a pattern, occurs when the same event is followed by two different events). With regard to the serial position hypothesis Restle and Brown state:

TABLE 1[†]

INITIAL FORM AND VARIATIONS OF EACH PATTERN

Sequence	Location									
	1	2	3	4	5	6	7	8	9	10
Pattern 1 (N = 110)										
Initial form (n = 26)	1	2	3	5	4	3	3	2	3	4
Transposed form (n = 28)	2	3	4	6	5	4	4	3	4	5
Inverted form (n = 27)	5	4	3	1	2	3	3	4	3	2
Transposed and inverted form (n = 29)	6	5	4	2	3	4	4	5	4	3
Pattern 2 (N = 15)										
Initial form (n = 32)	1	2	3	4	2	3	2	5	4	3
Transposed form (n = 25)	2	3	4	5	3	4	3	6	5	4
Inverted form (n = 26)	5	4	3	2	4	3	4	1	2	3
Transposed and inverted form (n = 32)	6	5	4	3	5	4	5	2	3	4

Note - The numbers 1-6 in table body refer to the event lights from left to right across S's panel.

[†] After Restle and Brown (1970a), page 121.

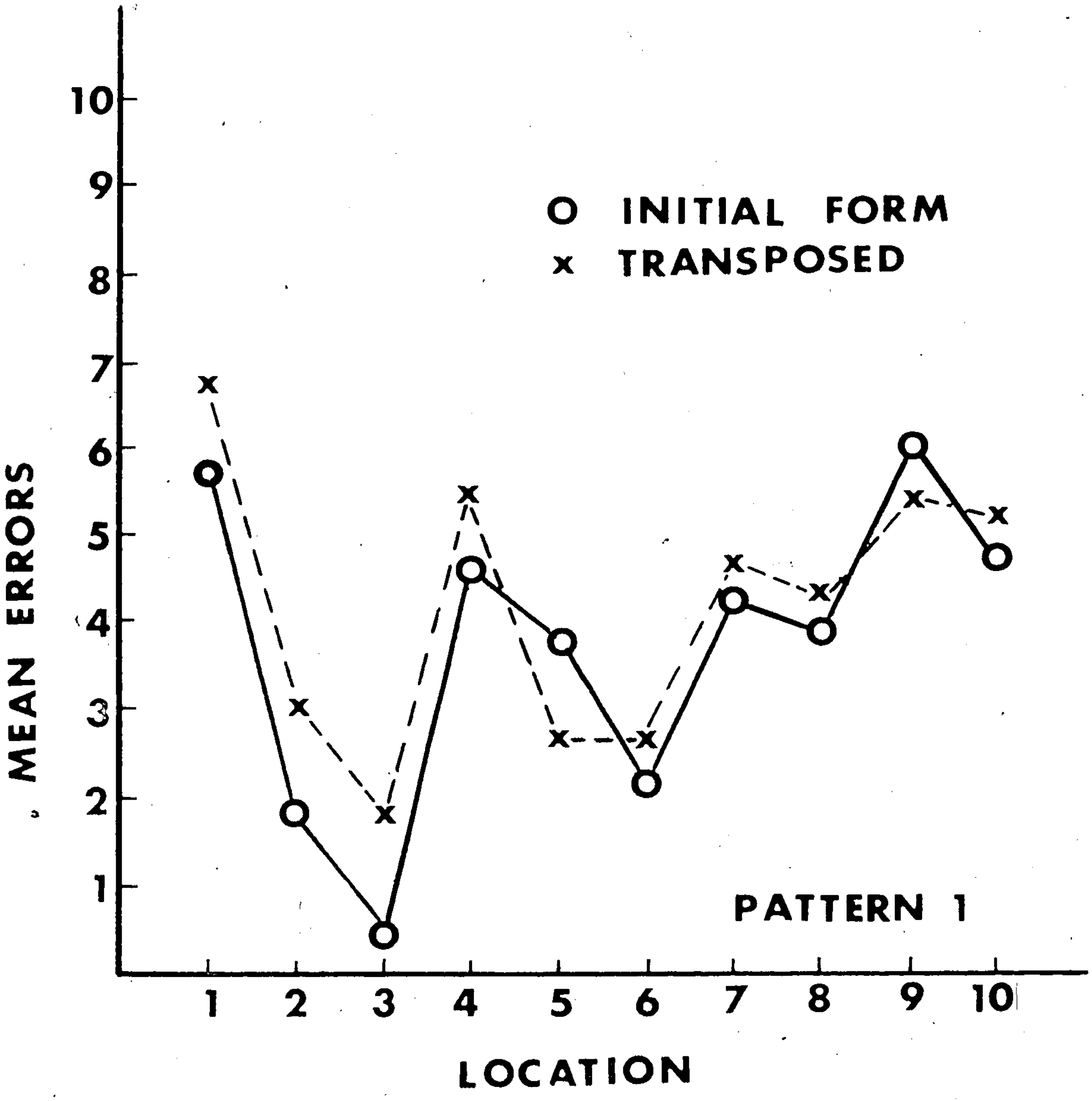


Figure 1

Mean errors at each location (serial position) for each *initial* and *transposed* form of Pattern L. The *inverted* and, *inverted and transposed* forms showed parallel error profiles to the two forms illustrated in this graph.

(After Restle and Brown 1970a, p. 122).

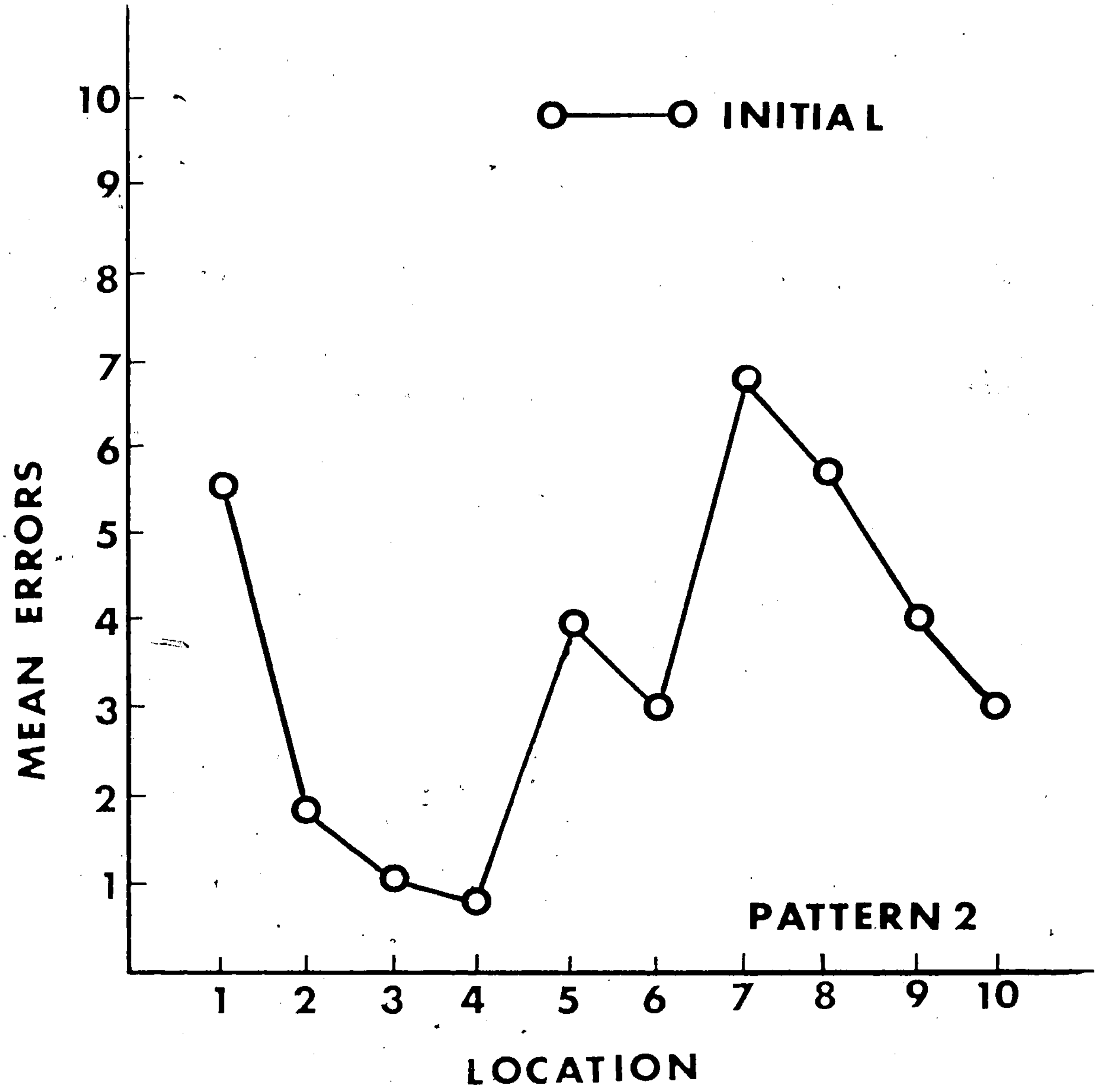


Figure 2

Mean error at each location for the *initial* form of Pattern 2. The *transposed, inverted* and *inverted and transposed* all had similar, parallel error profiles.

(After Restle and Brown 1970a, p. 122).

> "As stimuli, the serial positions should be comparable, and the 10 locations of each pattern should be equally difficult or else display some version of a serial position effect. . . Since the profiles are jagged and quite different in shape for the two patterns, learning must depend on more than just the serial positions of the events, and mastery of the sequence is not attributable to Ss' use of serial position cues." (1970a, pp. 122).

Discussing their results, Restle and Brown suggested that subjects generated subunits of the pattern using simple abstract properties. These subunits took the form of "runs" (e.g. subunit 2 3 4) and "trills" (e.g. subunit 2 3 2). The run being a more preferable organization unit than the trill. A closer examination of Figures 1 and 2 should clarify these assumptions.

In an extension of the above study, Restle and Brown (1970b) pretrained subjects on runs (1234) and trills (3434). The two groups were tested on an ambiguous serial pattern (2123434565). This pattern could be organized via a run bias [2(1234)(3456)5]; or via a trill bias [(212)(3434)(565)]. The profile of errors and the frequencies of run- and trill-overextension errors were symptomatic of how the test pattern was organized. The results supported earlier conclusions (Restle & Brown, 1970a) and also indicated that run and trill tendencies transfer between two patterns, even when the particular direction or location of the subunits is changed.

Restle (1972) examined the role of phrasing in serial pattern learning. In this experiment Restle combined both spatial and temporal information within his pattern. Phrasing was defined as an added organizational cue via a temporal medium. The time between stimulus presentation was varied. Good phrasing is described as having longer intervals between subunits and uniformly shorter time intervals between events that are within subunits. Bad phrasing is viewed as having the longer intervals and shorter intervals almost randomly assigned throughout the pattern of events. Subjects passively viewed the patterned events aided by these extra stimulus cues (good phrasing and bad phrasing). Then the subjects learned by anticipation the same pattern with no temporal manipulation three seconds between each event. The findings showed good phrasing facilitated performance on the anticipation learning task. Restle proposed that good phrasing has its effects not because it allows extra time at moments of high information processing load, but because it helps divide the pattern into its appropriate parts (i.e. it is an added organizational cue for the subject).

A problem solving approach to serial pattern learning has been evident in recent literature (Simon & Kotovsky, 1963; Simon, 1972; Kotovsky & Simon, 1973). In an earlier paper Simon and Kotovsky (1963) had proposed an information processing theory of human acquisition of concepts from sequential patterns. The patterns used were of the sorts used in the Thurstone Letter Series Completion Test. This theory relied upon a computer program that performed the task. The program consisted of:

(a) "pattern generator" - this took the sequence as input and extracted from it a pattern description, concept or rule of the sequence;

(b) "sequence generator" - this took the pattern description as input and extrapolated the letter sequence from it.

Kotovsky and Simon (1973) attempted to provide further empirical data to test their earlier theory. Specifically they examined:

(a) The order in which subjects looked at letters in a sequence.

(b) The hypotheses they formed about probable solutions.

(c) The methods subjects used for recognizing periodicity in the sequence.

(d) The manner in which they extrapolated it once they had discovered the concept.

(e) The type of errors the subjects made.

It was hoped that this data would test the detailed hypotheses[†] that are an interelated part of their computer program.

Subjects were given 15 Thurstone-type letter series completion problems (e.g. Problem 1 - cdcdcd: Problem 6 - qxapxbqxa). The subjects' thinking-aloud verbalizations were recorded. The letter sequence was presented one letter at a time. This was controlled by the subject. The data obtained were organized into six categories:

(1) Problem difficulty. Table 2 shows the sequence and the rank order of difficulty as measured in mean time from beginning of problem to problem solution.

(2) Feature of each sequence first noticed by subject. The priorities the subjects used in noticing a feature of the pattern were generalized to: (i) the I relation (same) is noticed before the N relation (Next). (ii) Relations involving broken sequences (denoted by /) - I/, n/, BN (Backward next)/ - are noticed before periodic relations

---

[†] A full list of the hypotheses can be found in Kotovsky and Simon (1973, pp. 400-402).

TABLE 2[†]

DIFFICULTY MEASURES[a]

		Mean Time	Number correct
		Group of 14 Ss	Group of 14 Ss
P1	ededed	19.6/1	14/1
P2	aaabbbcccdd	33.7/2	11/6.5
P3	atbataatbat	114.5/10	10/10
P4	abmcdmefmghm	30.1/3	13/3
P5	defgefghfghi	111.1/9	11/6.5
P6	qxapxbqxa	162.4/12	8/12.5
P7	aduacuaeuabuat	177.0/14	7/14
P8	mabmbemedm	73.9/5	10/10
P9	urtustuttu	87.1/7	6/15
P10	abyabxabwab	52.2/4	13/3
P11	rsedstdetuef	86.4/6	11/6.5
P12	npaoqapraqsa	149.6/11	13/3
P13	wxaxybyzczadab	175.8/13	8/12.5
P14	jkqrklrslmst	100.1/8	11/6.5
P15	pononmnmlmlk	199.6/15	10/10

[a] Rank order after slash /.

[†] After Kotovsky and Simon (1973), page 403.

(denoted by <>)<N>, <BN>. The method of presentation was thought to be a contributing factor to this finding.

Another feature noticed was the "double next" relation (labelled N^2). This can be derived simply by applying N twice. Some subjects changed part of the sequences to counting sequences, that is substituting numbers for letters and then employing the N relation on the alphabet of integers.

(3) Periodicity. After noticing some significant feature or features, most subjects found the periodicity in the sequence. They then used this in constructing a pattern description. Where they did not find a period or where they found the wrong one, they failed to solve the problem.

(4) Pattern Descriptions (Concepts). There is a general agreement between the theory proposed in Simon and Kotovsky (1963) and the findings relating to pattern description in this study. More specifically, subjects possess a pattern generator that solves patterns by generating and fixating a pattern description associating the relations I, N, BN, with the serial positions within the period of the sequence. Most of the concepts used were describable (in expanded form) in the language used.

(5) Initialization. Once the subject has attained a pattern description from the sequence he then uses the pattern description to extrapolate the sequence. Generally, in order to use a pattern description to produce an extrapolation, a subject has to initialize (set a pointer). Subjects tended to use the beginning or middle initializations on harder problems, and end initialization on the easier problems.

(6) Errors and Sources of Problem Difficulty Among the errors noted were extrapolation errors and concept errors. The most frequent errors were in extrapolating correct concepts. Subjects had obtained a [illegible] pattern description but were unable to use it to produce [illegible] correct extrapolation. In addition, placekeeping as a source of error was also evident. The subject had difficulty utilizing more than one placekeeper during extrapolation. This difficulty was due to the subject's inability to assemble or use coherent pattern descriptions and the subject's avoidance of the memory burden by extrapolating by position.

> "In extrapolating by position the letters occupying a specific position in the period of the answer are initialized and extrapolated separately from the letters occupying other positions. When a problem is classified as extrapolated by position, every position for that problem was initialized and extrapolated separately." (Kotovsky & Simon, 1973, pp. 417)

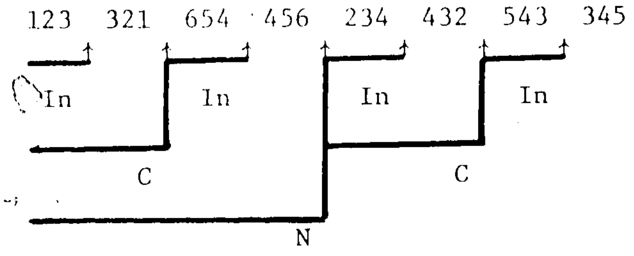
The authors concluded that as a result of their findings an enlargement of the pattern description language is needed to account for the hierarchical nature of certain concepts used by subjects.

The most recent research that has dealt with serial pattern learning has been that of Jones (Jones & Zamostny, 1975; Jones, 1976a; b). Jones and Zamostny (1975) conducted two experiments that investigated memory load, rule frequency and rule arrangement in the prediction learning of serial digit patterns. Support for the hierarchical models of serial pattern learning proposed by Restle and Simon has come mainly from studies (e.g. Restle & Brown, 1970c) that compared prediction learning of hierarchical patterns with that of randomly arranged pattern subgroups. Alternatively Jones and Zamostny's study attempted to reveal the flexibility of subjects in adjusting to nonhierarchical rule structures. They compared the learning of linear and hierarchical patterns. In experiment 1 the structural form of the patterns differed in relative rule frequency as well as in memory load per rule. Experiment 2 had identical rule frequencies but differed in memory load and rule arrangement.

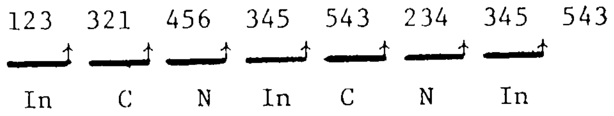
Two hierarchical patterns and 1 linear pattern of 24 digits (a finite digital set of 1→6) were constructed for experiment 1 (explanation of a linear pattern and its hierarchical counterpart is shown Figure 3). Each digit appeared in the window of a memory drum, in the spatial location compatible with its numerical value. The digits appeared at a rate of one per second with a two second pause separating the lower order digit groups of three. The anticipation learning procedure was used, with a 4.3 second interval between pattern repetitions. Subjects were informed that specific rules were used to construct these patterns and that they had to learn the different rules if they were to accurately anticipate the sequence. The criterion was two perfect pattern repetitions.

A characteristic jagged profile was found when mean predicted errors were graphed against serial position. The finding was as expected. Errors appeared to be related to the relative rule frequency, with more frequently occurring rules gathering fewer errors. The differences between linear and hierarchical forms resulted from the fact that rules in the latter patterns occurred with relatively frequencies of 4:2:1, while linear patterns had rule frequencies consistent with 3:2:2. This led to a difference in the gradient of prediction

Hierarchical pattern



Linear pattern



The three rules applied to these expanding series are: -

In = Inversion → reverses prior events in the pattern.

C = Complement → converts a digit to its compliment in the alphabet.

N = Next → adds or subtracts one unit depending on the context.

Figure 3

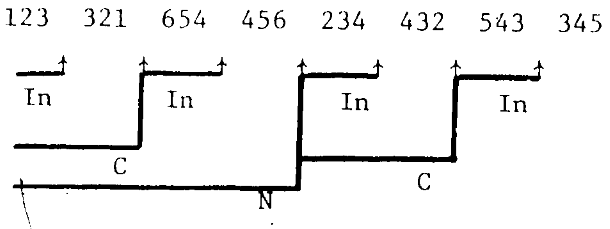
Example of Hierarchical and Linear patterns as generated by Jones and Zamostny (1975).

errors. Subjects predicting linear patterns found the first halves of these patterns easier than did the subjects predicting hierarchical patterns. However the reverse was true for the second half of the patterns. Jones and Zamostny explain this via the subjects' working memory strategies.

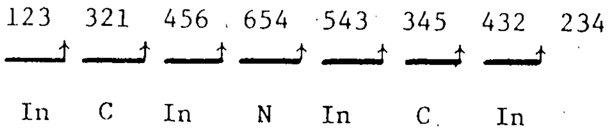
> "This is because hierarchical and linear patterns both incorporate all three component rules in their first halves, but these rules overlap and apply to increasingly larger units in hierarchical patterns. With linear patterns the inversion, complement, and next rules only apply to three prior events and hence place fewer demands on memory. However if a subject recalls the first 12 digits in a linear pattern and the next rule, this only guarantees her correct predictions of the next 3 digits not the remaining 12. . . . In contrast once a subject has mastered the first half of the hierarchical pattern the entire second half can be generated with the recall of a single rule." (Jones & Zamostny, 1975, pp. 300)

Similar procedure was used in experiment 2 as in experiment 1. The relative rule frequency was held constant and three conditions were used corresponding to three different patterns. (1) Hierarchical pattern, (2) linear symmetrical pattern, and (3) linear random pattern. These were generated via three basic rules, Inversion, Next, and Complement. The relative rule frequency was 4:2:1 (4In; 2c; 1N). Figure 4 was drawn up to show how these patterns were generated. Results showed that predictions differed significantly across these three conditions, it would appear therefore, that relative rule frequency is not the sole determinant of performance. Patterns that involved well structured

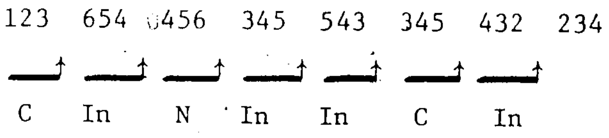
Hierarchical pattern (H-P_1)



Linear symmetrical (LS-P_1)



Linear random (LR-P_1)



All patterns in this example use the rules in the ratio 4 (Inversion): 2 (Complement): 1 (Next).

Figure 4

Jones & Zamostny (1975) Expt. 2. use three conditions of pattern generation (a) Hierarchical pattern (b) Linear symmetrical (c) Linear random. All generated using the ratio 4:2:1.

subsymmetries were easier predicted than those with random rule application. Subjects predicting the linear random sequences responded to advantageous serial placements of several rules. Rules occurring near the beginning and end of a series are easier to learn than those in the middle. In summary, Jones and Zamostny state that both the nature and serial location of component rules are important determinants of serial event prediction and overall learning. They feel that these factors and distinctions between underlying surface regularities have not been adequately represented in current theories of serial pattern learning.

Serial Pattern Learning: Theory

Theoretical considerations of Serial Pattern Learning have been evident in the literature over the past two decades. Since Lashley (1951) outlined the problem of serial order, many authors have used a great deal of empirical data to formulate theories of how a person integrates a sequence of responses that are organized in some meaningful way. It is not intended, here, to outline all the theories of serial pattern learning. The contemporary theories to which the data has been presented will be reviewed. These theories fall into category under the names of the researchers concerned. The order of presenting these theories has no significance.

W.R. Garner

Although Garner (1974) has not proposed any theory relating to the perception and learning of temporal patterns, he has suggested certain principles that control performance. He refers to these principles as "Holistic Organizing Principles of Perceptual Organization".

From the research data he has accumulated he has noted that holistic configurational principles are operative during the perception and learning of the binary event pattern sequences. These principles that a subject uses are:

(a) Temporal Balance. Using "X" and "O" to denote the occurrence of a binary [illegible] the subject seems to prefer the events to be balanced (e.g. XXXO[illegible] would be 3,2,2,3).

(b) Temporal [illegible]ession. The pattern should progress in a left-to-right manner. [illegible] preference [illegible] r patterns would be given to XXXXOOOXO, which wo[illegible] 3,1,1.

(c) Temporal [illegible] subje[illegible] had preferred events in the sequence 5,1,2,1 then a [illegible] second preference would be 1,2,1,5.

(d) Figure Ground Eff[illegible] Pre[illegible]ser, Garner and Gottwald (1970) investigated which of the binary events was the "figure" and which was the "ground". They worked from the assumption that the two-element binary sequences are made up to two, one-element sequences. Their results showed that structure or simplicity did not determine which is figure and which is ground, and that the determination of figure-ground affected the perceived goodness (Gestalt) and difficulty of the pattern. One of Garner's major concerns has been his distinction between perception and learning. Although his studies have shown many underlying commonalities between the two processes, with respect to organization of temporal patterns, the differences observed serve as the distinguishing factors. Temporal patterns, that Garner believes rely mainly upon perceptual organization, have a stimulus presentation rate of 2 events per second or faster. Results show that this gives the subject an experience so strong that the pattern has a distinct beginning and end.

If it is terminated at some point other than its natural ending a sense of incompletion occurs.

Tasks that are presented at slow speed (one event per second or slower) and fast speed (two events per second or faster) are processed differently by the subject. Garner (1974) demonstrated this difference by the effects of two variables. At slow presentation speeds, how the sequence is started has a great effect upon performance (non-preferred starting position giving poorest performance). The starting point of the sequence had no effect at faster presentation rates. The second variable that distinguishes between perception and learning is modality of stimulus presentation. At high speed of presentation modality has some effect upon performance. Temporal patterns are processed more easily in an auditory mode. This appears reasonable since audition is easily adapted to cope with temporal properties of the stimuli. However at a slow speed of stimulus presentation modality has no effect. From this evidence Garner proposed that each event is encoded into a different form, which is thought to be verbal. The fact that such encoding occurs early, on essentially the first trial, is suggested by the strong interfering effect of starting position on the pattern. This encoding is thought to be the underlying factor that differentiates perception and learning.

Garner sees the process of perceiving organization as quite straight forward and does not involve very high level cognitive processing. The alternative approach to the processing of temporal patterns involves rule learning of complex strings of elements (Restle, 1970).

> "There is a possibility that the two approaches will interrelate, but not perfectly. If so, then I would expect the approach I and my coworkers used to be more successful in situations that are clearly perceptual, and at rates of presentation now allowing much high level cognizing on the part of the subject. Alternatively, the rule-learning approaches should be more successful in situations where more complex behavior can be engaged in." (Garner, 1974, pp. 66)

F. Restle

Throughout his research into the area of serial pattern learning Restle has proposed and modified his theories to account for the data. Restle's theory of two-choice behavior, ("simple grammatical theory" (Restle, 1967)) will not be dealt with here. The six-choice systems provide a clearer view of the underlying process. Therefore Restle's (1970) theory of serial patterns via "Structural Trees" will be given consideration.

The theoretical problem was divided into two fundamental areas:

(a) A study of the parts into which subjects subdivide long serial patterns and the structure of that part.

(b) The relationship between parts and the way they are connected together to generate the whole sequence.

In all of his experiments Restle found that two prominent organizing tendencies were evident. The subjects organized the patterns into runs and trills (explained earlier). The data confirmed that (i) the later events in a run are learned with very few errors. (ii) Runs are frequently overextended (e.g. after (2,3,4,5) subjects will predict 6 even if it is incorrect). (iii) The use of trills as sub-sequences can be detected but this tendency is noticeably weaker than runs. This would give information relating to the first theoretical problem, that of structure of parts, but it says little of how subjects come to impose this structure upon the pattern to be acquired.

The second problem, that of relationship of parts, led Restle to proposing the "E-I theory" (Events and Intervals theory). Let $E = \{e_1, e_2 \ldots\}$ be the of events, and $I = \{i_1, i_2 \ldots\}$ be the set of intervals. If $E = \{2,3,4,5\}$, $I = \{-1\}$, the starting point within E has been designated at 5, then the (E,I) pair will determine the sequence (5432). The rule system that generates runs and trills are then uniquely determined by the E-I rule system. However the trill gave Restle difficulty. If $E = \{3,4\}$ and $I = \{-1,+1\}$ then the sequence produced would be (3434....). This means there is no way within the rule system of terminating the sub-sequence at the correct point in the pattern.

This theory of subunits is not itself a theory of serial pattern learning until it explains how the subunits are integrated together. Restle's "Recursive E-I" theory gave an economical approach to the integration of sub-sequences. This theory combines E-I rule systems by a similar event, interval equation. For example the sequence (123234) cannot be generated unambiguously. It is therefore necessary to divide this into subparts that can be unambiguously generated by the E-I rule system. This would give, $[E = \{123\};\ I = \{+1\}]$ which shall = A and $[E = \{234\};\ I = \{+1\}]$ which shall = B. Therefore the high level generating system is $C = [\{A,B\};\ \{-1\}]$ where -1 refers to the transition between 3 and 2 in the middle of the sequence (123_234). This however was Restle's second problem. How did subjects combine two E-I rule systems? This Recursive theory dictates that it is combined at the transition, but this is not necessarily the case. This problem together with the infinite trill series led Restle to propose a much more general and complete theory, that of a structural tree.

> "The general idea of a truly hierarchical model for sequential learning is that the total sequence 'concept' or system of rules serves to generate a sequence of certain elements." (Restle, 1970, pp. 486)

An example of a structural tree and an explanation of the language Restle uses is given in Figure 5. In an unpublished study reported by Restle (1970), results showed that the difficulty of any location might be predicted from the level of transition immediately preceding it. The level in the structural tree that the subject is operating at would then determine the difficulty of transition between subunits. The structural tree allowed Restle to resolve the problem of ending and connecting subparts, also the problem of the infinite trill series was resolved. (The theory of structural trees would generate (3434) as R T 3.)

The simple binary structural tree however finds difficulty in expressing a relatively long run (e.g. 11223344). An extension of Restle's theory assumes the construction of a "Right-Branching Tree". For the development and language used in this tree see Figure 6. Restle's theory and language can now be used to describe most complex organization of patterns. In addition to this rather complete theory Restle (1973) studies three higher order transformations that were not included in his earlier theory. These were Extension ((12) into (123)); Elaboration ((345) into (334455)) and Interspersal ((222) + (456) into

M: Mirror image

T: Transposition

R: Repeat

e.g. If x = (1,2)

M(T(R(x))) = M(T(R(12)))
= M(T(1212))
= M(12122323)
or = 12122323 65655454

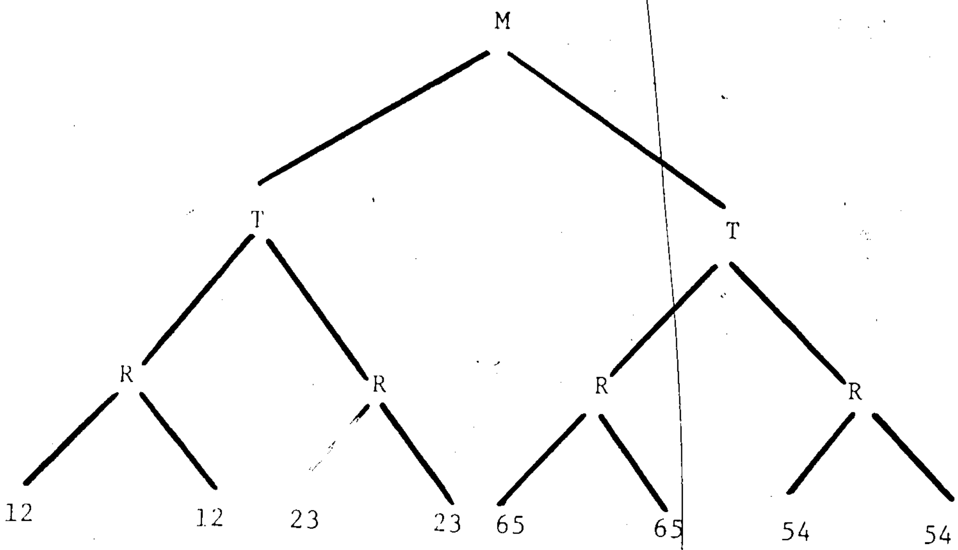


Figure 5

Restle's (1970) Structural tree and language of description

In a *binary tree:*

$$S \rightarrow S_1 + S_1'$$

where S_1' is some transition from S_1

But in a *right-branching tree*:

$$S \rightarrow x + S'$$

where x is either an element or a small subtree

Therefore: -

(12345) can be written as $T^4(1)$ the superscript shows how many times the transition is still to be used.

$$T^4(1) \rightarrow 1 + T^3(t(1))$$

where t(1) is the *transpose* of 1 namely 2

$$\therefore \quad T^4(1) \rightarrow 1 + T^3(2)$$

continuing until

$$T^4(1) \rightarrow 1 + 2 + 3 + 4 + 5$$

OR

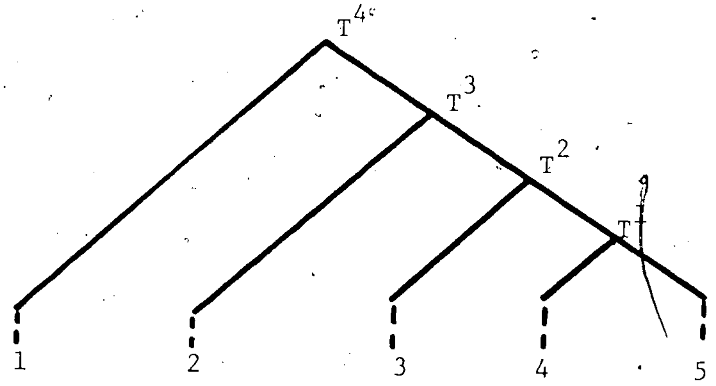


Figure 6

Restle's (1970) Right Branching Tree. An extension of the structural tree.

(242526)). The purpose of his study was to determine if subjects can detect and make use of these higher order structures and benefit from the resulting regularity in the sequence. These higher order transformations act upon the structure of the pattern but not upon the events in sequence (e.g. similar to grammatical transformations that act upon the phrase marker but not upon the words of a sentence).

Results showed that Extending and Interspersing allowed the subject to retain lower order structures he may have already educed while he builds upon them. Both transformations facilitated performance. The transformation called Elaboration forced subjects to disrupt a lower-order structure they already had learned and replace it with a new lower-order structure, while retaining the nature of the structure of the old sequence as a guide for assembling new substructures. This transformation did not significantly improve performance. However, the actual sequence the subjects had to learn was extremely complex and more trials may be needed before the subjects show any differential performance with respect to this transformation.

H.A. Simon

The problem solving approach used by Simon and co-workers is based on the idea that a subject must induce a conclusion consistent with a series of prior events in a sequence. The conclusion is in the form of a principle that generates the series. Simon and Kotovsky (1963) assumed that, by developing a description of the sequential pattern in some of the items, the subjects would learn or discover the principle. The subjects were thought to use this description to generate the next item and then compare the generated item for consistency with the real next item.

Simon (1973).reviews this, and other theories in a paper that emphasized the importance of an encoding analysis of serial pattern learning. He uses the contemporary information processing analysis of the phenomena.

> "Information theory does not provide us with an unambiguous index of sequence complexity, but only measures complexity relative to some particular code. The complexity rankings of the sequences in a set can be changed at will by altering the encoding scheme on which the index of complexity is based." (Simon, 1972, pp. 371)

The encoding alphabet used in the patterns yield varying amounts of information (measured in bits). For example an alphabet of digits allows more than 3 bits of information ($10>2^3$) and the Roman alphabet can encode between 4 and 5 bits per symbol ($2^4<26<2^5$). Miller's (1956) chunking hypothesis shows the need for code lengths to be measured in symbols and not bits. The E.P.A.M. (Elementary Perceiver and Memorizer) theory of verbal learning (Simon & Feigenbaum, 1964) states that fixation of long term memory requires a constant time per symbol (or chunk) and not a constant time per bit. Anything recognizable by a subject as a chunk, as the result of previous training or experience, is assumed to be codable into a symbol. These symbols then compromise the available coding alphabet. The judgment of complexity is then influenced by the presence or absence of a particular alphabet in long term memory.

Simon (1972) defines common pattern of the sequence as the number of symbols in the encoding when the alphabets and coding procedures common to the culture are used. The complexity of the sequence is measured by the length in symbols of this pattern. A pattern is a finite string of symbols that states the rule governing the indefinite continuation of a nonterminating sequence. The language used therefore must express: the relations themselves; the names of the symbols that enter as dependent variables; and names of the symbols that enter as independent variables. An example Simon uses is the pattern sequence (ABCD. . .). This is broken down to symbolic language:

$S_0 = A; Si = n((Si - 1)); i(1:*)$

S indicates member of the alphabet

* would mean the sequence extends from one to infinity.

The complexity index would be 24. This is a counting of all symbols and punctuation marks.

Relations used: s = repeat (same as Restle's "r")
n = next (same as Restle's "t")
p = immediate predecessor
ck = complement (when k is an integer)
\+ = sum (operation on integer)
\- = difference (operation on integer)

Simon criticizes Restle's use of m relation (mirror) in order to permit complementation.

> "He (Restle) does not, however, use the relation consistently, and hence his various examples do not all fit the same definition of it." (Simon, 1972, pp. 374)

Simon's model is named a push-down encoder. The learner applies the rules (outlined earlier) successively but always to the first group of digits. Rules now become operations upon the alphabet. These reset a working memory marker in that list after each group is generated. In this model the person copes with memory limitations by relating upcoming events only to the initial terms. Simon argues that Restle's generative formula places high memory load on short term memory which is in fact equal to half the list. Simon's concept of a push down list allows only the first 3 or coded element to be held in working memory.

Complexity and difficulty have been well distinguished by Simon (1972). He believes sequence complexity can be measured against sequence difficulty. The length of the encoded pattern is the basis for the subjects' judging the complexity of the sequence. As Glanzer and Clark (1962) have noted in their "verbal loop hypothesis", in a perceptual recall task the subject translates visual information into a series of words. The subject then holds this verbalization in memory and makes his final response on the basis of that. Complexity is identified with the length of the subject's verbalization. Complexity is divided into two categories: a priori complexity is the complexity as the experimenter views the task; judged complexity is the complexity which is subjectively judged by the subject. Difficulty is the objective measure of the subject's performance. There are three measures of difficulty then available to the subject: (a) difficulty of discovering the pattern, (b) difficulty of fixating the pattern in long term memory, and (c) difficulty of holding in short term working memory place keepers required to produce the sequence for patterns. These measures are consistent with Simon and Kotovsky's (1963) theory that leads to the computer program of a pattern descriptor and pattern generator.

M.R. Jones

Jones (1976a) offers a linear alternative to both Restle and Simon. According to Jones both Simon and Restle have found support for their theories in the jagged shapes of serial pattern profiles that arise with prediction learning of hierarchical patterns. The "linear encoding model" proposed by Jones places fewer constraints, than other models, on overall rule distribution. This model assumes limitations on working memory (as does Simon (1972)). The learner is seen as applying rules to the presented string of events (similar to Restle (1970)) and not as operating upon the alphabet list (as Simon (1972)) does.

The rule language and notations are very similar to Restle's (1970). These are given in detail with examples in Table 3. Jones uses n (for next) as equivalent to Restle's t (for transpose). A comparative example of a hierarchical sequence as opposed to a linear sequence is given in Figure 3.

The problem of nominal, ordinal or interval patterns is also included in Jones' model for serial pattern learning. The nominal relationships such as same and different have been investigated by Garner (1974), and Vitz and Todd (1967). Whereas the ordinal relationships (i.e. greater or less) and interval relations (e.g. +1, +2) have been researched by Kotovsky and Simon (1973), Restle and Brown (1970a, b) and Jones (1974).

The rule system permitting a priori manipulation of these several levels of structure is described by Jones (1976) and shown in Table 3. The set of rules in Table 3 form a larger group of rules, and the entire rule system Jones refers to as the Group Grammar System. The

TABLE 3[†]

RULES, RULE NOTATION, AND EXAMPLES OF RULE APPLICATION TO A DIGIT-GROUP i FOR TWO RULE SETS

Rule	Notation	Definition	Exemplar[a]
		Set 1	
Identity	I	$I(i) = i$	$I(i) = 123$
Transpose	T	$T(i) = i + \Delta$	$T(i) = 456$
Complement	C	$C(i) = 2\Delta + 1 - i$	$C(i) = 654$
Reflection	R	$R_\ell(i) = \Delta + 1 - i$ (if $i<\Delta$) $= 3\Delta + 1 - i$ (if $i>\Delta$)	$R_\ell(i) = 321$
		Set 2	
Identity	I	$I(i) = N^5 = i$	$I(i) = N^6(i) = 123$
Next^1	N^1	$N^1(i) = i + 1$	$N^1(i) = 234$
Next^j	N^j	$N^j(i) = i + j$ for any j	$N^2(i) = 345$ for $j=2$
Next^{-j}	N^{-j}	$N^{-j}(i) = i - j$ for any j	$N^{-2}(i) = 561$ for $j=2$

Note: Alphabets of both rule sets (S) are 6 digits: 123456; $\Delta = S/2$.

[a]1 = 123.

[†] After Jones (1976), page 477.

rules from Set 1 give both nominal and interval rule regularity in their relations, e.g.:

$$1 \xrightarrow{T} 4 \xrightarrow{R_\ell} 6 \xrightarrow{C} 1 \xrightarrow{T} 4 \xrightarrow{R_\ell} 6 \xrightarrow{C} 1$$

when the rules are combined to repeat a rule sequence (T, R ,C) the result is the identity rule.

When Set 2 rules are applied in the same fashion, they only give interval rule regularity. The result is other "next" rules, e.g.:

$$1 \xrightarrow{N^1} 2 \xrightarrow{N^2} 4 \xrightarrow{N^{-1}} 3 \xrightarrow{N^1} 4 \xrightarrow{N^2} 6 \xrightarrow{N^{-1}} 5$$

(N^1,N^2,N^{-1}) is repeated and the rule produces 5 not 1.

This Group Grammar System is said to illustrate a connection between the opposing theories and principles offered in this paper.

Serial Pattern Learning: Organization and Acquisition of a Motor Act

The majority of the literature on serial pattern learning has looked at how subjects organize a sequence of patterned events. These events being, the occurrence of a set of six lights (Restle & Brown, 1970a, b, c); the presentation of two lights or sounds (Garner, 1974); the presentation of a sequence of digits on a memory drum (Jones & Zamostny, 1975); the presentation of a pattern, formed by letters of the Roman alphabet (Kotovsky & Simon, 1973); the presentation of sequence made from the alphabet of two letters (Keller, 1963, cited in Restle & Brown, 1970c). The general procedure used has been for the subject to anticipate the occurrence of each stimulus event. The anticipatory response has ranged from, pressing a button, to turning on a light, to writing down the next occurrence on a piece of paper. The problem has been one of stimulus organization. The actual execution of the response has been of secondary importance to many of these studies.

The exception to this general trend has been by researchers of Motor Skill learning and performance. Fitts and Posner (1967) believe the performance of a skilled act invariably involves an organized sequence of activities and that, intrinsic to this performance, is the organization of movements and the organization of symbolic information. According to Robb (1972), what is learned, during the early stages of sequencing a motor skill, is the serial, sequential organization and hierarchical structuring of simple movement components that bring about a successful outcome. In a similar way Miller, Galanter and Pribram (1960) discuss elemental T.O.T.E. units becoming organized through learning, into complex behavior repetoires.

The assumption made therefore, is that skilled behavior which brings about a predetermined end result is learned behavior; it is complex behavior, in terms of the sequential and hierarchical ordering of simple response units; and it is also intentional.† The execution of a skilled act depends upon the organization of these sub-skills that make up the complex behavior.

The purpose of this series of experiments is to investigate the organizational units a person would use to acquire a complex motor act made up of a sequence of patterned movements. A pursuit tracking task will serve as the vehicle for analysing such skilled performance.

Pursuit Tracking

Poulton (1957a) has suggested that pursuit tracking can be recommended as a task for study in the laboratory for several reasons:

(a) Target movement can be varied along psychological dimensions from simple and repetitive to more complex and irregular.

(b) Frequency and amplitude can be varied.

(c) Both input and response can be recorded simultaneously.

The nature of the match or mismatch between stimulus and response enables the experimenter to specify some of the psychological processes which are involved in the performance.

The decision to make rapid aiming movements involves predictions. These predictions are part of a simple learning process (Poulton, 1952).

---

† "Whatever processes may be involved in human skill learning and performance, the concern is with *intentional* attempts to carry out motor act which will bring about predetermined end results." (Whiting, 1972b, pp. 10)

The subject makes a particular response because he believes that from past experience he should be correct. For the subject to be correct he has therefore, to know in advance the position which the target will occupy at the time his response movement finishes. Two possible sources of information are available to the subject. Poulton (1952a) describes these as "receptor anticipation" and "perceptual anticipation":

(a) Receptor Anticipation. When information is presented to the subject in advance, his use of this advance information is called receptor information (e.g. any spatially extended display which is visible for certain distances ahead of the point at which responses have to be made).

(b) Perceptual Anticipation. When no advance information is given, but the subject is able to deduce the nature of the future signals from his past experience, his use of this information is called perceptual anticipation.

When the subject is involved in "perceptually anticipating" the track, he can use two sources of information (Poulton, 1952b). These relevant sources of information are "velocity" (possibly acceleration) and "course":

(a) Speed Anticipation. From this the subject can predict the position of the pointer one response time later and thus achieve approximate alignment at this time.

(b) Course Anticipation. This is used when a subject draws from memory information about the characteristics of the course. Although speed anticipation is important at the early stages of track acquisition, the present speed of the stimulus pointer becomes of less value to him. However the subject relies heavily upon course anticipation throughout the experiment (Poulton, 1952b).

Learning the statistical properties of the input has been investigated by using step-function tracking. Poulton (1957b) had subjects trace with a pencil courses which consisted of constant slopes separated by sudden discontinuities in direction to meet a time criterion. Half the courses were patterned and prediction could be used. Half the courses were not patterned. Results showed that subjects overshot the corners when the position of the corner could not be predicted, either from sequential structure of previous part of non-patterned course or from knowledge of the common statistical properties of the course. This error was significantly less evident when prediction using the patterned course was available.

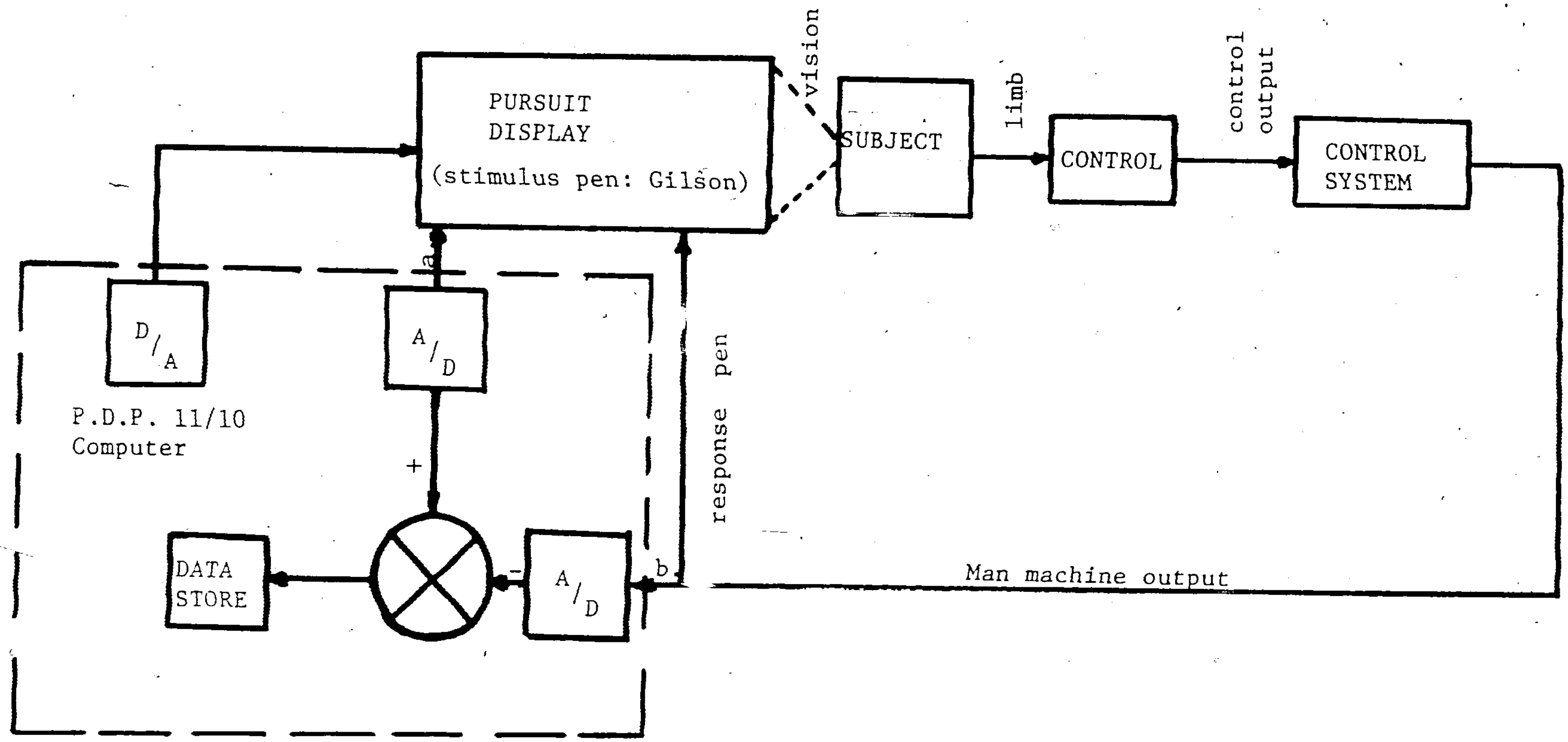
Klemmer (1967) suggests, that in order for the occurrence of the response to be perceived as simultaneous with the perception of the stimulus, the response would have to precede the stimulus. He found that while tracking a binary event (tone) subjects could stay in phase at two per second but difficulty arose only at three per second. Rather than responding after the stimulus as instructed, the subjects responded before the stimulus by several milliseconds. Subjects seem to be synchronizing two responses. Subjects were synchronizing the arrival of neural feedback from the responses. This synchronization was the perception of their own response with the perception of the stimulus. Keele's (1977) view of an "efference copy" appears to be, in some ways, consistent with this explanation. Support of this view has also come from Schmidt and Christina (1969). They found that proprioceptive feedback, in addition to its commonly accepted role as a regulatory mechanism, may also serve as a mediator in tasks requiring precise anticipation and timing of a motor sequence.

Previous research, therefore, strongly suggests that pursuit tracking would be a useful task with which to investigate the acquisition and organization of a motor act.

Apparatus and Task

A pursuit tracking task utilizing step function characteristics was used in the following experiments. A schematic representation of the apparatus is given in Figure 7 and a photograph of the experimental equipment can be seen in Figure 8.

A P.D.P. 11/10 Computer controlled the experiment. A Gilson Polygraph Recorder was modified to be used as tracking apparatus for these experiments (see Figure 9). The computer was programmed to give variable digital-to-analog signals (ranging from 0 → +5 volts) to the servo-channel of the Gilson recorder. A pen (stimulus pen) was mounted on a rack and pinion slide and served as a stimulus pointer. The movement of this stimulus pen was controlled by changes in voltage through the servo-channel, from the computer. The subject held a pen (response pen) which was mounted on a rack and pinion slide in a similar manner to that of the stimulus pen. Both stimulus and response pens were also attached to separate ten-turn potentiometers. A 5 volts supply (Electro Model N.F.B.R. Filtered D.C. Power Supply) was connected to both potentiometers and the output of each potentiometer was in turn connected to one of two analog-to-digital channels of the computer. Therefore when the stimulus and response pens moved, the distance traversed was converted to voltage change at the respective



a. → signal output

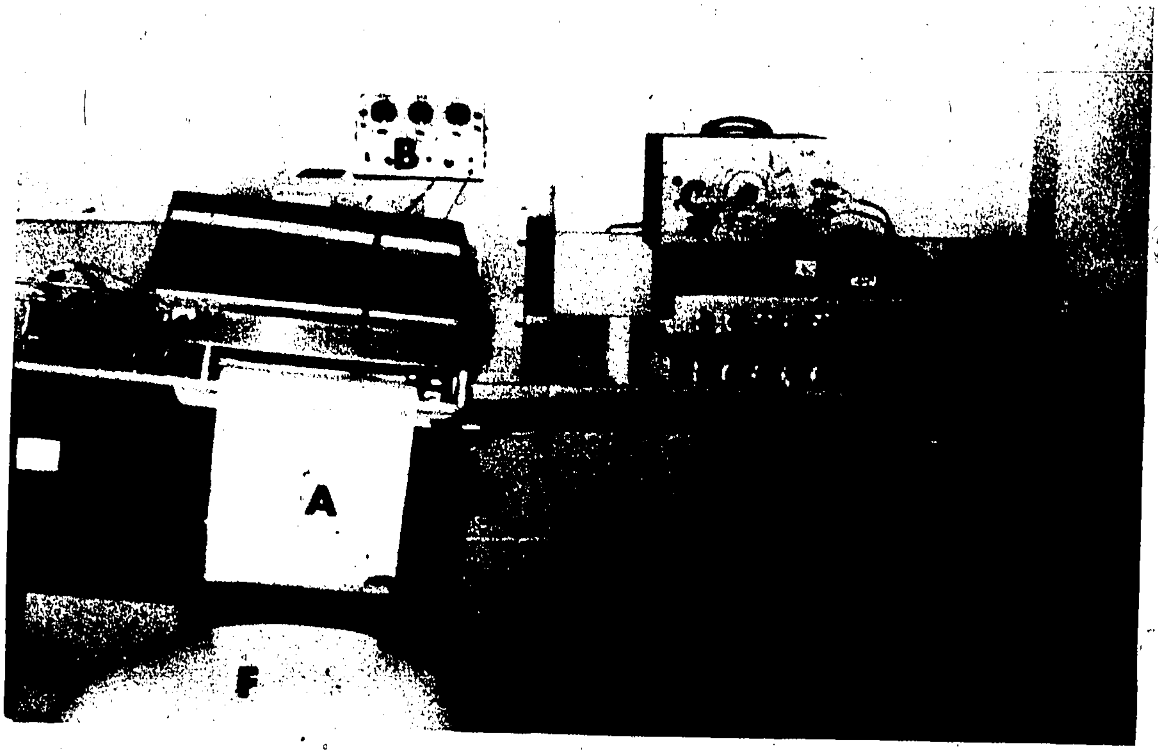
b. → response output

D/A → Digital to Analog

A/D → Analog to Digital

Figure 7

Schematic description of the pursuit tracking task controlled by the P.D.P. 11/10 computer.



A → Gilson polygraph recorder

B → Power supplies

C → Square Wave Generator

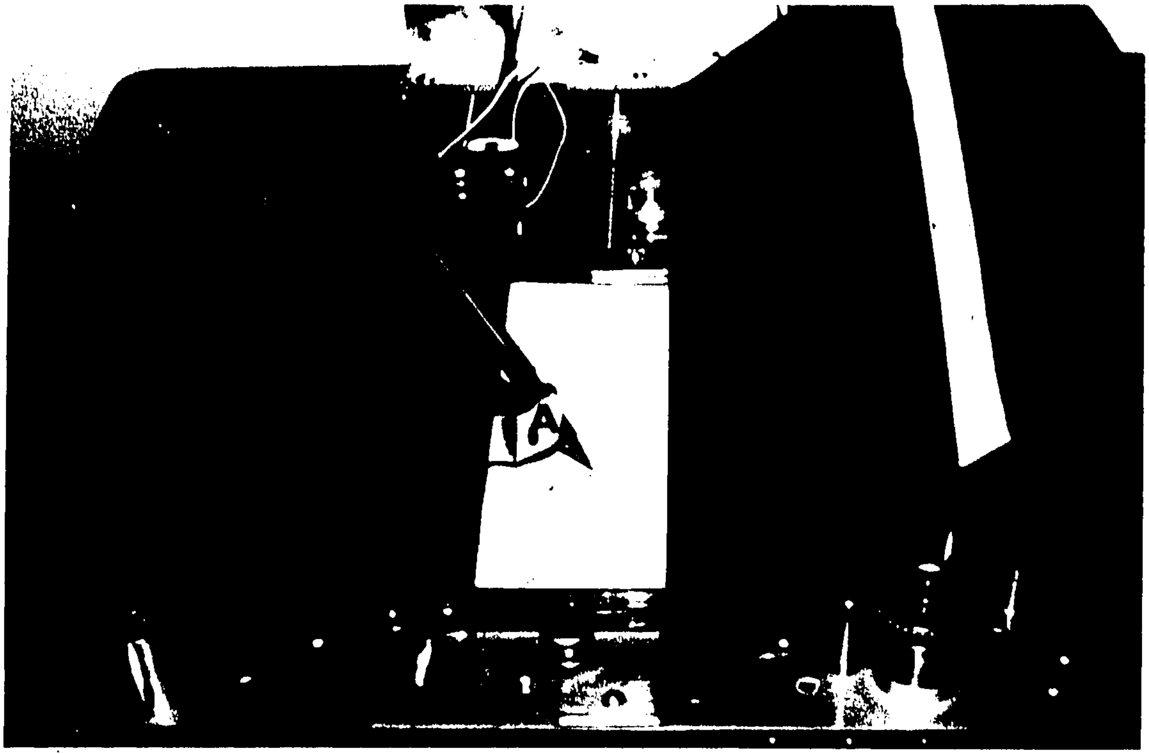
D → Amplifier

E → Speaker

F → Chair

Figure 8

Apparatus used in all experiments.



A → Response pen (experiment I)

Figure 9

Modified Gilson polygraph recorder. Paced contour track used in experiment I.

stored its equivalent digital value (a digital range of 0 → 1023 is equivalent to 0 → +5 volts).

The computer also controlled an auditory tone, which acted as an event indicator to the subject. The tone was generated by the computer activating a solid state switch (via a digital-to-analog converter channel). This switch operated a L.S.I. Bogen Challenger Amplifier and an E.I.C.O. Audio Square Wave Generator.

Both stimulus pen and response pen allowed unidimensional movement, with zero order control. The range of movement of both pens was 180 mm in length. The speed of the response pen was constant through (140 mm per second) the experiments. The rack and pinion assembly allowed resistant-free movement of the response pen.

The task consisted of the subject holding the response pen in his right hand (see Figure 9) and tracking the movement of the stimulus pen. The stimulus pen was programmed to move a predetermined pattern. The acquisition and organization of these patterns by the subjects is the major concern of this series of studies.

EXPERIMENT I

A number of studies have been carried out to demonstrate the effect of increasing track redundancy on a pursuit tracking task. Poulton (1952b), Noble and Trumbo (1967), Trumbo (1970), Trumbo, Fowler and Noble (1968) all came to the general conclusion that the subjects' errors in tracking increased disproportionately when the track's redundancy was decreased. They also found that highly redundant tracks improved tracking performance. Although these studies used continuous[†] pursuit tracking as the required motor response, the organization of this motor response into subjective units was not a major concern to these authors.

An alternative perspective has been taken by researchers, who have structured the stimulus events into a serial pattern, and required a discrete response to each event. Royer's (1967) subjects depressed a key in response to the occurrence of a patterned sequence of binary events (lights or tones). Morgenstern, Haskell and Waters (1971) required their subjects to type out visually presented letters on a typewriter; while Restle and Burnside (1972) presented a sequence of patterned events (six lights) to which the subject had to simultaneously depress a compatibly positioned key. The general findings of these studies suggest that subjects organize their response into subunits of the whole sequence. The results from Restle and Burnside study replicated the main results reported by Restle and Brown (1970a, 1970b, 1970c) and Restle (1970) with regard to serial pattern learning

---

[†] Continuous is used here to distinguish this type of tracking from the discrete event tracking used by authors such as Garner (1974), Keele (1975), Royer (1967) and Restle & Burnside (1972).

by anticipation. All the main indicators of cognitive structure that were found in serial pattern learning were shown to occur in serial tracking. Although these later studies examined the organization of a series of motor responses, the characteristics of the movements employed by the subject indicate the response at the required event, was not controlled or considered by the experimenters.

A complex motor act, consisting of a series of controlled, continuous movements is evident when a subject is engaged in a unidimensional continuous pursuit tracking task. When the characteristics of the track are of a step function nature and these steps are organized into a pattern, it becomes possible to examine the subject's organizational strategies by investigating the location errors made within the sequence.

This experiment was designed to parallel the study of Restle and Brown (1970a) as closely as possible, with the tracking variations that have been outlined earlier. The results will be discussed, and comparisons made, in the light of Restle and Brown's data. It was hypothesized that the subjects would use the organizational units of runs and trills while acquiring this series of continuous, unidimensional movements.

Method

Subjects

Ten graduate students from the University of Alberta participated in this experiment. They all wrote with their right hand.

Apparatus and Task

The stimulus pen produced a series of step functions (Figure 10), marked in green ink on fan-fold Gilson paper (8 1/2 inches wide), which moved toward the subject at a rate of 10 mm per second. The paper was divided into six channels, each channel was 30 mm wide and the boundary lines were marked in red ink. All six channels were centered in the middle of the 8 1/2 inch, leaving approximately 11 mm of non-working area on each side of the paper.

The stimulus pen was programmed (see Appendix A) to move to the center of each channel and remain in that channel for 0.7 seconds, therefore the stimulus pen was stationary for a distance of 7 mm. This pen would then move to the center of another channel at a speed of 140 mm per second and again remain there for 0.7 seconds. The program allowed the stimulus pen to move to twenty predetermined channels in this manner.

The subject was seated in front of the modified, Gilson tracking apparatus, holding the response pen in his right hand. The preview of the contour track was limited to one second with a postview of two seconds. Using a blue marker pen the subject tracked the green stimulus course as closely as possible.

There were two experimental sessions. The subjects were required to track a different sequence pattern at each session. A "Structured Pattern" and a "Random Pattern" were used in this experiment. The structured pattern was generated using the sequence formed by Restle and Brown's (1970a)[†] Pattern 1, Initial form, (1235433234). This sequence was repeated to give a sequence of 20 locations (12354332341235433234). This then served as the Structured Pattern. The Random Pattern was formed by randomly generating 10 numbers from a set of digits (1 → 6). The sequence produced was repeated to give (21364425132136442513). This sequence then served as the Random Pattern.

Design

The experimental design is a repeated measure split plot design, in which subjects are randomly assigned to levels of the first factor and each subject is then tested under all levels of the second factor. The first factor was order of presentation, and the second factor was sequence pattern. Five subjects received the Structured Pattern followed one week later by the Random Pattern. The other five subjects received these two conditions in reverse order, also a week apart.

Both factors are fixed with subjects randomly nested within levels of the first factor.[††]

[†] The lights of Restle and Brown's study relate to the six channels of this experiment. An event (light) occurrence in Restle and Brown's study relate to the movement of the stimulus pen into the respective channels.

[††] See Appendix B for complete table of Source of Variation; degrees of freedom; expected values and appropriate error term.

Procedure

An audible tone indicated a warning to the subject that the experiment was to begin. The contour track moved to home position (see Figure 10). The subject had four seconds to align his response pen with the track. A double tone then indicated the beginning of the track movement. The subject then responded to the contour track of twenty discrete movements which lasted a total of 23 seconds. A further double tone indicated the end of the first presentation of the complete track. The contour track then moved to the home position (far left of paper) for 3 seconds. The subject then tracked the contour to one of the channels, where it remained stationary for 2 seconds. From this channel the track then replicated three movements within the sequence, which the subject was required to track. A double tone was used as a probe to indicate to the subject to move his response pen to the next channel in the sequence while the contour track remained stationary. The subject was instructed to keep his response pen in the chosen channel until he received knowledge of his results. If the subject's choice was correct (i.e. the fourth movement was in sequence) the contour track would move to the far right of the paper and back to home position (giving a "spike" in the track). An incorrect choice would result in the track moving to home position. After a period of 6 seconds at home position the subject would again receive the warning tone that the step function track was beginning. This was repeated for 20 presentations of the same step function track.

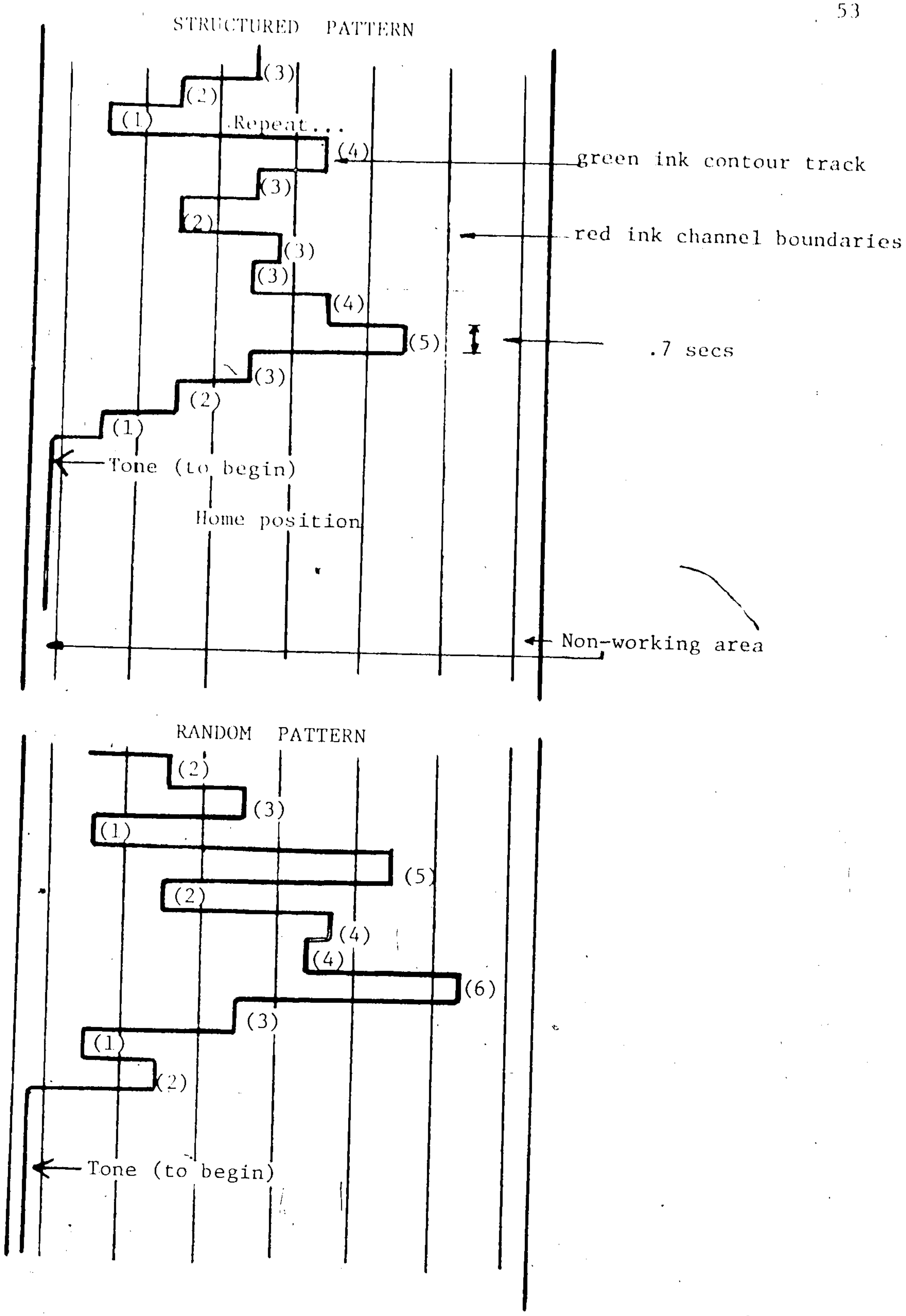


Figure 10

Random and Structured patterns. The path of the contour track in Experiment I. The sequence of 10 was repeated to give a pattern of 20 steps across the channels.

Results

The results obtained in this experiment are in close agreement with data obtained by Restle and Brown (1970a) on their Pattern I Initial Form sequence. The graph in Figure 11 plots the location errors of both the Structured and Random pattern. The two patterns produced quite different detailed performance. A correlation of −0.11 was calculated for location errors between Random and Structured patterns. Using a reflective matrix of a Pearson Product-Moment correlations, no significant correlations were found for errors between each corresponding location point of the Random and Structured pattern.

Table 4 indicates data relating to the effects of presentation order and differences in errors made with respect to sequence pattern. No significant differences ($p > .05$) were found.

By inspection of the Structured pattern profile of errors in Figure 11, the location errors of interest are at serial position 1, 4, and 7. Data relating to these errors are presented in Table 5.

Discussion

The differences between the performance of subjects acquiring the Structured movement pattern as opposed to the Random movement pattern is evident from the data. This suggests that the acquisition of a series of patterned movements was a function of the structure of movements within the series. Conversely, subjects in this experiment did not appear to use the serial list position as an organizational factor.

While performing a complex motor act, subjects used similar organizational units as those proposed by Restle (1970), Restle and

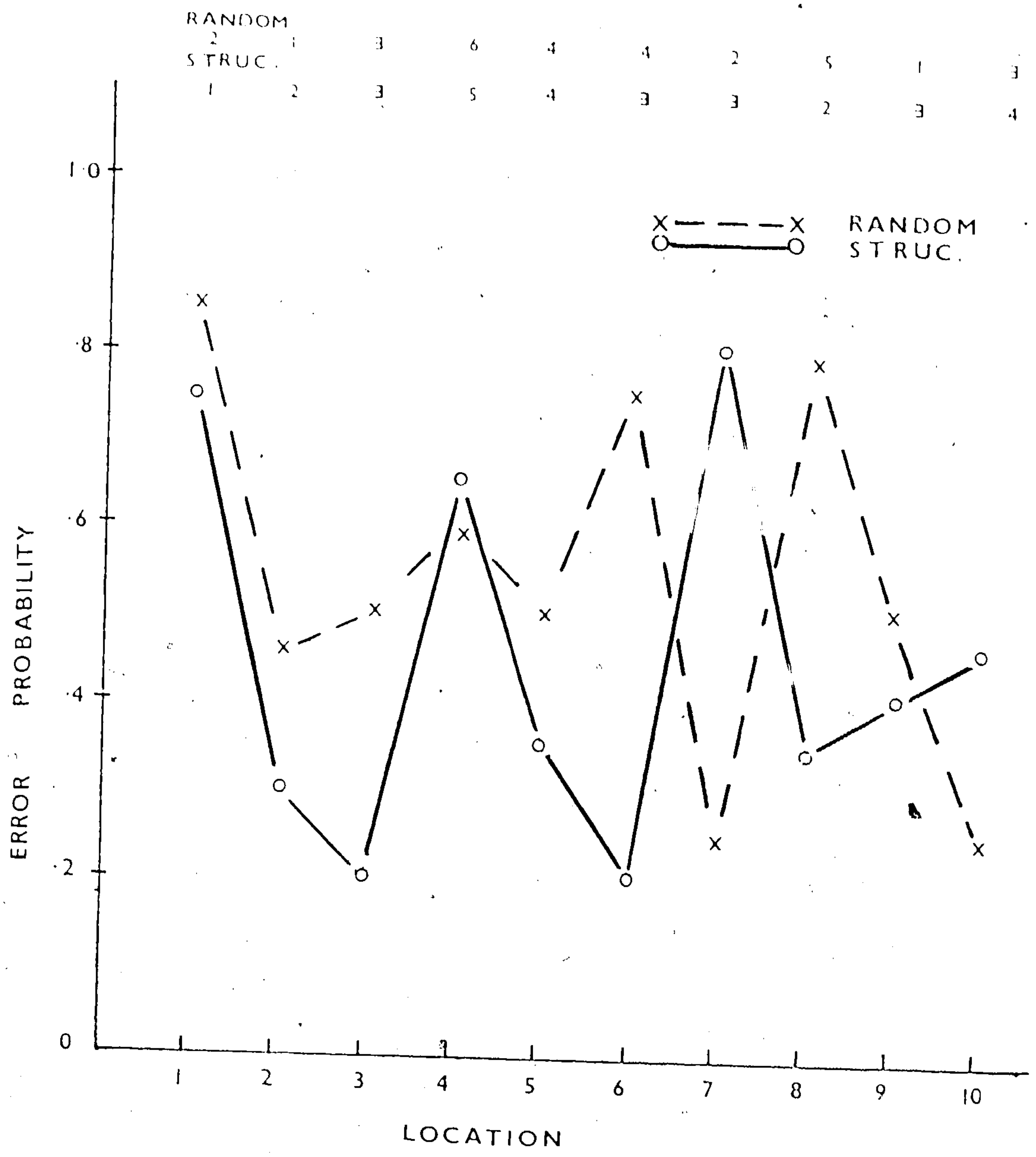


Figure 11

Probability of recall error for the 10 locations of the Structured and Random patterns.

TABLE 4

A.N.O.V.A for Structured and Random Pattern Under Order of Presentation (Expt. I)

Source	S.S.	d.f.	M.S.	F
Order of Presentation (a)	31.25	1	31.25	3.23
Subjects nested within A[S(A)]	77.30	8	9.67	
Pattern (B)	22.1	1	22.1	2.78
A x B	26.4	1	26.4	3.32
S(A) x B	63.5	8	7.94	

TABLE 5

Most Frequent Errors Recorded at Locations 1, 4, and 7, for the Structured Pattern

Location	Channel error recorded most frequently	% of total errors made at that location
1	(3)	40%
4	(4)	61%
7	(2)	38%

Brown (19 , b, c), and Restle and Burnside (1972), these units being runs and trills. The strong tendency for subjects to use runs as a subunit within the movement is supported by the data in Table 5. Subjects erred at location 4 with a response to channel 4, which is a run over-extension of the subsequence (123). A further run over-extension is evident at location 7, with subjects moving to channel 2 after the subsequence (543). Although the trill is not as strong an organizing unit as the run, there is evidence that subjects may transfer this subunit structure once presented with it. For example, after receiving (323) subjects will preferably respond (343), with the last 3 of this sequence being an error in the pattern.

The results obtained in this experiment would agree in part with the findings of Restle and Burnside (1972). These authors concluded that serial information is organized by a rapid process. It would appear, therefore, that the acquisition of a complex motor act, of the type used in this experiment, is controlled by a rule structure. This rule structure divides the task into subunits, each of which is governed by a simple rule system. The subunits of the task are not viewed by the subject as arbitrary, but depend upon the experimentally imposed structure of the task. The subunits used are made up of runs and trills.

Despite the strong support for Restle and Burnside's (1972) findings there were several methodological problems that were inherent in the task. The subjects' use of preview and postview could have reduced the usefulness of the movement information acquired during the task. Although the time between moves (.7 secs) is seen by Restle and Burnside as being insufficient time for verbal description and elaboration, the preview and postview would allow more time for the subjects to use examine the extent of learning at the time of executing the appropriate movement. This procedure also confounded any list effects relating to middle and primary items, by probing positions 1, 2, and 3 in an equivalent manner to positions 11, 12, and 13.

Experiment II was designed to eliminate these problems.

EXPERIMENT II

both the receptor and perceptual anticipation that Poulton (1964) has outlined. The preview of the track in Experiment I allowed the subject to use both receptor anticipation (nulling behavior) and the memory of the track from previous presentations (perceptual anticipation). A method by which this problem could be overcome is to use a pursuit tracking task, where the subject does not track a contour, but he tracks a moving cursor. This would allow no preview or postv[illegible] and [illegible]jects should be responding on the basis of perceptual anticipation [illegible]. With the velocity of the stimulus cursor being held constant, [illegible] only [illegible]ion available to the subject would be the course informat[illegible] [illegible]n, 1974).

Each subject in Experiment I was questioned as to the strategy he used to learn the movement sequence. All of the subjects reported that the time interval between movements within the sequence (0.7 secs) enabled them to encode the track information using numerical values given to each channel. Because of this the subjects stated that the [illegible]tual movement per se was reduced to secondary importance. The comments are in agreement with Garner and Gottwald (1968), in that the sequence of movements is perceived as a succession of single elements that are derived, recoded and intellectualized. Restle and Burnside [illegible]972) however see this process as being very rapid.

> "Tracking, using only about 1 second per event, is so rapid that the subject is likely not to be able to control it by verbal means, so that any structure found in tracking experiments cannot plausibly be attributed to verbal descriptions or formulated hypotheses." (Restle & Burnside, 1972
>
> pp. 30[illegible]

Garner and Gottwald (1968) as being a task predominantly of temporal pattern perception. This rate of presentation is regarded by Garner (1974) as the approximate distinguishing boundary between the processes of perception and learning.

A number of experiments have shown that the recoding and intellectualization processes are intrinsic to the learning of a motor act. Vince (1953) investigated the relationship between intellectual processes and hand movements during the tracking of an irregular zig-zag pattern. He stressed that intellectual activity was important in learning to formulate the problem and to correct errors but could not be considered separate from motor activity, since responses were limited by the "idea of the pattern". The development of intellectual activity was partly dependent upon the character of the motor response and vice-versa. This study was given support by Davol and Quinn (1972) who alluded to a visual and kinaesthetic integrating process that was available to fifth grade subjects. They found that the young subjects had used figural transformations while tracking several spatial representations. The authors suggested that verbal mediation, which involved a transformation of a set of spatial operations into a linguistic construction of the pattern, had been used to learn the task. While manipulating the two variables of display specificity and verbal training, Trumbo, Ulrich and Noble (1965) examined the verbal coding and display coding in the acquisition of a tracking skill. The study was concerned with facilitation of the coding of a skilled task both by increasing the specificity of display cues and by pretraining the subjects on a verbal code to aid in tracking. The major finding of the study was that improved display and verbal code pretraining facilitated the acquisition of a motor skill.

When investigating the acquisition of a motor act (comprised of a sequence of movements), the part played by the cognitive processes early in learning is highly relevant to the execution of the motor response. To attempt to separate the two processes would not only be highly suspect from a methodological viewpoint, but would also be unrealistic to the learning situation. A major concern therefore with this experiment and subsequent experiments is to make the subjects more heavily reliant upon the movement information in the learning of the task. This has been done by reducing the interval between movements within the sequence to 0.5 seconds. This time interval does not violate Garner's (1974) assumptions relating to perception and learning. It also avoids the problems of the psychological refractory period relating to the time interval between two steps within a track. Vince (1948), Welford (1952), and Smith (1967) found that subjects cannot start to react to the second step during his reaction time to the first step. The time interval, between steps, should not be, therefore, equal to or less than one reaction time.

It has been suggested by Whiting (1972a), that at a subjective level, as a person becomes more skilled at a particular task, he needs to give less attention to both display and the actual initiation of the response. A procedure that utilizes this assumption should therefore allow measurement of performance at the various stages of learning within a sequence of patterned movements. The employment of a second task temporarily overlapping a primary task has been the design of a number of human performance studies for a variety of purposes.

Bahrick, Noble and Fitts (1954) used extra task performance as a sensitive measure of learning in a primary task. The effects of secondary verbal tasks on tracking performance were examined by Trumbo, Noble and Swink (1967). While examining the locus of the interference of a secondary task, Noble, Trumbo and Fowler (1967) concluded that attending to and learning a secondary task did not interfere with tracking unless the secondary task was accompanied by overt response selection. However, McLeod (1973), who attempted to replicate Noble *et al's* study, found that Noble's "No Response" group were probably not "attending to and learning" during the experimental task. McLeod found subjects who attended to and learnt a second task had significant decrement in tracking behavior whether or not this second task is combined with a response selection and execution.

If there is differential learning of the movements within a patterned sequence, as suggested by Experiment I, the internalization and reduced utilization of central processing capacity occurs as a result of practice (Bahrick and Shelly, 1958; Fleisman and Rich, 1963; Posner, 1969; Posner and Keele, 1969). Posner and Keele (1969) studied the attentional demands of movements which were controlled by external and internal cues. Delay in a reaction time to a secondary signal was used as a measure of attention to the movement task. The purpose of the secondary task was to absorb the subjects' attention as completely as possible without producing any impediment to the performance of the primary task, except whatever may be the direct results of reduced processing capacity. In an experiment that studied the processing demands during movement, Kerr (1975) used secondary task scores as a measure of processing demands during movement.

During the learning of a patterned sequence of movements, the attentional demands of the task will vary as a function of the structure of the sequence. A probe reaction time, secondary task, given at the transition of the movements within the sequence should be a sensitive measure of the attention given to the subsequent movements. From the results of the first experiment, it can be expected that the attentional demands of the task should be greater at the transitions between organizational units, (e.g. runs and trills) than within organizational units.

In a summary of the literature on time sharing Wickens (1976) identified two specific classes of the effects on information processing that result from the division of attention. The two classes outlined are:

(a) time delay effect - an increase in the time to process the information;

(b) noise-added effect - the reduction in fidelity of the information transmitted or an increase in variability of response.

The attentional demands required in acquiring a sequence of movements should therefore take into account not only the time to respond to a secondary task (probe reaction time) but also the accuracy of the primary task (pursuit tracking) at that time. Therefore a measure of the subjects' lag time, behind the stimulus cursor, during and after the probe was combined with reaction time to give a more complete measure of the attentional demands required. The combination of these two measures served as a dependent variable in the present study.

In earlier studies, that have employed fully predictable step tracking as the experimental task, subjects have been found to use two extreme strategies. Slack (1953) noted that some of his subjects started to move before the step had appeared. The subjects were using what Poulton (1974) refers to as perceptual anticipation. This strategy was labelled by Slack as "locking in". The other subjects in Slack's study employed a different strategy. These subjects had always to wait until a step had appeared before reacting. Zohar (1974) termed this strategy as "wait and move". If the dependent variable of reaction time and lag time is to be a useful measure of the acquisition of a sequence of movements, it is necessary the subjects employ a "locking in" strategy during their task. Training procedures and instructions used by Adams and Creamer (1962a, b), and Noble and Trumbo (1967) was found to be reliable in encouraging subjects to lock in. It is necessary therefore to utilize a pretraining period in which instructions specific to the strategy of locking in are given to each subject prior to the test sequence of movements.

To test the methodological modifications of the present study, a structured pattern, similar to the one used in Experiment I was utilized. Restle and Brown's (1970a) Sequence Pattern I Transposed form was used (2346544345), along with a random pattern (6246223563) which was generated in the same manner as the random pattern in Experiment I. Since Restle and Brown's (1970a) study found both of these patterns (Initial form used in Experiment I and Transposed form) to have significantly parallel location error profiles, it is expected that the location error data obtained in this experiment will be similar to that found in Experiment I

Method

Subjects

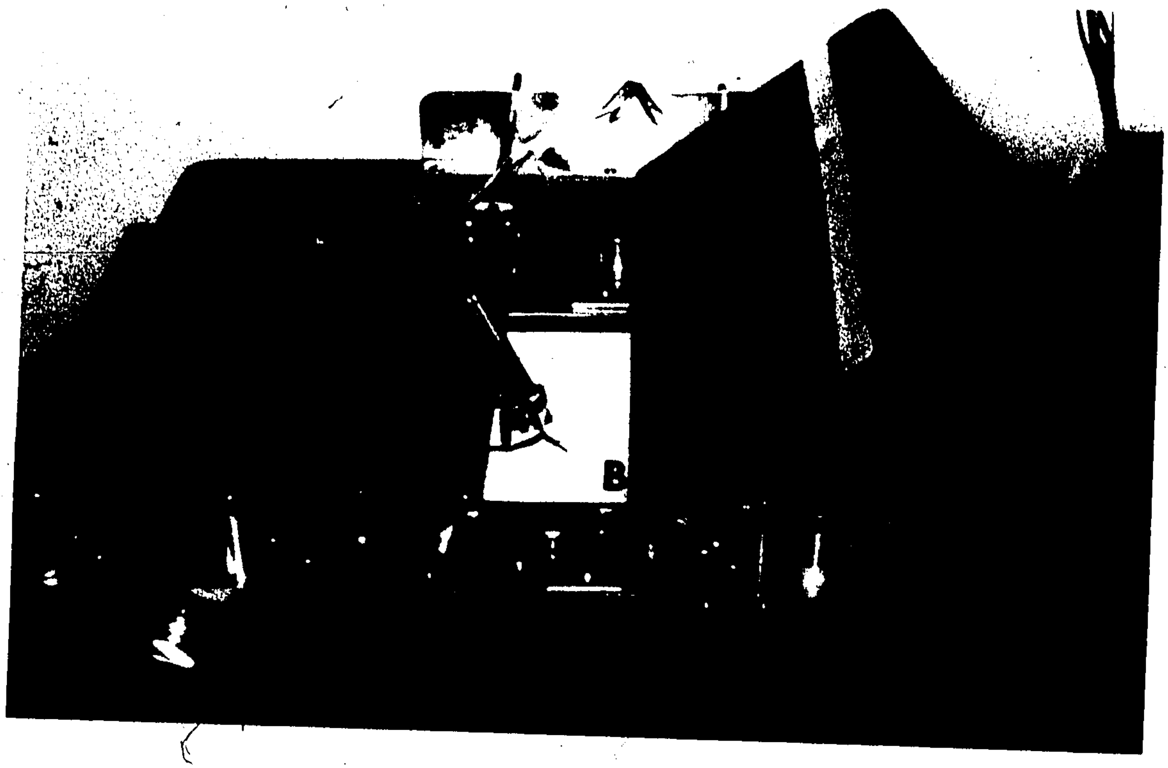
Twelve graduate students from the University of Alberta were used in this experiment. All of the subjects wrote with their right hand.

Design

The experimental design used in this experiment was identical to the one used in Experiment I. A repeated measure, split-plot design in which subjects are randomly assigned to the two levels of, order of presentation, and each subject is tested under two levels of pattern (Random and Structured).

Apparatus and Task

Modifications were made to the tracking apparatus used in Experiment I. The stimulus pen, that had been producing the green ink contour track, had a fine, metal tube cursor attached to it. This cursor extended under the metal shield and was visible to the subject. The paper on which the contour track was marked in Experiment I, was now fixed and served as a white background for the movement of the cursor and response pen. The six channels used in Experiment I were again marked in red on this paper and served as an additional stimulus cue. The response pen was made compatible with the stimulus cursor. A fine metal tube was attached to the nib of the pen, and this tube was raised off the paper. The metal tube was extended toward the stimulus cursor at a distance of 4 mm from the end of the stimulus cursor (see Figure 12).



A → Response pen

B → Stimulus cursor

Figure 12

Apparatus modifications made in experiment II. A pursuit tracking task was used.

The stimulus cursor was programmed to move to the centre for a designated channel. The order of movement was determined by the pattern used. The time interval between each movement was 0.5 secs. The cursor moved at a speed of 140 mm per second. The subject, who was seated in front of the Gilson recorder, held the response pen in his right hand. The right foot of the subject was resting upon a foot switch (Linemaster, Compact Switch). Depression of this switch would close a circuit carrying 5 volts from a Grass Instrument, S.M.6., Stimulator Power Supply to one of the analog-to-digital channels of the P.D.P. 11/10 Computer. This signal indicated the subjects' reaction time to an auditory probe (tone).

The task would require the subject to track the stimulus cursor and simultaneously respond to the auditory probe by depressing the foot switch. The auditory probe was programmed to occur at the transitions of the movements. The location of this probe was varied for each subject throughout the sequence.

The program controlling the experiment (see Appendix C) recorded the movement of the stimulus cursor and the movement of the response pen almost simultaneously (asynchronous sampling at a rate of 10,000 samples per second). These recordings made it possible to calculate the subjects' lag time and integrated tracking error. After initial instructions to the subject, the entire experiment was controlled by the computer with the subject alone in a testing room.

Procedure

On each subject's first experimental session precise instructions as to the nature of the task were given. These instructions were:

"Two tones will serve as a warning that the experiment is to begin. The cursor will move to the left and after three seconds it will begin to move across the paper, varying its position with discrete movements. Your primary task is to keep the response pen aligned with the cursor. Any deviation from alignment will be noted as error. The movements have some pattern to them that will be repeated several times. To reduce the error of the task it would be advantageous to you to try and predict the movement of the cursor. While you are tracking the cursor a sharp tone will be heard at varying times throughout the movement sequence. Your additional task will be to respond as fast as possible to this tone by depressing the foot switch. You will now receive a short practice trial after which you will receive the test trial." After these instructions the subjects began tracking a practice sequence. (This pattern was generated randomly from a set of digits 1→6 to make up a pattern of 10 channel positions 1453166524). This sequence pattern was repeated for 10 consecutive presentations with no interval between presentations other than the 0.5 secs allowed between each movement within the sequence. Twelve reaction time probes were given during the practice session. A double tone marked the end of the practice session which lasted for a total of 3 minutes.

After a short break, to allow the subject to ask questions, the test session began by a double tone warning. The subject tracked either the Structured or the Random pattern for 20 consecutive presentations with no break between presentations. Thirty reaction time probes were given during the test session. The location of the probe was randomly allocated with restrictions that each presentation of the pattern contained from 0 to 3 probes. The number of probes per presentation and their location within the pattern were randomly allocated and counterbalanced for each subject. Also no probes were given in the first two presentations. A double tone marked the end of the testing session which lasted approximately 9 minutes.

The subjects returned a week later. On this occasion they were tested on the remaining pattern condition. No practice trial was given to the subjects prior to testing. The instructions, that were given on the previous session, were repeated.

Data Analysis

Tracking Performance Measures

Root mean squared tracking error (R.M.S.) was obtained from off-line analysis of the input and output on the P.D.P. 11/10 Computer. Detailed discussi[illegible]s to the suitability of this measure, its compatibility with parametric statistical tests and computation can be found elsewhere (Poulton, 1974, pp. 35).

Each movement of both the stimulus cursor and response pen was sampled at five equal time periods during the movement from one transition to the next. These data points were stored in memory, via the analog-to-digital channel of the computer. A permanent storage file was made of these data. The tracking errors were calculated by a subsequent program that accessed this data file. The R.M.S. was calculated for each movement within a sequence.

Reaction Time and Lag Time Performance Measures

The time from the onset of the tone to the depression of the foot switch was recorded in milliseconds. The computer program controlling the experiment recorded this time in memory and transferred the 30 reaction times per subject to a permanent file after the completion of each experimental session.

The lag time between the movement of the stimulus cursor and the movement of the response pen was recorded for two conditions within the experiment. A mean lag time was computed for a subject's performance at the transition points that received no probe. The transitions that received an auditory probe also had a mean lag time calculated.

For each location within the pattern a combined measure of reaction time plus difference in lag time for probe and no probe condition was calculated. This combined secondary performance measure was concerned with the subsequent movement and the eventual next location, as was the primary tracking error concerned with the movement to the next location.

Results and Discussion

No significant ($\underline{F}(1,10) = 4.12$, $p > .05$) effects are due to the order of presentation of the patterns (see Table 6). These results and those from Experiment I show that this counter-balanced design with the 7 day interval between experimental sessions controls for possible transfer effects. However, significant ($\underline{F}(1,10) = 58.42$, $p < .001$) difference in total errors were found,

TABLE 6

A.N.O.V.A. For Structured and Random Pattern (R.M.S. Error) Under Order of Presentation (Expt. II)

Source	S.S.	d.f.	M.S.	F
Order of Presentation (A)	1227.91	1	1227.91	4.12
Subjects nested within A[S(A)]	2982.91	10	298.29	
Pattern (B)	2787	1	2787	58.42*
A x B	2.09	1	2.09	0.04
S(A) x B	477.16	10	47.71	

* $p<.001$

performance on structured pattern. The subjects' tracking errors on the random pattern were greater than those on the structured pattern, indicating the randomly generated pattern was more difficult to track.

The comparative profiles of tracking errors made during movements to each location within the structured and random pattern are shown in Figure 13. The differences in total errors and differences in location errors between the two patterns are evident from these results. This would suggest that performance while tracking a patterned sequence of movements is a function of the pattern imposed upon the sequence. Additional support for this assumption is shown when the comparison between identical movements at the same locations within each pattern is made. In both the structured and random pattern the subject is required to move from channel 4 to channel 6 between location 3 and 4. A t-Test for related measures indicates that subjects produce significantly greater R.M.S. error during performance on the random pattern than on the structured pattern, $\underline{t}(11) = 3.106$, $p<.01$.

The jagged profile of location errors found by Restle and Brown (1970a) and also found in Experiment I was again evident in the structured pattern of this experiment. Subsequences of the pattern, 2-3-4, and 6-5-4 are the organizational units termed run, and these were at locations 1,2,3 and 4,5,6 respectively. The subjects showed evidence of using these runs as organizational subunits of the sequence. This is shown by the high tracking errors obtained at the transition between subunits and the comparatively low tracking errors obtained within a subunit. These two subsequences are highly comparable to the results obtained in Experiment I and in Restle and Brown's study.

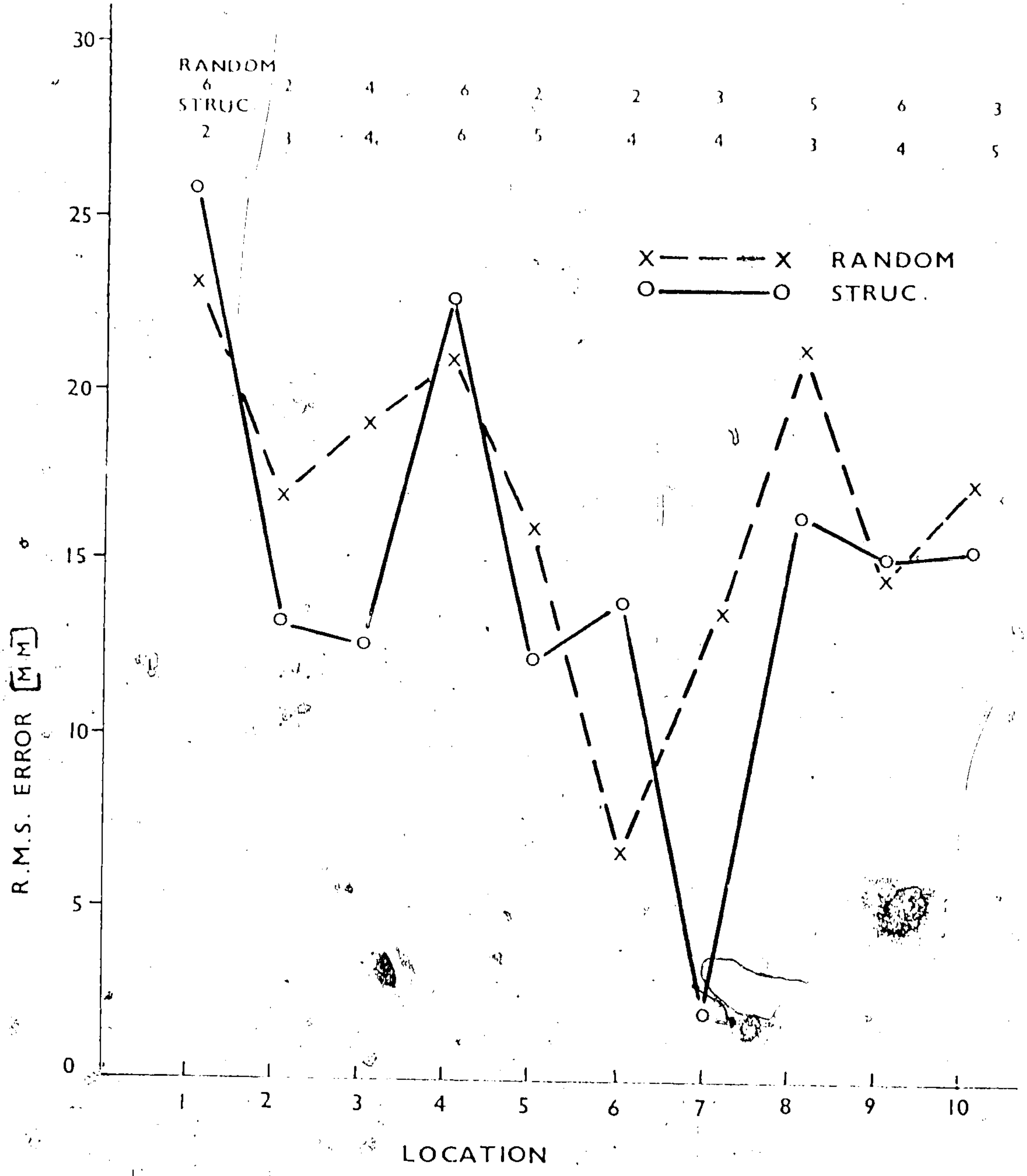


Figure 13

Root mean squared tracking error (mm) for movements to the 10 locations of the Structured and Random patterns.

The structured pattern used was derived from the Restle and Brown (1970a) pattern I transposed form. At location 7 the event occuring is: (a) light 4 repeating (Restle and Brown); and (b) stimulus cursor remaining in channel 4 (the present experiment). Although Restle and Burnside (1972) found evidence that subjects utilize "repeat" as the type of organizational unit the motor act being investigated in this experiment would equate "no movement" with "repeat". The no movement portion of the sequence is seen by the subjects as increased transition delay which varies the time interval. Tracking errors recorded at this location were mainly obtained when subjects made false predictions regarding this delay, hence the tracking error is at a minimum in comparison with the other location errors.

Although the subsequence 3-4-5 (at locations 8, 9, and 10) is a run, it shows the influence of the preceding trill (4-3-4 at locations 7, 8, and 9). This was probably responsible for the uncharacteristic low transition error at location 8. Due to the nature of the task and the structure of the pattern no real evidence for the existence of subjects utilizing a trill has been found, although the inclusion of such a trill has shown its transfer effects in the following subsequences of the pattern. Further evidence of this effect was obtained from comparisons made between identical movements at different locations within the sequence. Movement from channel 3 to channel 4 is evident between location 2 and 3 and also between location 8 and 9. Subjects produced significantly greater tracking errors moving to location 9 than in moving to location 3 in the structured pattern, $\underline{t}(11) = 4,437$, $p<.001$.

The results of the combined reaction time and lag difference time scores at each location of the structured and random patterns are illustrated in Figure 14. The profiles are evidently different. While the random pattern graph indicates little or no evidence of organizational units being used, the structured pattern results show a high degree of correspondence to those of the tracking error scores of Figure 13. A more realistic interpretation of the effect on subjects when repeating an event is gained from this dependent measure. The subsequence 3-4-5 at location 8, 9, and 10 is more distinct as an organizational unit in this figure. It could be suggested from these results therefore, that a subject's attentional demands prior to movement within organizational subunit (i.e. run) are less than his attentional demands at transitions between organizational subunits.

Results obtained from both this experiment and Experiment [illegible] show evidence that the subject utilizes the run as an organizational subunit. Dependent measures of this phenomenon have been percent recall, R.M.S. error during the movement, and a combined, reaction time and lag time difference prior to movement within the sequence. Investigation as to the nature of what constitutes a run is necessary, if inferences are to be made regarding the subjects' organization of a patterned sequence of movements.

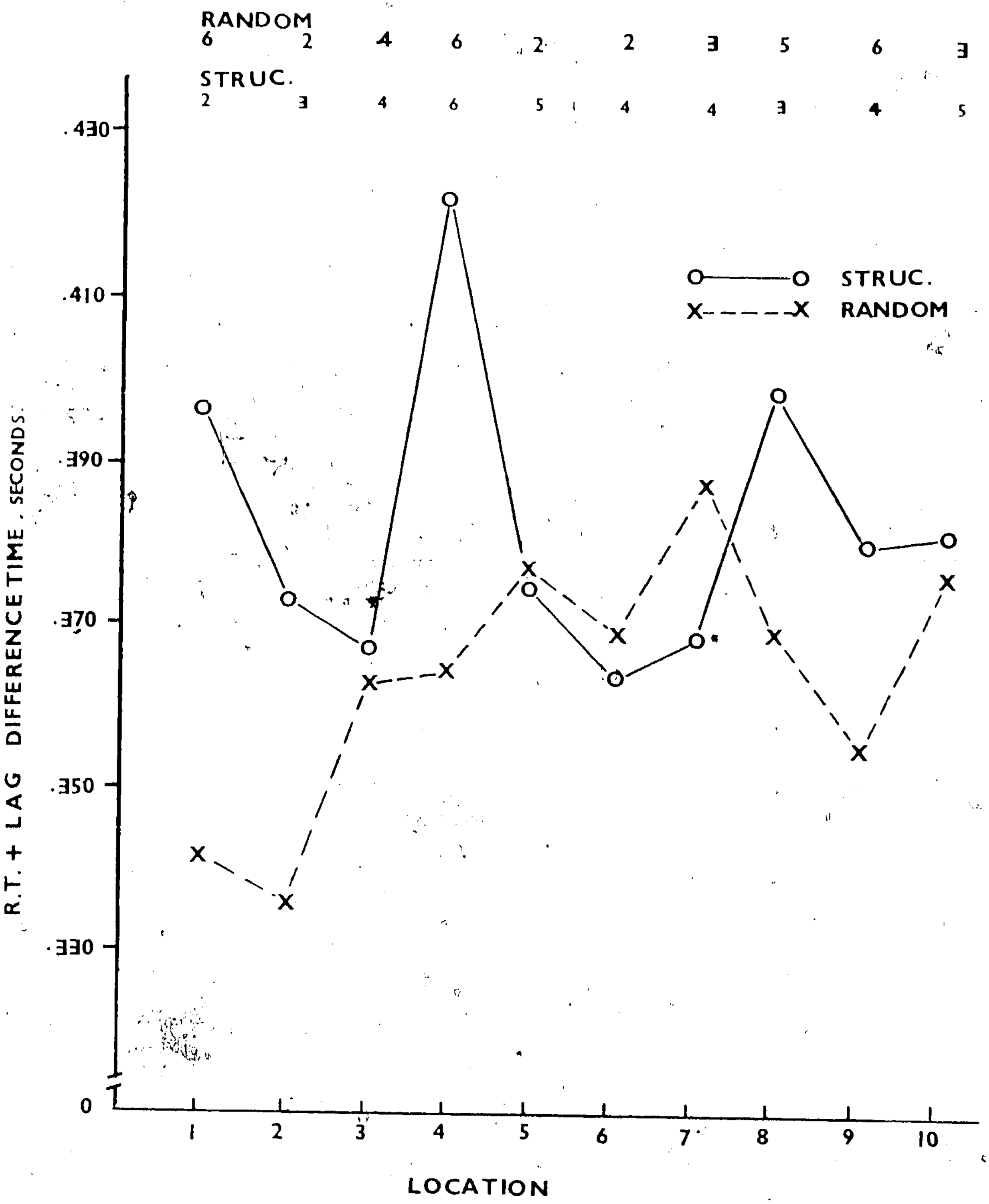


Figure 14

Reaction time plus lag time difference in seconds, for auditory probes prior to the movement to each of the 10 locations in Structured and Random pattern.

EXPERIMENT III

Several recent studies have been concerned with the attributes of movement. Diewart (1975, Laabs (1973), and Marteniuk (1973, 1975) mainly studied distance and location (comprising of start point and end point) attributes using a unidimensional task. In addition to distance and location, Hall and Leavitt (in press) investigated directional cues in movement using a two dimensional task. Other authors (Marteniuk, Shields and Campbell, 1972; Pepper and Herman, 1970) have also measured the effects of varying the timing, velocity and force of the movement.

The perceptual motor task used in this series of experiments holds force, time, velocity and acceleration constant. However the previous two experiments have had distinct location cues (i.e. channel markers) available, with the start point and end point of each movement within a sequence, remaining constant throughout the multi list presentation. Since Laabs (1973) has shown that location information is rehearsable and has different retention characteristics than distance, it should be suggested that the previous experiments are concerned more with the acquisition of locations during the sequence than with the acquisition of movements between the locations.[†]

In the present study location information was made irrelevant, to ensure subjects were not influenced in making their course predictions via *absolute* location of start point and end point. However, since the task involves a movement sequence, the *relative* location information within an organizational subunit was available. The channel markings

[†] All previous studies by Keele (1975), Restle and Brown (1970a, b) and Restle and Burnside (1972) have dealt specifically with location information.

from the previous experiment were also removed and the stimulus cursor moved back and forth against a white paper background.

The rule *transposition*, evident in the run (e.g. $T^2(1) \rightarrow 123$) and generated by the right-branching tree (Restle, 1970), is directional. Therefore one of the criteria for a run, as applied to movement, must be *in the same direction*. In a unidimensional task, runs executed in either direction (to the right and to the left) should exhibit similar error profiles.

Two attributes of movement were considered as major components of the organizational subunit run. These attributes were distance and direction. If the run as defined by Restle (1970) is a transposition to the n^{th} power acting upon any member of the defined alphabet, therefore $T^2(0) \rightarrow 0+1+2$ (from Restle's right-branching tree). Applying this sequence in a Log_2 relationship, would generate three distances $2^0(\theta)$, $2^1(\theta)$, $2^2(\theta)$, [where θ is a constant digital value given by the P.D.P. 11/10, D/A converter ($0 \rightarrow 1023$)]. Adding a constant value β to each of these distances would vary the location start point and end point. The run therefore, can consist of three movements of increasing distance. The increase in distance is logarithmic and start point and end point of the movement sequence can be varied. Each run sub-sequence is possible for movements to the right or the left.

Movements that suffix and prefix an organized subsequence have been the concern of Garner and Royer (1970). To eliminate problems associated with starting position of the sequence they increased the presentation rate to a speed that was unperceivable by the subject. This rate was gradually decreased until the subject could perceive the binary sequence. The present experiment embedded the subsequences being studied in a scrambled sequence of random movements. This embedding eliminated serial list learning effects due to primary or recency items within the movement list, it also enabled the experimenter to compare pattern conditions within one sequence presentation.

It was expected that integrated tracking errors throughout the movement within the subsequence would show similar profiles to that shown in Experiment I and II, i.e., the root mean squared error would decrease as the subject moves within the run subsequence. A control pattern of equal distances but randomized order (Random pattern) was compared to the run pattern (Structured pattern).

Method

Subjects

Twenty-four students from the University of Alberta participated in this experiment. All subjects wrote with their right hand.

Apparatus and Task

The apparatus and task used in Experiment II was identical to that used in this experiment with certain exceptions. The probe reaction time secondary task was not used. Root mean squared tracking error was the only dependent variable measured. Each movement was sampled at ten equal time periods between transitions. This increase in sampling rate allowed more precise error scores to be taken. The distance extent of the stimulus cursor and response pen was increased from 180 mm to 240 mm. This allowed more variation in start point location of the subsequence.

The structured pattern was a movement sequence consisting of three distances arranged in ascending order (16 mm, 32 mm, 64 mm). The random pattern contained the same distances but the order of presentation of these distances was randomized (64 mm, 16 mm, 32 mm). Both the structured and random pattern were produced moving to the right and to the left of the display. This produced four pattern conditions: SL (Structured pattern, movement to left), SR (Structured pattern, movement to right), RL (Random pattern, movement to left), RR (Random pattern, movement to right).

Procedure

Each subject tracked a randomly assigned practice sequence of steps for three minutes. This session was used to familiarize the subject with the apparatus and the control characteristics of the response pen. The only instructions given prior to this session were with regard to the error scores and how to minimize them (i.e. "Error scores are taken throughout each movement. It is therefore advisable to keep the response pen aligned with the stimulus cursor at all times."). After the practice session the subject was given time to ask questions relating to the tracking apparatus.

A tone sounded, as a warning, that the test session was to begin. Three seconds after the warning tone a double tone indicated the movement of the stimulus cursor. The cursor moved back and forth across the width of the display and then began to move to the designated positions within the programmed sequence. The four pattern conditions were embedded within sequences of ten movements (scrambled movements[†]). Therefore five sequences of ten scrambled movements served to suffix and prefix the patterned conditions. This produced a presentation list of 62 movements. The list of movements was generated continuously for 3 presentations. A tone indicated to the subject the end of the first session. The subject was asked to comment on the list and on his method how he reduced his error scores. After a 2 minute interval the subject was presented the test list for 3 more presentations. This was repeated

---

[†] Scrambled is used so as to avoid confusion with random pattern. These scrambled movements were randomly generated distances, produced at the time of testing by the computer.

for 5 sessions, making a total of 15 list presentations in all.

The P.D.P. 11/10 computer again controlled the entire experiment, allowing the experimenter to be absent from the testing room throughout all list presentations.

Design

The experiment utilized a repeated measure, treatments by treatments by subjects design with treatments fixed and subjects randomly allocated to order of treatments. The order of presentation was counterbalanced across the twenty-four subjects. The first factor was pattern consisting of two conditions (structure and random). The second factor was direction consisting of two levels (right and left).

Results and Discussion

Significant differences (p<.001) in the [illegible] of pattern and direction are evident in Table 8. The means [illegible] four conditions, structured pattern left, structured pattern right, random pattern [illegible] and random pattern right, indicate that the random pattern is less errorful than the structured pattern. Also, the movement subsequences to the left are more accurate than movements to the right. The latter of these findings was expected and has much support in the literature. That is movements made towards the midline of the body are more accurate than those made away from the midline of the body. The unexpected finding was that the random pattern was less errorful than the structured pattern. Several explanations are offered for this contradictory finding.

One explanation is that subjects tracking the patterned subsequences had a two choice decision to make after the first movement. This was a

TABLE 7 [†]

Statistical Design of Experiment III

Source	Degrees of Freedom	Appropriate Error Term
Rows (Subjects)	23	
Columns (Treatments)	3	
A (pattern)	1	S x A
B (direction)	1	S x B
A x B	1	S x A x B
Rows x Columns (S x T)[a]	69	
S x A	23	
S x B	23	
S x A x B	23	

[a] If interaction terms are equal or equal to zero then pooling (S x A), (S x B), and (S x A x B) gives within treatment.

[†] Edwards (1972)

TABLE 8

A.N.O.V.A. for Integrated Tracking Error (R.M.S.) in Expt. III

(A Treatments by Treatments by Subjects Design)

Source	S.S.	d.f.	M.S.	F
Total	1023.81	95.00		
Subjects	492.91	23.00		
Pattern	322.25	1.00	322.25	131.27*
Direction	95.46	1.00	95.46	57.85*
Pattern x Direction	1.27	1.00	1.27	1.66
Error Pattern	56.46	23.00	2.45	
Error Direction	37.95	23.00	1.65	
Error Pattern x Direction	17.51	23.00	0.76	

*$p < .001$

decision made on the two remaining movements. The structured pattern allowed the subject a choice of the 64 mm movement or the 32 mm movement, while the random pattern left the subject with a choice of moving a distance of either 32 mm or 16 mm. Amplitude errors made at this transition between the first and second movements of the subsequence could lead to greater integrated tracking error in the structured pattern than in the random pattern.

Verbal reports from the subjects following the experiment indicated that none of the 24 subjects recorded any knowledge of the patterned subsequences within the list of 62 movements. Only 16 percent of the subjects reported that they detected any repetition of the 62 movement list within a session of three continuous list presentations. Ten of the 24 subjects reported that there was evidence of a repetition of movements between the 5 sessions of the experiment.

It appears from the reports given by the subjects that the list of 62 movements was too long for the subjects to gain essential course information from the repeated list presentations. Therefore, subjects could have treated each movement as an unrelated event within the list of movements. The application of a wait and move approach to tracking appears to be the most likely strategy adopted by the subjects. The paucity of course information most likely negated attempts by the subject to impose structure upon the list.

The exact nature of the run as an organizational unit has not been evident from these results, leaving several questions pertaining to this experiment unanswered. Experiment IV was undertaken in an attempt to answer some of these questions.

EXPERIMENT IV

The questions which arose earlier in Experiment III underlined several design problems. Consequently Experiment IV was designed to partially replicate Experiment III as well as take these problems into consideration.

The verbal reports from the subjects in Experiment III suggested that the movement list length was too long. Three modifications were directed toward this criticism. First, while retaining the identical conditions of Experiment III (SL, RL, SR, RR) and maintaining constant the distances moved (16 mm, 32 mm, and 64 mm), the randomized moves in which they were embedded was reduced to 20. That is, four randomly generated movements suffixed and prefixed the four experimental conditions. This reduced the list length to a total of 32 movements.

Second, a tone indicated the beginning and end of the movement list.

Third, specific instructions were given to the subject that a list of movements would be repeated several times. Also the subjects were to learn the movements and anticipate subsequent movements within the list.

Directional errors at the transitions between movements are classified as undershooting errors, underestimation of the distance previously moved and overshooting errors, overestimation of distance moved (Noble and Trumbo, 1967). The relationship of these errors to measures of track acquisition were of interest to this study because directional errors have shown specific trends in studies by Noble and Trumbo (1967). These errors may reflect the strategy of subjects who do not exhibit any perceptual anticipation of the track. It could therefore be possible for subjects to reduce their integrated tracking error and show increases in directional errors. If this was the case in Experiment III (and may therefore be responsible for the significant pattern effect), erroneous assumptions could be made using integrated tracking error as the only dependent variable. To accommodate for this additional analysis of directional errors, a paced contour tracking task, similar to the one described in Experiment I was used. The course preview and postview was reduced to 0.1 seconds and 0.2 seconds respectively. This modification was made to substantially reduce the possibility of subjects using receptor anticipation.

Poulton (1974) has outlined the difficulty in comparing the errors made while tracking steps of different sizes, smaller steps being less errorful than steps of greater amplitude. It was necessary therefore to convert the errors made within a subsequence to a percentage error ratio.

In the subsequence of three distances (16 mm, 32 mm, 64 mm) the total errors made should be accounted for in the ratio of 1:2:4 for the 16 mm, 32 mm and 64 mm distances respectively. Therefore the small distance should account for 1/7 of the total error, while the middle distance (32 mm) should account for 2/7 and the long, 4/7 of the total errors made while tracking the subsequence. These expected errors were computed by dividing the total errors by into the ratio 1:2:4. The actual errors were those calculated for the individual movements within the subsequence. A ratio of the actual to the expected errors was computed by dividing the expected error into the actual error for each specific movement within the subsequence.

A ratio value of unity would signify that the errors made were as expected, and subjects were not treating the movements within a sequence differentially. A percent error ratio value of unity was expected in early trials. Any deviation of this value from unity, over trails could reflect a subject's organizational tendencies within the movement sequence.

Method

Subjects

Ten, right-hand dominant students from the University of Alberta were used in this experiment.

Apparatus and Task

The apparatus described in Experiment I and shown in Figure 9 was used in this experiment. The preview and postview was reduced to 1 mm and 2 mm respectively. This was done by masking the display with black cloth. The modified Gilson tracking apparatus produced the green contour line that represented the stimulus course. The subject used a blue felt pen to produce his response on the white, unmarked paper. The paper moved toward the seated subject at a speed of 10 mm per second.

The subjects tracked a list of 32 movements. The transition time between each movement was 0.4 seconds. The structured pattern and random pattern subsequences were identical to those used in Experiment III. The order of presentation of the four conditions, within the movement sequence, was counter balanced across the ten subjects. The four subsequences, each consisting of three movements (16 mm, 32 mm, 64 mm), were embedded into 20 randomly generated movements. A P.D.P. 11/10 computer was programmed to randomly select the position the green contour track would move to. Consequently four randomly generated movements served to suffix and prefix each of the four conditions, SR, RR, SL, and RL.

The list of movements was presented eight times with a five second interval between presentations. A tone, which was generated by a square wave generator (described earlier), indicated the beginning and end of each list. Each session required 5 minutes to complete.

Constant position error was used as a dependent variable. Measurements were taken at 5 mm intervals along the line. In addition to being compatible with parametric statistical tests, constant position error allows the total errors of a subsequence to be measured. Total errors are needed when calculating the second dependent variable, that being percent error ratio. The third dependent variable used was directional errors. These errors included overshooting and undershooting errors. Undershooting and overshooting errors were defined as occurrences of amplitude errors in excess of 2 mm deviation from the stimulus course. These measurements were made vertically at the transitions of the movements.

Procedure

The subjects were allowed time to familiarize themselves with the apparatus after they were seated in front of the modified Gilson tracking apparatus. Instructions were given to the subjects, "You will be presented with a series of steps given in the form of a green contour line. Your job is to keep the blue line superimposed upon the green track. A tone will indicate the start of a trial and the end of a trial. The same list will be presented to you 8 times and you will receive a 5 second rest period between trials. To minimize your error it would be advisable to try and learn the movements of the track and anticipate the following movement whenever possible."

The experimenter left the testing room and started the computer program which sounded a tone indicating the commencement of the first trial. After 8 trials the subject was asked to comment upon the experiment.

Results and Discussion

The results from the ANOVA computed on the integrated tracking errors are given in Table 9. Movements toward the midline of the body were significantly ($p<.05$) less errorful than movements away from it. This finding supported the earlier findings of Experiment III. There was, however, no differences in errors relating to the patterned organization of the three movements. Analysis of both undershooting errors and overshooting errors showed no significant differences relating to the direction of the subsequence of movements or the pattern of the movements. There was a lack of a significant trend of either of the directional errors over the first seven trials. Therefore these results do not resolve the question posed by the findings in Experiment III, relating to the significant difference in error for the two pattern conditions. Further studies will need to be made before a substantive answer is forthcoming.

The integrated tracking errors, graphed against Trials 1 to 7 are shown in Figures 15 and 16. Improvement in tracking skill is evident when viewing trials 1, 2, and 7 for all conditions. These trials were therefore used to examine the percent error ratio of both structured and random patterns.

The change over trials in the value of the percent error ratio for the subsequence patterns is shown in Figures 17, 18, 19, and 20. In all conditions the percent error ratio for the first movement increases (it accounts for more of the errors made within the whole subsequence). Also, evident in all conditions, the percent error ratio for the second movement decreases and is less than the ratio for the first movement. In

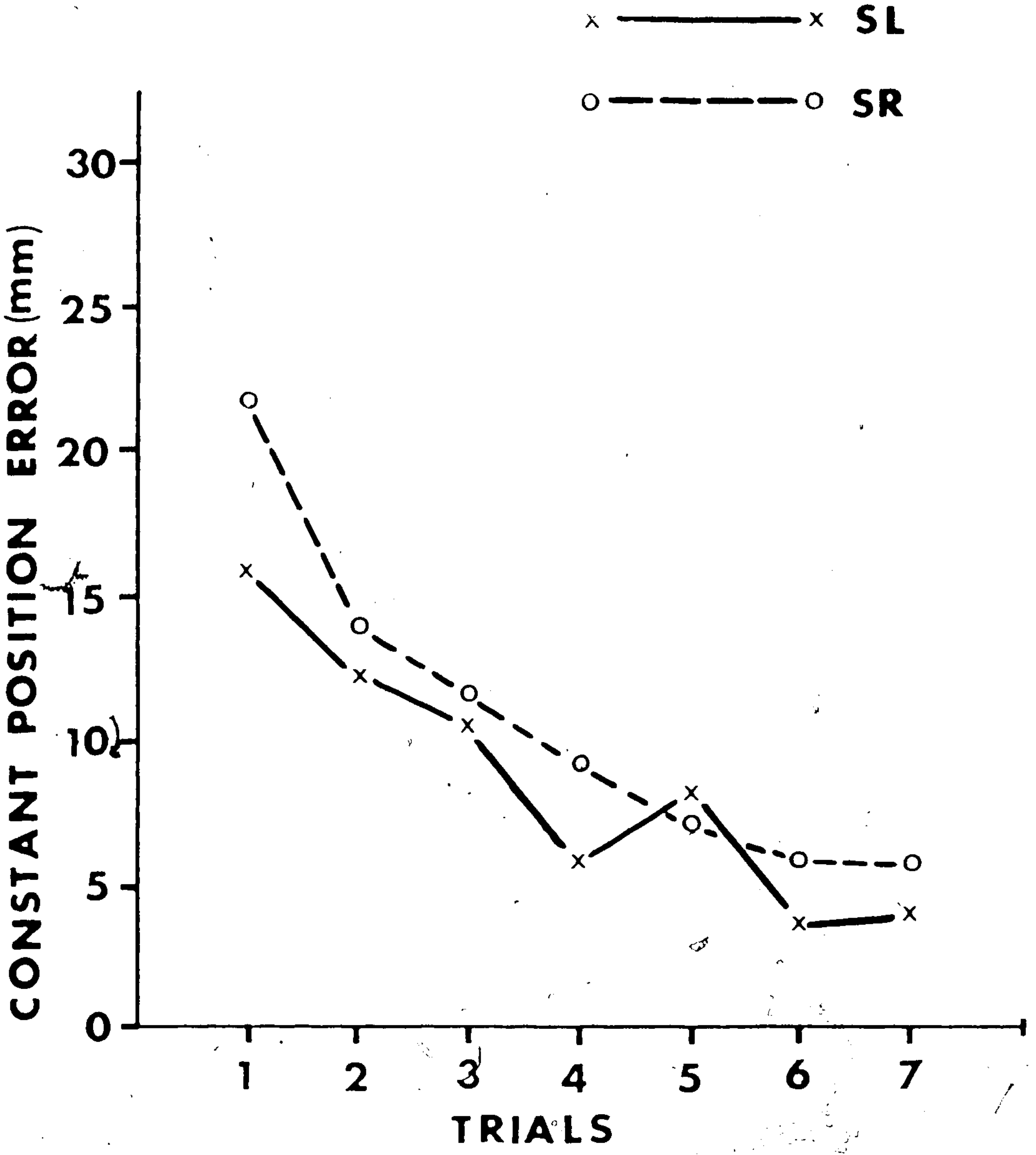


Figure 15

Integrated tracking errors for the structured patterns for trials 1-7 (Expt. IV).

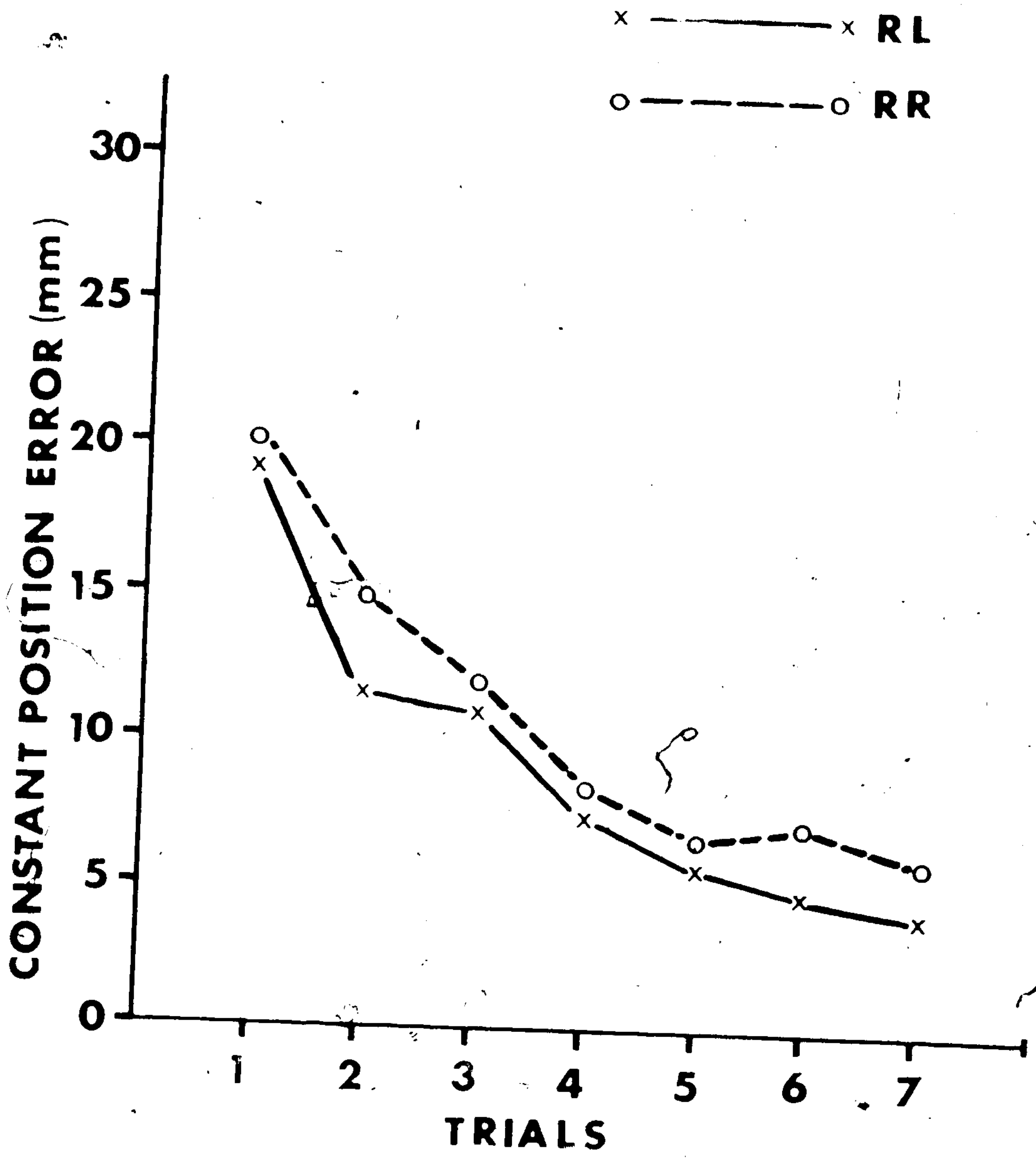


Figure 16

Integrated tracking errors for random patterns for trials 1→7 (Expt. IV).

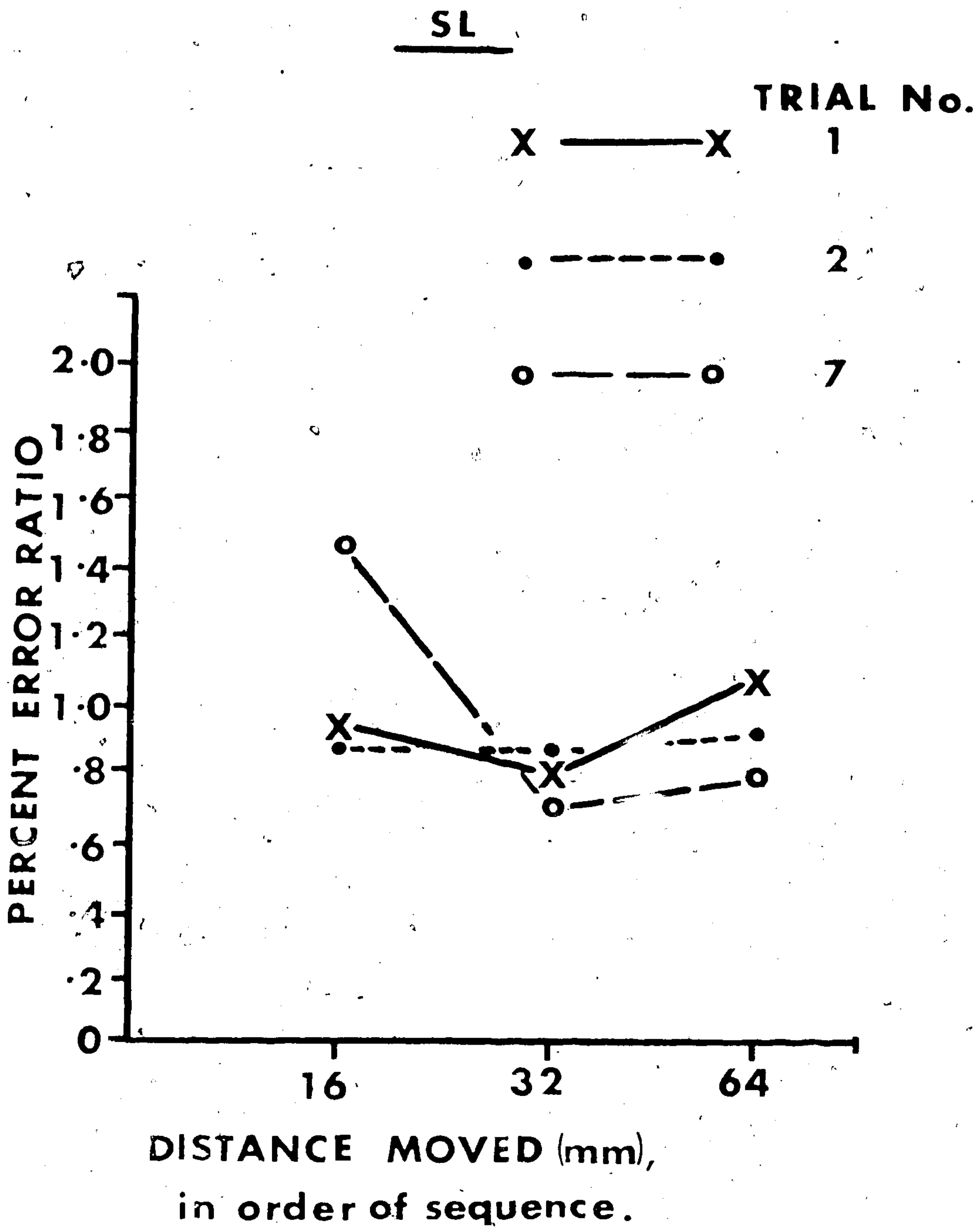


Figure 17

Percent error ratio of each of the movement distances for the SL condition on trial 1,2, and 7.

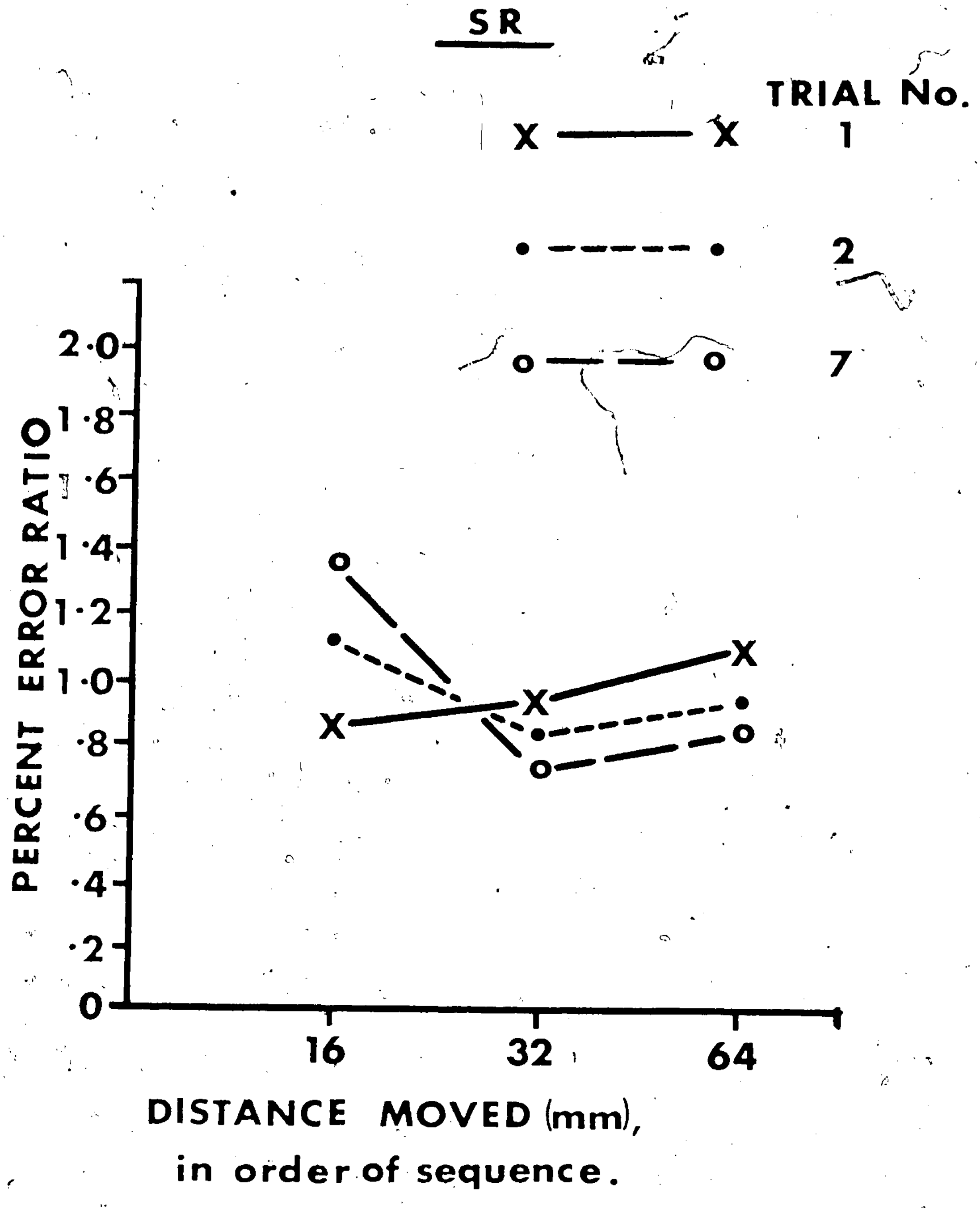


Figure 18

Percent error ratio on each of the movement distances for the SR condition on trial 1,2, and 7.

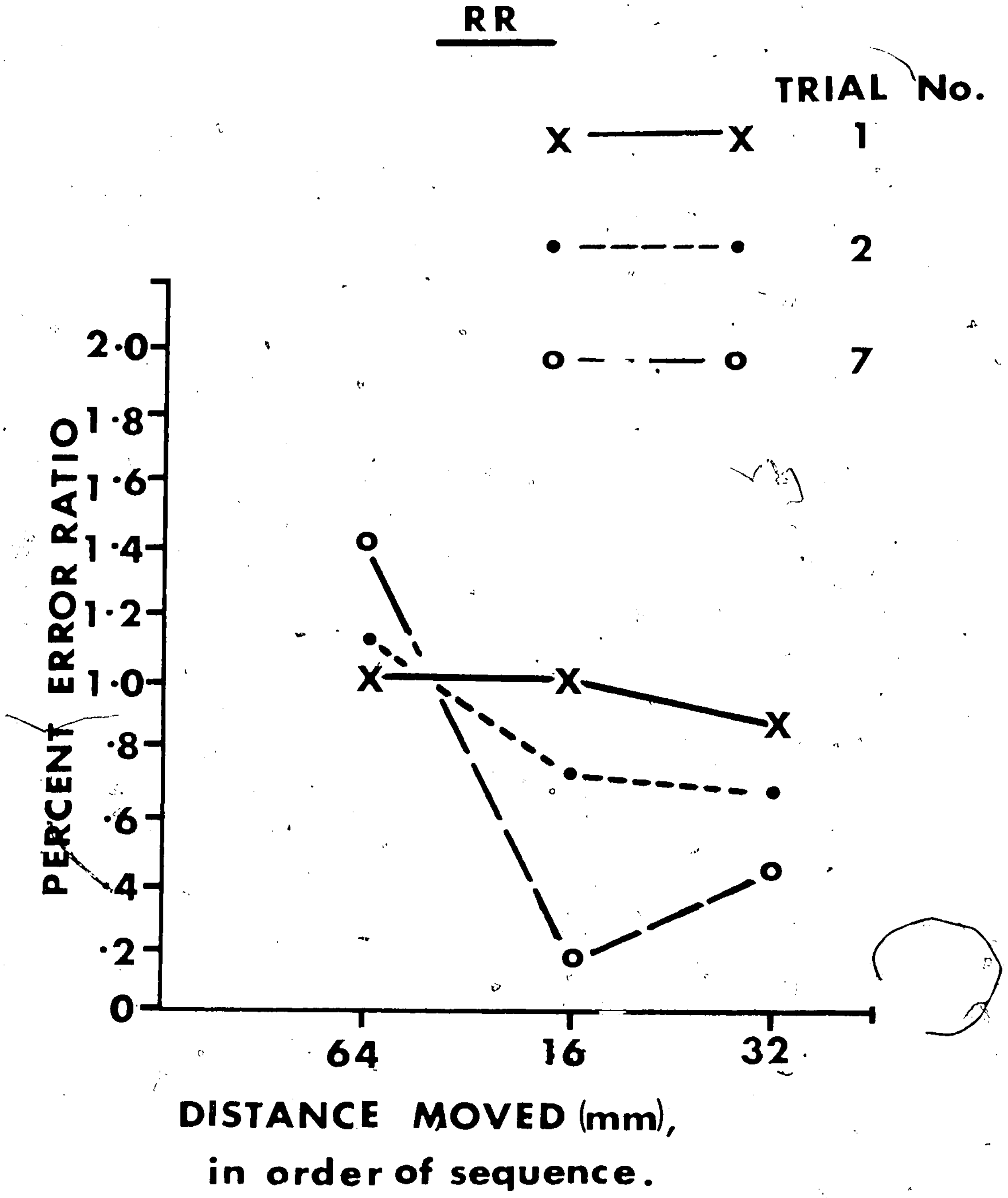


Figure 19

Percent error ratio of each of the movement distances for the RR condition on trial 1,2, and 7.

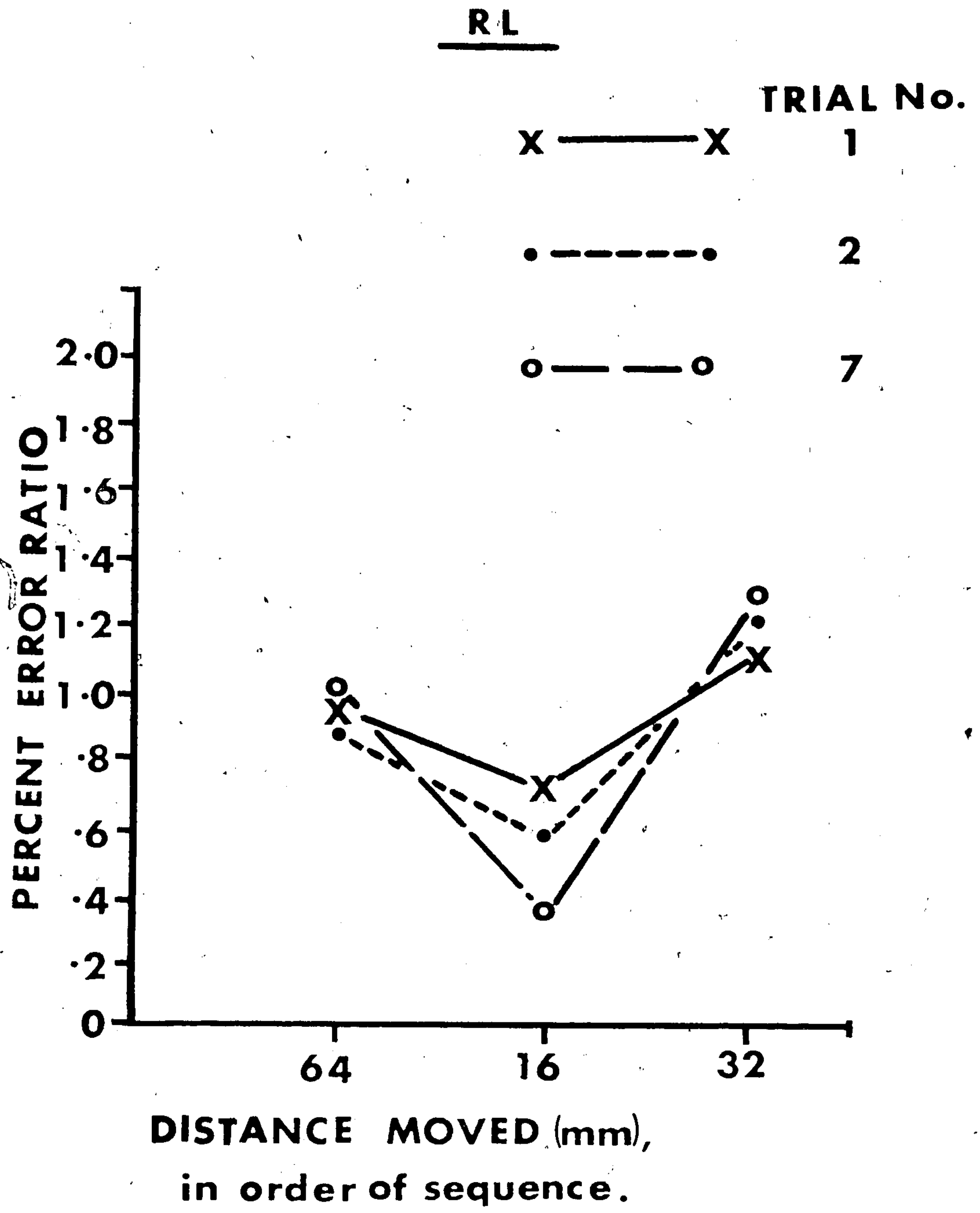


Figure 20

Percent error ratio of each of the movement distances for the RL condition on trial 1,2, and 7.

all, but condition RL, the last move decreases in its value of percent error ratio but is accountable for more of the total error than the preceding movement. It therefore appears that subjects in the RR, SR, and SL conditions are exhibiting evidence of developing an organizational subunit. The movements that are responsible for entering the unit are proportionally more errorful than movements within the subsequence. It also appears from these results that subjects are proportionally more errorful in the final movement of the subsequence than they are in the preceding movement. In condition RL the last movement of the subsequence (i.e. 32 mm in the subsequence 64 mm, 16 mm, 32 mm to the left) increased in percentage error ratio and was responsible for the majority of errors made in that subsequence (see Figure 20). Further investigation of the directional errors made in the subsequence revealed that all of the directional errors made at the transition of the final movement were undershooting errors. It was this tendency for subjects to terminate the last movement too early, that caused the increase in tracking error for the last movement of the RL condition. It appears possible that subjects would have preferred a move of equal length or shorter than the preceding movement in the subsequence (16 mm).

From the results of this experiment it appears that the organizational unit run cannot be defined in terms of distances moved in a logarithmic relationship. However, subjects did impose organizational structure upon the movement list. The subunit used by subjects can be defined as three movements following each other in the same direction. The movements within this subunit exhibit differential error scores similar to that shown in organizational subunits of the serial pattern learning studies described earlier.

GENERAL DISCUSSION

The performance of a skilled act involves an organized sequence of activities. The sequential organization and hierarchical structuring of the components of these activities has been of central importance to this series of studies. The experiments reported here have been concerned with the nature of the organizational units that subjects use when involved in a perceptual motor act. The tracking of a step function input was used as the vehicle for these studies. In studying the response organization to this task, the stimulus coherence[†] was varied with respect to spatial uncertainty, the temporal uncertainty was held constant at zero.

The findings suggest that when a subject was asked to track a series of patterned stimulus events, which comprise a sequence, he organized his response to these events. Such an organization evolves when the subject actively imposes a structure upon the sequence of events. It appears from the results of Experiment I and II that the coherency of these stimulus events making up the sequence, have a direct effect upon the structure that is imposed upon the sequence. This controlling rule structure divides the task into organizational subunits, each of which is governed by a simple rule system. The organizational subunit that was evident in the first two experiments is termed by Restle (1970) as a run.

Experiments I and II utilized Restle and Brown's (1970a) patterned

---

[†] Stimulus coherence refers to the degree to which there is a consistent pattern in a sequence of stimulus events.

lists of sequences. Comparisons were made of a subject's response organization to these movement lists as opposed to a randomly generated movement list. The three dependent measures were:

(1) percent recall of the movement within the sequence;

(2) root mean squared tracking error of the movement;

(3) reaction time to an auditory signal plus lag time for the subsequent movement, calculated prior to the movement.

These all reflected the use by the subject of the organizational subunit run. Although subjects showed a strong preference for using the run as an organizational subunit, their use of the subunit trill was less evident. However, the subjects' rule structure was influenced by the inclusion of the subunit trill into the sequence of stimulus events. These results reported earlier provide substantial support to the findings of Restle (1970).

The run, which has its origins in the E-I theory, was more completely developed by Restle's (1970) right-branching tree (an extension of Restle's structural tree theory). The operation which acts upon the stimulus elements to produce the subunit run is transposition. The definition of transposition implies increments of equal intervals (Restle and Brown, 1970a, pp. 124). When applied to a set of movement elements, the definition would infer that the run is dependent upon the distances of the movements within the subsequence being equal in length. The parameters of the earlier experimental tasks restricted the use of the run to operations upon specific locations. This was done in order to parallel the work of Restle and Brown (1970a); hence there was a need for six distinct channel markings across the stimulus display.

Experiments III and IV were undertaken to determine if Restle's definition of the run could be extended to include a logarithmic increase in distance as a property of the organizational subunit. The subject's possible stimulus elements were increased from six to infinity within the confines of the stimulus display. No preference for this specific formula for increase in movement distance was found in either experiment III or IV. Although there was no evidence of a run operating within the movement list, an organizational subunit was formed. This subunit could be defined as having three movements in the same direction follow each other in serial order. This was noticeable in Experiment IV when analysing the percent error ratio values of the movements within the subsequence.

Although the results of Experiments III and IV were not conclusive, they represent a step toward a more complete understanding of the way in which subjects organize their responses during a perceptual motor act. The problem may not be to know the general kind of organizing structure that is used by the subject on a given task; it may be more important to understand the detailed implications of the particular structure the subject is trying to use.

The values of percent error ratio reported in Experiment IV reflect the development of a subject's performance while responding within an organizational subunit. It appears from these findings, that before a subject is aware of the stimulus coherency of the task, he responds to each stimulus event within the sequence as if it were an unrelated, isolated event. As the subject becomes aware of the course redundancy he begins to organize his responses to the stimulus events. The result is the formation of subunits. The uncertainty upon entering the subunit is reflected by the increase in percentage error attributed to the first movement of the subsequence. This is consistent with the findings of researchers of serial pattern learning which were outlined earlier. The subjects become proportionally more accurate in the second move of the subsequence. The last movement of the three movement subsequence reflects a decrease in percent error ratio. However this last movement does not exhibit the same characteristics of error scores as would be witnessed in the serial pattern learning data. The serial pattern learning data that was reviewed earlier showed the last element in the subunit to be less errorful than all other elements in the subsequence.

All the final movements of the patterned subsequences ended toward the edges of the stimulus display. Knowing that the next movement involved a change of direction (i.e. a major course change), the subject becomes uncertain of the termination point of the movement. This uncertainty could have been responsible for the comparatively large error for this position within the subsequence.

In general these results tend to support earlier contentions made by Noble and Trumbo (1967):

> ". . . the subjects organize their responses in a manner consistent with, though not always proportional to, the kinds and amount of information available in the stimulus." (pp. 21)

Further investigations are needed in this area in order to define the preferable organizing units subjects use when performing a perceptual motor act. At present the theories of serial pattern learning are only relevant to finite elements within the stimulus alphabet that is available. These theories have used data relating to a finite set of stimulus events, such as lights, tones, numerals, etc. When applying these rule systems to movement sequences, limitations are inevitable. The human subject has an infinite set of movements available to him. To incorporate these into the existing theories would be problematic. It is therefore proposed that a more comprehensive theory of the organization of movement sequences is needed.

REFERENCES

Adams, J.A., and Creamer, L.R. "Anticipatory timing of continuous and discrete responses". *Journal of Experimental Psychology*, 1962, *63*, 84-90. a.

Adams, J.A., and Creamer, L.R. "Proprioception variables as determiners of anticipatory timing behavior". *Human Factors*, 1962, *4*, 217-222. b.

Bahrick, H.P., Noble, M., and Fitts, P.M. "Extra-task performance as a measure of learning a primary task". *Journal of Experimental Psychology*, 1954, *48*, 298-302.

Bahrick, H.P., and Shelly, C. "Line sharing as an index of automatization". *Journal of Experimental Psychology*, 1958, *56*, 288-293.

Bower, G., and Winzenz, D. "Group structure, coding and memory for digit series". *Journal of Experimental Psychology, Monograph Supplement*, 1969, *80*, No. 2, Pt. 2, 1-17.

Braveman, N.S., and Fischer, G.J. "Instructionally induced strategy and sequential information in probability learning". *Journal of Experimental Psychology*, 1968, *76*, 4, 674-676.

Davol, S.H., and Quinn, B.A. "Effects of stimulus preview and supplemental visual cues on childrens spatial representation and perceptual-motor anticipation in a discrete tracking task". *Perceptual and Motor Skills*, 1972, *35*, 599-610.

Diewart, G.L. "Retention and coding in motor short term memory: a comparison of storage codes for distance and location information". *Journal of Motor Behavior*, 1975, *7*, 183-190.

Edwards, A.L. *Experimental Design in Psychological Research (Fourth Edition)*. New York: Holt, Rinehart and Winston, 1972.

Fitts, P.M., and Posner, M.I. *Human Performance*. California: Brooks/Cole, 1967.

Fleishman, E.A., and Rich, S. "Role of kinesthetic and spatial-abilities in perceptual-motor learning". *Journal of Experimental Psychology*, 1963, *66*, 6-11.

Garner, W.R. *The Processing of Information and Structure*. New York: J. Wiley and Sons, 1974 (p. 49-72).

Garner, W.R., and Gottwald, R.L. "Some perceptual factors in the learning of sequential patterns of binary events". *Journal of Verbal Learning and Verbal Behavior*, 1967, *6*, 582-589.

Garner, W.R., and Gottwald, R.L. "The perception and learning of temporal patterns". *Quarterly Journal of Experimental Psychology*, 1968, *20*, 97-109.

Glanzer, M.S., and Clark, H.H. "Accuracy of perceptual recall: An analysis of organization". *Journal of Verbal Learning and Verbal Behavior*, 1962, *1*, 288-299.

Glencross, D.J. "Serial organization and timing in a motor skill". *Journal of Motor Behavior*, 1970, *Volume 2, No. 4*, 229-237.

Gottsdanker, R. "Psychological refractoriness and the organization of step-tracking responses". *Perception and Psychophysics*, 1973, *14*, 1, 60-70.

Hall, C., and Leavitt, J. "Encoding and retention characteristics of direction and distance". *Journal of Human Movement Studies*, (In Press).

Harcum, E.R. *Serial Learning and Paralearning*. New York: John Wiley and Sons, 1975.

Johnson, N.F. "Chunking and organization in the process of recall". In G.H. Bower (Ed.), *Psychology of Learning and Motivation.* New York: Academic Press, 1970.

Johnson, N.F. "Organization and the concept of a memory code". In A.W. Melton and E. Martin (Eds.), *Coding Processes in Human Memory.* Washington: Wiley, 1972.

Johnson, N.F. "Higher order encoding: Process or state"? *Memory and Cognition*, 1973, *1*, 4, 491-494.

Jones, M.R. "Cognitive representations of serial patterns". In B. Kantowitz (Ed.), *Human Information Processing: Tutorials in performance cognition.* Potomac, Md.: Erlbaum, 1974.

Jones, M.R. "Levels of structure in the reconstruction of temporal and spatial serial patterns". *Journal of Experimental Psychology: Human Learning and Memory*, 1976, *2*, 475-488 (a).

Jones, M.R. "Time, our lost dimension: Toward a new theory of perception, attention and memory". *Psychological Review*, 1976, *83*, 5, 323-355 (b).

Jones, M.R., and Zamostny, K.P. "Memory and rule structure in the prediction of serial patterns". *Journal of Experimental Psychology: Human Learning and Memory*, 1975, *104*, 3, 295-306.

Keele, S.W. "The representation of motor programmes". In P.M.A. Rabbitt and S. Dornic (Eds.), *Attention and Performance V.* London: Academic Press, 1975 (p. 357-365).

Keele, S.W. "Current status of the motor program concept". In R.W. Christina and D.M. Landers (Eds.), *Psychology of Motor Behavior and Sport - 1976.* Illinois: Human Kinetics Publisher, 1977.

Keele, S.W., and Boies, S.J. "Processing demands of sequential information". *Memory and Cognition*, 1973, *1*, 85-90.

Kerr, B. "Processing demands during movement". *Journal of Motor Behavior*, 1975, *7*, 15-27.

Klemmer, E.T. "Sequences of responses to signals encoded in time only". *Acta Psychologica*, 1967, *27*, 197-207.

Kotovsky, K., and Simon, H.A. "Empirical tests of a theory of human acquisition of concepts for sequential patterns". *Cognitive Psychology*, 1973, *4*, 399-424.

Laabs, G.J. "Retention characteristics of different reproduction cues in motor short-term memory". *Journal of Experimental Psychology*, 1973, *100*, 168-177.

Lashley, K.S. "The problem of serial order in behavior". In L.A. Jeffres (Ed.), *Cerebral mechanisms in Behavior*. New York: Wiley, 1951.

Marteniuk, R.G. "Retention characteristics of motor short-term cues". *Journal of Motor Behavior*, 1973, *5*, 249-259.

Marteniuk, R.G. "A cognitive information processing model of motor short-term memory". In B.S. Ruchall (Ed.), *The Status of Psycho-motor Learning and Sport Psychology Research*. Halifax: Sport Science Associates, 1975.

Marteniuk, R.G., Shields, K.W., and Campbell, S. "Amplitude, position, timing and velocity as cues in the reproduction of movement". *Perceptual and Motor Skills*, 1972, *35*, 51-58.

McLeod, P.D. "Recovery strategy during temporary obscuration of a tracked target". *Ergonomics*, 1972, *15*, 1, 57-64.

McLeod, P.D. "Interference of "Attend to and Learn" tasks with tracking". *Journal of Experimental Psychology*, 1973, *99*, 3, 330-333.

Me[illegible]aw, E. [illegible] "Direction and extent uncertainty in step-input tracking". *Journal of Motor Behavior*, 1972, *4*, [illegible]71-186.

Mill[illegible].A. "The magical number seven, plus or minus two: Some limits on our capacity for processing information". *Psychological Review*, 1956, *63*, 81-97.

Miller, G.A., and Chomsky, N. "Finitary models of language users". In R.D. Luce, R. Bush, and E. Galanter (Eds.), *Handbook of Mathematical Psychology, Vol. 2*. New York: Wiley, 1963.

Miller, G.A., Gallanter, and Pribram, K.H. *Plans and Structures of Behavior*. New York: Holt, Rinehart and Winston, 1960.

Morgenstern, F.S., Haskell, S.H., and Waters, P.D. "Distributive reaction times in single and multiple response units". *Ergonomics*, 1971, *14*, 2, 219-230.

Noble, M., and Trumbo, D. "The organization of skilled response". *Organizational Behavior and Human Performance*, 1967, *2*, 1-25.

Noble, M., Trumbo, D., and Fowler. "Further evidence on secondary task interference in tracking". *Journal of Experimental Psychology*, 1967, *73*, 146-149.

Orenstein, H.R. "Reaction time as a function of perceptual bias, response bias, and stimulus discriminability". *Journal of Experimental Psychology*, 1970, *86*, 138-142.

Pepper, R.L., and Herman, L.M. "Decay and interference effects in the short-term retention of a discrete motor act". *Journal of Experimental Psychology*, 1970, *83*, (2, Pt. 2).

Pitz, G.F. "Response variables in the estimation of relative frequency". *Perceptual and Motor Skills*, 1965, *21*, 867-873.

Posner, M.I. "Reduced attention and the performance of "Automated" movements". *Journal of Motor Behavior*, 1969, *1*, 4, 245-258.

Posner, M.I., and Keele, S.W. "Attention demands of movements". *Proceedings of the XVIth International Congress of Applied Psychology*, Amsterdam: Swets and Zeitlinger, 1969, 418-422.

Poulton, E.C. "Perceptual anticipation in tracking with two-pointer displays". *British Journal of Psychology*, 1952, *43*, 222-229 (a).

Poulton, E.C. "The basis of perceptual anticipation in tracking". *British Journal of Psychology*, 1952, *43*, 295-302 (b).

Poulton, E.C. "On prediction in skilled movement". *Psychological Bulletin*, 1957, *54*, 6, 467-478 (a).

Poulton, E.C. "Learning the statistical properties of the input in pursuit tracking". *Journal of Experimental Psychology*, 1957, *54*, 1, 28-32 (b).

Poulton, E.C. "Sequential short-term memory: Some tracking experiments". *Ergonomics*, 1963, *6*, 117-132.

Poulton, E.C. "Postview and preview in tracking with complex and simple inputs". *Ergonomics*, 1964 *7*, 257-266.

Poulton, E.C. "Tracking a variable rate of movement". *Journal of Experimental Psychology*, 1967, *73*, 1, 135-144.

Poulton, E.C. *Tracking Skill and Manual Control.* London: Academic Press, 1974.

Preusser, D., Garner, W.R., and Gottward, R.L. "Perceptual organization of two-element temporal patterns as a function of their component one-element patterns". *American Journal of Psychology*, 1970, *83*, 151-170.

Provins, K.A. "Handedness and skill". *Quarterly Journal of Experimental Psychology*, 1956, *8*, 79-95.

Provins, K.A. "The effect of training and handedness of the performance of two simple motor tasks". *Quarterly Journal of Experimental Psychology*, 1958, *10*, 29-39.

Restle, F. "Grammatical analysis of the prediction of binary events". *Journal of Verbal Learning and Verbal Behavior*, 1967, *6*, 17-25.

Restle, F. "Theory of serial pattern learning". *Psychological Review*, 1970, *77*, 6, 481-495.

Restle, F. "Serial patterns: The role of phrasing". *Journal of Experimental Psychology*, 1972, *92*, 3, 385-390.

Restle, F. "Serial pattern learning: Higher order transitions". *Journal of Experimental Psychology*, 1973, *99*, 1, 61-69.

Restle, F. "Critique of pure memory". In R.L. Solso (Ed.), *Theories in Cognitive Psychology: The Loyola Symposium*, Maryland, Potomac: 1974.

Restle, F., and Brown, E.R. "Serial pattern learning". *Journal of Experimental Psychology*, 1970, *83*, 1, 120-125 (a).

Restle, F., and Brown, E.R. "Serial pattern learning: Pretraining of runs and trills". *Psychonomic Science*, 1970, *19*, 6, 321-322 (b).

Restle, F., and Brown, E. "Organization of serial pattern learning". In G.H. Bower (Ed.), *Psychology of Learning and Motivation*, New York: Academic Press, 1970 (c).

Restle, F., and Burnside, B.L. "Tracking of serial patterns". *Journal of Experimental Psychology*, 1972, *95*, 299-307.

Robb, M.D. *The Dynamics of Motor Skill Acquisition.* New Jersey: Prentice-Hall, 1972.

Royer, F.L. "Sequential complexity and motor response rates". *Journal of Experimental Psychology*, 1967, *74*, 199-202.

Royer, F., and Garner, W.R. "Response uncertainty and perceptual difficulty of auditory temporal patterns". *Perception and Psychophysics*, 1966, *1*, 41-47.

Royer, F.L., and Garner, W.R. "Perceptual organization of nine-element auditory temporal patterns". *Perception and Psychophysics*, 1970, *7*, 115-120.

Schmidt, R.A., and Christina, R.W. "Proprioception as a mediator in the timing of motor responses". *Journal of Experimental Psychology*, 1969, *81*, 2, 303-307.

Semjen, A., and Requin, J. "Movement amplitude, pointing accuracy and choice-reaction time". *Perceptual and Motor Skills*, 1976, *43*, 807-812.

Simon, H.A. "Complexity and the representation of patterned sequences of symbols". *Psychological Review*, 1972, *79*, 369-382.

Simon, H.A., and Feigenbaum, E.A. "Elementary perceiver and memorizer: Review of experiments". In A.C. Hoggatt and F.E. Balderston (Eds.), *Symposium on Simulation Models*. Cincinnati, Ohio: South-Western Publishing, 1963.

Simon, H.A., and Kotovsky, K. "Human acquisition of concepts for sequential patterns". *Psychological Review*, 1963, *70*, 534-546.

Slack, C.W. "Learning in simple one-dimensional tracking". *American Journal of Psychology*, 1953, *66*, 33-44.

Smith, M.C. "Theories of the psychological refractory period". *Psychological Bulletin*, 1967, *67*, 202-213.

Trumbo, D. "Acquisition and performance as a function of uncertainty and structure in serial tracking tasks". *Acta Psychologica*, 1970, *33*, 252-266.

Trumbo, D., Fowler, F., and Noble, M. "Rate and predictability in rate tracking tasks". *Organizational Behavior and Human Performance*, 1968, *3*, 366-377.

Trumbo, D., Noble, M., and Quigley, J. "Sequential probability and the performance of serial tasks". *Journal of Experimental Psychology*, 1968, *76*, 364-372.

Trumbo, D., Noble, M., and Swink, J. "Secondary task interference in the performance of tracking tasks". *Journal of Experimental Psychology*, 1967, *73*, 2, 232-240.

Trumbo, D., Ulrich, L., and Noble, M.E. "Verbal coding and display coding in the acquisition and retention of tracking skills". *Journal of Applied Psychology*, 1965, *49*, 368-375.

Tulving, E. "Intertrial and intratrial retention: Notes toward a theory of free recall verbal learning". *Psychological Review*, 1964, *71*, 219-237.

Tulving, E. "Subjective organization and the effects of repetition in multi-trial free-recall learning". *Journal of Verbal Learning and Verbal Behavior*, 1966, *5*, 193-197.

Tulving, E. "Theoretical issues in free recall". In T. Dixon and D. Horton (Eds.), *Verbal Behavior and General Behavior Theory.* Englewood Cliffs, N.J.: Prentice-Hall, 1968, p. 2-36.

Vince, M.A. "Corrective movements in a pursuit task". *Quarterly Journal of Experimental Psychology*, 1948, *1*, 85-103.

Vince, M.A. "The part played by intellectual processes in a sensori-motor performance". *Quarterly Journal of Experimental Psychology,* 1953, *5*, 75-86.

Vitz, P.C., and Todd, T.C. "A model of learning for simple repeating binary patterns". *Journal of Experimental Psychology,* 1967, *75,* 108-117.

Welford, A.T. "The 'psychological refractory period' and the timing of high speed performance - a review and a theory". *British Journal of Psychology*, 1952, *43*, 2-19.

Whiting, H.T.A. "Theoretical models for an understanding of perceptual motor skill performance". *Quest*, 1972, *17*, 24-34 (a).

Whiting, H.T.A. "Overview of the skill learning process". *Research Quarterly*, 1972, *43*, 266-294 (b).

Wickens, C.D. "The effects of divided attention on information processing in manual tracking". *Journal of Experimental. Psychology: Human Perception and Performance*, 1976, *2*, 1, 1-13.

Zohar, D. "Amount and order of redundancy as determinants of continuous tracking performance". *Journal of Motor Behavior*, 1974, *6*, 3, 165-178.

APPENDIXES

Appendix A

Experiment I Computer Program

```
C:  Focal-11S V1  (RT-11) 12-Jan-75

1.10 x FTIC(5,1);X FBUF(100)
1.20 x FCRT(0,128);X FCRT(1,0,0);
1.30 x FCRT(2)

2.10 S C=0;
2.20 S J=0
2.30 S E=0;S M=0;S G=1
2.40 S T=0

3.10 L M 1,S8P1[1]/Z/V:N(0)
3.20 L O 2,HOMER1/V:K(0)
3.30 L O 3,PR8P1/V:M(0)
3.40 L M 4,R8P1[1]/Z/V:P(0)
3.50 L O 5,CHPR8/V:L(0)
3.60 L M 6,POS8[1]/Z/V:Z(0)

4.10 F B=1,20 ;S K(B)=K(B) ;
4.20 F A=1,20 ;D 5 ;D 8 ;
4.25 X FDLY(2000)
4.30 G 9
4.40 G 7

5.10 F I=1,100;S X=-1;X FCRT(1,X,Y)
5.20 X FDLY(300);
5.30 F I=1,20;S Y=50;X FCRT(1,X,Y)
5.40 F I=1,10;S Y =516;X FCRT(1,X,Y)
5.45 D 5.30;D 5.40;
5.50 X FDLY(200)
5.60 F B=1,20;D6
5.70 X FDLY(430)
```

Appendix A (cont'd)

```
5.80 D 5.30;D 5.40;D 5.30;D 5.40;
5.85 F I=1,50;S X=-1;X FCRT(1,X,Y)
5.90 X FDLY(200)
5.95 D 7

6.01 S V=0;I (B-1)6.05,6.05,6.02
6.02 I (K(B))6.30,6.03,6.03
6.03 I ((FABS(K(B)-K(B-1)))-350)6.04,6.07,6.07
6.04 I ((FABS(K(B)-K(B-1)))-1)6.08,6.05,6.05
6.05 S V=25;D 6.10;R
6.07 S V=65;D 6.10;R
6.08 S V=25;D 6.20;R
6.10 F I=1,V;S X=K(B);X FCRT(1,X,Y);R
6.20 F I=1,V;S X=K(B)-50;X FCRT(1,X,Y);R
6.30 I ((FABS(K(B)-K(B-1)))-370)6.35,6.07,6.07
6.35 I ((FABS(K(B)-K(B-1)))-1)6.07,6.40,6.40
6.40 F I=1,60;S X=K(B);X FCRT(1,X,Y)
6.50 F I=1,40;S X=K(B);X FCRT(1,X,Y)
6.52 X FDLY(200)
6.60 RETURN

7.10 I (M(A)-3)7.20,7.20,7.30
7.20 S J+M(A)+10 G 7.31
7.30 S J=M(A)
7.31 S B=(J-3)
7.35 F I-1,30;S X=K(B);X FCRT(1,X,Y)
7.37 X FDLY(150)
7.40 F B=(J-3),(J-1);D 6
7.50 X FDLY(300)
7.70 D 5.30;D 5.40;
7.80 X FDLY(300)
7.82 S C=C+1
7.84 X FSAM(1,3+32) S D(C)=FSAM(0,1) I (D(C))7.84,7.86,7.86
7.86 D 10
```

Appendix A (cont'd)

```
7.88 I (FABS(N(C)-L(C)))7.90,7.90,7.95
7.90 S P(C)=0;
7.91 F I=1,10;S X=30;X FCRT(1,X,Y)
7.92 F I=1,10;S X=900;X FCRT(1,X,Y);
7.93 D 5.30;D 5.40;
7.94 RETURN
7.95 S P(C)=1;
7.9[illegible] D 5.30;D 5.40;

8.20 X FDLY(500)

9.10 L C 1
9.15 F I=1,10;S Z(I)=0
9.20 F A=1,20;D 11
9.30 G 12
9.40 L C 4
9.50 L C 5

10.10 I (D(C)-410)10.15,10.15,10.20
10.15 S N(C)=1;R
10.20 I (D(C)-505)10.25,10.25,10.30
10.25 S N(C)=2;R
10.30 I (D(C)-610)10.35,10.35,10.40
10.35 S N(C)=3;R
10.40 I (D(C)-703)10.45,10.45,10.50
10.45 S N(C)=4;R
10.50 I (D(C)-810)10.55,10.55,10.60
10.55 S N(C)=5;R
10.60 S N(C)=6;R

11.10 I (M(A)-1)11.15,11.15,11.20
11.15 S Z(1)=Z(1)+P(A);R
11.20 I (M(A)-2)11.25,11.25,11.30
```

```
11.25 S Z(2)=Z(2)+P(A);R
11.30 I (M(A)-3)11.35,11.35,11.40
11.35 S Z(3)=Z(3)+P(A);R
11.40 I (M(A)-4)11.45,11.45,11.50
11.45 S Z(4)=Z(4)+P(A);R
11.50 I (M(A)-5)11.55,11.55,11.60
11.55 S Z(5)=Z(5)+P(A);R
11.60 I (M(A)-6)11.65,11.65,11.70
11.65 S Z(6)=Z(6)+P(A);R
11.70 I (M(A)-7)11.75,11.75,11.80
11.75 S Z(7)=Z(7)+P(A);R
11.80 I (M(A)-8)11.85,11.85,11.90
11.85 S Z(8)=Z(8)+P(A);R
11.90 I (M(A)-9)11.95,11.95,11.96
11.95 S Z(9)=Z(9)+P(A);R
11.96 S Z(10)=Z(10)+P(A);R

12.04 F I=1,100;S Y=-50;X FCRT([illegible])
12.05 F I=1,10;S Y=516;X FCRT(1,[illegible]
12.10 L C 1;
12.11 S Y=516;X FCRT(1,X,Y)
12.12 S N=0;X FSAM(1,1+32);S N=FSAM(0.1)
12.13 I (N-500)12.12;S V=FTIC(M)
12.14 S D=D+1
12.15 S P(D)=(V/500)-.09
12.16 S G=G+1;R
12.20 L C 2;
12.30 L C 3;
12.40 L C 4;
12.50 L C 5;
12.60 L C 6
```

Appendix A (cont'd)

```
13.05 S E=E+1
13.10 X FSAM(2,3+32,6+32);S Q(E)=FSAM(0,1);S R(E)=FSAM(0,2);R
*
```

Appendix B

Factor A → Order of Presentation

Factor B → Pattern (Structured or Random)

S (A) → Subjects randomly nested within A

Factors A and B are fixed with S(A) random

Source	d.f.	Expected Value	Appropriate Error Term
A	1	$\sigma^2[1+(b-1)p]+b\sigma^2_{s(a)}+sb\theta^2_a$	S(A)
S(A)	8	$\sigma^2[1+(b-1)p]+b\sigma^2_{s(a)}$	~
B	1	$\sigma^2(1-p)+\sigma^2_{s(a)b}+sa\theta^2_b$	S(A) x B
A x B	1	$\sigma^2(1-p)+\sigma^2_{s(a)b}+s\theta^2_{ab}$	S(A) x B
S(A) x B	8	$\sigma^2(1-p)+\theta^2_{s(a)b}$	~

Appendix C

Experiment II Computer Program

Random pattern:

```
C:FOCAL-11S V1    (RT-11) 12-Jan-75

1.10 X FTIC(3,20);X FBUF(100)
1.20 X FCRT(,128);X FCRT(1,0,0)
1.30 X FCRT(2)

2.10 S A=0;S B=0;
2.20 S S=0;S D=0;
2.30 S E=0;S M=0;S G=1
2.40 S T=0

3.10 L O L,HOMER2/V:K(0)
3.20 L O 2,RT6/V:L(0)
3.30 L M 3,S6TR[9]/Z/V:Q(0)
3.40 L M 4,P6TR[9]/Z/V:R(0)
3.50 L M 5,S6RTR[1]/Z/V:P(0)

4.10 F I=1,100;S X-100;S FCRT(1,X,Y)
4.20         11;
4.2             00)
4.30 F         ;D 5
4.40 G 7

5.40 F B=1,10;D 6
5.50 RETURN

6.05 I (A-2)6.50,6.50,6.10
6.   I (B-L(G))6.50,6.20,6.50
6.20 D 12
6.50 F I=1,5;S X=K(B);D 13;X FCRT(1,X,Y)
6.52 X FDLY(200)
6.60 RETURN
```

Appendix C (cont'd)

```
7.10 D 11;D11;
7.20 D 11
7.30 S T=d;
7.40 F D=1,T;D 8.20
7.50 G 9

8.20 T D,"RT",P(D),!

9.10 L C 1
9.20 L C 2
9.30 L C 3
9.40 L C 4
9.50 L C 5

10.10 Q

11.10 F I=1,10;S Y=50;X FCRT(1,X,Y)
11.20 F I=1,10;S Y-516;X FCRT(1,X,Y)

12.05 S V=0
12.10 S Y=-50;S M   IC(0);X FCRT(1,X,Y)
12.11 S Y=516;X FCRT(1,X,Y)
12.12 S N=0;X FSAM(1,1+32);S N=FSAM(0,1)
12.13 I (N-500)12.12;S V=FTIC(M)
12.14 S D=D+1
12.15 S P(D)=(V/500)-.09
12.16 S G=G+1;R

13.05 S E=E+1
13.10 X FSAM(2,3+32,6+32);S Q(E)+FSAM(0,1);S R(E)= FSAM(0,2);R
*
```

Appendix D

Experiment III Computer Program

```
C:FOCAL-11S V1   (RT-11) 12-Jan-75

1.01 E
1.02 T "CONDITION",!," SL-7:5",!,"SR=6:16",!,"RL=15:5",!
1.03 T "RR=8:16".!,":5 IMPLIES LEFT.:16 RIGHT",!!!
1.05 T "TYPE IN ORDER IN WHICH CONDITIONS ARE GIVEN",!!
1.06 T "1ST.";A V;A V;T !
1.07 T "2ND.";A Z;A W;T !
1.08 T "3RD.";A CA;A BA;T !
1.09 T "4TH.";A EA;A DA;T !
1.10 X FTIC(3,20);X FBUF(100)
1.20 X FCRT(0,128);X FCRT(1,0,0)
1.30 X FCRT(2)
1.35 F I=1,20;S Y=50;X FCRT(1,X,Y)
1.38 F I=1,20;S Y=516;X FCRT(1,X,Y)
1.40 F I=1,200;S X=800;X FCRT(1,X,Y)
1.45 F I=1,200;S X=250;X FCRT(1,X,Y)
1.46 F LZ=1,10;D 1.40;D 1.45
1.50 S N=1;S DD=0;S GA=0;s E=0;
1.60 L O 9,SCRAM/V:H(0)
1.65 L O 1,LEFT/V:L(0)
1.70 L O 2,RIGHT/V:M(0)
1.75 L M 3,S4[4]/Z/V:RMS(0)
1.80 D 1.35;D 1.38;

2.62 S DD=DD+1
2.63 I (1-DD)2.67,2.65,2.65
2.65   T=1,1;D 3
2.67   1.80;D 1.80;D 1.80;D 18;Q
2.70 G 17
```

Appendix D (cont'd)

```
3.10 D 4;D U;X FDLY(200);D V
3.20 D 4;D W;X FDLY(200);D Z
3.30 D 4;D BA;X FDLY(200);D CA;
3.40 D 4;D DA;X FDLY(200); D EA;
3.50 D 4;
3.60 S O=O;S N=1;

4.05 S O=O+O
4.10 F J=N,O;D 9
4.20 S N=O+1

5.54 S P=P+1;S A=X;S C=M(P);
5.55 I (A-C)5.60,5.60,5.65
5.60 S B=20;G 5.70
5.65 S B=-20;
5.70 F I=A,B,C;S X=I;X FDLY(25);X FCRT(1,X,Y)
5.80 X FDLY(100)

6.05 S X=780
6.10 S A=X;S C=A-70;D 10;D 12
6.20 S A=X;S C=A-140;D 10;D 12;
6.30 S A=X;S C=A-280;D 10;D 12

7.05 S X=280
7.10 S A=X;S C=A+70;D 10;D 12;
7.20 S A=X;S C=A+140;D 10;D 12;
7.30 S A=X;S C=A+280;D 10;D 12;

8.10 S X=780
8.15 S A=X;S C=A=280;D 10;D 12;
8.20 S A=X;S C=A-670;D 10;D 12;
8.30 S A=X;S C=A-140;D 10;D 12;
```

Appendix D (cont'd)

```
9.01 D F=C
9.03 I (D-H(J))9.04,9.04,9.06
9.04 S B=20;G 9.10
9.06 S B=-20
9.10 F I=D,B,H(J);S X=I;X FDLY(30);X FCRT(1,X,Y)
9.15 I (J-O)9.20,9.18,9.18
9.18 RETURN
9.20 X FDLY(100)

10.05 I (A-C)10.07,10.07,10.09
10.07 S B=15;G 10.10
10.09 S B=-15
10.10 F I=A,B,C;s X=I,D 10.12;X FCRT(1,X,Y)
10.11 RETURN
10.12 S E=E+1;X FSAM(2,3+32,6+32);S S(E)=FSAM(0,2);S R(E)=FSAM(0,1)

12.02 X FDLY(100)

15.05 S X=280
15.10 S A=X;S C=A+280;D 10;D 12;
15.20 S A=X;S C=A+70;D 10;D 12;
15.30 S A=X;S C=A+140;D 10;D 12;

16.29 S Q=Q+1;S A=X;S C=L(Q)
16.30 I (A-C)16.40,16.40,16.50
16.40 S B=20;G 16.60
16.50 S B=-20
16.60 F I=A,B,C;S X=I;X FDLY(25);X FCRT(1,X,Y)
16.70 X FDLY(100)

17.10 RETURN
```

Appendix D (cont'd)

```
18.05 L C 0;
18.10 L C 1;L C 2;
18.20 L C 3;L C 4;
18.30 S K=E
18.40 F E=1,K;T E,"S",S(E),"R",R(E),!
*
```

Appendix E

Experiment IV Computer Program

```
C:FOCAL-11S V1   (RT-11) 12-Jan-75

1.10 L O 1,T1/V:D(0)
1.20 X FTIC(3,20);X FBUF(100)
1.30 X FCRT(0,128);X FCRT(1,0,0)
1.40 X FCRT(2)
1.50 X FDLY(2000)
1.60 F I=1,20;S Y=-50;S FCRT(1,X,Y)
1.70 F I=1,20;S Y=516;X FCRT(1,X,Y)
1.80 F I=1,50;S X=750;X FCRT(1,X,Y)
1.90 F M=1,8;D 2
1.94 D 2.04;D 2.04
1.95 G 5

2.02 D 1.80
2.04 D 1.60;D 1.70;D 1.60;D 1.70
2.10 F I=1,32;D 3
2.20 D 1.60;D 1.70;
2.30 I (M-10)2.40,2.50,2.50
2.40 X FDLY(1500)
2.50 RETURN

3.02 I (1-I)3.05,3.03,3.03
3.03 S V=50;G 3.10
3.05 I ((FABS(D(I)-D(I-1)))-150)3.07,3.07,3.09
3.07 S V=50;G 3.10
3.09 S V=60;G 3.10
3.10 F R=1,V;S X=D(I);X FCRT(1,X,Y);

5.10 L C 1
*
```