AN ABSTRACT OF THE THESIS OF

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Title: AN EXAMINATION OF INVERSE SEQUENTIAL (SERIAL) LEARNING AS A METHOD OF SKILL TRAINING IN INDUSTRY: A HUMAN FACTORS ENGINEERING APPROACH

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Dr. Edward D. McDowell

The necessity for the evaluation of training methods on a between methods basis is suggested. Current methods of training evaluations are considered, and found to be generally deficient for their lack of between technique comparisons. The necessity for an outline of planned comparative analysis of training methods is indicated and a method using Gagné's hierarchy of tasks is suggested. A comparison of chaining techniques, forward or inverse, for the learning of a non-verbal serial task is proposed and the superiority of the inverse chaining technique is hypothesized.

A machine driven non-verbal maze tracing task is used to train subjects in forward and inverse directions of learning with each direction having the same three levels of pacing for task performance. The maze is presented as two separate spans of seven elements each with ten possible trace alternatives within each element. The two spans are then combined into one 14 element sequence as the final phase of training for whole task performance. Pacing levels impose

decision speeds of 4, 5.7 and 7 seconds per element and all training phases require one error free performance prior to proceeding to the next training phase. Errors, time, and cycles required to achieve criterion are used as performance measures to allow statistical inference of the best performance method.

Experimental findings do not support the original hypotheses as forward sequence learning is found to significantly decrease time required for learning at the fastest pacing level and some evidence of fewer cycle starts and errors is determined to be present. Other pacing effects do not achieve acceptable statistical significance levels but some evidence of pacing effects on cycle starts and time are found in the individual span phases of training.

An Examination of Inverse Sequential (Serial) Learning as a Method of Skill Training in Industry: A Human Factors Engineering Approach

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Bernis Burl Conatser Jr.

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Assistant Professor of Industrial and General Engineering
in charge of major

Redacted for Privacy

Acting Head of Department of Industrial and General Engineering

Redacted for Privacy

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AN EXAMINATION OF INVERSE SEQUENTIAL (SERIAL) LEARNING AS A METHOD OF SKILL TRAINING IN INDUSTRY: A HUMAN FACTORS ENGINEERING APPROACH

I. INTRODUCTION

Training is an activity with which most members of the industrial community are already familiar. According to Webster's (1968) to train is "to direct in attaining a skill, to develop skills or habits," or, "to teach or exercise in an art, profession, trade or occupation." In industry the skills are of interest because they either allow for the production of a desired output, or, they enhance the probability of achieving some state of production. If this desired state of productivity is sensitive to the training methods used to achieve that state, then methods of training may be worthy of more interest, particularly by those individuals concerned with productivity.

Basic Concepts of Productivity

Productivity has recently emerged as a topic engaging the renewed interest of many professional, governmental and academic institutions. The convergent realization by all corners of this triad is that the classical definition of productivity as an output to input ratio is far too limited. However, any attempt to expand that classical definition must grapple with boundary and quantification difficulties.

The boundary difficulty is one of determining at which level the (sub)system being optimized is to be isolated from the greater system. Is it possible that what is good for "ABC" company is not good for society? How do we quantify societal benefits if they must be included in the system to be optimized? At what system level will the costs of increasing the model size, and, the opportunity costs of not optimizing at a higher level, become the minimum cost?

Exemplary of the realization of definitional inadequacy, with a resulting attempt to find an improved definition of productivity, is the creation, by the American Institute of Industrial Engineers, of the AIIE Productivity Task Force. In the first of a series of articles (DeWitt, 1976) sponsored by that task force, the difficulty of boundary establishment is indirectly considered and then resolved by placing it at the company gate and stating that all tangible and intangible business environment considerations can be incorporated into intra- and intercompany indexes. This position presumed that all necessary considerations are transmitted, via the marketplace and the employees, to the company, thereby satisfying the requirements of any higher level system.

The examples provided by DeWitt (1976) for developing the indexes of productivity used a variation of output to input ratios, i.e., requisitions processed per man-year, and of revenue analysis, i.e., dollar value revenue per customer, profit per dollar invested and value-added-per-customer costs. It seems strange that, having discussed the factors of inflation, unemployment, competition and efficiency, DeWitt chose to return to a variation of traditional methods of productivity measurement. That choice was made in spite of the fact that reference was made to the contention by Drucker (1974) that any increase in the productivity of employed persons, at the expense of other resources being made less productive, may actually be a decrease in the productivity of the larger system at the next higher level.

Productivity in Systems

It is apparent that productivity, like beauty, is defined by the vision of the beholder. The adoption of a "company," industry or societal viewpoint will depend upon the perceived probabilities of continued existence by the level performing the definition. If the growth of concern for societal interdependence continues, as evidenced by the fluoro-carbon versus ozone layer and effluent versus aquatic balance controversies, and the finite existence of resources is accepted, then a societal viewpoint will gain increasing acceptance. It seems reasonable to assume that subsequent attempts to define productivity will include a systems approach beyond some extrapolation of the general systems concepts described by von Bertalanffy (1968), Laszlo (1972), Klir (1972), van Gigch (1974) and others.

The development of the expanded concept of productivity will probably require analytical tools, one of which may be the graphic portrayal of resource availability, resource consuming activities and system solution methods provided by Resource Planning and Management System (RPMS) networks (Riggs and Inoue, 1975). RPMS has previously been conceptualized, by its authors, as a possible method of evaluating environmental systems that include industrial and societal subsystems.

Productivity and Training

In the case of productivity, as it might be affected by training, we are concerned with the basic relationships that exist between resources and the processes that convert those resources into demanded goods and services.

If a production process activity was isolated by the appropriate boundaries and extracted from a descriptive RPMS network, it might be simplified and portrayed as follows.

The diagram in Figure 1-1 illustrates the resources necessary to sustain the process and in turn the process produces the resources to be used by subsequent activities in the system. An examination of these produced resources subsequent to the process reveals, in this simplified case, that a fixed usable goods requirement will increase the resources required if waste material or rejected items are

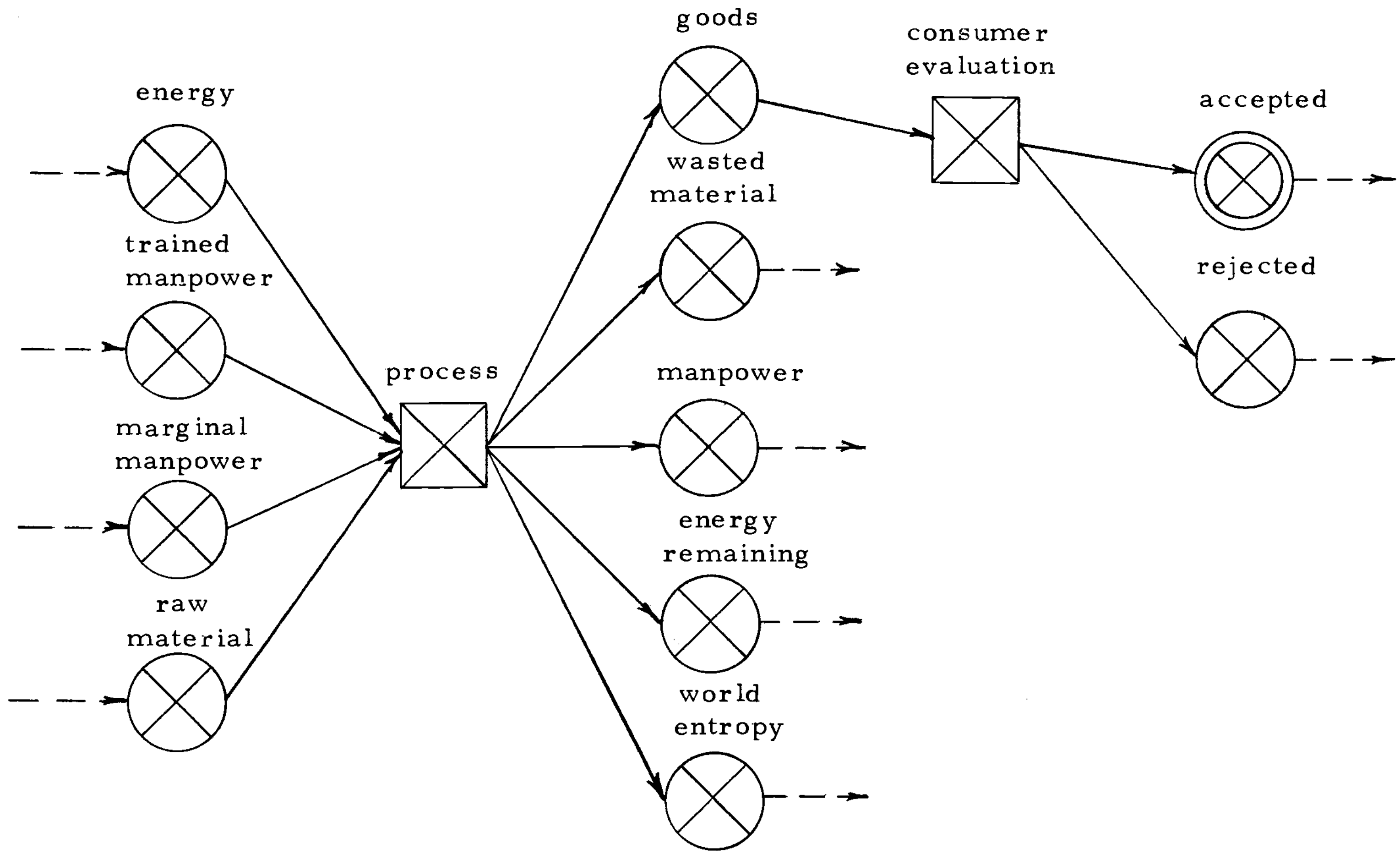

Figure 1-1. Production Process Activity Isolated from Larger RPMS Network.

allowed to increase. If the required goods level is higher than can be supported by the trained manpower resource then the more costly marginal manpower will be required to be used to meet the requirement. Such occurrences will depend on both the quality of the trained manpower and the extent to which the marginal manpower can be trained or retrained to meet the required levels of production.

This oversimplifed diagram illustrates the impact of inefficient or poorly trained productions workers on a larger system that lies beyond the production system. A decrease in the wasted materials and rejected items resulting from a more efficient process, provided that all other elements of the system are held constant, will decrease the energy and raw material resource requirements of this process, thus increasing the amounts available for other societal endeavors.

Training Evaluations

The probable first reaction to this discussion is that only well trained personnel should be used in a production process. As appealing as that thought might be, the fact is that insufficient evaluation has been accomplished in the analysis of the people capitalization process we call training. A training text will fault training planners for not planning a training evaluation and then proceed to evaluate the training on a before and after basis instead of against other training methods (Bass and Vaughan, 1966; Howell and Goldstein, 1971).

What we should be concerned with is to find out whether those people we label as well trained could be better trained by other superior methods, and, would it be possible to decrease the marginal manpower or reduce the numbers of untrained persons by better methods of basic skills training.

If we reexamine Figure 1-1 it becomes evident that any faulty or nonexistent evaluation of the training methods used to create the trained manpower resource will have contributed to inefficiencies of the system by affecting the coefficients for resources required in producing each unit by the isolated process of Figure 1-1. Worse still, is the probability that the losses due to training inadequacies will go undetected. This is because methods of comparative evaluation of training techniques suitable to situations determined to require a training solution have not been adequately developed (Duncan, 1973; Tilley, 1969).

The training of humans begins at birth and exists as a lifetime requirement in order to adapt to changing environments, social norms and the advances of technology. During the early part of life a person acquires a basic outfitting of fundamental skills which are applied to a chosen sustaining endeavor. The individual then enters a variable cycle of retraining to adapt his skills to changes in products, machines, technology and position. This retraining represents a cost to the sponsoring individual, industry or society at the time of retraining. It may also represent a hidden continuing cost if the methods used produce a hidden inefficiency in the man-machine process of production.

Training and Man-Machine Engineering

Man-machine engineering and efficiency of the man-machine interface has long been the concern of Industrial Engineering (IE). This concentration on the system of man and machine has resulted in such benefits as decreased lost motion and machine idle time. His experience has introduced the IE to methods of predicting increased production levels by using learning curves (Riggs, 1970). Yet, throughout his concern for production efficiency he has accepted the worker in being as a basic given, a point from which any future solution to any present problem must begin. What might be the effects of not accepting the basic given of the production force? This necessitates directing some attention to events preceeding a present situation or acting as an intervening variable between the present situation and a future desired state of affairs.

The event or variable of interest in this case is the training methods used to "form habits or impart proficiency" and create the present situation, or, using the same methods, could serve to achieve some desired future state of training. This concern for a better present or future state can be considered using the previously mentioned concept of learning curves. If we use a learning curve to portray production growth based on current production levels and system states, we might then compare that improvement curve to a hypothetical learning curve representing achievements by an increased initial proficiency level of the production force. This comparison in Figure 1-2, though at this point hypothetical, becomes another contemplation of curve alteration or manipulation such as to increase predicted production levels while decreasing some measure of cost associated with that production.

In order to make the improvement curves more meaningful, representative resource costs are incorporated on a sister diagram, similar to the technique of denoting costs on a cash flow diagram, and illustrate that if better training methods were used, though possibly at an increased cost, the initial production levels might be increased. This increased level might be what would normally be expected after several hundred units of production, and initial losses due to waste or rejected production may have been reduced, thus reducing the resource cost per unit of production.

It is because of this increased production level or decreased costs, or both, that might result from improved training methods, that we should examine one possible method of altering the production improvement curve. That possible method is training and more efficient training methods should bring a better return on equal

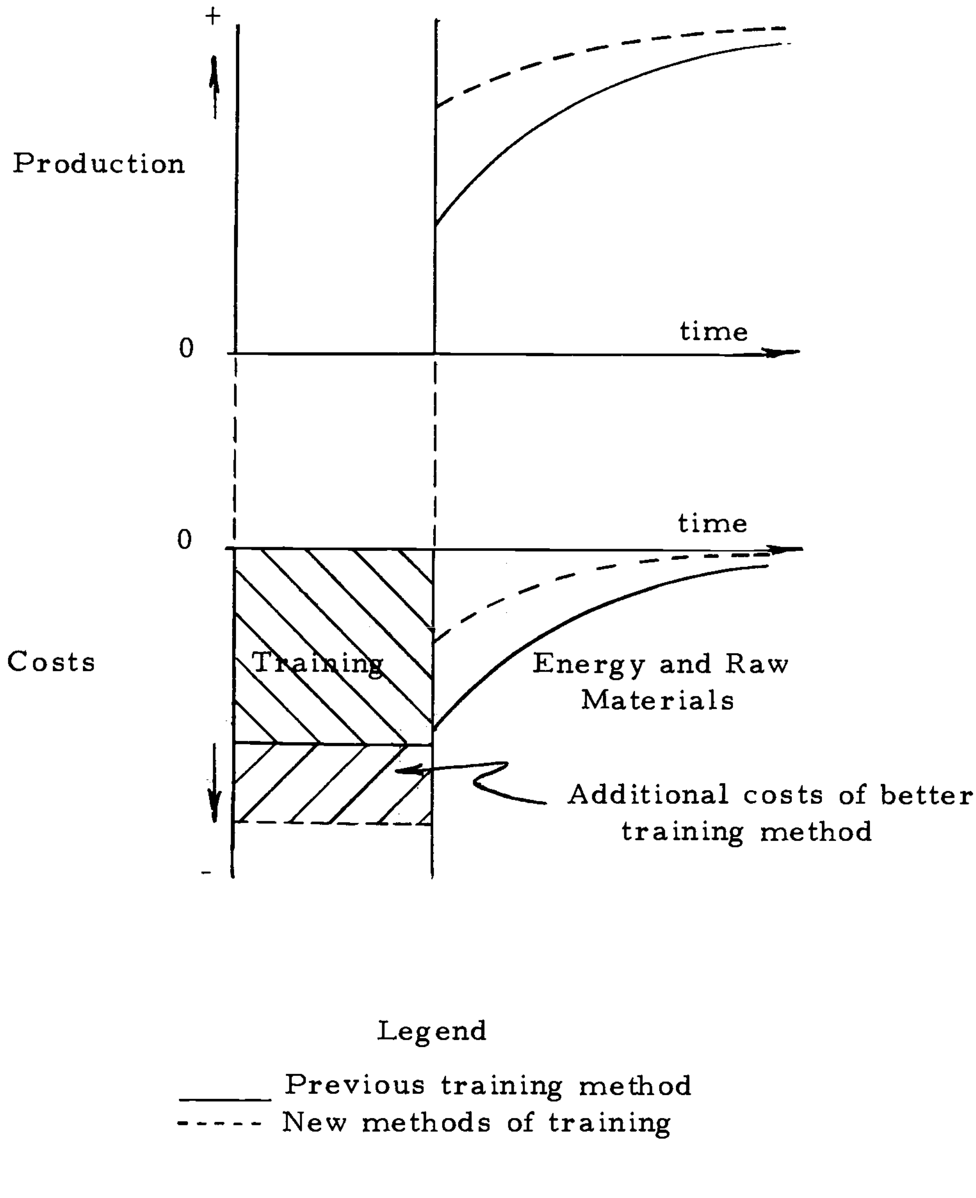

Figure 1-2. Comparison of Hypothetical Production Improvement and Reduced Cost Curves Resulting from Better Training.

investment by the sponsor. In fact the diminished waste consideration may eventually become a societal survival necessity.

Almost as important may be the goal of increasing the skill retention resulting from training. If errors can be decreased in the performance of critical but infrequently used skills, such as those required in emergency procedures for aircraft and nuclear power plants, then the pursuit of this and future evaluations will have been further justified.

A Search Directionalized

It would seem then that the time has come to bring the lack of between methods evaluation into focus, and, to launch a systematic analysis of training requirements, and methods, in order to achieve a matching of "best" methods with identified requirements for training. The benefits of such an analysis to industry may be immediate, long term and of a financial nature, but any effect on society will be forever.

Every beginning must itself have a beginning and this thesis proposes to begin the systematic comparison of training methods. One type of task, the sequential or serial task, will be investigated in a comparison of methods of training. The primary purpose of this comparison will be to determine the answers to two questions about the task: (1) Can we learn it quicker?; and (2) Will we forget less about it? If one method can teach the task quicker and/or reduces the amount forgotten, then a "best" method for similar tasks might be inferred. Thus, the long road to providing between method comparisons will have begun.

II. A SURVEY OF THEORIES AND APPLICATIONS

The stated purpose of this thesis is to evaluate but one of the many methods of training, because that evaluation must begin somewhere. To be unconcerned about training is to be unconcerned about the human resource, because training is the management of learning and learning is the acquisition of new skills by that valuable resource. If we ignore training then we allow learning to go unmanaged, and an unmanaged resource is usually a wasted resource, thus denying the resource the opportunity to contribute fully to its environment.

Any examination of this management of new skills acquisition should begin with a consideration of those principles, ideas and theories that attempt to account for the learning process.

Learning - A Definition

"Learning is a relatively permanent change in behavior that occurs as a result of practice or experience" (Bass and Vaughan, 1966, p. 8).

This definition of learning is short and somewhat concise but not unlike the definition one might find in most training texts. An expanded version would be found in an educator's (Snelbecker, 1974) or psychologist's (Hilgard and Bower, 1975) definition, primarily accounting for internal or environmental conditions, but the similarity of definitions is remarkable. Yet, when a theorist's explanation of how learning is accomplished is sought, the student (of learning) is overwhelmed by the number of discordant theories of learning in existence.

Learning Theories - An Historical Overview

Theories of learning began to evolve when philosophers began to account for man's actions through a pleasure-seeking, pain-avoidance hedonistic philosophy (Snelbecker, 1974). The time enduring aspect of behavior eventually gave birth to associationism to describe man's ability to associate actions or ideas and affect future behavior. These initial ill-defined and informal philosophies or learning evolved into the epistemological classifications of rationalism and empiricism (Hilgard and Bower, 1975).

Rationalism was that view established by the philosophical conviction that man's ability to reason was his source of knowing and knowledge. The goal of all examinations of knowledge was considered, by those holding this view, to be understanding of the process of knowing. It was in the garden of the rationalist's viewpoint that the seeds of what became loosely classified as the cognitive theories were sown and fertilized by succeeding intellectual investigations.

An opposing viewpoint, attributed to the empiricist, was that without experience there could be no knowledge. Experience was the only source of the collection of knowledge and man could not know if he did not experience. This view had a close kinship with the sensory aspect of experience and the associations between the sensing and experience formed a part of man's knowledge. Some allowance was made for the synthesis of prior knowledge that would lead to experiential relationships. It was the empiricists and associationists that are given credit (Hilgard and Bower, 1975) for the birth of experimental psychology related to the learning process, and these investigators developed the theories that came to be loosely classified as the behaviorist or stimulus-response (S-R) theories.

Hilgard and Bower (1975, p. 22) have posed six questions that a learning theory must attempt to answer:

(1) "What are the limits of learning?" What is man's capacity to learn?

(2) "What is the role of practice in learning?" Does improvement depend on repetition or are there other conditions?

(3) "How important are drives and incentives, rewards and punishments?" How do goals and rewards/punishments affect behavior?

(4) "What is the place of understanding and insight?" How do we explain the difference between ease and difficulty of learning?

(5) "Does learning one thing help you to learn something else?"

What are the causes or effects of learning transfer?

(6) "What happens when we remember and when we forget?"

They also note three major issues (p. 24-25) on which the two camps of learning theory are divided:

(1) Peripheral versus central intermediaries.
(2) Acquisition of habits versus acquisition of cognitive structures.
(3) Trial and error versus insight in problem solving.

In the peripheral or central intermediary question, the stimulus-response, or S-R, view is that an organism reacts to the stimulus, while the cognitivists are convinced that a cognitive or "mental" evaluation and subsequent "command" results from the stimulus reception. In the habits or cognitive structures dispute, the reaction habits of experience are established by the stimulus experienced, according to the S-R advocates, while the cognivitist's belief is that a mental structure is developed and then expanded or modified to account for subsequent experience. For the problem solving explanation, the S-R theorist views the performance in a novel situation as one of approximating the stimulus to a previously encountered stimulus and, if unsuccessful in resolution, beginning a trial and error process of using responses appropriate for increasingly dissimilar stimuli. The cognitivist theorizes that an assembly of structures from prior perceptual experiences allows an insight to possible solutions to be revealed.

Other issues that fall into both camps, and are not resolved between all theories within one camp, are such things as contiguity, reinforcement, extinction, increments of learning and kinds of learning.

The era of attempting to solidify a comprehensive learning theory occurred primarily during the two decades ending at mid-century (Snelbecker, 1974). Though Thorndike's writings were published in 1898, 1903, 1911, 1913 and 1914, his laws of exercise, use, disuse, effect and readiness (Snelbecker, 1974) were to exert a developmental influence and occupy the position of dominance among learning theories for the first half of the century (Hilgard and Bower, 1975). His three-volume Educational Psychology (1913-1914) was the reference source of Thorndike's connectionism.

Concurrent with Thorndike's efforts a Russian physiologist, Ivan P. Pavlov, was conducting the experimental investigations that led to his formulation of conditioned reflexes (Deese and Hulse, 1967) which was restated as the conditioned response by American psychologists (Hilgard and Bower, 1975). Pavlov considered himself to be a physiologist though he often quoted psychologists and thought well of Thorndike. The results of Pavlov's experimental works and concepts of stimulus conditioning were to have far reaching effects on the subsequent development of the behaviorist theories of, among others, Guthrie, Hull and Skinner.

While the complementary works of Thorndike and Pavlov were in process an opposing cognitive view was being developed by three German psychologists - Wertheimer, Kohler, and Koffka with a strong influence by Lewin (Snelbecker, 1974). These theorists saw a synergism in the collection of complex inputs to behavior and could not abide the reduction of complex behaviors to the smallest common element. Their concern was with the human ability to perceive and organize perceptions, and the ability to solve problems (Hilgard and Bower, 1975). Learning to them was an incidental event that occurred during perception, perceptual reorganization and refinements of the problem-solving process. This concern for insight is often illustrated as the necessity to account for the "aha" experience of solution revelation.

Subsequent contributions of the S-R viewpoint were made: by Guthrie with his contiguity conditioning and the belief that a stimulus was in fact a multi-dimensional stimulus, with practice allowing a greater awareness of more elements of the stimulus; by Hull with his theorizing of discomfort reduction in organism drive satisfaction; and by Skinner's concern for the consequences of behavior and the effects of behavior reinforcement (Snelbecker, 1974).

B. F. Skinner extended the works of Thorndike and Pavlov insofar as to separate what he termed respondent and operant behavior (Hilgard and Bower, 1975). Skinner associated the former, or, as he termed it, S-type, with the stimulus or conditioned substitute stimulus type of behavior. Type R, or operant behavior, was that behavior that was response reinforced such that the reinforcing reward was associated with the behavior itself and not necessarily with any environmental stimulus. Thus the organism exhibited a behavior to obtain a reward, not as a result of a stimulus association (Snelbecker, 1974).

Just prior to Skinner's work, Tolman, having been exposed to gestalt psychology with Koffka in 1912 and the Giessen gestalt group in 1923, began to develop his cognitive behaviorism theory. When he published his Purposive Behavior in Animals and Men (1932) he was criticized for his philosophical excesses, though in many ways his work was a description of the present information processing theory of learning (Snelbecker, 1974). It was Tolman's contention that not all learning was demonstrated by observable behavior and that in fact cognitive changes occurred in the organism before the overt action could be observed.

The Coming of Age - Contemporary Theories

With the passing of mid-century psychologists began to realize a growing desire to quantify the complex interactions of behavior. The foundations of such quantitative learning theories had long been advocated by Hull and new developments commenced during the decade of the 50's when Estes, Burke, Bush and Mosteller began to develop the class of models known as stochastic learning models. These models and other mathematically formulated models, came to be known as mathematical learning theory, not because of the existence of an unique theory, but because of the common usage of mathematical techniques to formulate and test behavioral hypotheses (Hilgard and Bower, 1975). The first such models developed were divided into: (1) operator models, where the probability of a correct response in a prelearning state was one-half, and, as learning progressed, positive increments of that probability were experienced until a probability approaching one, as a probability of obtaining a correct response, had been achieved for the fully learned response; (2) state models, typically described as the Markov model, with two or more states running from unlearned to learned, and with the significant points being that starting states can be varied, that prior state memory does not exist, and that levels of learning can increment or decrement, thereby eliminating any requirements by the design for an increasing probability of learned response (Snelbecker, 1974).

The mathematical models development has occurred as an extension of S-R and behaviorist theories, having developed around the situational events of those theories and is the current activity forum for the examination of the behaviorist's theoretical constructs (Hilgard and Bower, 1975).

Notwithstanding the quantitative interests of the theorists, there was also a renewal of academic curiosity about the cognitive processes during the 50's and 60's (Snelbecker, 1974). This interest followed in the wake of Shannon's (1948) development of information theory and paralleled the development of computer hardware and software. New credence was granted to the cognitive processes with the newly acquired ability to develop cognitive process descriptions using the legitimatized language and symbology of computer simulation and information processing. The increased sophistication resulted in a comparable increase in the sophistication of quantitative techniques used by the information theorists and they, like the mathematical learning theorists, have increasingly resorted to the precision and rigor of mathematical techniques to describe the dynamic cognitive structures within their models (Hilgard and Bower, 1975).

As information theories began to evolve into an analysis of man's ability to process information, attention was shifted to the computer simulation of cognitive behavior processes (Snelbecker, 1974). This evolving interest in the throughput of information, and the associated program to execute the simulation, has served as the basis for classifying information processing, as described by Newell and Simon (1972) in their analysis of man as an information processor and problem solver, as a learning theory. Their theory and their General Problem-Solver program, in being since 1957 with the most current version being in their book (Hilgard and Bower, 1975), will probably continue to exert a significant influence on current and future developments in information processing learning theory.

One last major contribution during this era was the incorporation of the concept of short-term memory into almost all models and theories. This simultaneous incorporation by opposing camps was almost as if the concept had been discovered (Hilgard and Bower, 1975).

From Theory to Application

While psychologists have pursued the elusive comprehensive learning theory, other professions have been faced with trying to extract the practical values and methods of education and training from those concepts, given the theoretical constructs and the debris of experimental investigation. These attempts to gain practical value from the laboratory result have been less than satisfying (Bass and Vaughan, 1966). As early as 1962, Gagné (1962) had expressed his concern for better methods of teaching and in 1964 Gage (1964) voiced grave concern that the learning theorists had not done more toward a theory of application.

The development of the instructional theories has closely paralleled the underlying philosophies of the parent learning theory.

The teaching machine and programed instruction were products of the Skinnerian philosophy of operant behavior conditioning and was founded in his principle of reinforcing the response behavior (Snelbecker, 1974). This technique has also been applied to the contingent response reinforcement methods of behavioral modification and though the major concern is for the type R, or response reinforcement behavior, it is still basically a behaviorist, or S-R based concept.

Bruner on the other hand was more nearly identified with the cognitive camp through his Cognitive-Development Theory embodying three modes of learning. These were enactive or learning by doing, iconic or mental imagery and symbolic or the verbal equivalence of experience (Hilgard and Bower, 1975). This theory of instruction does acknowledge elements of S-R learning theory related to activity learning, and elements of Piaget's developmental theory are identifiable in the acknowledgement of mental imagery learning.

A third viewpoint, not unlike the functionalists of learning theory, is what might be called a class of task analysis theories. Representative of this group is Gagné's Hierarchical theory. Gagné attributed the initial development of his theory to the inability to relate laboratory findings of the learning theorists to the experiences he had encountered in training situations (Snelbecker, 1974). This eventually led him to extract relevant ideas from a wide range of experimental endeavors, generated from the many learning theories, in the creation of a task analysis taxonomy. This hierarchical taxonomy consisted of eight types of tasks, each of which required the preceeding skills to accomplish the next higher skill. This building block concept of task learning was, by Gagné's (1970) standard, possibly not complete and he acknowledged that it did not account for environmental factors that impinge upon any learning situation. His eight types of learning (Gagné, 1970, p. 63-64) were:

Type 1 Signal Learning. The individual is conditioned to respond to a stimulus signal.

Type 2 Stimulus Response Learning. The individual discriminates between stimuli and learns a precise response to the selected stimulus.

Type 3 Motor Chaining. A sequence of two or more stimuli with their associated responses.

Type 4 Verbal Association. Verbal chains similar to type 3.

Type 5 Discrimination Learning. Learning to discriminate among similar stimuli, each of which has its own response.

Type 6 Concept Learning. One response is elicited by one class of stimuli.

Type 7 Rule Learning. Concept chaining with rules of concept relationships.

Type 8 Problem Solving. Cognitive concept and rule synthesis that creates rules and concepts appropriate to the solution of a previously undescribed problem.

Between the preceeding theories of learning and instruction and the following discussion of various aspects of training lies a discontinuity which is not easily bridged. This gap is not without semantic difficulty though it has been recognized that psychologists, educators and training specialists have on occasion collaborated (Snelbecker, 1974) and with beneficial result. Still, both sides are faulted for failing to achieve the benefits of increased exchanges of experience, and greater interaction is encouraged (Bass and Vaughan, 1966).

The Training Spectrum Narrowed

Tilley (1969), in his examination of the definition of training requirements, proposes that there is a requirement to develop a technique of determining the skills and knowledge that will improve the probability of high quality task performance. He also noted that training research investigators have failed "to explore how the interaction of task characteristics, student characteristics and training methods affect achievement" (Tilley, 1969, p. 244). To facilitate the analysis of tasks and the development of a taxonomy of tasks, Tilley reviewed several generalized models. The models, in brief, were:

(1) Hierarchical - the building block or class within class classification such as the eight types of task learning proposed by Gagné (1970);

(2) Morphological - the overlapping or intersecting categories of task behavior; and

(3) Operational - information processing and transformation.

Still other investigators and authors envisioned training as a requirement for the analysis of required skills (Salvendy and Seymour, 1973) and in one case a procedures analysis gave rise to a whole training technique based on the concept of chaining.

Chaining, or the stringing together of responses to form a serial or sequential task is a well known method of animal training (Johnson and Senter, 1965). This method allows the trainer to remove an animal from the immediate vicinity of the goal response, or, as it will often be termed, the temporal (mental) distance from the goal response will be increased. In order to accomplish this increase in temporal distance, the trainer must begin by teaching the rewarded performance, i.e. the goal response, and then sequentially increase the intervening task requirements until, from a starting distance of several intermediate responses, the animal can still reach the rewarded performance goal by performing the intervening task requirements. This backward chaining technique has also been used with significant success in the training of retarded humans (Linde and Kopp, 1973).

The previously mentioned training technique based on chaining was proposed by Gilbert (1962a), and termed mathetics, which, according to Webster's (1968), means "the science of learning." Gilbert's method was, by his own admission, heavily influenced by Skinner's work in operant conditioning. His expansion of the chaining method was to classify a stimulus-response series as an operant if that S-R series established one new unit of behavior during its exercise. When the length of the S-R series approached the largest single gain possible toward task mastery during one exercise, it was defined as an operant span. This operant span is very akin to the span of "chunks" of information described by Miller (1956). The operant spans are then chained together, beginning at the final response in the chain, as illustrated in Figure 2-1, and, in the manner of Figure 2-1, mastery of the entire task is added to the skill repertory of the subject.

Subsequent development by Gilbert (1962b) was directed primarily at the design of each of the teaching exercises containing an operant or operant span. This design included a rather complex system for the super- and subscripts of the stimuli and responses of the operants, but, no empirical testing data was presented.

First Exercise (observed)	- $R_{14}{\bullet}S_{14}$
Second Exercise (prompted)	- $S_{13} \rightarrow R_{14}{\bullet}S_{14}$
Third Exercise (observed)	- $R_{13}{\bullet}S_{13}$
Fourth Exercise (prompted)	- $S_{12} \searrow$
(spontaneous)	- $R_{13}{\bullet}S_{13} \rightarrow R_{14}{\bullet}S_{14}$
Fifth Exercise (observed)	- $R_{12}{\bullet}S_{12}$
Sixth Exercise (prompted)	- $S_{o} \searrow$
(spontaneous)	- $R_{12}{\bullet}S_{12} \rightarrow R_{13}{\bullet}S_{13} \rightarrow R_{14}{\bullet}S_{14}$
Final Exercise (spontaneous)	- $S_{o} \rightarrow R_{12}{\bullet}S_{12} \rightarrow R_{13}{\bullet}S_{13} \rightarrow R_{14}{\bullet}S_{14}$

Figure 2-1. The Mathetics Method of Exercise Development.

Johnson and Senter (1965) conducted and reported an investigation comparing forward and backward chaining techniques in the teaching of verbal tasks consisting of three-letter nouns, numbers, consonants and nonsense syllables. In three experiments: (1) a forward chain, learned as a 1, 1-2, 1-2-3 sequence and repeated as a 1, 1-2, 1-2-3 sequence, and a backward chain that was presented in a 1, 1-2, 1-2-3 sequence but repeated in a 1, 2-1, 3-2-1 sequence; (2) a forward chain as in experiment one, and a backward chain presented in a 15, 14-15, 13-14-15 sequence and repeated in a 15, 14-15, 13-14-15 sequence; and (3) the same types of forward and backward chains as in experiment two were repeatedly presented on a screen, with a requirement to anticipate a new item before it became visible using a one second stimulus exposure and a one-half second interstimulus interval. Whole chain recall was not attempted until the ten repetitions of the chain had been viewed, and though the items were exposed in a paced presentation format, no time limit was placed on the recall tests conducted at the conclusion of the repetitions.

Direction of chaining was not found to be significant in the first experiment. Forward chaining was superior ($p < .01$) in the second experiment, as it was in the third experiment if only the first recall trial was used in scoring ($p < .01$). The effect of the number of tests for recall in the third experiment was significant ($p < .01$) and performance on recall had converged to no difference by the third recall trial.

During the same period, Cox and Boren (1965) were testing the training of airmen in a Nike-Hercules missile launch procedure using forward, backward and whole task chaining. A 72 actions checkoff list was reduced to seven operant spans for the forward and backward chaining, and the unreduced list was learned from beginning to end in the whole task procedure. The results of their evaluation were that there was no difference between any two of the methods used for training.

Another examination (Slack, 1964), as reported in the Johnson and Senter (1965) report, had found the backward chaining learning technique to be superior in the teaching of meaningful verbal sequences.

However, the only statistically significant result was yielded by a questionable procedure that used uncommon sequences for the two chaining directions. A second procedure that was properly controlled did not achieve statistical significance.

A detailed search of available literature did not produce reports of any other related experimental result and the issue would appear to remain as one of contradictory evidence and contradicting or non-supporting results.

Gilbert's efforts were associated with his endeavors to improve methods of programed instruction design (Snelbecker, 1974). His contributions to that medium have been both complemented, and complimented, by others (Glaser, 1965) but progress in the mathetics method has not been reported in the literature.

Training Today

Current texts dealing with the problems of industrial and skill training take an eclectic approach to the offerings of the various learning and instructional theories. Most training authors acknowledge the impact of such things as motivation, knowledge of results, reinforcement, extinction, spontaneous recovery, forgetting, mediating responses and transfer of learning (Bass and Vaughan, 1966), and then provide a taxonomy of training methods. The methods are classified in some manner and a laundry list of training techniques is presented within each classification (Salvendy and Seymour, 1973).

Many of these same authors also advocate a systems approach to the development of the training program (Warren, 1969; Bass and Vaughan, 1966) which generally translates into insuring that training is a solution to the problem being considered, and, that an evaluation of the training method should be planned before the selected training method is introduced into the organization. Only one author was found to deviate from a within, or before and after, training method evaluation. Duncan (1973) advocated a between method evaluation of training techniques before method selection. He also acknowledged that the costs versus accuracy, speed and performance aspects must be evaluated by the decision maker. This advocacy of between method evaluation is a clarion call for investigators to examine the efficiency of teaching methods and quality of learning produced by each training method. The maximization of training benefit at a minimized resource investment cost, subject to resource availability, couches such a between methods of training evaluation in a verbal format familiar to the quantitative analyst.

Before an evaluation of training methods can be proposed, selected factors of learning should be reviewed in order to better understand the intended meanings of efficiency and quality of training intended in this thesis.

Training Factors

The consideration of the individual or individuals to be trained is of paramount importance in any training design. The maturity, prior experience, and desire to learn combine to create a level of readiness to learn in the individual being trained (Bass and Vaughan, 1966). The training program must be designed to either use the experience, or skilled response repertoire, of the trainee(s), or, add to that repertoire those skills necessary to achieve the skilled performance levels desired as a product of training.

Another consideration is the provision for providing knowledge of results, or feedback, to the trainee so as to provide him with a measure of his performance. This necessity for feedback presumes active participation by the trainee, reflecting McGehee's (1958) second postulate that requires that the trainee make a response, or, as McGehee phrased it, the program is "immediately suspect." Bass and Vaughan (1966) emphasize that this knowledge must serve as a yardstick of the differential between actual and desired performance with the latter already being known by the trainee, must be specific, and delay between performance and feedback must be minimized. In addition to the knowledge and performance benefits of feedback, Fitts and Posner (1967) contend a potential motivation of the trainee and a reinforcement of desired performance when feedback regarding performance is provided. This factor can be summarized by Welford's (1968, p. 302) quote of Sir Frederick Bartlett that "It is not practice but practice, the results of which are known, that makes perfect." Feedback must be provided through one of the trainee's sensory mechanisms. These feedback stimuli, defined as changes in the energy levels being projected onto a sensory mechanism (Fitts and Posner, 1967), must not only be sufficiently above the sensory detection threshold of the trainee but must also overcome environmental masking and perceptual bias of the trainee. Welford (1968) classifies perceptual bias as a selective filtering of stimuli. Others consider perceptual bias to be sensitive to the cognitive constructs, prior expections and positive or negative preferences of the perceiver (Howell and Goldstein, 1971). Fitts and Posner (1967) include trainee motivation and instructional quality as factors in any increased or decreased sensitivity of perception thresholds.

It has been reasonably well established that the stimulus detection threshold is a within-individual variable and that a Theory of Signal Detection (TSD) (Swets, Tanner and Birdsall, 1961) holds more promise than the earlier fixed threshold concept (Fitts and Posner, 1967). The TSD introduces a statistical decision-making aspect into the perception process which might be considered as another recognition of Welford's filter. Other evidence has been presented that fatigue and boredom displace perception thresholds (Poulton, 1970) as do environmentally induced discomforts (Murrell, 1965).

More often than not, any training program will be conducted at a higher complexity level of learning than S-R learning. This higher level of complexity will be affected by what was previously referred to as experience but which might now be more accurately labelled as mediating responses and transfer of training.

A mediating response is a form of enabling intermediate response wherein the trainee uses prior learning to develop, from environmental stimuli information received, different information that allows him to elicit the performance response sought as a part of the training exercise (Bass and Vaughan, 1966). These enabling responses are usually of a verbal or symbolic nature, such as arithmetic skills or word definitions, though they may also be physical or emotional intermediate responses. The prior possession of these enabling response skills is of definite concern to the training planner to insure that presumed trainee links do exist, or remedial training measures must be incorporated into the training program if they do not exist.

Transfer of training can be classified as positive or negative according to the similarity of new responses and their stimuli to some previously acquired set of S-R behavior (Fitts and Posner, 1967). The content of the trainees S-R repertoire will have some effect on whether old habits can be converted or transitioned to new skills as a positive transfer, or, whether prior habits and learned responses will be dysfunctional to new skill formation, thus being negative transfer.

Holding (1965) constructed a table of transfer, based on several earlier experimental works, that illustrates the four categories of transfer resulting from a comparison of old and new S-R similarity. The positive transfer of different stimulus-same response is attributed to the trainee already possessing the response skill thus contributing to the ability to establish the new S-R relationship.

Table 2-1. Table of S-R Transfer (Holding, 1965, p. 105).

	Stimulus	Response	Transfer
1	Same	Same	High
2	Different	Different	None
3	Different	Same	Positive
4	Same	Different	Negative

Two theories of transfer exist, both with reasonable amounts of substantiation (Bass and Vaughan, 1966). One theory states that identical elements exist in the old and new S-R situation, and the other theorizes that previously learned S-R situations cause generalizations to be applied to classes of stimuli. The generalizations become a collection of principles that are subsequently applied to any newly experienced situation. The most important aspect of this transfer of learning factor is to insure a positive transfer of training to actual task performance (Briggs, 1969). Any training performance not required in task performance is wasteful of training resources but any task element response that differs from the training response learned for like stimuli will degrade task performance due to the negative transfer of training responses to performance situations.

Reinforcement of correct training performance is, as the word implies, done for the purpose of strengthening desired performance. One method previously mentioned is to provide feedback thereby providing confirmation of correct performance or information on how to correct errors (Bass and Vaughan, 1966). The feedback can be provided either as verbal praise or rebuke, as a physical or symbolic reward or punishment, or as adequate information for the self-judgement of performance quality. The immediate elimination of errors, or in the case of the early stages of training, the prevention of errors (Welford, 1968), is very desirable due to the difficulty of eliminating incorrect responses that have been allowed to be repeated. In some cases incorrect responses may not be serious and errors of no consequence are permitted while the trainee is attempting to "discover" the correct response or would be unduly inhibited by frequent correction (Bass and Vaughan, 1966).

However, while there is some evidence that errors should usually be corrected, there is also evidence that correct performance should not be rewarded on every occasion of performance. Learning will be better facilitated if only occasional rewards are offered for correct performance (Bass and Vaughan, 1966). It is also true that reinforcement must be provided such that the response will be associated with the reinforcement.

Throughout the training process, and even beyond, there must be a concern for the trainee's ability to receive and process the stimuli information, considering the limitations of his immediate or short-term memory, and the necessity for transfer of information into long-term memory. The works of Hick (1952), Hyman (1953) and Miller (1953) indicate a requirement for an increased reaction time as the number of response alternatives available to the trainee increase. This requires that sufficient time be allowed for the trainee to discriminate amongst stimulus response alternatives. There is also considerable evidence that items of information, or stimuli , must be processes sequentially (Fitts and Posner, 1967), that active responses to a stimulus will inhibit the receiving of any new stimulus presented during the period of response, and that excess stimuli information overload will cause the trainee to selectively disregard information being presented (Welford, 1968). Redundancy of information is one method of countering loss of information and, in the case of a language, has been shown to be relevant to the learning rate (Fitts and Posner, 1967).

It is now a generally accepted concept that information received is first placed in short-term memory (Hilgard and Bower, 1975) and can remain there as long as physical or mental rehearsal can be accomplished (Poulton, 1970). It has also been noted that any transfer of information from short-term memory, which has a high information loss rate, to long-term memory probably requires mental or physical rehearsal to move the information into long-term memory, but, that physical recall or action of one of several items stored in short-term memory will tend to destroy other information held in short-term memory (Welford, 1968). Thus, even though it has been hypothesized that the span of immediate, or short-term memory is seven plus or minus two "chunks" (Miller, 1956), or items, of information, the full use of that span may inhibit learning (Fitts and Posner, 1967). There is also some evidence that an individual can increase the amount of information held in short-term memory if he chooses to recode the information (Miller, 1956) using mnemonics or other symbolic systems (Hilgard and Bower, 1975).

Even after information is successfully transferred from immediate to long-term memory, forgetting may take place. The primary theory of forgetting is interference theory (Hilgard and Bower, 1975) but it is advocated in two versions. The retroactive inhibition theory states that prior knowledge and skill is interferred with, i.e. recall is inhibited, by new learning (Bass and Vaughan, 1966). A similar theory of proactive inhibition blames old learning and skills for interferring with, and confusing, new skills or learning. While no one theory seems to dominate the other, the important point is that the interference between old and new learning seems to result in some loss of learning from memory. A lesser form of forgetting is called reactive inhibition which infers a loss of learning due to a lack of reinforcement, the classical S-R extinction, but reactive inhibition also applies to fatigue losses. This loss of learning can be countered by appropriate measures of reinforcement for desired performance and by adequate rest.

During the design of training, provisions must be made for the quantity of information to be learned during each period of instruction. This decision, to teach the whole task or to use a selected sequence of learning parts of the task, must be integrated with the decision to undertake the learning either in a continuous, or massed, practice until the task is mastered, or, to divide the task practice into spaced intervals of training (Welford, 1968). The whole task method seems to be advantageous (Bass and Vaughan, 1966) provided the task is not so complex as to overwhelm the intelligence level of the trainee (Fitts and Posner, 1967). This method is also best when task components are interdependent or require coordinated activity such as playing a musical instrument during task performance (Welford, 1968). However, if the task is composed of independent parts, of a low complexity nature, then part task practice would seem to be a superior method of training. If the task is composed of independent components, with varied levels of complexity, then the more difficult task components should receive more practice. This will speed the rate of learning when they are combined with the less difficult elements because of the increased proficiency, due to over-practice, in difficult performance, and, the decreased between element interference (Bass and Vaughan, 1966).

There may be some degradation of performance when part task elements are combined or if elements are learned and then shelved until all other components are learned. This can be effectively countered by a modified part-whole task method (Welford, 1968; Bass and Vaughan, 1966) that calls for a periodic review of all previously learned task components, combined in a multi-component assembly, that progresses to become a review of the whole task. This is similar to the accretion learning method of adding new components to existing skill chains (Johnson and Senter, 1965).

The question of spaced versus massed practice seems to be best answered, with a few exceptions, by using distributed practice (Fitts and Posner, 1967). Rest intervals should be shorter, but more frequent, during the initial stages of training to counter the effects of memory interference losses (Bass and Vaughan, 1966). Massed practice of simple or highly meaningful tasks is preferred, and massing of practice can usually be increased if the trainees are very talented with high experience levels. Rest "breaks" of a few seconds or a minute may be as beneficial as a one day interval between practice periods (Welford, 1968). The lengths and amounts of practice will also be affected by any fatigue or boredom introduced by the task being learned. Heavy muscular activity in motor learning (Fitts and Posner, 1967) or the boredom induced by rote memorization of symbolic associations will probably require either a part-task, or shorter periods of distributed practice approach to learning (Bass and Vaughan, 1966).

It is important during learning that active participation methods, requiring active responses by the trainee, be used if at all possible. Passive or observational learning has been noted as a method of learning (Hilgard and Bower, 1975) but active participation has proven to be a generally superior method of new skills training. It is also important that the use of cues and augmented guidance, i. e. guidance that insures a correct response for a stimulus, be limited to early training and be minimized (Bass and Vaughan, 1966). Otherwise, the learner will become cue and guidance dependent such that when the cues and/or guidance are removed performance will be seriously degraded (Welford, 1968; Holding, 1965).

One last factor of training is the learning to learn phenomenon that is classified as a special case of positive transfer (Deese and

Hulse, 1967). Learning to learn is the result of an increased ability to master a new task, or to solve a previously unknown problem set, as a result of prior experiences of a similar nature. Thus the relevant stimulus, or stimuli , can be discriminated from its background, with a reduced exposure to the correct response being required by the trainee prior to correct performance being demonstrated (Bass and Vaughan, 1966). It has been suggested that the ability of well trained workers to limit their attention to relevant task stimuli is probably the primary reason their performance is unhurried and more coordinated than the newly trained employees (Welford, 1968). This same ability may also benefit retraining or new learning due to its compatibility with the learning to learn phenomenon.

Techniques of Training

The many techniques of training, as listed in Table 2-2, are essentially divided between the categories of on-the-job and off-the-job training. On-the-job training has the advantage of learner participation requiring active responses, but it may be less than satisfactory due to a lack of tutoring skills, poor supervision, environmental stress, fatigue and reduced levels of production. Off-the-job techniques allow the training environment to be controlled and permits task component isolation, if required, for training. The disadvantages of the off-the-job methods are a tendency toward reduced levels of trainee participation, the transfer of learning to the actual task performance may be reduced, expensive equipment support may be required and on-the-job reinforcement of off-the-job learning is often not planned (Bass and Vaughan, 1966) as a part of the total learning experience.

Table 2-2. Table of Training Techniques (Bass and Vaughan, 1966).

On-the-Job	Off-the-Job
Orientation	Vestibule
Job Instruction	Lecture
Apprenticeship	Special Study
Job Rotation	Films
Internship	Instructional TV
Assistantship	Conference-Discussion
Coaching	Case Study
Junior Board	Role Playing
	Simulation and Gaming
	Team Training
	Programed Instruction
	Computer Assisted Instruction
	Laboratory Training
	Group Exercises

A Proposed Training Method Evaluation Model

Having reviewed the theories of instruction and factors and methods of training, and considering the dearth of between method evaluations based on measures of learner performance, an heuristic evaluation model would seem to be necessary. This heuristic might use the task hierarchy of Gagné (1970) and a modified version of the information processing model, Figure 2-2, of Tilley (1969) as a method of constructing the initial "best method" selection matrix, given the task to be learned and the associated model component that is within the information process segment to be affected by training. This model association allows examination of both skills and components to insure that a training solution is appropriate to the problem requiring solution.

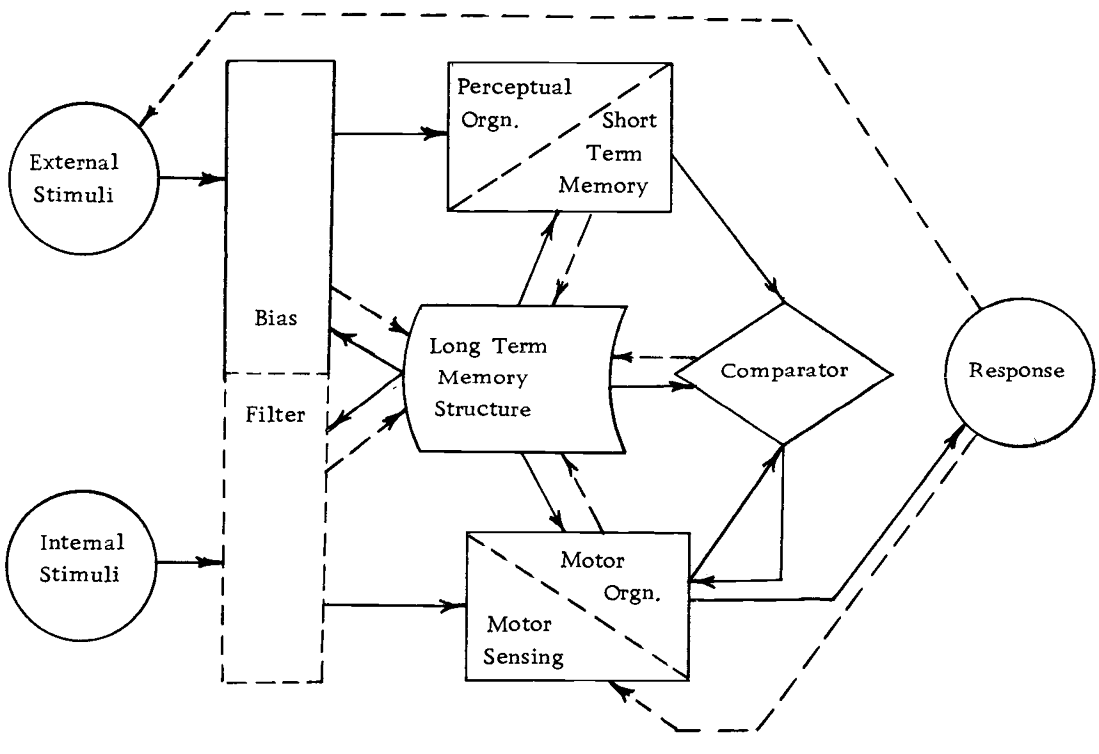

Figure 2-2. Information Processing Model (modified from Tilley, 1969, p. 245).

The training method evaluation now becomes an evaluation of the combinations of tasks, techniques, and modelled individuals for rank ordering of techniques within classes of individuals by hierarchical task type. Classes of individuals may be necessary because of individual variables, such as age, sex, socio-economic class, industrial work level, education level, etc., and some consideration of environmental stresses, such as speed, arousal, and interference, may have to be incorporated into the task being evaluated.

While discrete evaluation levels of the several variables is proposed, these variables probably combine to form an interactive continuum of trainability ranging from the physically and/or mentally retarded to the physically and/or mentally gifted individual. This continuum might be conceptualized as a three dimensional space of trainability.

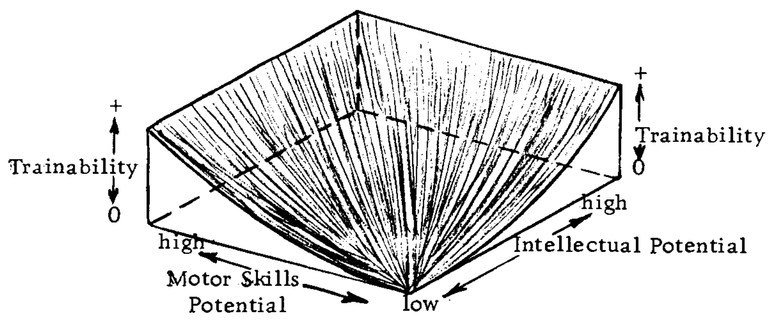

Figure 2-3. Surface of Trainability.

Even after the effort, which would be considerable, of locating those discrete points at which the evaluation would be conducted, the problem of surrogate laboratory task selection will still exist. This task selection will surely incur the risks, so eloquently described by Chapanis (1967), of generalizing from the laboratory to the field.

However, the construction of this hypothetical evaluation model is not the intended purpose of this thesis. The purpose is to examine but one of the task types contained in Gagné's hierarchy plus the effects of applying selected alternative methods of training to that task type.

Development of The Hypotheses

Gagné's type 3 task, chaining, is to be examined for a determination of the effects on efficiency, or, performance achievement requiring least resource investment, and quality, or, retention resistance of the learned task to forgetting, when forward and backward chaining methods are applied to serial learning under conditions of several levels of pacing.

Efficiency is considered to be related to the costs of training and training costs can be a considerable investment. This is illustrated by the report that the American Telephone and Telegraph Company's salary cost for non-managerial formal training, in 1963, was 75 million dollars (Howell and Goldstein, 1971). If that report is used as a point of departure, an insight into the magnitude of present day costs of training, considering all of industry, is provided.

Quality is also related to cost if it is considered to be related to the infrequent recall of learning necessary to save a machine or facility under the increased stress conditions of emergency action. An increase in the results of training as a result of improved procedures for the selection of "best" method should prove to be cost beneficial.

The chaining to be examined will require the learning of a serial task which relates to the requirement for the stimulus for performance of a within-serial component to be the response element of the preceeding task component (Deese and Hulse, 1967). This sequence of performance is a fixed sequence with the learning of the correct sequence being of primary importance. Therefore, it is hereafter referred to as sequence, or sequential, learning.

The learning of sequential tasks was the basis for Gilbert's (1962a) mathetics, and, as was previously mentioned, subsequent experimental evaluations of verbal learning, using Gilbert's inverted presentation method, achieved mixed results. The following intellectual questions are therefore raised.

Would a non-verbal sequential task be better learned in a forward or inverse sequential training approach? If the non-verbal task is a paced task, what will be the effects of varied speeds of pacing on learning? Finally, does one method increase the quality of learning retention?

If we return to the suppositions that new learning must be processed through short-term memory, that transfer of new learning from short-term to long-term memory probably requires rehearsal, either physical or mental, that any activity requiring short-term memory recall tends to cause a loss of other elements of learning held in short-term memory, and, that as temporal distance from a stimulus increases the probability of a correct response decreases, introducing error associations for that stimulus, then a plausible case for the use of backward chaining might still be developed.

The prior experimentation by Johnson and Senter (1965), Cox and Boren (1965) and Slack (1964), may have been confounded by the ability of subjects to move verbal task sequence elements from short-term to long-term memory at a higher rate than expected. This may have been due to the familiarity with the components of each response, even though the combinations and appropriate responses for each stimulus were unfamiliar. A lesser rate of displacement of learned information from short-term to long-term memory would increase the number of items required to be held in short-term memory if a partially learned specified sequence is to be maintained in an unbroken chain.

The accuracy of recall from short-term memory might be affected by the necessity to recall previously learned information as was demonstrated by Shepard and Sheenan (1965) in their telephone dialing experiment. Total dialing errors were reduced by about 50 percent when the position of familiar prefixes and unfamiliar four digit postfixes were reversed. This occurred even though the number of dialing errors within the three number prefix-now-postfix were doubled. The immediate recall from immediate memory had a significant effect on error reduction if intervening recall interference was reduced. It should also be noted that there was some interference with recalled information caused by new, and similar, information preceeding the recalled information. This may imply that reduction of the temporal distance to new components of task performance will increase the probability of accurate recall performance, thereby decreasing the probability of error associations being introduced and permitting transfer to long-term memory to begin. In this manner recall and overlearning of the remainder of a task sequence might be practiced in conjunction with the learning of a new element or task component at the beginning of the sequence.

An often replicated experimental result is the positional effect on performance in serial task recall (Deese and Hulse, 1967). In general, best performance occurs on those items or elements occurring first in the sequence. Inverse sequential learning might additionally benefit from the fact that the newest components or elements would be first in the recall sequence. As learning of that sequence is accomplished a new "first" element is added, and, in a manner similar to a moving average forecast effect, the quality of performance of the sequence being practiced is increased by virtue of each element having been first in the sequence when that element was first introduced for learning and the subsequent sequence recall.

The effects of pacing might also be inferred from the reported effects of pacing being applied to tasks previously learned to high degrees of proficiency. Bertelson, et al. (1965) conducted an experiment in pacing using experienced postal letter sorters. The sorters performed at a 60 letter per minute rate with a two percent error rate when unpaced. During machine paced performance, the rate had to be reduced to 40 letters per minute to maintain the two percent error rate, and at a 60 letters per minute paced rate the combined error plus unsorted letters rate had grown to 20 percent of the items presented. This points up the inflexibility of pacing and its lack of allowance for variable operator decision rates such that the operator must either wait for the machine on some of the cycles, or be overtaken on other cycles (Poulton, 1970). Related evidence of pacing effects indicate an age and sex sensitivity to the speed stress of pacing, with women over 40 and men over 45 less capable of coping with induced stress (Murrell, 1965).

Using the paced task performance results, it is probable that paced learning will either cause the trainee to slow to machine speed, or, in speeding up to achieve the pace rate, errors of performance will be inflated. This may be a consideration if training at operational speed, such as on-the-job training, is being considered, and may affect the preferred sequence, forward or inverse, of combining task components when an external source of pacing is present in the learning situation.

The Hypotheses

Thus the following generalized hypotheses are considered:

H_o : The learning of a sequential task involving unfamiliar performance requirements will be better accomplished by using an inverse sequential chaining method of training.

H_o': Changes in the level of pacing may reverse the desirability of the inverse sequential chaining method over the forward sequential chaining method.

H_o'': Learning accomplished by the inverse sequential method of chaining will be of a higher quality and less susceptible to losses of retention.

III. EXPERIMENTAL PROCEDURE

The scope of this experimental research was limited to the examination of a single non-verbal chaining task requiring sequence recall, the purpose of which was to formulate specific answers, for a specific case, to the following questions: (1) Can we learn quicker?; and (2) Can we forget less as a result of the training method used?

The methods of training to be compared in this evaluation are forward chaining and backward chaining techniques of learning management in a paced task learning situation.

Design

The laboratory surrogate task chosen was one of maze tracing. Such a task choice allows the observation of non-verbal responses to non-verbal stimuli that are not of a language type. In this manner a sequential task of a non-verbal nature can be created in the laboratory. Initial impetus to the specific design of the maze used came from two sources, the first being von Wright's (1957) binary choice maze as described in Welford (1968) for the idea of using a motor driven maze as a paced task. The second source was the report of Cook's (1937) "spider" maze in Holding (1965) that provided subjects with an eight choice route selection opportunity at sequential decision points.

The final maze design in this experiment was one of sequential maze elements, each with ten alternatives for route selection, joined together by a single route of trace between elements. The maze required subjects to choose a route for each hand through each element with the restriction that the hands could not cross over each other. This requirement was effectively reinforced with an equipment design that prohibited such a crossover. In this manner, the use of five routes in each element, with a designated route for each hand to trace, allowed the creation of ten possible alternatives, and elevated the complexity level to a point consistent with the memory capacity limits hypothesized by Miller (1956), Hilgard and Bower (1975) and others, regarding stored "chunks" of information.

The maze contained 14 elements, numbered 1 thru 14, and was divided into two operant spans, span A consisting of elements 1 thru 7 and span B consisting of elements 8 thru 14. A sample of one maze element, Figure 3-1, and a schematic of the maze sequence, Figure 3-2, are provided. The responses for the maze sequence were generated using a table of random numbers. A table of the correct response for every sequence element, is contained in the Appendix A. The route of the trace for the right hand was designated by the circle symbol, with the triangle likewise being used for the left hand, and served as the confirmation of performance during the experiment.

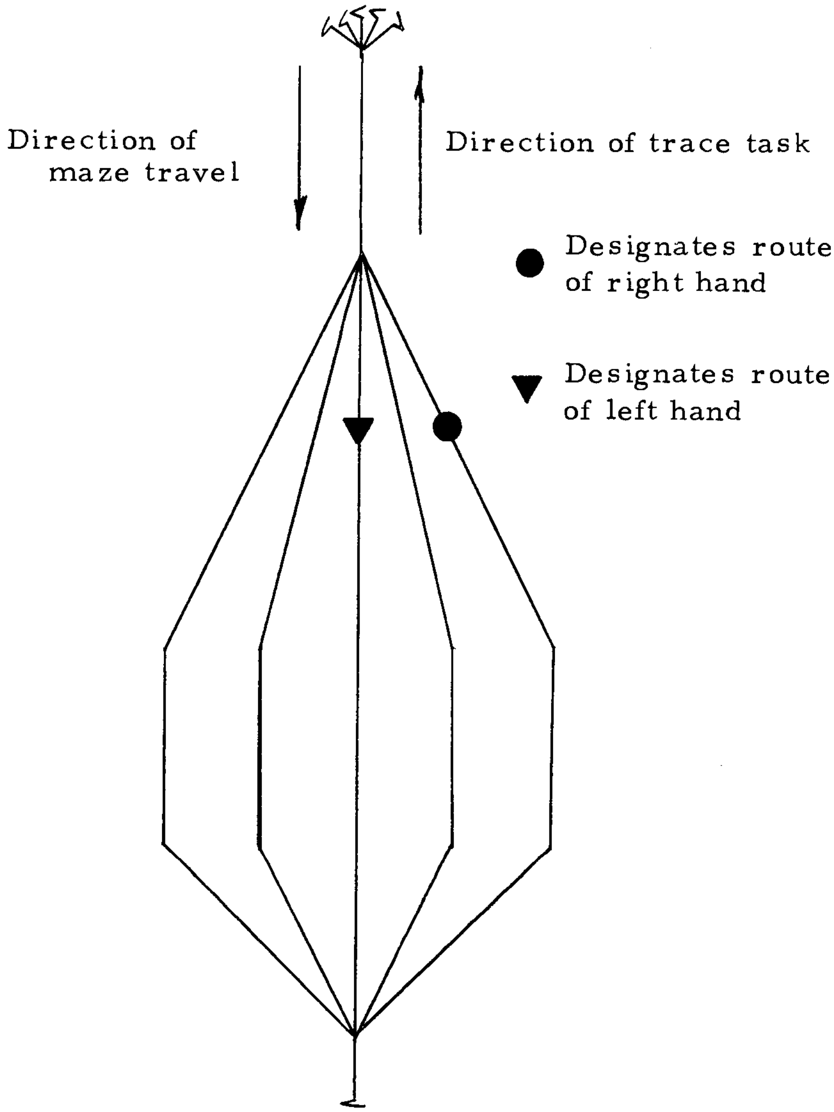

Figure 3-1. Sample Maze Element.

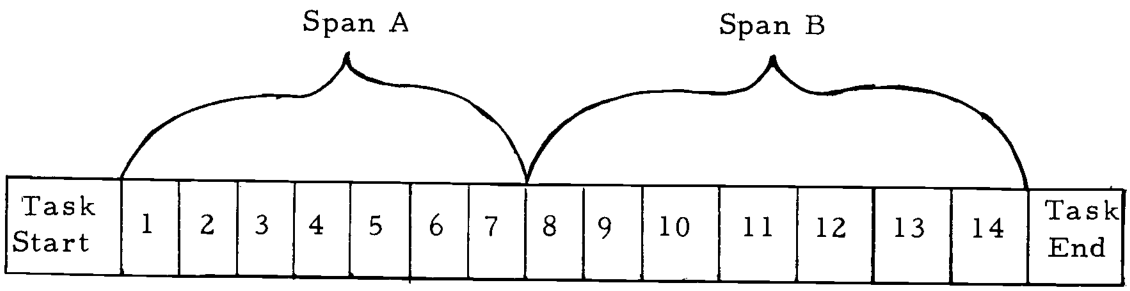

Figure 3-2. Schematic Diagram of Entire Task to be Learned (Traced).

The medium of presentation of the maze was by video monitor. This was a consideration in determining the dimensions of the maze element in order to limit the linear amount of an element visible on the video screen at any one time. The maze was drawn on a continuous paper roll and then video taped as it was pulled across a viewing surface by an electric motor driven roller. The speed of the motor drive could be varied from approximately 4.5 inches/second to 1.25 inches/second, but once a speed had been selected the motor drive would operate at a constant speed. A special effects generator was used during recording of the maze to allow maze and element information to be recorded in the bottom half of the video recording.

The speed information was changed for each speed of pacing and a "page number" marking was provided for each maze element and manually changed during recording.

Pilot testing of the experimental procedure was conducted, using six volunteer subjects, to determine the feasibility of completing training sessions within a 50 minute training period, and to provide some information on which speeds of pacing might have a measurable effect on performance. The 21 element maze used in pilot testing required between 60 and 150 minutes to achieve criterion but 14 elements were accomplished in less than one hour in all cases. This finding resulted in the length of the maze being reduced to the 14 element length used in the experimental procedure.

Observation of subject performance during pilot testing revealed a moderate level of stress when a speed of four seconds per decision was used, and a tendency toward boredom when the seven seconds per decision speed of pacing was used. This subjective observation of stress and boredom became the range of the speeds of pacing with 4, 5.5 and 7 seconds per maze element being selected as the three levels of pacing. Performance observation also resulted in changes to the tape recorded instructions given to the subject at the beginning of the training session.

During the experimental design phase, consideration was given to the methods of evaluation of the experimental results in order to select a statistical model for data analysis. When the length of the training session required was considered in conjunction with the fact that all subject participation would be on a volunteer basis, it became evident that training in multiple maze, maze direction and speed combinations for each subject was not feasible. This eliminated the latin square design statistical model, notwithstanding its increased capabilities.

The randomized block models were likewise eliminated because of the necessity for repeated measures for the same subject and the fear, on the part of the experimentor, that an artificial bias of the error terms might be introduced by such a model. This fear was based on a combination of the inability to distribute the within subject variation across all levels of treatment, and a lack of prior knowledge concerning the magnitude of that variation in the performance of the selected task. The possibility that the learning to learn phenomenon would be present was increased if several mazes had to be learned. This also increased the possibility of artificially skewing the distribution of performance during the assignment of subjects to treatment combination cells. Finally, between maze interference would have been present during training and recall testing. Any attempt to create distinctive stimuli for each maze would have further eroded any remaining symmetry, and the effects of proactive and retroactive interference precluded the use of like stimuli for different mazes. Thus a completely randomized factorial model was selected as the design outline for data collection, and subjects were trained once, with the same maze used for all subjects.

Subjects were randomly assigned to the six combinations of training direction and paced speed using the roll of a fair die. This method placed six subjects in each treatment combination cell after 36 subjects had been trained.

Selection of Dependent Variables

The criterion for successful performance, regardless of the sequence being attempted in training, was an error free trace of the maze segment being learned. A segment was defined as that portion of the maze being attempted, as a continuous sequence of one or more elements for that stage of training. If an error was made, the segment was repeated until an error free trace had been accomplished. Therefore errors were recorded, with positional notation, as a measure of task performance during training. Errors were also recorded during subsequent recall testing but the sequence was not repeated if an error was made.

A second measure of performance was the number of times a trainee attempted a given element of the maze, during any segment of the maze that contained that element, summed across all elements that composed the total maze. This gross total of the elements, also called frames, was tabulated as a measure of the time to criterion.

The last dependent measure of performance was the number of times the maze segment had to be attempted, summed across all segments of the maze that constituted the total training exercise. This measure, called starts, was considered comparable to cycle starts in any complex process wherein the cost of each cycle start is a significant expense of a more serious consequence than imbedded errors. Thus, if a task is learned in fewer starts, even though errors may be higher, a different training method allowing fewer starts would be indicated.

Subject Selection

Volunteer subjects were utilized and were solicited from several classes being conducted within the Department of Industrial and General Engineering. Procedures were established to limit the possibility of pretraining preview of the task to be learned. A profile of subjects is tabulated in the Appendix B.

Experimental Procedure

The training session for each subject began with the signing of an experimental procedure consent form, a copy of which can be found in the Appendix C. They were then seated in front of a television monitor with a mechanical pointer device before them, and at the base of the television set, and then given initial instructions by a tape recorded message. A schematic diagram of the physical arrangement of the equipment used in the experiment is contained in Figure 3-3. That figure also contains a simplified sketch of the mechanical pointers used by the subjects to trace the maze.

The pointers were of the self-centering type, operated by grasping knobs affixed to each pointer arm, and had a stop to stop arc of sufficiently large radius to allow the end of the pointer to sweep from one side of the screen to the other while remaining at or slightly above a horizontal line through the center of the video screen. The bottom half of the video screen was covered to prevent the subject from being aided by the maze identification and page marking information displayed across the bottom of the screen.

The tape recorded instructions, a transcript of which is contained in the Appendix D, began by instructing the subject to manipulate the pointers and operate the television screen brightness control. The brightness control had been extended mechanically to allow easy access by the subject and was dimmed during maze rewinding to reduce the possibility of additional preview by the subject. A sample maze segment was then shown to the subject, with pauses while he was instructed in how to properly position his pointers on the lines with circles and triangles. The subject was then instructed to center

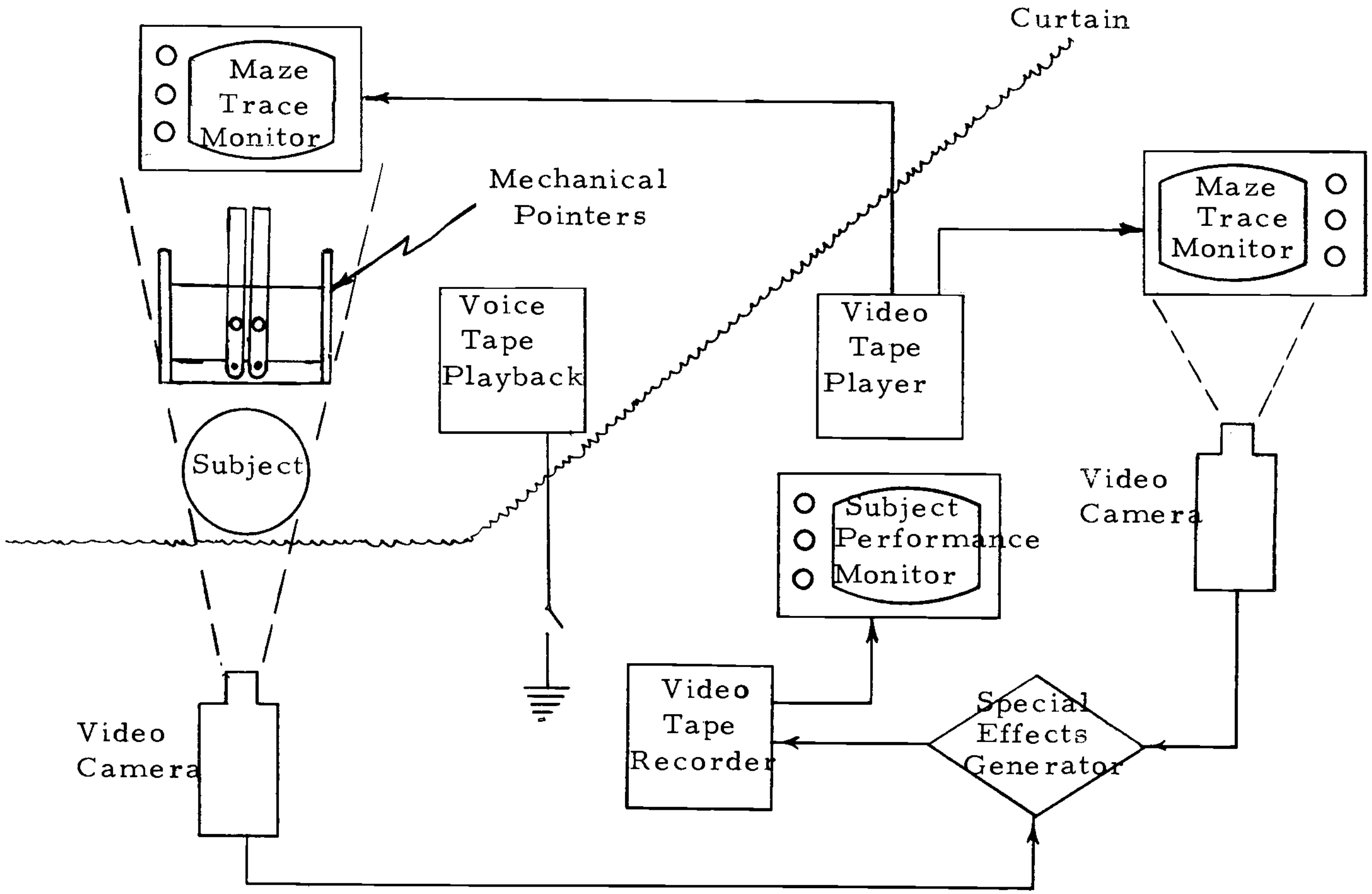

Figure 3-3. Experimental Equipment Schematic Diagram.

the pointers between each segment of the maze and given a demonstration of the error decision point, which was as the parallel vertical lines of the maze passed from view on the screen. Instantaneously afterward the circle and triangle would come into view and confirm the subjects performance.

At this point the recorded instructions became different for the forward and inverse presentation techniques, and began by announcing to the subject in which direction he would learn the maze. The forward learners were told that they would begin by learning span A of the maze starting at the first element and advancing to the seventh element after which they would learn span B in the same fashion. The two spans were then combined into one continuous maze sequence running from element 1 through element 14. Elements of the maze were added, one at a time, to the segment of the span being learned and as a subject completed an errorless segment the maze continued to run at paced speed to the next set of circles and triangles. There it halted for one second of viewing after which the subject was asked to dim the video screen, and then rewound to the beginning of the sequence. This was continued until one error free trace of the span being learned had been completed. When an error occurred within a sequence being recalled, the maze was halted for one second to allow the subject to view the correct response and to accentuate the commission of the error. The sequence was then continued from that point to the end of the segment being learned and then, without adding a new element, the sequence was repeated until an errorless trace of that segment had been accomplished.

After both spans had been accomplished and combined into one sequence, errors during combined span performance were accentuated, as before, and then the remainder of the 14 element sequence was continued. After completion of the error contaminated sequence, the subject returned to the beginning to again attempt an error free combined span trace.

Those subjects designated as inverse sequential learners were advised that they would learn the maze by beginning at the end of the maze and working back to the beginning. This meant that they would learn span B and then span A. Within span training was accomplished by adding the new element of the span segment being attempted at the beginning of the new segment. Element 14 was demonstrated and, without the subject dimming the TV screen, the element was backed up to the beginning of that element and the trace was attempted. The subject then dimmed the screen and, if the previous trace had been errorless, the maze was rewound to the triangle and circle portion of element 13, the screen brightened, and, after one second, the maze was backed up to the beginning of element 13 without dimming the video screen. The maze sequence of element 13 followed by element 14 was then attempted, and, if successfully traced without error, the maze was rewound to the circle and triangle portion of element 12 and repeated as before. If an error was committed during any segment of a span being attempted, a new element was not added and the error was handled in the same manner as with the forward learners. This same technique was applied to span A when an error free trace of span B had been accomplished. Span A training began at element 7 and worked backwards to element 1.

When both spans had been accomplished, they were combined in the same manner of the forward sequence learners and span A followed by span B was traced in one continuous sequence. Errors and error free trace requirements were the same as for forward learners.

The completion of the tape recorded instructions, given prior to beginning the training session, contained the information that the sequence learned and the paced speed at which the sequence was learned would be the same as that used for the 24 hour and one week recall tests. At the completion of training the subjects were cautioned to not create any written or drawn memory aids and a post-test questionnaire was administered. This questionnaire was used to validate subject participation and to obtain subject descriptive information. It also validated the recorded instructions as being very clear. A copy of the questionnaire is appended as Appendix E.

The training post-tests were administered at the end of 24 hours, and one week after training, to measure retention of the maze trace.

The recall test consisted of one tracing of the maze, at the paced speed presented in training, without any hesitation for errors committed. The error count was the only item of interest in the recall test.

Throughout the conduct of the experiment the experimentor endeavored to minimize the interaction of subjects and experimentor to the maximum extent controllable by the experimentor. After the initial instructions were given by tape, the subsequent conditional instructions such as "Dim the screen", or "There are no new elements in the sequence" were given by the experimentor in a monotone voice to limit feelings of approval/disapproval being communicated to the subject.

While one video tape recorder was providing the maze to be traced, another video tape recorder was recording the performance of the subject. The recorded information consisted of a horizontally split screen output from a special effects generator, with the top half of the screen recording subject performance and the bottom half of the screen being an input of the speed and "page mark" information from the bottom half of the maze trace picture. This picture being recorded was also displayed on a monitor to allow the experimentor to anticipate errors and take appropriate action in halting the maze momentarily and repeating the sequence without adding a new element to the segment being traced.

Experimental Data Translation

Errors were counted as errors if part of the pointer silhouetted against the video screen was not touching the correct line for that hand and both pointers had to be on the correct line for that element when the parallel vertical lines passed from view. In some cases, usually while training shorter subjects, some allowance for parallax had to be made. The required performance was almost always readily distinguishable from error performance. All errors, with positional notation, were recorded during training and during recall testing.

The element count, or frame count as it came to be called, was, as previously stated, the number of times an element was attempted, summed across all elements attempted. The minimum number of frames in each span, 28, and the minimum number of frames for training, 70, were subtracted as appropriate when statistical significance of frames difference was being calculated but were retained when time to criterion was being compared, due to the use of the three different pacing speeds.

The minimum number of starts possible during training was 15 with any requirement to repeat a sequence incrementing the number of starts by one. The minimum number was subtracted, as a constant, from total starts when determining whether differences were statistically significant.

IV. EXPERIMENTAL RESULTS

Raw data for the 36 subjects trained and tested during the experiment are contained in the Appendix G. Portions of that data will be repeated as necessary for clarity. In all cases the raw data have been corrected by subtracting the minimum requirements for training, seven starts within a span and 15 starts within the training session, or 28 frames within a span and 70 frames within the training session, when appropriate.

Pacing levels have been nominally labelled 4, 5.5 and 7 second levels throughout the experiment in lieu of the actual decision speeds of 3.96, 5.68 and 6.96 seconds per maze element. However, the actual times vice the nominal times were used to convert the frame count into a representative time measurement for each subject. The time obtained was the duration of training required beyond the minimum training time that would have resulted from an error free performance throughout every phase of training. The use of the time that the subject was actually tracing some portion of the maze eliminated the introduction of irregular times caused by the rewinding of video tape, equipment adjustments, etc., and provided a consistent measure of the time required to achieve an error free performance criterion.

Data Categories

The data have been divided into five basic categories, with sub-categories as appropriate, and the applicable score of each subject was recorded for analysis within those categories. The categories are:

(1) Total performance, or a scoring of the measurement criterion across all performance of maze tracing during the training period.

(2) Single span, or part task performance that includes all performance on one span, A or B, during training and excludes performance on that span when the whole task was attempted.

(3) Sum of single spans, or the sum of scores for the criterion measure for span A training and for span B training, but still excluding the performance on these spans when they were combined for whole task training.

(4) Combined span, or the scoring of the criterion for performance on the combined spans A and B but exclusive of any performance during preceding training on each single span.

(5) Recall testing, or the performance on recall of subjects using the errors criterion only.

Analysis

The analysis of data obtained required the use of two statistical models, the first being used to evaluate the single measurement of a subject, and the second being used to evaluate repeated measures of the same subject. The first, or single measurement case, refers to the fact that the subject was only trained once, at one speed and in one direction of learning. The second model was required to evaluate the two recall tests administered to each subject for the measurement of decay of learning over time.

The first statistical model is a two-way completely randomized full factorial design with two levels of training direction and three levels of pacing. This model, a CRF-2.3 design, is clearly outlined in Kirk (1968) as a method of analysis of variance. During data collection, subjects were randomly assigned to the cells of the model, with one cell existing for each combination of the treatments.

The second model, also contained in Kirk (1968), is of the SPF-2.3.2 or split-plot factorial design that accommodates repeated measures of the same subject within that subject's treatment combination cell.

The five data categories were analyzed statistically, with graphic presentations as necessary, considering the previously described errors, elements or frames, and starts used as measures of performance criteria. As a review, errors were recorded, with positional notation, if either pointer deviated from its correct trace path. Frames were counted as the number of times an element was attempted as a part of learning a maze segment, for all elements and all segments constituting the sequence being learned. Again, starts were the number of cycles through a sequence being learned as each element was added to the segment being learned, or each time the whole maze cycle was attempted.

Each measurement criterion was accumulated across the specified categories such that an analysis of total performance and a comparison of selected portions of task performance could be accomplished. All analysis will be presented in the same sequence as the previously established data categories.

Total Performance

Analysis of total training performance, as measured by the criterion of total frames required for training, yielded statistical significance, $p < .10$, for the effects of training direction with best average performance being achieved by the forward sequence trainees. The analysis of variance for treatment effects, as measured by frames, is presented in Table 4-1. The minimum number of frames for training, 70 frames, was subtracted as a constant from the raw data score of all subjects prior to ANOVA calculations.

Table 4-1. ANOVA Table for Total Frames Required in Training.

Line	Source of Variation	DF	MS	F
(1)	Direction	1	2.08803E 04	3.1065*
(2)	Speed of Pacing	2	1.06956E 04	1.5913**
(3)	1 x 2	2	1.70158E 03	NS
(4)	Error	30	6.72141E 03	
	Total	35		

*p < .10 **p < .25

Elucidation of the significance is possible using a graphical plot of the average number of frames for each treatment combination against the level of pacing. This particular criterion measure achieved marginal statistical significance, $p < .25$, for the effects of pacing. The shapes of the line graphs obtained by plotting the mean values for frames prompted further investigation for significance in the effects of the two fastest levels of pacing. A comparison of means, also known as contrasting and described in Kirk (1968), was used to test for a difference but significance still only achieved the $p < .25$ level.

The total frames were converted to time by multiplying the frame counts by the actual frame speeds, 3.96, 5.68 and 6.96 seconds as appropriate, allowing the graphs of Figure 4-1 to be converted to a measure of the time required that was in addition to the minimum possible time to complete training. The resulting times after

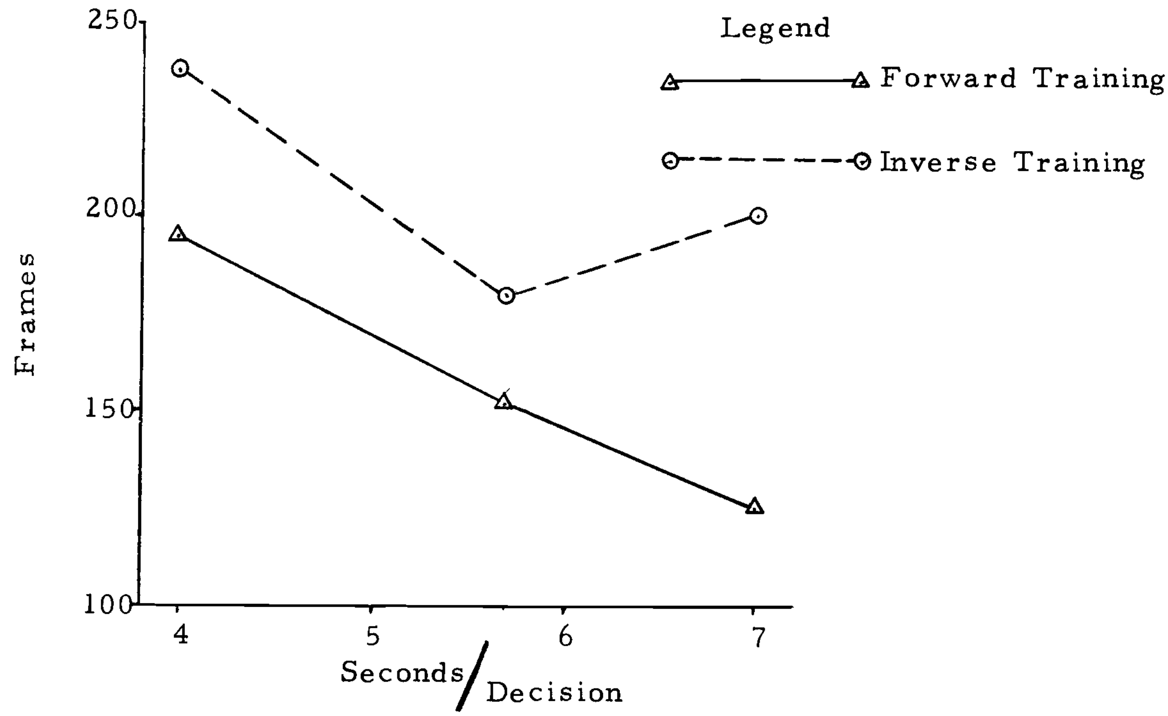

Figure 4-1. Total Frames Required to Achieve Error Free Task Performance.

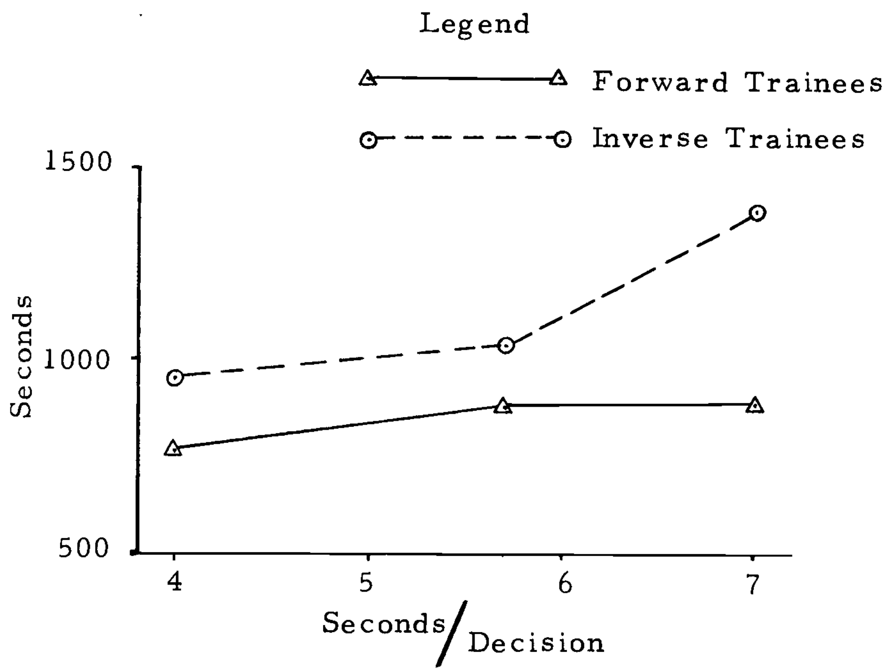

Figure 4-2. Time Beyond Minimum Required to Achieve Error Free Task Performance.

conversion are plotted in Figure 4-2. Effects of training direction remained significant, $p < .10$, but the effects of levels of pacing became statistically significant, $p < .05$, with performance remaining best for the forward trainees in the analysis of time required to achieve error free task performance. Thus the time penalty resulting from the committing of errors was statistically significant.

Curves similar in shape to those of Figure 4-1 were obtained if the mean values for total errors were graphically displayed, with a significance of $p < .25$ resulting from the effects of direction of training. The difference in starts required also only achieved a $p < .25$ significance level but the plotted means of Figure 4-3 yielded somewhat different curves than the Figure 4-1 graph.

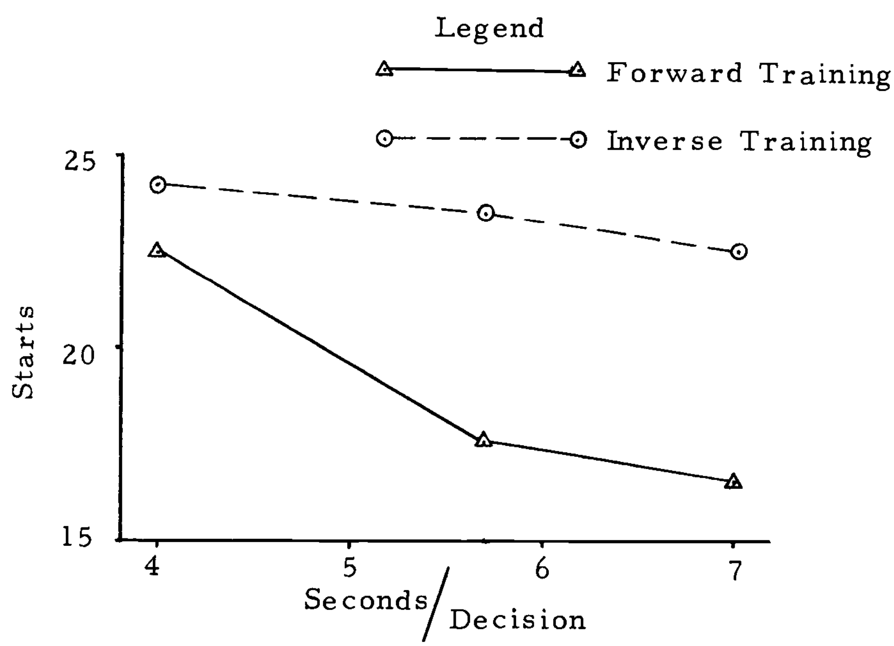

Figure 4-3. Total Starts Above Minimum to Achieve Error Free Performance.

Single Span Performance

Single span performance analysis included performance during training on span A only or span B only plus a comparison of performance on the first span learned, A for the forward learners and B for the inverse learners, and the second span learned, B for forward and A for inverse learners. Span B performance differences did achieve statistical significance, $p < .01$, for direction of training effects, with best performance from the forward sequence trainees, by all measurement criteria. The second span learned was almost as significant as forward trainees again performed best though errors only achieved the $p < .05$ level. Span A achieved significance, $p < .01$, for starts, with inverse sequence trainees achieving the best performance, but errors and frames were not significant at the $p < .10$ level. First span learned achieved significance at $p < .05$ for frames and $p < .10$ for starts with better mean performance being achieved by the inverse sequence trainees at the highest and lowest pacing levels, but this span did not achieve significance at a $p < .10$ level for errors. The effects of levels of pacing were marginally significant, $p < .25$, on span B as measured by starts and frames. The associated mean values are graphed in Figures 4-4 through 4-6.

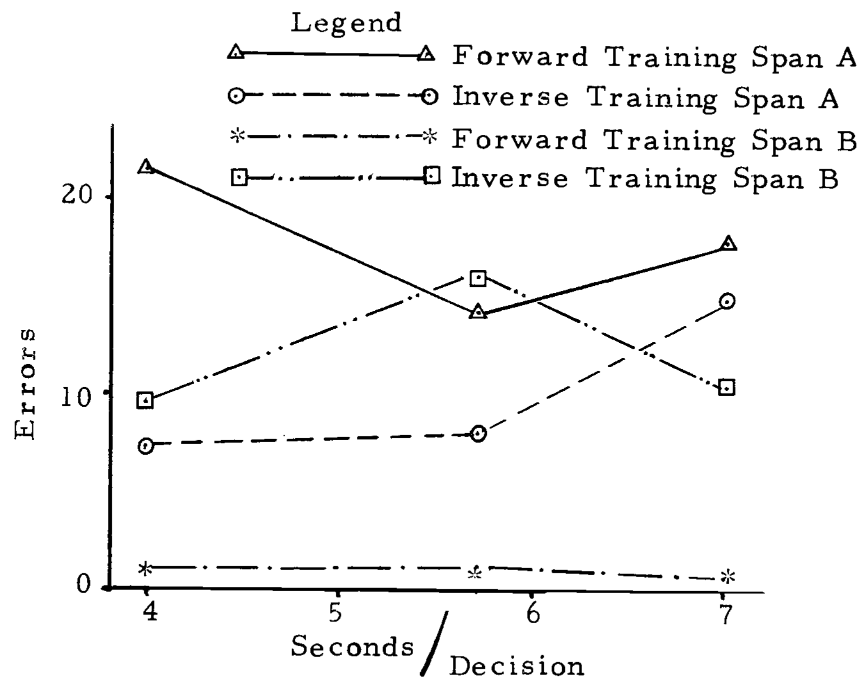

Figure 4-4. Errors by Single Span of Training.

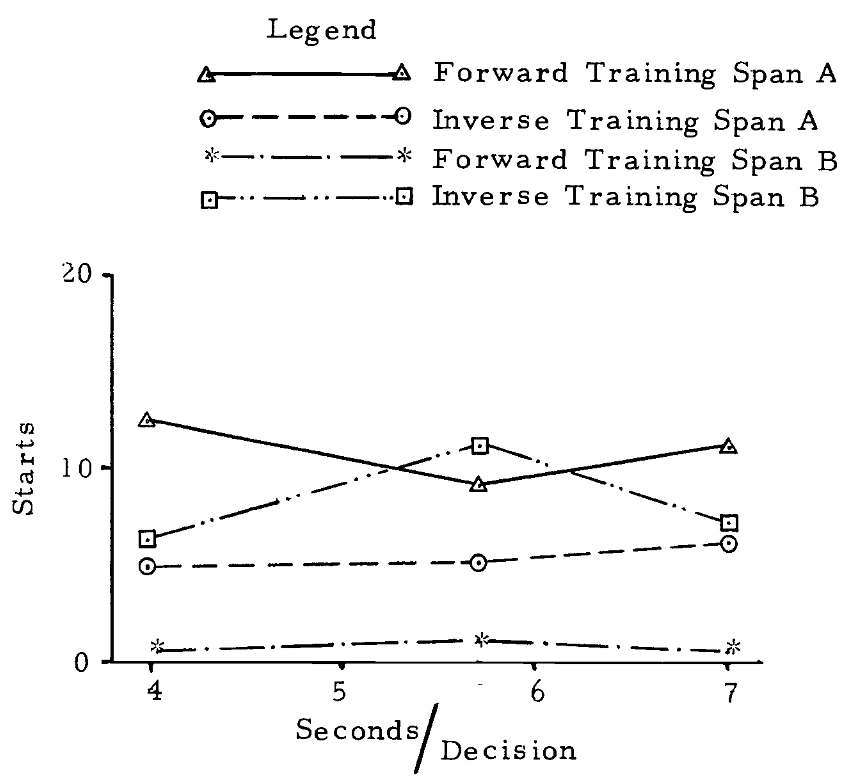

Figure 4-5. Starts by Single Span of Training.

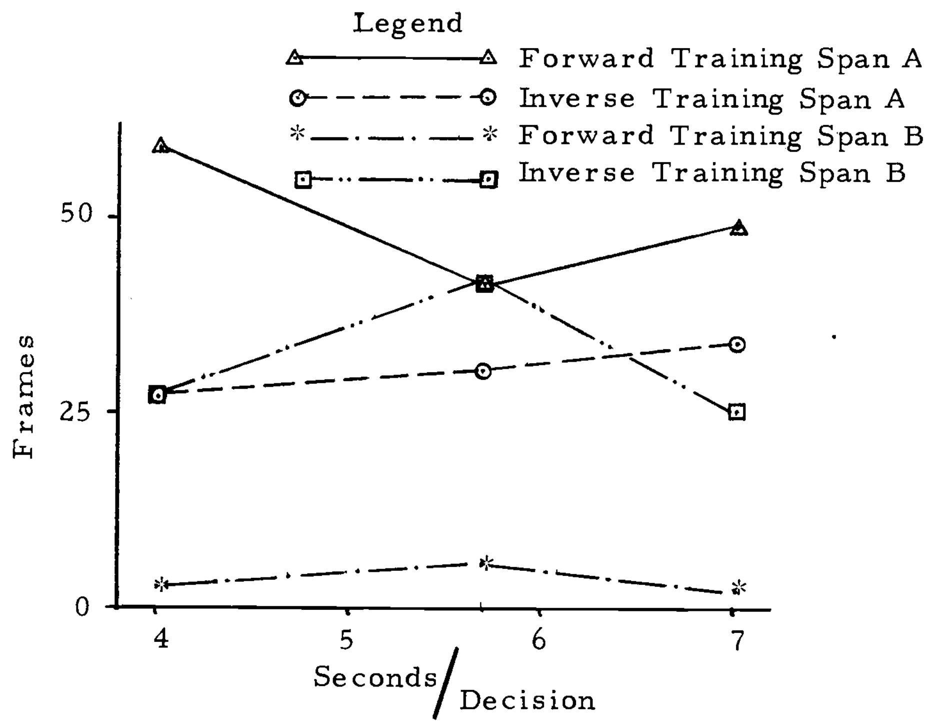

Figure 4-6. Frames by Single Span of Training.

It should be noted that in all cases the performance on the first span learned can be compared between forward and inverse learners by comparing the graph lines marked by triangles and squares, and second span comparisons can be made in a like manner by comparing lines marked by the asterisk and circle. Forward learners were superior in their performance on span B, their second span, but had the worst average, in almost every case, for span A, their first span of learning. Note, also, that performance improved as the forward sequence trainees progressed from the first span learned to the second span. In all cases except the slowest pacing level for errors and frames, inverse sequence trainee performance was equal or improved slightly as they progressed from the first to the second span learned.

Sum of Single Spans Performance

When performance measures for each single span were summed to obtain performance across the whole maze and then analyzed, there was no significant difference in performance attributable to treatment levels.

Combined Span Performance

During that phase of training occurring after the subject had learned each individual span, the two spans were joined together in a combined span A followed by span B sequence. This combined span sequence was then practiced until it was traced from beginning to end without error at which time the training session was terminated. Scoring of the combined span phase was accomplished for starts and errors but errors were recorded according to whether they occurred within the span A or span B portion of the whole maze. An error total was obtained for each subject by summing that subject's within span A and within span B error scores.

The analysis of the two-span or whole maze tracing task yielded statistical significance, $p < .01$, for direction of training effects for errors occurring within the span B half of the whole maze with better performance being obtained from forward sequence trainees. Errors for whole task performance during the combined span phase of training achieved significance only at the $p < .25$ level for direction of training effects as did starts except that starts achieved the $p < .25$ level for both the direction and the pacing treatment effects. Errors occurring within span A were not significant.

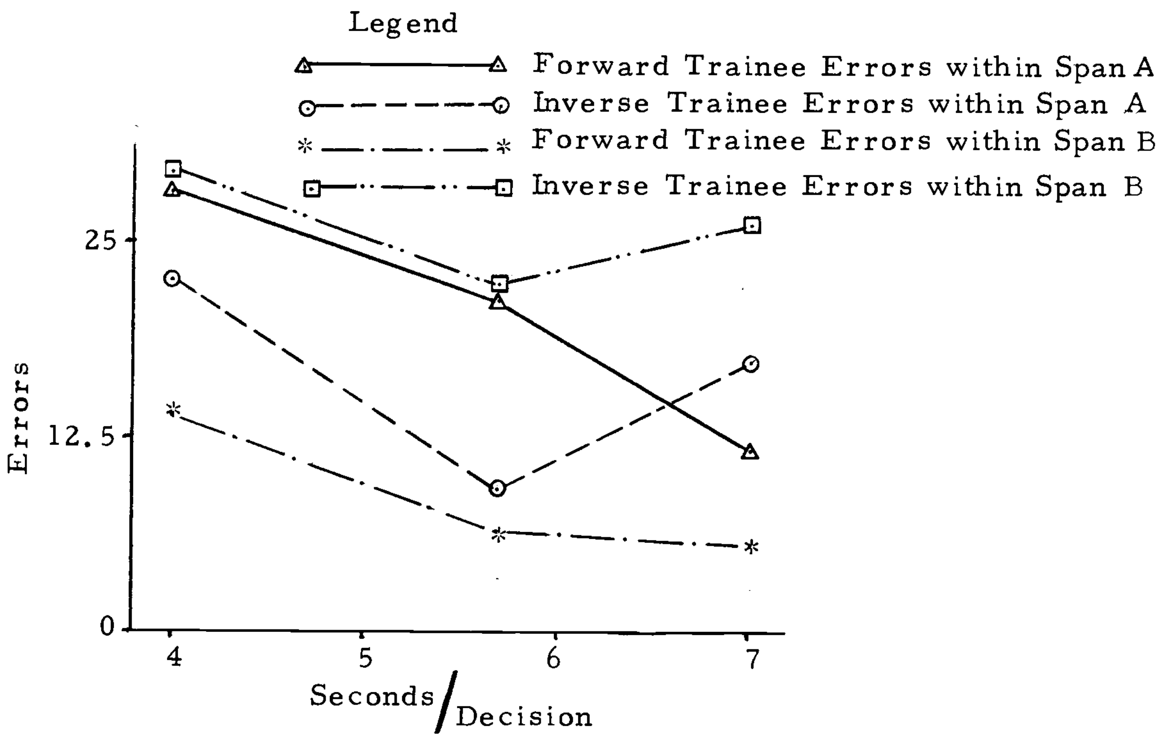

Figure 4-7. Errors in Combined Span Performance by Span Location of Occurrence.

The graphs in Figures 4-7 through 4-9 indicate that the forward sequence of training produced a higher average performance in combined span training except in the case of errors within span A. Slower pacing rates appeared to have a positive effect on all performance up to the 5.7 second decision rate after which the average performance of inverse sequence trainees deteriorated in all cases.

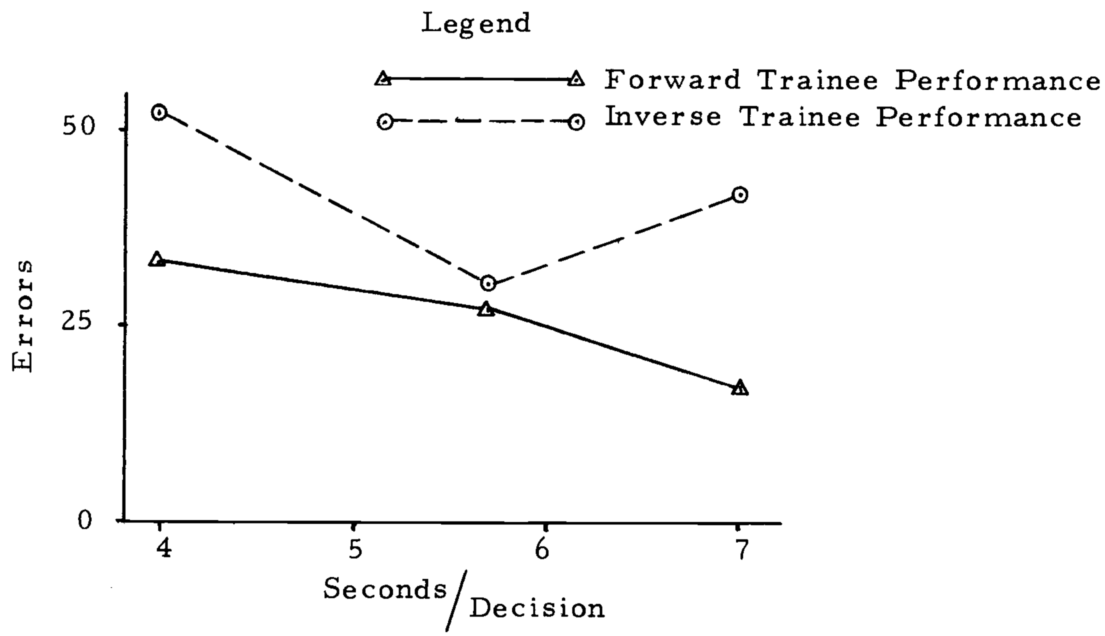

Figure 4-8. Errors During Combined Span Performance.

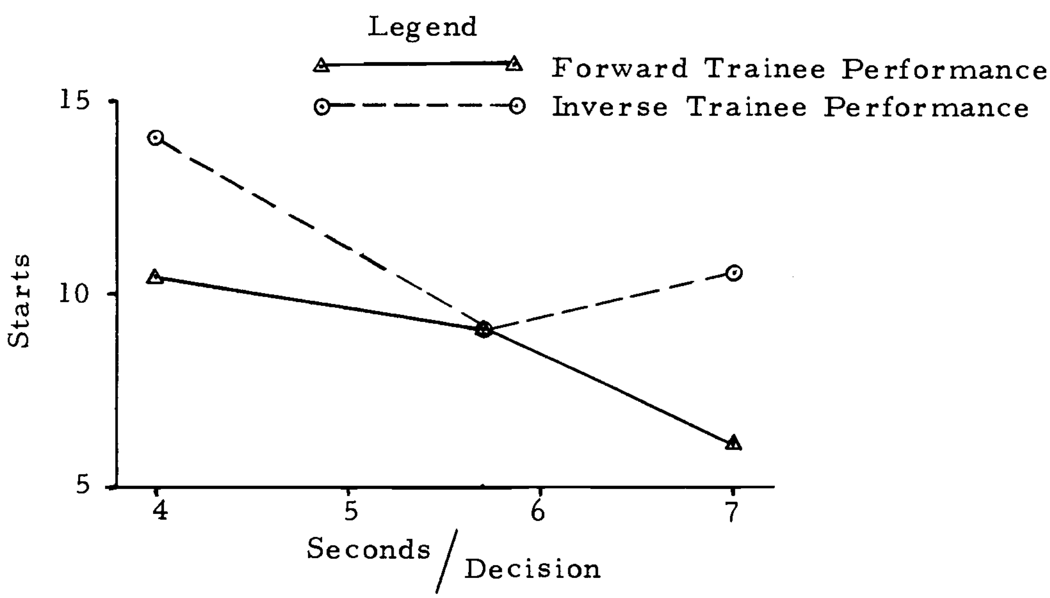

Figure 4-9. Starts Required for Combined Span Performance.

It should be noted that both forward and inverse direction trainees exhibited better performance within the most recently learned portion of the combined span task. This is indicated by the mean value plots showing better performance within span B for forward trainees and span A for inverse trainees.

Recall Test Performance

Neither of the treatment effects achieved statistical significance using the CRF-2. 3 model for analysis of recall test performance. A memory retention loss did achieve significance, $p < .01$, when the results of a subject's 24 hour and one week recall tests were compared. This comparison was accomplished using the SPF-2. 3. 2 model for analysis, and direction and pacing effects were still not statistically significant. The analysis of variance table for that model is contained in Table 4-2.

When average performance on recall of the trainees was graphically presented, the similarity of curve shapes was immediately evident. The forward learner was either not affected or the performance slightly improved by a decreased speed of pacing. The performance of the inverse learners also improved in a like manner until the last decrement of pacing where the trend was reversed and performance was degraded by the slower speed.

Table 4-2. SPF-2.3.2 ANOVA Table for 24 Hour and One Week Recall Performance Decay.

Source	SS	df	MS	F
Between subject	380.82	35		
A (direction)	8.68	1	8.68	.798
C (pacing)	11.86	2	5.93	.529
A x C	24.2	2	12.1	1.08
Subjects within groups	336.08	30	11.027	
Within subjects	81.5	36		
B (recall delay)	23.35	1	23.35	12.20*
A x B	.12	1	.12	NS
B x C	.53	2	.265	NS
A x B x C	.08	2	.04	NS
B x Subjects within groups	57.42	30	1.914	
Total	462.32	71		

*$p < .01$

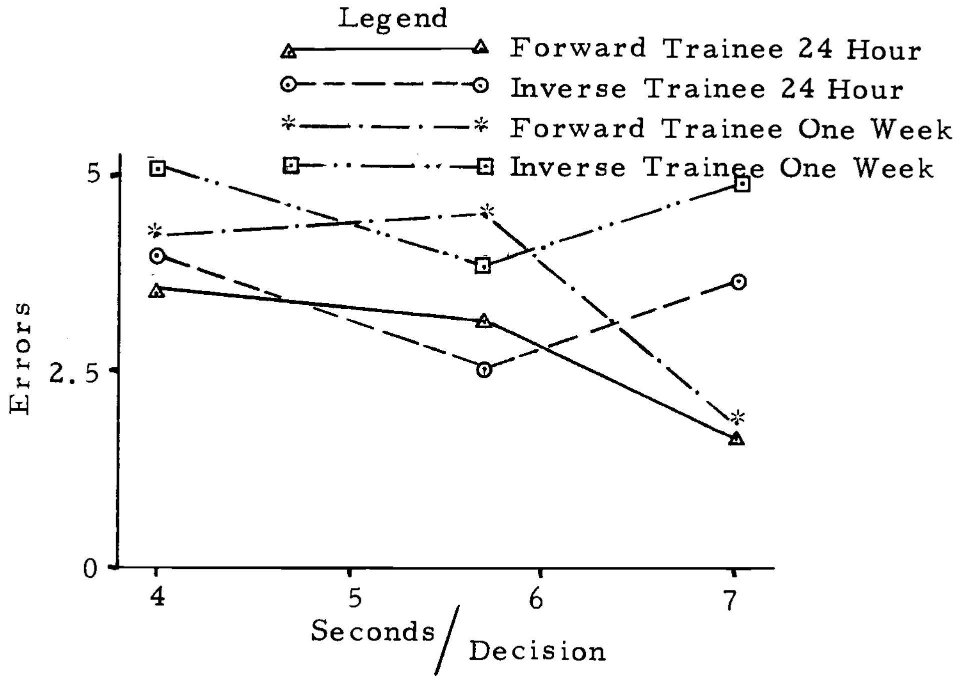

Figure 4-10. Errors of Recall After 24 Hours and One Week.

Data Analysis Summary

The statistical significance of all levels of treatment in all categories considered and using the selected criteria is summarized in Table 4-3. All ANOVA Tables not previously presented can be found in Appendix H.

In no case did the effects of the pacing treatment exceed the $p < .25$ level of significance. The graphs presented should be cautiously considered in the drawing of conlusions being mindful of the significance achieved by the criterion of measurement in any given category. Trends that may seem obvious when studying the graphs were in many cases clouded by the range of scores within a treatment combination cell.

Table 4-3. Summary Table of Significance.*

Categories	Direction of Learning			Speeds of Pacing		
	Errors	Starts	Frames	Errors	Starts	Frames
Total	$p < .25$	$p < .25$	$p < .10$ (time $p < .10$)	NS	NS	$p < .25$ (time $p < .05$)
Single Span						
Span A	$p < .25$	$p < .01$	$p < .25$	NS	NS	NS
Span B	$p < .01$	$p < .01$	$p < .01$	NS	$p < .25$	$p < .25$
First Span	$p < .25$	$p < .10$	$p < .05$	NS	NS	NS
Second Span	$p < .05$	$p < .01$	$p < .01$	NS	NS	NS
Sum of Single Span	NS	NS	NS	NS	NS	NS
Combined Spans						
Total	$p < .25$	$p < .25$	--	NS	$p < .25$	--
Span A	NS	--	--	NS	--	--
Span B	$p < .01$	--	--	NS	--	--
Recal Tests						
24 Hour	NS	--	--	NS	--	--
One Week	NS	--	--	NS	--	--

*NS = Not Significant

Interaction of the direction and pacing treatments did not achieve significance, with the single span training category for span B starts and first span learned starts and frames being the only interactions to achieve significance at the $p < .25$ level.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The objective of this thesis was to examine forward and inverse sequential training, under specific levels of pacing conditions, to determine the best method of teaching a sequential task skill. This objective was accomplished using the reported experimental endeavor as a data source for statistical inference of the better method.

Conclusions - The Hypotheses Revisited

Results obtained indicated at a marginally significant level that the forward training sequence produced a higher rate of error free criterion achievement for a non-verbal sequential task involving unfamiliar performance requirements. This finding was in consonance with the findings of Johnson and Senter (1965) regarding verbal chaining tasks. This finding also tends to reject the original hypothesis that inverse sequential learning would be the superior method.

The effects of pacing, though failing to achieve statistical significance, did appear to exert an adverse effect on performance as measured by errors and cycle starts. However, time required to achieve criterion was significantly diminished as the speed of learning was increased for the forward sequence trainees. Inverse sequence trainees seemed to perform best at the middle level of pacing but reversal of the desirability of training methods did not occur. This was especially emphasized by the measure of the time required to achieve a specified error free criterion of maze tracing. At best, a parity of inverse and forward learners' performance was achieved at the middle level of pacing. This lack of reversal of method desirability, as measured by performance, tended to reject the original secondary hypothesis. The concavity of most of the curves for inverse trainee performance, seems to support the rejection of that hypothesis.

Quality of learning, as measured by recall testing to determine task retention, did not achieve significance for the effects of direction or pacing. However, this measure is confounded by the fact that, on the average, the inverse sequence trainees received more training exposure due to their increased starts and higher frame counts. This implies that a higher quality of recall may have resulted from their increased exposure. If a training program was administered that presented a fixed quantity of training, the inverse sequence learners might demonstrate a lesser quality of recall. The additional training exposure, considered in conjunction with the nearly nonexistent memory decay on the part of the forward sequence learners at the slowest pace level, tends to reject the tertiary hypothesis that inverse sequential learning would produce a higher quality of learning with less memory loss.

Discussion of Hypotheses Related Conclusions

The conclusions are primarily applicable to on- and off-the-job methods of training that require the learning of non-verbal sequential tasks. If efficiency, as measured by elapsed training time, is important, then a faster pace level, while producing more errors and requiring more starts, would seem to be a desirable alternative. This is consistent with the contention of Salvendy and Seymour (1973) that operators should be trained at operational speed instead of some lesser speed for training.

Conversely, if there is a high penalty cost associated with the numbers of errors or cycle starts, then the slower pace of learning would be more desirable. At first glance this might also seem true for increased recall if the ability to reproduce error free performance, such as in an emergency procedure, is the primary consideration. The evidence herein was that the slower pace would have a higher time cost, and there remains a question of whether the recall performance was superior due to better retention or because the trainee had more interstimulus time to conduct a memory search of alternative selections. The experimental evidence of Hyman (1953) and the analysis of Fitts and Posner (1967) would indicate that performance would be better solely on the basis of the subject having more time to consider his decision.

The latter point concerning the additional decision time was sufficient to reject the acceptance of the superiority of slower pace levels to improve recall performance if that acceptance was on the basis of the results of this investigation. Another consideration might be that emergency recall usually occurs under high stress conditions, and, a surrogate stress, in the form of increased speed stress, should probably be applied in the laboratory if simulation of emergency performance is being attempted.

The major question though is one of why the trainee performed better under forward learning conditions instead of, as originally hypothesized, under inverse sequence learning conditions. This explanation would seem to require a renewed consideration of both short-term memory and the requirement for a previous response to serve as the stimulus for a subsequent response.

As mentioned previously, with regard to short-term memory, mental rehearsal is apparently required to maintain items in short-term memory (Hilgard and Bower, 1975) and rehearsal, either mental or physical, is probably required to move items of information from short-term to long-term memory. It was also noted that recall from short-term memory tends to destroy items held there (Fitts and Posner, 1967) but recall from long-term memory only tends to interfere with items in short-term memory. The implication here is that the forward sequence learner may have mentally rehearsed a new element in a maze sequence while he proceeded through the elements, each possessing varying probabilities of long-term memory recall capability, that preceded the new element. Thus items recalled from long-term memory tended to interfere with trace information for the new element, but at the same time the mental rehearsal tended to move the correct trace information to long-term memory. This implication is consistent with Ellis', et al. (1971), findings of improved performance on serial list items thought to be of a critical nature by the trainee.

Conversely, the inverse sequential learner immediately recalled the new element correct trace information from short-term memory, tending to cause that information to be lost from short-term memory (Welford, 1968), and no subsequent rehearsal was accomplished because the goal performance became one of achieving the end of the sequence without error instead of remembering, that is rehearsing, the new element information. This was akin to the "directed forgetting" described by Hilgard and Bower (1975) but in this case was an internal event. Thus what was partially accomplished by the forward learner using mental rehearsal had to be accomplished by the inverse learner using physical rehearsal. This dictated an increased number of task cycles to achieve the same level of learning.

Another possible influence may have been the configuration of the stimulus that elicited the new response. In the forward sequence every new element added a refinement to the grand stimulus of all prior maze responses, as an S_o, and the trainee responded by being able to discriminate increasingly finite differences in the stimulus (Snelbecker, 1974) preceding a new response as that response was added to the stimulus-response chain. However, in the inverse sequence the trainee was always faced with an identical S_o which had to elicit a different response at each new stage of training. This required the trainee to first learn the new response to the old S_o thereby enduring a negative transfer influence (Holding, 1965). The trainee then had to learn to elicit an "old" response to the newly added maze element. The new element had replaced S_o as the stimulus for the "old" response now resident as the second response in the S-R chain. Further changes to the stimuli for every subsequent maze response had to be made as a new finite element had to be discriminated for all previously learned responses, considering the fact that all preceding S-R combinations formed the S_o' for any subsequent maze element (Deese and Hulse, 1967). This constantly changing S_o' may have confounded the ability of the trainee to learn at a rate equalling that of forward sequence trainees. This would be consistent with Holding's (1965) finding that precision of performance was related to proficiency in the skill components of that performance.

While no absolute proof can be presented, it does seem that the delayed response, or increased temporal distance, was beneficial instead of detrimental to the learning of the sequence, by virtue of a subject's intrinsically motivated and goal directed behavior causing new items of information to be mentally rehearsed in anticipation of recall (Welford, 1968). This mental rehearsal facilitated learning whereas the immediate recall of information by inverse sequence trainees tended to cause a loss of that information from short-term memory thereby inhibiting its displacement from short-term to long-term memory.

Interference theory might also be relevant to the seeming inferior learning performance of the inverse sequence trainees. As previously noted, performance is facilitated for the trainee in those areas of greater component skill proficiency (Holding, 1965), thus eliminating uncertainties and increasing the probability of a correct response (Fitts and Posner, 1967). If the stimulus for a desired response was continually modified, as in the case of the inverse sequence learners, then the uncertainty resulting from a reduced proficiency in discriminating amongst a "new" sequence of stimuli for the old response repertory, would interfere with performance as a result of prior learning being affected by the new learning requirements.

Other Conclusions

During the conduct of the experiment reported by this thesis and the subsequent analysis, certain of the previously discussed learning phenomena were observed or at least were thought to be observed. Basically, two phenomena were observed and appeared to be supported by the data collected, and, one reinterpretation of prior experimentation was considered.

The first observation was that of learning to learn as subjects being trained in a completely unfamiliar task did improve their performance in sequential task learning as they went from the first maze span learned to the second maze span learned. The second observation was one of interference theory with the more recently learned maze span being performed with greater proficiency during the combination of spans, but, the combination of that task with a span learned previous to that task caused an apparent degradation of the proficiency in performing that half of the whole maze task.

The last conclusion is one of reinterpreting the results of the telephone dialing experiment reported by Shepard and Sheenan (1965) in light of the experimental results herein reported.

Discussion of Other Conclusions

With regard to the learning to learn as a special case of positive transfer (Deese and Hulse, 1967), the subjects did improve their performance between the first and second span regardless of the direction in which the unfamiliar task was learned. This increased performance occurred despite the influences of treatments and the apparently differing complexity level of maze sequences as viewed by a forward or inverse sequence trainee. This increased ability to discriminate finite components within a stimulus presented, and, the development of an increased ability to code or recode the information discriminated, described by Miller (1956) and Hilgard and Bower (1975), did appear to be present. Thus, though the trainee still had to learn a finite and distinct response to a stimulus, he apparently became increasingly proficient at acquiring the appropriate skill information from each element presented for learning.

This phenomenon would seem to support a method of presenting appropriately challenging learning situations to trainees in a sequence that would develop their ability to systematically acquire skill at a least investment level of time or training cost. Such a sequence would take advantage of the learning to learn phenomenon for those elements of new skills that are more costly or more time consuming. This phenomenon might also be better developed in the simpler part task components prior to attempting the more complex components of that task. Such an approach would take advantage of the trainees higher proficiency in acquiring the new skill as an offset against the greater learning demands of the more complex task. This would be consistent with Bass and Vaughan's (1966) contention that more practice must be devoted to the more complex components. It may indicate a sequence of presentation versus complexity consideration that facilitates complex skill acquisition by using the learning to learn transfer to the advantage of training efficiency.

With regard to interference theory, the results indicated that when part task components, in this case span A and span B, were combined into a whole maze task the trainee exhibited a higher performance proficiency within the most recently learned span of the combined span. However, in the case of the forward trainees, a subject's performance on that span tended to be degraded from the performance level of single span training. Thus, some evidence of interference resulted from the combining of a recently learned task with a previously learned similar task. However, the previously learned task, which had been learned to the same error free criterion as the newly acquired task, had deteriorated to a proficiency level worse than that of the more recently learned task. These findings did not uniquely support either proactive or retroactive interference as the cause of forgetting. However, they certainly did imply that recency of learning was significant and therefore that all learning has an effect on all subsequent performance with the interference probably varying and depending on recency of learning and similarity of task components.

The last conclusion was one of a reevaluation of the original interpretation of Shepard and Sheenan's (1965) findings by considering the requirement for repetitious performance of the memory task instead of considering the recall performance as being related to temporal distance. If the subject was only required to make one recall response, the reduced temporal distance was very significant in their telephone dialing experimental results (Hilgard and Bower, 1975). However, if the number had been required to be dialed on two consecutive occasions the physical recall would probably have tended to cause the information to be lost from short term memory and the second dialing effort may have produced a much higher error rate. Thus, temporal distance was a very important consideration in immediate recall, but if multiple recall of the same information is required then a reasonable increase of temporal distance may be more desirable as an aid to learning.

The conclusion implied here then is to decrease temporal distance for short term retention and one-time recall performance, but to increase temporal distance in multiple recall performance requirements, so long as memory storage capacity is not exceeded.

Recommended Future Research

The conduct of the examination of inverse versus forward sequential training has generated three questions that might be investigated as potential areas of additional research.

The first of these areas is the question of whether to use paced or unpaced training to achieve a task performance criterion, especially as it might relate to performance of a task that is either paced at a different rate than the training pace, or, a paced task with an unpaced training technique. The performance of paced tasks by previously well qualified workers has been examined, (Bertelson et al., 1965) but the case of untrained workers might be worthy of increased examination. The level of pacing examined should include or approach the hypothetical interstimulus versus number of alternatives available for response selection times empirically established by other experimental endeavors and should probably include the first five types of Gagné's (1970) learning tasks, through discrimination learning for multiple stimuli. A variation of this investigation might examine retention and recall performance using a fixed training exposure time and an alternative fixed number of repetitions for items of information. This procedure might also incorporate measures of the effects of time and repetition on the simulated high speed emergency recall.

A second area that would probably require significant resource support is one of conducting a similar experimental investigation, but using a model allowing multiple training and testing of each subject with all subjects chosen from an industrial vice college population.

Such a balanced design would provide some measure of within subject variability to determine if some trainees are more trainable in the inverse direction in certain classes of tasks than they are in other tasks. The development of a pre-test in conjunction with such an examination might then be correlated with performance to serve as a low cost method of individualizing instruction for each trainee. This investigation would probably require research grant support to allow the compensation of subjects for their significant time contribution.

The last area that should be considered for additional investigation is that of the sequence for learning of task components wherein the components are varied in their level of complexity. Here again, the influence of pacing and the sequence of combining the task components into larger units for the part-whole task method training and practice may be of significance. However, the primary question concerns the effects of levels of complexity on sequence positioning for most efficient skill learning and/or recall performance. The question of being first or last in the training sequence might also include finding a preferred mix that distributes complex independent components amongst those components rated as less complex.

A Final Perspective

This study has primarily been concerned with human performance as an average achievement by trainees with some between trainee variability. The individual trainee, as a contributing member of the social system and a possessor of many human needs, capacities, and frailties, has not been the primary emphasis in this study but most assuredly that individual cannot be disregarded. The trainee that has not been adequately considered in the forum of humanity will probably not be receptive to any training method regardless of how efficient that method might have proven to be within the analytical confines of the laboratory.

The caution of Chapanis (1967) still haunts this or any other laboratory finding that has not been examined in the glare of real world applications. It is hoped that this study will provide additional capacity for the adequate planning of resource commitment by those decision makers that examine and are examined in that glare of real world applications.

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APPENDICES

APPENDIX A

Table of Trace Sequence. (Maze lines numbered 1 thru 5 from left to right).

Operant Span	Element Number	Left Hand Route	Right Hand Route
A	1	3	5
	2	2	3
	3	1	4
	4	4	5
	5	3	5
	6	1	3
	7	2	3
B	8	4	5
	9	3	4
	10	2	3
	11	2	3
	12	4	5
	13	2	5
	14	1	3

APPENDIX B

Profile of Volunteer Subjects Used for Experimental Data Collection

Age

Range - 20 - 29 yrs
Mode - 21 yrs
Ave. - 21.75 yrs

Distribution	Percent
College Year	
Sophomore	2.8
Junior	47.2
Senior	30.6
First Year Graduate Student	19.4
College Major	
Industrial Engineering	69.4
Business	13.9
Systems Technology	8.3
Mechanical Engineering	2.8
Agricultural Engineering	2.8
Computer Science	2.8
Sex	
Male	94.4
Female	5.6

APPENDIX C

Subject Consent Form

Consent To Serve As A Subject
In The Project Entitled

Inverse Sequential Training

I consent to serve as a subject in the research investigation named above. The nature of and general purpose of the experimental procedure have been explained to me by Bernie Conatser . He has advised me that there are the following risks (abnormal) involved in the research and what precautions have been taken to minimize these risks.

No abnormal risks. TV monitor hazards are comparable to in-home viewing hazards.

In addition he has explained to me that during the experiment I will be required to perform the following tasks.

To trace lines, designated by a circle and triangle, using a mechanical pointer system, to demonstrate the learning of a trace sequence in a line maze. The maze lines will appear at the top of a TV screen and exit at the bottom of the screen. Learning of the maze will be either by starting at the end of the maze and working backwards to the beginning or by beginning at the start and working to the end.

Furthermore he has advised me that I will not be subjected to any unpleasant stimuli, neither physical or psychological nor will the experimental procedure result in embarrassment or loss of dignity.

I have also been informed that the scores or data collected as part of this experiment do not in any way reflect on my basic human worth.

I understand that it is not possible to identify all potential risks in an experimental procedure, but believe that reasonable safeguards have been taken to minimize both the known and the potential but unknown risks.

I have been informed that I may terminate my service as a subject on this experiment at any time.

Subject   Date

Experimentor   Date

APPENDIX D

Transcript of recorded instructions to subject

(Time required - 05:55)

Please sit down in front of the TV set.

(Pause)

In front of you is a set of movable pointers. Please grasp the knobs and operate the pointers to the left and right. Now operate the TV brightness control.

(Pause)

The purpose of this experiment is to have you use the pointers to point to the correct lines on the TV screen. The lines will be like roads and you are going to learn to trace those roads with your pointers as they pass from top to bottom of the TV screen. The maze containing these roads, or lines, looks like this on TV. Please brighten the TV screen.

(Pause, show sample maze on video)

It will move like this.

(Pause, advance sample maze one frame)

Your task is to trace the line that is designated by a circle or triangle like this.

(Pause, advance sample maze)

Please move the pointer controlled by the right hand to point to the line that leads to the circle.

(Pause)

Now move the left hand controlled pointer to point to the line that leads to the triangle.

(Pause)

You have now correctly placed the pointers for tracing this maze segment.

(Pause)

You should always point to the circle with the right hand and the circle will always be to the right of the triangle.

(Pause)

Notice how the lines come together to form one single line between each segment of the maze like this.

(Pause, advance sample maze)

It is intended that you center the pointers between each segment of the maze. There will be two groups of seven elements, or 14 elements to learn.

(Pause)

Notice that the pointers are designed such that you cannot reverse them. Please dim the TV set.

(Pause)

Your purpose is to memorize the sequence of the maze and trace that sequence with your pointers. If you make an error in the trace, it is recommended that you correct that error as soon as the circle and triangle come into view, but the sequence will be interrupted and you will be allowed to view the correct response. The maze will then be continued from that point, but you will be required to repeat that sequence without a new element being added. Please brighten the TV screen.

(Pause)

Error decisions will be made at the instant the parallel vertical lines leave the screen, like this.

(Pause, advance maze frame to error decision point)

Just prior to the circle and triangle coming into view like this. Please dim the TV screen.

After each group of seven elements has been learned, a new and separate group of seven elements will be learned. Upon completion of learning both groups, the two groups will then be attempted in a 14 element sequence.

(Forward/inverse sequence)

You have been chosen to learn the maze in the forward/inverse sequence. This means that you will learn the maze groups from (beginning to end)/(end to beginning) by starting with the first/last element of the first/last group. After you have learned the first/last element you will then practice the (first and second)/(last and next-to-last) elements, then the (first thru third)/(third from last thru last) etc. After you have learned the first/last group we will proceed to the second/first group.

(Pause)

You are reminded that after the completion of both groups we will combine the two groups into one 14 element sequence which you will then practice until an error free 14 element sequence has been accomplished. This will also be the sequence you will attempt during your retest tomorrow and one week from today. Here is the first/last element of the first/last group. Please brighten the TV screen.

APPENDIX E

Post-Training Questionnaire

____ __________

NAME AGE

1. Year in school? ______
2. Major? ______________
3. How much sleep have you had in the preceeding 24 hours?
   less than normal normal more than normal
   (circle one please)
4. How many hours do you consider to be a normal nights sleep?
   _________ hours
5. Have you recently taken or are you taking any types of cold medicines, antihistamines or other types of stimulant or depressant medicines? Yes No (circle one)
6. If the answer to the preceeding question is yes, how recently was the last dosage? _____________
7. Are you suffering from the aftereffects of overindulgence of alcohol or other narcosis agents? Yes No
   Alcohol? _____ Other? ______
8. Did the maze tracing exercise give you any feelings of vertigo or nausea? Yes No (Circle one)
9. Did you understand directions? ____________________________
   ____
10. Did you label or otherwise encode the maze lines as a memory aid? Yes No (Circle one)
11. How did you code the lines? ________________________________
    ____
12. Did the equipment or apparatus give you any physical discomfort? Yes No How? ________________________________

APPENDIX F

Scoring Sheet for Subject Performance

<u>Legend</u>
F - Frame Number ____
S - Start Number ____, or total starts required to learn that frame.
E - Total Errors during learning of sequence with frame newly added.

Date _____ Subject No. ____ Speed ____ Direction ___

Span A Frames	F / S	1 2 3 4 5 6 7	Span B Frames	F / S	8 9 10 11 12 13 14
1 S = ___ E = ___			8 S = ___ E = ___		
2 S = ___ E = ___			9 S = ___ E = ___		
3 S = ___ E = ___			10 S = ___ E = ___		
4 S = ___ E = ___			11 S = ___ E = ___		
5 S = ___ E = ___			12 S = ___ E = ___		
6 S = ___ E = ___			13 S = ___ E = ___		
7 S = ___ E = ___			14 S = ___ E = ___		

Frames	F / S	1 2 3 4 5 6 7		8 9 10 11 12 13 14
1 - 14 S = ___ E = ___				
24 Hr				
1 Week				

APPENDIX G

Tables of Subjects' Raw Scores by Data Category

1. All raw scores have been corrected by removal of any constant factor dictated by training method and therefore not variable according to subject performance. This only applies to the number of starts, frames and time to criterion measures.

Raw Score Correction Factors

Measurement Criterion Affected	Units Subtracted from Raw Score for:		
	Single Span	Combined Span	Total Training
Starts	7	1	15
Frames	28	14	70
Times	(Use Corrected Frame Count)		

2. Legend of table presented values.

Forward			Inverse		
4	5	7	4	5	7
$\bar{x}_{ij}$	$\bar{x}_{ij}$	$\bar{x}_{ij}$			
$\bar{\bar{x}}_i$			$\bar{\bar{x}}_i$		

Forward - Direction of Training
Inverse - " " "
4 - 4 seconds/decision speed
5 - 5.7 " / " "
7 - 7 " / " "
$\bar{x}_{ij}$ - Mean value for that direction and speed
$\bar{\bar{x}}_i$ - Mean value for that direction

3. Tables of data by category.

a. Total Performance.

Errors					
Forward			Inverse		
4	5	7	4	5	7
57	37	28	52	51	66
19	33	25	30	22	104
22	36	24	39	54	77
80	32	48	50	59	109
100	49	50	68	67	31
110	72	42	178	80	26
64.67	43.17	36.17	69.5	55.5	68.8
	48.0			64.6	

Starts					
Forward			Inverse		
4	5	7	4	5	7
22	14	12	22	26	22
9	14	9	17	27	17
38	15	21	30	26	15
12	17	14	13	8	31
22	20	19	26	24	40
32	25	24	37	29	10
22.5	17.5	16.5	24.2	23.3	22.5
	18.83			23.33	

Frames					
Forward			Inverse		
4	5	7	4	5	7
170	117	116	201	137	181
111	101	96	160	211	196
308	146	152	259	222	113
67	134	85	108	72	320
195	173	142	241	200	295
307	241	159	455	229	87
193	152	125	237.3	178.5	198.6
	156.67			204.83	

Time					
Forward			Inverse		
4	5	7	4	5	7
673	668	808	795	782	1260
439	833	668	633	1204	1364
1219	987	1058	1025	1266	787
265	577	592	427	411	2227
771	765	989	954	1141	2053
1215	1375	1107	1801	1306	606
764.3	866.4	870	939.8	1017.5	1382.4
	833.56			1113.34	

b. Single Span Performance.

(1) Span A.

Errors					
Forward			Inverse		
4	5	7	4	5	7
10	10	11	4	7	14
20	24	24	1	1	1
19	5	5	2	12	2
3	17	13	4	0	69
57	18	33	20	20	4
22	11	22	13	8	0
21.8	14.2	18	7.3	8	15
	18			10.1	

Starts					
Forward			Inverse		
4	5	7	4	5	7
10	8	6	3	5	9
13	11	13	1	1	1
12	5	4	2	8	1
2	11	12	3	0	22
24	11	15	11	10	4
14	8	16	8	6	0
12.5	9	11	4.7	5	6.2
	10.83			5.3	

Frames					
Forward			Inverse		
4	5	7	4	5	7
35	33	32	16	26	54
13	57	44	19	0	144
44	59	71	6	7	6
119	55	68	66	68	24
67	13	12	10	47	6
71	30	64	49	37	0
58.2	41.2	48.5	27.7	30.8	39
	49.3			32.5	

(2) Span B.

Errors					
Forward			Inverse		
4	5	7	4	5	7
1	0	0	8	32	7
0	0	0	9	3	23
0	1	0	7	14	5
0	1	0	19	16	11
1	1	0	16	11	8
2	3	3	0	20	8
.67	1	.5	9.83	16	10.33
	.72			12.05	

Starts					
Forward			Inverse		
4	5	7	4	5	7
1	0	0	7	18	5
0	0	0	7	3	13
0	1	0	6	10	4
0	1	0	11	14	9
1	1	0	8	8	6
2	3	2	0	12	5
.67	1	.33	6.5	10.8	7
	.67			8.11	

Frames					
Forward			Inverse		
4	5	7	4	5	7
6	0	0	17	69	15
0	0	0	54	60	25
0	7	0	32	9	62
0	7	0	39	42	19
7	6	0	24	38	22
12	15	11	0	38	17
4.2	5.8	1.8	27.7	42.7	26.7
	3.9			32.3	

c. Combined Span Performance.

(1) Total.

Errors					
Forward			Inverse		
4	5	7	4	5	7
69	27	17	40	12	45
37	9	1	20	18	80
42	30	19	30	28	70
0	17	35	27	43	29
19	30	17	32	36	19
36	58	17	165	52	18
33.8	28.5	17.7	52.3	31.5	43.5
	26.7			42.4	

Starts					
Forward			Inverse		
4	5	7	4	5	7
12	7	7	13	4	9
10	4	2	6	5	19
14	10	7	10	10	13
1	6	8	13	11	10
8	9	7	12	9	6
17	15	7	30	12	6
10.3	8.5	6.3	14	8.5	10.5
	8.37			11.0	

(2) Errors by Span.

Span A					
Forward			Inverse		
4	5	7	4	5	7
36	22	11	23	1	12
28	5	1	2	2	40
31	24	11	10	11	37
0	14	23	12	20	8
15	23	11	1	4	3
60	44	13	87	14	5
28.3	22	11.7	22.5	8.7	17.5
	20.66			16.22	

Span B					
Forward			Inverse		
4	5	7	4	5	7
33	5	6	17	11	33
9	4	0	18	16	40
11	6	8	20	17	33
0	3	12	15	23	21
4	7	6	31	32	16
26	14	4	78	38	13
13.8	6.5	6.0	29.8	22.8	26.0
	8.78			26.22	

d. Recall Test Performance. The "24" column contains the 24 hour recall score and the adjacent "w" column contains the same subjects one week recall test error score.

Forward						Inverse						
4		5		7		4		5		7		
24	w	24	w	24	w	24	w	24	w	24	w	
8	9	2	6	3	5	7	8	3	5	7	6	
3	2	4	9	0	1	4	4	2	9	0	0	
3	8	5	2	4	5	1	1	4	3	6	5	
0	0	2	2	3	4	7	8	3	3	2	8	
2	1	3	3	0	1	2	6	3	3	3	6	
5	6	3	5	0	0	3	3	0	0	4	5	
3.5	4.3	3.2	4.5	1.7	1.8	4	5	2.5	3.8	3.7	5	Ave.
		2.78						3.39				24 Hr. Ave.
		3.54						4.61				One Week Ave.

APPENDIX H

Analysis of Variance Tables for Experimental Data Categories

All ANOVA Tables have resulted from calculations using the corrected data contained in Appendix G. Experimental constants subtracted from raw scores are described in Appendix G, and ANOVA Table results are presented in Chapter Four.

1. Total Performance

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.48336E 03	2.2978*
(2)	Speed	2	1.07553E 03	NS
(3)	1 * 2	2	6.22194E 02	NS
(4)	Error	30	1.08076E 03	
	Total	35		

* $p < .25$

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.82250E 02	2.5055*
(2)	Speed	2	4.80833E 01	NS
(3)	1 * 2	2	1.80833E 01	NS
(4)	Error	30	7.27389E 01	
	Total	35		

* $p < .25$

Time

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	7.03921E 05	3.9919**
(2)	Speed	2	7.07225E 05	4.0107*
(3)	1 * 2	2	1.22438E 05	NS
(4)	Error	30	1.76335E 05	
	Total	35		

* $p < .05$ ** $p < .10$

2. Single Span Performance
   a. Span A

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	5.60111E 02	2.5158*
(2)	Speed	2	9.05278E 01	NS
(3)	1 * 2	2	1.05861E 02	NS
(4)	Error	30	2.22633E 02	
	Total	35		

* $p < .25$

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.77778E 02	9.1609*
(2)	Speed	2	1.00278E 01	NS
(3)	1 * 2	2	1.21944E 01	NS
(4)	Error	30	3.03222E 01	
	Total	35		

* $p < .01$

Frames

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.53344E 03	2.3363*
(2)	Speed	2	2.17194E 02	NS
(3)	1 * 2	2	4.24194E 02	NS
(4)	Error	30	1.08438E 03	
	Total	35		

* p < .25

b. Span B

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.15600E 03	37.33*
(2)	Speed	2	4.01944E 01	NS
(3)	1 * 2	2	3.05833E 01	NS
(4)	Error	30	3.09667E 01	
	Total	35		

* p < .01

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	4.98778E 02	55.625*
(2)	Speed	2	2.10278E 01	2.345**
(3)	1 * 2	2	1.33611E 01	1.49**
(4)	Error	30	8.96667E 00	
	Total	35		

* p < .01 ** p < .25

Frames

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	7.25336E 03	37.219*
(2)	Speed	2	3.44444E 02	1.767**
(3)	1 * 2	2	1.61778E 02	NS
(4)	Error	30	1.94883E 02	
	Total	35		

* $p < .01$ ** $p < .25$

c. First Span Learned

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	3.18028E 02	2.801*
(2)	Speed	2	8.36111E 00	NS
(3)	1 * 2	2	1.50194E 02	NS
(4)	Error	30	1.13528E 02	
	Total	35		

* $p < .25$

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	6.66944E 01	3.041*
(2)	Speed	2	2.52778E 00	NS
(3)	1 * 2	2	4.96944E 01	2.266**
(4)	Error	30	2.19278E 01	
	Total	35		

* $p < .10$ ** $p < .25$

Frames

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.58403E 03	4.647*
(2)	Speed	2	9.64444E 01	NS
(3)	1 * 2	2	8.21778E 02	1.478**
(4)	Error	30	5.56106E 02	
	Total	35		

* $p < .05$ ** $p < .25$

d. Second Span Learned

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	7.93361E 02	5.6639*
(2)	Speed	2	4.97500E 01	NS
(3)	1 * 2	2	5.88611E 01	NS
(4)	Error	30	1.40072E 02	
	Total	35		

* $p < .05$

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.91361E 02	11.022*
(2)	Speed	2	1.02778E 00	NS
(3)	1 * 2	2	3.36111E 00	NS
(4)	Error	30	1.73611E 01	
	Total	35		

*$p < .01$

Frames

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	7.62711E 03	10.583*
(2)	Speed	2	8.66944E 01	NS
(3)	1 * 2	2	1.46028E 02	NS
(4)	Error	30	7.20711E 02	
	Total	35		

* p < .01

3. Sum of Single Spans

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.06778E 02	NS
(2)	Speed	2	1.96944E 01	NS
(3)	1 * 2	2	1.76361E 02	NS
(4)	Error	30	2.56333E 02	
	Total	35		

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	3.21111E 01	NS
(2)	Speed	2	2.77778E 00	NS
(3)	1 * 2	2	4.81111E 01	NS
(4)	Error	30	4.09667E 01	
	Total	35		

Frames

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.21336E 03	NS
(2)	Speed	2	1.55278E 01	NS
(3)	1 * 2	2	8.72861E 02	NS
(4)	Error	30	1.23216E 03	
	Total	35		

4. Combined Spans
   a. Total

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.24044E 03	2.716*
(2)	Speed	2 .	6.55528E 02	NS
(3)	1 * 2	2	4.07694E 02	NS
(4)	Error	30	8.24800E 02	
	Total			

* $p < .25$

Starts

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	6.13611E 01	2.399*
(2)	Speed	2	5.50278E 01	2.152*
(3)	1 * 2	2	1.55278E 01	NS
(4)	Error	30	2.55722E 01	
	Total	35		

* $p < .25$

b. Span A

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	1.77778E 02	NS
(2)	Speed	2	4.39194E 02	1.30
(3)	1 * 2	2	2.79861E 02	NS
(4)	Error	30	3.36900E 02	
	Total	35		

c. Span B

Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	2.73878E 03	16.244*
(2)	Speed	2	1.74333E 02	NS
(3)	1 * 2	2	1.47778E 01	NS
(4)	Error	30	1.68600E 02	
	Total	35		

$* p < .01$

5. Recall Test Performance

24 Hour Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	3.36111E 00	NS
(2)	Speed	2	4.08333E 00	NS
(3)	1 * 2	2	5.36111E 00	NS
(4)	Error	30	4.55000E 00	
	Total	35		

One Week Errors

Line	Source of Variation	DF	Mean Square	F
(1)	Direction	1	5.44444E 00	NS
(2)	Speed	2	2.11111E 00	NS
(3)	1 * 2	2	6.77778E 00	NS
(4)	Error	30	8.56667E 00	
	Total	35		