AN ABSTRACT OF THE THESIS OF

MUHAMMAD H. AL-HABOUBI for the degree of Master of Science in Industrial Engineering presented on January 28, 1982

Title: THE EFFECTS OF JOB INTERRUPTIONS ON HUMAN LEARNING

Abstract approved: Redacted for Privacy
Dr. Edward D. McDowell

It is a widely accepted premise of industrial management that an interruption in the performance of a task will be accompanied by a decrease in operator skill level upon resuming performance of the task. Moreover, it has been generally assumed that this loss of skill is related to several factors including the amount of prior experience on the task and the duration of the interruption period. The objective of this research was to examine the influence of both factors on the amount of forgetting (or retention) and on the learning rates during prerest and postrest periods.

Twenty college students were trained on a manual assembly task for either twenty or forty trials. Their performance was interrupted for either one or three days, at which time they performed twenty more trials. The recorded production times were fitted to an exponential function and a power function in two forms.

The experimental findings indicate the amount of skill forgotten and retained were influenced by the interruption and both were

statistically significant at 0.5 type I error. In addition, the results showed a significant difference between the rate of original learning and relearning. Generally, the lost skill was recovered in almost three trials. Unexpectedly, the levels of original experience and retention interval were insignificant. The exponential function seems to fit the historical data better but future performance tends to be predicted better by the power function.

THE EFFECT OF JOB INTERRUPTIONS ON HUMAN LEARNING

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

Completed January 28, 1982

Commencement June, 1982

APPROVED:

Redacted for Privacy

Associate Professor of Industrial and General Engineering
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Date thesis is presented January 28, 1982

Typed by Mary Ann Airth for Muhammad Al-haboubi

ACKNOWLEDGEMENTS

Praise be to God, whose bounties cannot be counted.

I wish to express my sincere gratitude and thanks to Dr. Edward McDowel for his interest, assistance, and encouragement throughout the investigation of this research.

I am grateful to the members of my committee, Professor Robert Schultz, Dr. Eldon Olsen, and Dr. Ken Funk for their helpful recommendations.

I would like to extend my thanks to all the volunteers who participated in the experiment for their precious time.

Special thanks to my mother for her continued prayers and patience and the pain she endured throughout my absence.

I offer my appreciation to my wife for providing me the comfort and support during the entire program.

My final thanks to Mrs. Mary Ann Airth for her skillful typing.

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THE EFFECT OF JOB INTERRUPTIONS ON HUMAN LEARNING

I. INTRODUCTION

The decrease in time per unit as a function of the number of units produced is known as the "learning effect", which may be described by learning curves. A common fallacy in the application of learning curves to production data is to ignore the effects of production breaks upon worker performance. It is generally believed that an interruption in a repetitive type job of a minimum of several days will have an adverse effect on the production time per unit. The production rate at the re-commencement of production might not be as high as when production ceased.

Consequently, the cost per unit produced would be expected to increase as a result of this interruption. Therefore, this increase should be considered in estimating the contract total cost.

A related issue is the contract time (scheduling). The time elapsed between the implementation of a contract and restarting another may be enough to cause a loss of learning, or forgetting.

Another potential area of application is in wage administration. If employees are paid according to their performance, then a worker who has not performed a particular task for a long time period should receive additional compensation upon resuming the job.

Generally speaking, if the production plan has been planned to be in a number of batches rather than one lot, then there will be cost penalties incurred because of increased set-up costs as well as the cost incurred by forgetting, while there will be money savings in inventory because the produced units are delivered immediately. Inventory control policies usually consider the set-up cost in determining the optimal batch size. If the forgetting effect is considered properly, then a more economical batch size could be obtained.

Because learning and forgetting effects intervene in almost all aspects of production, it is worthwhile to mention their influence on the evaluation of alternatives. Certainly, the selection of a manufacturing method from among a variety of others is concerned with performance times. Since, the rate of learning and forgetting varies with the chosen method of production, their inclusion in the analysis is inevitable.

The foregoing discussion shows including the forgetting effect in parallel with the learning effect may give very significantly different results in determining cost and time on contracts, job batch size, inventory, production rate, evaluation of alternatives, and mainly all applications where learning is considered.

Since the beginning of the chapter, the term "forgetting" has been repeated several times; it will now be defined. When a memory of past experience is not activated for a certain period of time, forgetting tends to occur. Obviously, experiences influence subsequent behavior is evidence of an activity called remembering. As defined in Webster's New Collegiate Dictionary (1980), to "forget" is to "lose the rememberance of". Learning could not occur without the function popularly named memory. Practice results in a cumulative effect on memory leading to skillful performance. Over a period of no practice what has been learned tends to be forgotten. Examples of every day life is the student who forgets taking his/her pencil at the first day of school, a taxi-driver forgetting the road directions to a regular customer's home who just arrived from a long trip, and a worker on an assembly line forgetting which part should be installed first after being laid off a certain period of time.

In technical terms, forgetting may result from job interruptions. The interruption may take different forms such as lay offs; job transfers, vacations, and time between contracts or batches. This research does not address the cause of interruptions, but rather is concerned with it's effect upon subsequent performance.

The phenomenon of forgetting may be influenced by more than one factor. This research will concentrate on two factors, the first being the degree of initial learning and the other being the duration of the interruption period, that is where the task is interrupted in the learning process and how much has been learned before the interruption.

Purpose for the Research

The objective of this research is to investigate the area of learning-forgetting interaction. Therefore, it was decided to run an experiment using a motor task to explore the effects of job interruption upon subsequent performance through answering some questions such as: Does forgetting result from job interruption, how does the rate of learning behave after the interruption is addressed, does the length of rest period affect forgetting or the rate of relearning, and does the amount of prior experience affect forgetting or the rate of relearning?

II. REVIEW OF THE LITERATURE

Definition

The terms retention and forgetting are used repeatedly in this research. According to Marx (1969), retention is used to denote the extent to which originally learned behaviors are still available in subjects' repertoire, whereas forgetting refers to the loss of such behaviors. Because one process is defined in terms of the other, both represent a common process and are governed by the same conditions. Differences in use of the terms are largely a matter of convenience or preference. It is common observation in everyday life that some things, once learned, seem to be well remembered for a long time, whereas others appear to be forgotten rather quickly. The term retention in experimental studies refers to the persistence of the learning after practice has ceased (Marx and Bunch, 1977). What is retained is often referred to as memory trace, and retention is no more observed than is learning. No one has seen a memory trace, but what is retained influences behavior in the test situation and thus provides us with behavior measures or indexes of the retention. In Webster's New Collegiate Dictionary (1980), forgetting is defined as "losing the rememberance of". Generally, distinction between forgetting and retention is hard to see, other than viewing them approaching the same problem from opposite sides.

Historical View

Memory was one of the first phenomena to be studied in a psychological laboratory. The trend of research on memory has been to focus on verbal memory, perhaps because the laboratory study of verbal behavior begain in 1885 (Ebbinghaus, 1964). For several decades, much attention was then given to memory, and various explanations of forgetting were formulated (Klausmeier and Ripple, 1971). The study of memory then lapsed, but it has been renewed during the last two decades.

Studies of the "higher mental processes" were first systematically conducted by Ebbinghaus (1885) who was concerned with the nature and course of retention (Marx, 1969). Ebbinghaus was able to demonstrate that not only was it possible to measure the temporal course of retention but that it was possible to study more detailed phenomena of retention such as the development of remote association. Moreover, Ebbinghaus made significant contributions to the development of the methodology of human learning and retention. Marx and Bunch (1977) comment that although the research on retention has focused on verbal learning; no definitive answers have been obtained. The resurgence of research on memory has prodded scientists with nonverbal research interests into action on the memory front. Research on the retention of motor responses has been livelier than at any time in psychology's history, although its volume is modest compared to that of verbal behavior.

Theories of Forgetting

Under the Retention and Forgetting title (Encyclopedia Britannica, 1978), the decay theory has been discussed. It has been theorized that as time passes the physiological bases of memory tend to change. With disuse, it is held that the memory trace in the brain gradually decays or loses its clarity. The same source proceeds to say that decay or deterioration does not seem attributable merely to the passage of time. Another source suggests that information deteriorates from memory solely as a function of time (Adams, 1967). Disuse is not satisfactory as the sole explanation, for we do not seem to forget while we are asleep (Klausmeier and Ripple, 1971).

The other major theory of forgetting is known as the interference theory. Schendel, Shields, and Katz (1980) explained the theory as follows. Learning one task may help in learning or performing another task (positive transfer) or may interfere with the second task (negative transfer). The Encyclopedia Britannica (1978) puts it this way: A pre-eminent theory of forgetting at the behavioral level is anchored in the phenomena of interference; in what are called retroactive inhibition (new learning interfers with retention of the old) and pro-active inhibition (old memories interfere with the retention of new ones). The main difference between the two is in sequence: in proactive inhibition, the interfering material is encountered first; in retroactive inhibition, it is encountered last. Both phenomena have great generality in studies of any kind of learning, although most research among humans has considered verbal learning.

The previous two theories are the most prominent, but Klausmeier and Ripple (1971) have put more explanations to forgetting by considering reorganization, obliterative subsumption, and motivated forgetting.

These explanations are not discussed here and interested readers are advised to refer to the source itself.

Factors Affecting Long-term Motor Retention

There is not an overall agreement on the factors affecting retention but current researchers agree that the degree of original learning, or as we will call it later "the amount of prior experience", is an important factor. Even after a task can be performed perfectly, continued practice (sometimes called overlearning) increases the "strength" of the memory (Encyclopedia Britannica, 1978). If there were one universal prescription for resisting forgetting, it would be to learn to a very high level initially.

The other factor believed to affect retention is the retention interval, or as it will be called later "the duration of interruption period", which is defined as the period of no practice between the acquisition and subsequent test of a performance. The absolute amount forgotten increases with time, whereas the rate of forgetting declines with time (Schendel, Shields, and Katz, 1980). The previous source is a review of the literature prepared in the U.S. Army Research Institute which has focused on the factors affecting long-term retention, two of which are mentioned above. The factors were dichotomized into task variables and procedural variables. Task variables relate to the trainee or to the training/test environment, whereas procedural variables relate to the manner in which training, final testing, or both occur. The task variables that may underlie the long-term retention of motor skill include the duration of the no-practice period, nature of the response required to accomplish a particular motor task, degree to which the learner can organize or impose order upon the elements that define the task, structure of the training environment, and initial ability of the learner to perform a task in the absence of prior practice. The procedural variables that may affect the long-term retention of motor skill include the degree of proficiency attained by the learner during initial training (amount of prior experience), amount and kind of refresher training, transfer of skills from one task to another task, interfering activities, scheduling of practice during training, use of part-task versus whole-task training methods, and introduction of extra test trials prior to final testing.

Due to limitation of the scope of this research, no attempt is made to discuss each variable. But it should be pointed out that the very two variables mentioned in this section, namely the amount of prior experience and the amount of length of interruption period, will be the only factors to be considered in the motor task of this research.

Engineering Work

There are not many papers dealing with the problem of job interruption from the engineering point of view. In fact, the Industrial Engineering Handbook (1971) is the only text found considering this problem from an engineering approach. On the chapter on learning curves, Hancock presented a formula to predict the time needed for the first unit in any lot in a situation where an operator is working with small lot sizes interrupted by breaks. The formula is based on the standard time, the number of units required to reach that standard, and the initial time of the first unit before any interruption occurred. However, no action has been taken to modify the learning rate after an interruption period.

Hoffmann (1968) has introduced the idea of changing learning rates. He said, "In particular, prior experience on highly similar products would affect both the time needed for the first unit of a new contract and the apparent percent learning". He developed a formula to calculate a new percentage learning rate from the preceding percentage learning rate taking into account the prior experience. Thus, the effect of previous experience produces a certain amount of units which would raise the percent learning rate. Hoffmann claimed a confirmation to his formula is accomplished by examining company data.

Concerning the same subject of the possibility of changing learning rate after a job interruption, Carison and Rowe (1976) expected the performance after the interruption period to continue improving at a rate equivalent to the initial learning rate. Not only this, but they have assumed a value for the forgetting rate during the no-practice period. In their paper, they describe a task cycle as consisting of three phases: the incipient, the learning, and the maturity phase. Following a similar logic, according to them, the forgetting cycle during the break can be described by a negative decay function comparable to the decay observed in electrical loses in condensers. They considered "how much" has been learned as the determinant of the rate and amount of decay. Although, they recognized that the initial rate of learning is a function of the amount of prior experience, the learning rate is considered unchanged in the example given. Concerning the amount of forgetting, Carison and Rowe said, "Some forgetting is always to be expected, but total forgetting does not occur within short periods of interruption. The rate and amount of forgetting decreases as an increased number of units are completed before an interruption occurs". They describe the forgetting curves as showing rapid initial decrease in performance followed by a gradual leveling off. The paper is concluded with learning-forgetting-learning models.

Since, we mentioned Carison and Rowe's opinion on the forgetting curve, it is suitable at this point to mention Sule's (1978) work in this regard. Sule assumed a formula for forgetting using the power function with a positive exponent. However, he did not specify on what basis the formula has been assumed. Sule derived a mathematical model which finds the number of days required to produce a batch of units in each work cycle and the adjusted cumulative number of days of experience retained at the end of a certain cycle of production. The model takes into account the forgetting effect in case the job is interrupted for several days.

Bilodeau (1968) has stated the following: "The shape of the curve of forgetting, long thought to be well known, is not really well described for human beings". The classical retention curve is plotted after the data collected by Ebbinghaus in the last century. It is a measure of savings in number of nonsense syllables recalled against the duration of retention interval. The curve has a concave appearance and looks exponential. The classical description is that verbal forgetting proceeds rapidly at first, and later more slowly. We are not going to elaborate on verbal forgetting curves, since our aim is directed towards motor skills; interested readers are advised to refer to Chapter 6 (Bilodeau, 1969).

Now we shift to another topic introduced by Adler and Nanda (1974). This study is concerned with the effects of production breaks in lot size manufacturing which is commonly ignored in learning curve applications. Adler and Nanda developed a formula to calculate the average time per unit after producing a certain amount of units in N lots and N-1 breaks in production (each of sufficient duration to cause a loss of learning). Using this formula, they continued to develop another formula to estimate the total incremental cost expressed as the sum of set-up, inventory and production costs. From the cost formula, the optimal lot size for a single product production can be obtained.

Steedman (1970) showed that if production is split into shorter runs, then the total cost (based on the power function) will increase as the number of runs increases. The assumption made here is that the time to produce the first unit is the same for all runs either because the runs are produced in parallel or because they are produced in sequence with such long time intervals between the runs that all the learning is lost. The ratio of the total cost of a production split into short runs to the total cost of the total production at one run is an increasing function of the number of runs (n) and the learning rate parameter of the power function (m), i.e. n^m. Evidently, this increase in cost is due to the loss of learning (forgetting), which could be obtained by simple subtraction of the total costs.

One cost accounting service bulletin (Anderhohr, 1969) suggests that a 50 percent loss of learning occurs over a three to six month break, and a 75 percent loss occurs over a period of twelve months. However, George Anderhohr's comment that such a suggestion is a general approach and it would be extremely difficult to support in cost negotiations. George suggested a method to estimate the lost learning based on five factors. These are production personnel learning, supervisory learning, continuity of production, improvement of special tooling, and improvement of methods. A hypothetical case is presented with a starting standard of 20 percent weight assigned to each of the five elements. According to the method, it is possible to find the percent learning lost for each element, one at a time. The method itself is simple, especially for the last three elements, because estimating the lost material can be identified. The difficulty of the method is in estimating the percentage lost in personnel and supervisory learning. Lastly, a company example is given in an attempt to estimate the time to produce the first unit in a second lot (after an interruption period) by knowing the percent total loss and last unit production time of the first lot.

Finally, is the question of what unit number should be used in the least squares regression method after a job interruption. Alden (1974) gave an example of a sample case involving four contracts for the same or essentially the same item. Based on historical data of the second contract, a buyer estimated the average cost per unit for the fourth contract. The estimation was derived by submitting the data to a least squares log-log regression. The first unit of the data is given a cumulative serial number, i.e. the first contract is considered as part of the same learning curve. The seller disagreed in handling the case because there was a shutdown period between the first and second contracts in which there was a large manpower turnover. So, the seller performed the analysis on the data with the initial unit of the second contract as unit number one which gives a far better fit than the buyer's curve. There is no doubt that the forgetting effect during the shutdown period was a major factor in proving the buyer's method as inappropriate because some experience has been lost during the interruption period. This is why starting the regression with a unit number based on the cumulative units produced would give a false estimation.

Psychological Work

Since the turn of the century there have been a number of experiments performed in the field of retention. The majority were related to verbal retention and those related to motor retention dealt with many factors. In this section, we will emphasize on the experiments concerned with long-term (days, months, years) motor retention and which consider the factors of our interest, i.e. duration of interruption period and the amount of prior experience. Those experiments with their results are presented here in a historical order.

Braden (1921) conducted an experiment with an easy task of tossing balls. A box, 12 feet away from the throwing line, with a 5 inch circular hole on top served as the target. Two hundred balls were tossed every day for one hundred days. Then the task was interrupted for 22 months and 11 days and a re-trial was carried on for 18 days. Again, the task was interrupted for 6 months and 20 days, and a second re-trial was carried on for 18 days, also. The results indicate that the improvement was rapid in the re-trials; and that the second re-trial showed a marked improvement over the first. No further analysis was shown in the paper, which apparently does not handle more than one group.

Bell (1949) conducted a pursuit rotor experiment involving several groups. In this investigation 457 subjects were used in the first experiment (prior to a one-year intervening period) with only 47 subjects completing in the second experiment. The subjects received 20 one-minute trials repeated by one-minute rests, except where longer rests were introduced as follows. For the early rest groups, rest periods of 10 minutes, 1 hour, 6 hours, 24 hours, and 30 hours were used after the fifth trial, and for the late rest groups, rest periods of the same duration were employed following the fifteenth trial. Then the groups left the task for one year and were given 20 one-minute trials. The conclusion states that only 29 percent of the experience gained before the one year had been lost and this was completely recovered after eight trials. Slight gains continued during the remaining trials. The performance of the 47 subjects prior to the one year interruption in all of the 20 trials is very similar to the control group (rested one minute after each trial) performance. This finding indicates the lack of differences among the groups in the first experiment, i.e. the level of prior experience and length of rest period factors are not significant prior to the one year interruption.

In another study by Neumann and Ammons (1955), similar results after one year of interruption are found. Their experiment involved 100 subjects distributed to 5 retention groups: 1 minute, 20 minutes, 2 days, 7 weeks, and one year. The subjects were college students who learned a circular sequence of eight randomly paired toggle switches to a criterion of two consecutive perfect trials. The results found indicate that the subjects took longer to relearn the longer the retention interval. Forgetting was substantial after as little as two days, and after one year it was almost complete.

An interesting result found from a study done by Ammons, Farr, Bloch, Newmann, Dey, Marion, and Ammons (1958) indicates that the greater the amount of original training, the more trials it took to regain the performance level reached before the interruption period. The experiment contains two different tasks. The first is a sequential manipulation of a series of controls and the other task called for a fairly complex type of compensatory pursuit skill (airplane control test). The first experiment contains groups from 40 to 47 subjects (total N = 538) and trained under each of 12 conditions representing two degrees of learning (5 trials and 30 trials) combined with 6 durations of no-practice intervals (1 minute, 1 day, 1 month, 6 months, 1 year, 2 years). The subjects were tested for retention and retrained for 10 trials. The second experiment contains groups from 41 to 58 subjects (total N = 465) and trained under each of 10 conditions representing two degrees of learning (1 hour and 8 hours) combined with five durations of no-practice intervals (1 day, 1 month, 6 months, 1 year, 2 years). The subjects were tested for retention for two hours after the interruption interval. The paper contends that the longer the no-practice interval the greater the loss in performance, and relearning is rapid. Both the effect of amount of training and duration of no-practice interval became significant on the number of trials to reach the achieved level on the last training trial.

In another tracking skill, Battig, Nagel, Voss, and Brogden (1957) have studied the behavior of transfer and retention of a bidimensional compensatory tracking after extended practice. Their experiment involves four subjects who completed 100 standard practice sessions for 100 days. The experiment has been modified for a few days, then interrupted for 227 days. The study was conducted on three of the original subjects where retention of the skill was found to be very high. In their discussion, the authors expressed that the tracking task used was relatively great in difficulty and that may be the major important factor in determining the results obtained.

Contrary to the results of Ammons (1958), which states, "the greater the amount of original learning, the greater the learning loss", the study by Jahnke (1958) showed the degree of prior learning is associated with increases in performance at both the initial and final stages of postrest practice. The experiment involved 240 subjects in 12 different groups, each with 20. The apparatus is a pursuit motor under a 15-45 second work-rest cycle. Each of four sets of three groups received either 1, 2.5, 5, or 10 minutes of pre-rest practice. One group from each set of three received either 10 minutes, one day, or one week of interpolated rest. Another finding indicates the length of interruption was not systematically related to initial post rest performance but during final post rest performance, gains occurred with increased rest up to one week in length. In agreement with the previous study, Fleishman and Parker (1962) reached nearly the same conclusion. Two groups of subjects were used, one group was not given formal training instructions while the other was given an initial explanation and demonstration of the task. The task is described as a complex tracking skill consisting of a tracking device constructed so as to stimulate roughly the display characteristics and control requirements of an air-borne radar intercept mission. The two groups had been divided further to subgroups with varying interruption periods of 1, 5, 9, 14, and 24 months. The results showed that retention of proficiency is extremely high, even for no-practice intervals up to 14 months. What small loses did occur were recovered in the first few minutes of relearning. Variations in retention interval from 1 to 14 months are shown to be unrelated to retention performance. The most important factor in retention was found to be the level of learning achieved initially.

The last finding contradicts the finding obtained by Roehrig (1964). The learning curves obtained appear to continue as though no time lapse intervened. This is found to be so, irrespective of the number of trials before the break. Seven subjects were trained to varying extents on a difficult balancing task. The subjects received three 1-minute trials at each session and rested for several minutes between trials. After each trial, the subjects were informed of the results. The subjects were staff members (4 males, 3 females) and practiced during a one month period, but testing was begun on later dates for some of them so the total number of sessions varies. The job was interrupted for 50 weeks and testing was resumed for a one week period. The task is described as difficult and puts quite a strain on the muscles. The subjects seemed to enjoy the task to the degree it virtually took the status of competitions. Roehrig has not identified for sure the reason for such high retention, but he mentioned two possibilities. The first is the high degree of motiviation, and second the high intelligence of the subjects (four Ph.D. holders and one M.A. degree holder).

High retention also was found by Meyers' experiment 1967 (Marx, 1977). A Bachman ladder was used as her research apparatus, and the score for 30-second trial was the number of rungs climbed. The task is described to require coordination, balance, and speed. After practice, retention intervals of 10 minutes, 1 day, 1 week, 4 weeks, and 13 weeks were given. The forgetting was trivial for all of the retention intervals.

The above results are partially inconsistent with the results of a study done by Naylor, Briggs, and Reed (1968) in the sense that the length of rest period plays a minor role. The subjects performed two tasks simultaneously: a three-dimensional tracking task and a nine-event monitoring task; they are classified as primary and secondary, respectively. There were three factors involved with two levels each, training time (2 or 3 weeks), retention interval (1 or 4 weeks), and monitoring task coherence (high and low). The study seems to emphasize the important role played by the coherence factor in skill acquisition and retention. However, the most consistently influential and the most powerful independent variable was the amount of original training. The effect of retention interval was less consistent than that of either of the other two independent variables.

Smith (1971) accumulated the acquisition and retention data of one subject during a five year period. Twelve practice sessions on a pursuitmeter device were given every other day. Sessions were three 3.81-minute cycles, separated by 9 minute rest. The retention data was obtained at monthly intervals for 18 months, followed by yearly intervals for two years and a final test after an 18 month interval. Fluctuations found in the first 18 months interval, but performance in the 2 year interval was almost as it was during the last day of acquisition. Thus performance slightly declined in the final test. Similar research to those presented could not be found in the last decade, which lead us to think that the effect of either the prior experience or the length of interruption factors on long-term retention of motor skills have not attracted attention during the last ten years. Currently, it seems that the U.S. Army is directing ongoing programs to develop procedures to insure that its personnel remain job proficient during peacetime. In their review on retention of motor skills, Schendel, Shields, and Katz (1978) said, "retention of skill decreases with time, depending on a host of variables, including the length of the no-practice period, the type of task, and the practice or interfering activities before or during the retention interval", and the level of original learning is described as "the single most important determinant of motor retention".

III. EXPERIMENTAL PROCEDURE

The objective of the research is to study the effect of interruption on learning of operators. There is little doubt that the effect of interruptions would be a loss of learning or forgetting, but the question is whether the amount of forgetting is significant or not. The influence of two factors on forgetting will be studied in depth. These factors are the amount of prior experience and the length of the interruption period.

The amount of learning retained or retention will also take part in the study. Another issue of equal importance is the influence of both the foregoing factors on the rate of learning in case of job interruption.

Scope of Research

As mentioned before, the research will be confined to the amount of prior experience and the duration of rest factors. It is every experimenter's wish to cover the subject of the experiment from all angles; but due to limitation on time we will be concerned with only two factors.

Another source of limiting the scope of the research is the difficulty of gathering subjects to perform the experiment. The subjects were collected on a voluntary basis without arranging to reward them either financially nor with any other incentive program other than appreciation. The result was few people showed interest in participating. Due to the above difficulty, only two levels were designed for each factor, as will be discussed later, and only five subjects will be assigned for each treatment.

If we had enough subjects, it would be nice to include more factors such as sex, to see if males are better than females, or vice versa, in performing and retaining the job. Another factor of interest is the level of education of subjects, for example, freshmen, juniors, graduates, etc.

The Subjects

The subjects of the experiment were college students from the Department of Industrial and General Engineering at Oregon State University. They are gathered from different classes, mostly undergraduate, males and females, on a completely voluntary basis. Therefore, the process of collecting the subjects is a random one. Subjects were randomly assigned to treatments.

Task and Procedure

The experiment is a simple type of assembly operation. The subjects are required to assemble a shovel-truck toy whose overall dimensions are about 3 in. x 1.5 in. x 1.5 in. The toy requires 18 different parts to complete and requires no prior skill. In fact, the last requirement is very essential since variation in subjects' skills would influence the performance and may give false results. The steps of assembly are sketched by the manufacturer, shown in Figure 3-1; it was available to the subjects all the time while the task is being

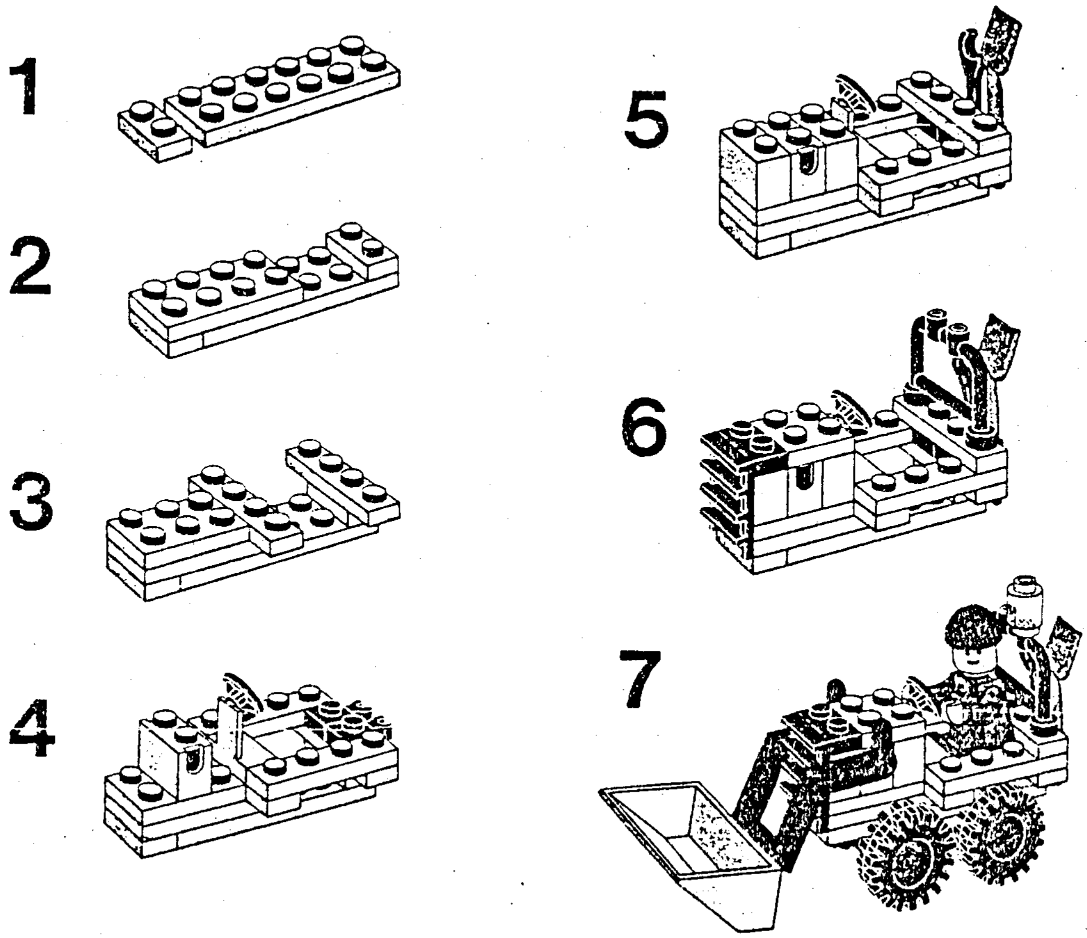

Figure 3-1. A sketch of the assembly steps

performed. The instructions of the experiment are shown in Appendix E. It must be read by each subject; afterwards, an opportunity for asking pertinent questions is encouraged before starting the job. The experimenter recorded the time consumed to assemble each unit except the very first one which is intended to familiarize the subjects with the nature of the job. Since there is only one observer available, each subject was run individually. All subjects were instructed to continue production, one unit after the other, until they were told to quit. The number of units required to be done by each subject exceeds the number of units purchased; therefore, the observer disassembled the assembled units and distributed the parts again in the specified places in a manner which does not bother the subject, nor interfers with his/her job.

The factors to be studied in this experiment are the amount of prior experience and duration of the interruption. In order to study the effect of both factors and the interaction that may occur, four groups of subjects are needed, each of which contains five subjects. Each subject performs the experiment on two days, DAY1 prior to interruption and DAY2 after the interruption. The number of units to be produced and the interruption period for each group are shown in Table 3-1.

The period of interruption varied between one to three days while the amount of experience gained in DAY1 varies between 20 to 40 units. In fact, the 20 units specified above had not been picked from the air, but rather found to be statistically satisfactory using the data from

Table 3-1

Layout of the Different Groups

GROUP #	CODE	DAY1 PRODUCTION IN UNITS	INTERRUPTION PERIOD IN DAYS	DAY2 PRODUCTION IN UNITS
1	G1	20	1	20
2	G2	20	3	20
3	G3	40	1	20
4	G4	40	3	20

a pilot experiment involving one subject who produced 32 units in DAY1, had 3 days off, and produced 32 units again in DAY2. The production for G3 and G4 in DAY1 was doubled to 40 units, allowing the subjects to be more experienced than either G1 or G2. It is worthwhile to mention the great enhancement of the pilot experiment in modifying the workplace and instructions in addition to yielding a better way to the experimenter in coordinating among time recording, inspecting the units, observing the task, disassembling and distributing the parts back to where they belong.

Experimental Design

The selection of the groups shown in Table 3-1 allowed us to apply the Complete Factorial Design (CRF-Pq). The reasons for choosing this design in most of the coming analysis in Chapter 4 are:

a) the subjects are gathered and assigned to different groups on a complete randomized manner.

b) The term factorial experiment refers to the simultaneous evaluation of two or more treatments in one experiment rather than to a distinct kind of experimental design. The two factors here are experience and length of break-in. The parameters p and q are the levels of each treatment (p = q = 2 levels), so the design for this experiment may be written as CRF-22. The block diagram of the CRF-22 design is shown in Figure 3-2.

		Duration of Interruption Period (I)	
		i_1 = 1 day	i_2 = 3 days
Amount of prior experience (E)	e_1 = 20 units	S_1	S_2
	e_2 = 40 units	S_3	S_4

Figure 3-2 Block diagram of CRF-22 design.

The amount of prior experience will be denoted by the capital letter "E", hereafter, and the duration of interruption period may be designated by the capital letter "I". The levels of each factor, E and I, are represented by the lowerrcase letters "e" and "i", respectively. The notations S_1, S_2, S_3, and S_4 refer to the four treatment combinations (Pq = 2*2 = 4), each involves a sample of five subjects bringing the total to 20 participants.

The Workplace

The subjects perform the task while sitting on a regular armless chair in front of a table where all parts are laid. A projection drawing of the workplace is illustrated in Figure 3-3.

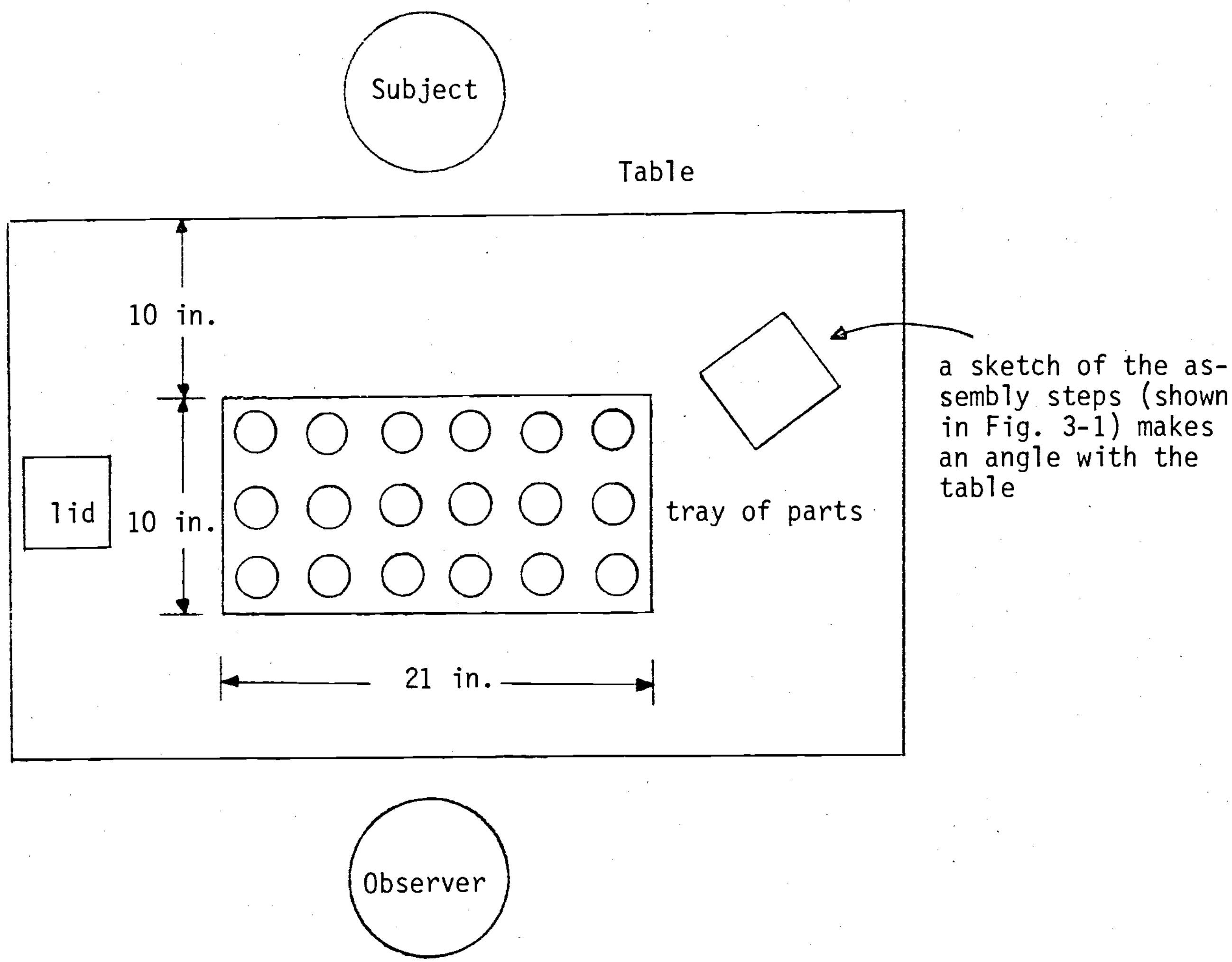

Figure 3-3. Illustration of workplace

The 18 different parts were contained in 18 different pockets and arranged so that the parts needed in the beginning were placed in front and the parts needed later are placed in the back. This design gave subjects the chance to concentrate on the assembly process more than spending the time in locating the desired parts. Each part had been given a code to make easy reference to a certain part in case of part fumbling.

Timing Technique

The time measured for each new unit begins when the subject starts moving any hand to reach for the first part and ends when the unit is placed on a can lid designed for finished products. The time is measured in seconds by a digital wrist watch with hours, minutes, and seconds displayed. This method of measurement is called the continuous one-watch method which has some disadvantages:

a) Subtraction of the recorded times is inevitable but does not affect the results beyond the possibility of error calculation.

b) The observer is trying to read a moving target. The possibility of reading errors could be significantly reduced by glancing at the seconds display first, because it is moving fast, then the minutes display at the instant when a unit has arrived to the lid.

c) Individual elements of the job cannot be traced thoroughly as opposed to using a film.

Despite those shortcomings, the hand watch is not less accurate, subjectively, than the stop watch where the accuracy is about ± .5 seconds. Obviously, this much accuracy is sufficient for the practical reasons of the experiment. To attain precise readings, the eyes of the experimenter, the watch, and the job must be kept in line.

The Data Sheet

The raw data sheets are not included in this paper but the assembly times for all subjects are summarized in Appendix A. A copy of the data sheet is contained in Appendix E where the following items are shown:

1) Subject #, where the serial numbers 1 through 5 belong to G1, 6 through 10 belong to G2, 11 through 15 belong to G3, and finally 16 through 20 belong to G4.
2) GROUP #, which could be any of the specified groups G1, G2, G3, and G4.
3) DAY #, where 1 designates DAY1 (the day before the break-in period) and 2 designates DAY2 (the day after the break-in period).
4) DATE, which keeps track the date of the experiment.
5) Sleeping hours the night before the day of the experiment.
6) Heavy activities done during the subject's assigned day and prior to doing the job.
7) Sex of subjects, which could be males or females.
8) Similar experience practiced by subject, i.e. any assembly type of toys played with, prior to performing the experiment.

The word NONE is stated if the subject never has had any experience of that nature before. In case the subject had played with not necessarily the same kind of toy during childhood period, the information will be provided.

The table just below the mentioned items contains:

9) Unit #, where there is a space for 20 serial numbers. This item will represent the variable X in discussing the mathematical models later.

10) Starting time which signals the outset of producing the associated unit. It is to be noted that not all the starting time columns are filled with times, in fact not more than a couple of them are recorded in each data sheet. However, the starting times for each unit assembled is recorded implicitly in the finish time columns.

11) Finish time, which signals the termination of the assembly process for the associated unit and at the same time signals the starting time for the succeeding unit. That is so because the subject, once finshed producing a certain unit, immediately starts producing another one.

12) Elapsed time consumed for each assembled unit. Of course, it is calculated by subtracting the starting time from the finish time in minutes, then converting to seconds. The elapsed time is denoted by Y_0 which includes 1000 data points.

13) Missing parts for each unit is recorded. If nothing is recorded, it is understood that not a single part is missing but it should not rule out the possibility of fumbles.

14) Remarks about abnormal behavior of subjects or fumbles in units or any other factor known to affect the experiment is recorded on the remark space below the table.

Sources of Variation

An experimenter would like to eliminate unwanted sources of variation as much as possible in order to obtain non-biased results. In this experiment, care was taken in this regard with respect to age, place, time, background, light, and weather. In the coming analysis, no attention will be given to some information listed in the data sheet not because they are useless, but on the contrary, they may be of much value in case something goes wrong. Such information would be like the sex of subjects and the number of sleeping hours. Actually, the objective of this research does not include those factors in the first place, and secondly there are not enough number of subjects by which more groups would be established. Meanwhile, a subjective investigation has been made to see the effect of those factors and found unnotable. However, it was made sure that all 20 subjects maintained the same level of experience, through observer to subject questions, before running the experiment. Naturally, most of the subjects had not touched nor seen the exact toy used in the experiment, while very few played with similar types of toys during their childhood period, which ranges between 10 to 15 years prior to the experiment time. By no means should one be worried about such incidents,for such a lengthy period of time is sufficient to cause total forgetting. Another important issue worth mentioning is fatigue immediately prior to starting the experiment. Since the variation of this factor would result in data disruption, it is essential to make sure that all subjects had not been under the influence of heavy activities mentally or phsyically. Unfortunately, no attempt has been made to justify either missing parts nor fumbles. Although few, but carefully listed, it would be difficult to induce a time penalty or other actions of adjustment in order to obtain purified data.

Before closing this section, it should not be noted that every precaution has been taken to let each subject perform the experiment at the same time, in the same place, and with the same environmental conditions in both days. The time of the experiment was selected to be during regular work hours, i.e. between 9:00 a.m. and not beyond 6:00 p.m.

Model Fitting

As discussed in Chapter 2, there is more than one curve that may represent a given set of data. However, not all of them fit the experimental data equally. In this study, the analysis will be confined to the most common learning curves. These are the power function and the exponential function which will be discussed briefly herein:

1) The power function

The formulation of the power function that will be used in future analysis takes the form (Garg and Milliman, 1961),

$Y_X = B_0 \, (A + X)^{B_1}$ where,

Y_X = the cumulative average time to produce the X-th unit.

B_0 = the time to produce the first unit (X=1).

A = the amount of retained experience.

X = the cumulative number of units.

B_1 = the learning rate parameter (negative fraction).

The percentage learning rate (%) could be obtained from the learning rate parameter (B_1) by manipulating with the equation, B_1=log %/log 2. A value of % near 100% means no learning is taking place and the value of B_1 approaches zero from the negative side. Accordingly, the value of Y in the function itself vanishes. This situation usually occurs for a large value of X where no improvement is expected, but in reality the time does not drop to zero. This is a disadvantage of the power function which is seen better from Figure 3-4 (Konz, 1979).

The reason for employing the power function despite its imperfections is simply because that situation does not apply to the experiment since the subjects produce 60 units at most. Also, the power function has proven historically to be a powerful tool in fitting assembly process data.

The retention variable will be used as having a zero value in one model and non-zero in another.

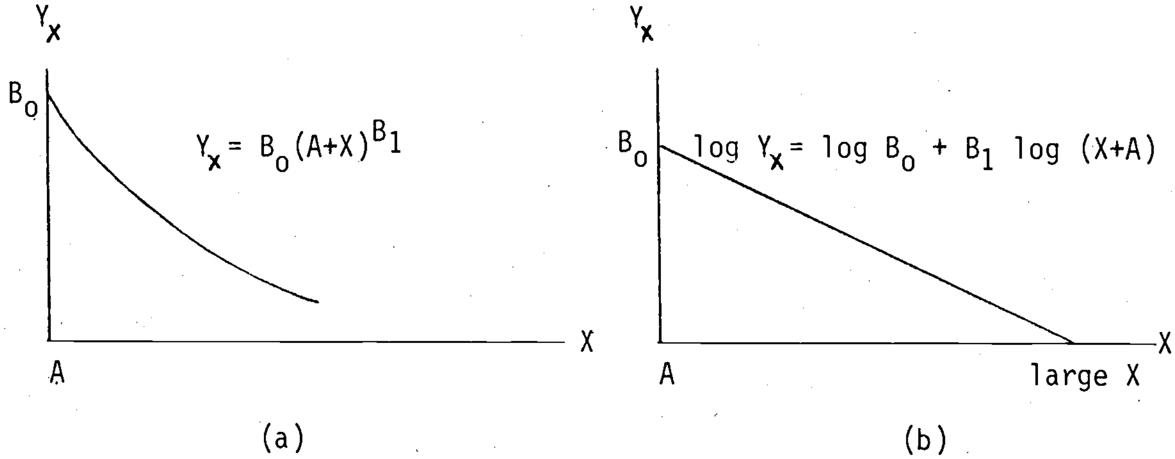

Figure 3-4. The power function on:
(a) a rectangular coordinates
(b) a log-log paper

2) <u>The exponential function</u>

The formulation of the exponential function that will be used in future analysis takes the form (Buck, Tanchoco, and Sweet, 1976):

$Y_X = B_0 + B_1 \alpha^X$ where,

Y_X = individual time to produce the X-th unit.

B_0 = asymptotic cycle time.

B_1 = coefficient of the learning rate term (α^X).

α = learning rate parameter.

X = cumulative production of units.

Apparently, the asymptotic cycle time is not restricted to zero as in the case of the power function. In this model, the value of Y_X converges to B_0 for a large value of X; here the advantage of the exponential curve over the power curve is evident.

The range of the learning rate parameter should be $0 < \alpha < 1$ in order to obtain a concave function with regard to the abcissa; a value of $\alpha > 1$ makes the shape of the curve convex. A sketch of the current model is shown in Figure 3-5. Both curves in (a) and (b) clarify the fact of leveling out to the asymptotic value B_0 after a relatively large value of X. This phenomenon represents what happens in real life assembly tasks, i.e. after the worker acquires most of the available learning, he/she tends to follow almost a constant time/unit if nothing unusual occurs.

A value of α near 1 means no learning is taking place and production consumes $Y_X = B_0 + B_1$ units of time. If the value of α is in the vicinity of zero, the value of Y_X drops to B_0 rapidly, which is only possible for very easy tasks. If the value of α happens to be less than and in the vicinity of 1, the values of Y_X gradually decrease until the value of B_0 is reached.

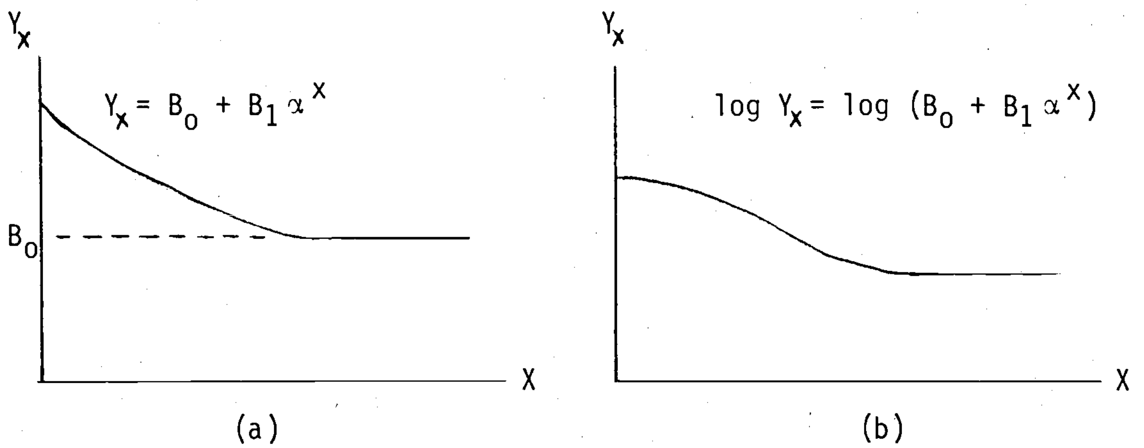

Figure 3-5. The exponential function on:
(a) a rectangular coordinates
(b) a log-log paper

IV. EXPERIMENTAL RESULTS

Introduction

As a reminder to the reader, this research is concerned with the effect of job interruption on learning with special consideration for two factors, the amount of prior experience and the duration of interruption. Two mathematical models were used in the analysis. The first being the exponential function with the form $Y_i = B_0 + B_i \alpha^i + e_i$ where i represents the serial number of the produced units by a certain subject and e_i is the error value imposed for unit i. The other model is the power function having the form, $Y_i = B_0 (A + i)^{B1} + e_i$ where e_i is again an error term. The latter model could have two versions; one excluding the A term and the other including it. In order not to lengthen the chapter extensively, consideration in the analysis will mostly involve the exponential function and the first version of the power function.

The analysis consists of a comparison between both models on the basis of better curve fitting using regular and paired t-tests. Although this portion does not contribute much to the problem of forgetting, it is helpful in evaluating the results later. Then each model will be analyzed separately from the other, serving the same goal and answering the same questions. Groups were matched for the predicted variables (e.g. ~~for~~ the time taken to complete the first unit and for the learning rate) to see if they are collected from the same population. The statistical tool used is a two-way completely randomized factorial design with two levels of training and two levels of interruption. This model, a CRF-22 design, is clearly outlined in statistical textbooks as a method of analysis of variance (Kirk, 1969). During data collection, subjects were randomly assigned to the cells of the design, with one group of subjects serving for each combination of treatments. The advantage of a factorial experiment is to evaluate the effects of each treatment with the same precision as if the entire experiment had been devoted to that treatment alone.

The design includes two factors. One is the amount of prior experience, designated by the letter E, and contains the level e_i = 20 units (those are the units produced by G1 and G2 in DAY1) and level e_2 = 40 units (those are the units produced by G3 and G4 in DAY1). The second factor is the duration of interruption period, denoted by the letter I, and contains the level i_1 = 1 day of interruption (for G1 and G3) and the level i_2 = 3 days of interruption (for G2 and G4). The objective reason for conducting this research will be discussed in this chapter through trials to answer questions like: Does forgetting result from the rest period? To what extent do the factors mentioned contribute to forgetting? Again, the same CRF-22 design will be used. Most of the dependent variable values are contained in the Appendix and will be referred to as required.

However, the chapter is enriched by graphs to clarify the points under investigation.

The analysis of the data will be based on the parameters of the exponential function and the power function. Fitting the data by hand calculation is impractical; therefore, the need for a computer program is inevitable.

1) Program to fit the data to the exponential function

With regard to the exponential function, the original equation is rearranged in terms of the error variable as $e_i = Y_i - B_0 - B_1 \alpha^i$. By squaring both sides and taking the summation of the errors associated with the number of units produced (N), the equation takes the following form: $\sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} (Y_i - B_0 - B_1 \alpha^i)^2$. The value of α is assumed fixed (known) at the moment in order to form two equations and two unknowns. The equations are obtained by taking partial derivatives of the last equation with respect to the variables B_0 and B_1, then equalizing each to zero as follows:

$$\frac{\partial \left(\sum_{i=1}^{N} e_i^2\right)}{\partial B_0} = \sum_{i=1}^{N} -2 \, (Y_i - B_0 - B_1 \alpha^i) = 0$$

$$\frac{\partial \left(\sum_{i=1}^{N} e_i^2\right)}{\partial B_i} = \sum_{i=1}^{N} -2 \, \alpha^i \, (Y_i - B_0 - B_1 \alpha^i) = 0$$

By manipulating the terms to put the equations in easier and flexible form, the following equations are obtained:

$$\sum_{i=1}^{N} Y_i = NB_0 + B_1 \sum_{i=1}^{N} \alpha^i$$

$$\sum_{i=1}^{N} \alpha^i \, Y_i = B_0 \sum_{i=1}^{N} \alpha^i + B_1 \sum_{i=1}^{N} \alpha^{2i} \quad \text{and}$$

$$SSE = \sum_{i=1}^{N} Y_i^2 - B_0 \sum_{i=1}^{N} Y_i - B_1 \sum_{i=1}^{N} Y_i \, \alpha^i$$

The last term is called the sum of squared errors which originally takes the form $SSE = \sum_{i=1}^{N} (Y_o - Y_p)_i^2$ where Y_o is observed unit time, Y_p is the predicted time for the same i unit, and N is the number of units to be considered (20 units) in a certain day.

Now, by picking a value for α from the allowable range ($0 < \alpha < 1$), it is possible to solve all three equations simultaneously to find the values of B_0, B_1, and SSE. Once those values are found, then a variation of Powell's Method (Beightler, C.; Phillips, D; and Wilde, D., Foundations of Optimization, 2nd Ed., Prentice-Hall, N.J., 1979) is used on α to reach the optimum solution as determined by minimizing SSE. A tolerance of 0.005 on α is used as a stopping criterion of the search, that is if α changes by 0.005 or less from one iteration to the next, then the procedure is terminated. The procedure just explained was coded in a computer program and that program is listed in Appendix B.

2) Program to fit the data to the power function

In fitting the power function, A is assumed to be zero and the variables B_0 and B_1 are found by regression analysis of the log-transformed equation. The following formulas are the result of this process.

$$B_0 = (\Sigma \log Y_i - B_1 \Sigma \log (I+A))/N$$

$$B_1 = \frac{N \Sigma (\log Y_i)(\log (I+A)) - \Sigma \log Y_i \Sigma \log (I+A)}{N \Sigma (\log (A+I))^2 - \Sigma \log (A+I))^2} \text{ and}$$

$$SSE = \Sigma (Y_i - B_0 * (I*A)^{B_1})^2$$

Once B_0 and B_1 are found, then the A variable is assumed a value different than zero ($A \neq 0$) and the Golden Section Method is used on A to reach the optimum solution again as determined by minimizing SSE. The final interval for A of 0.2 was used as a stopping criterion of the search. In fact, the ratios of the tolerance to the range of the variable involved in the search for both programs are set the same, i.e. 0.005 to 1.0 (range of α) is the same as 0.2 to 40 (range of A). The procedure just mentioned was coded into a computer program which is listed in Appendix B. The criterion for stopping the execution of both programs was to minimize SSE.

In addition to finding the parameters of the functions, the programs calculate the correlation of the observed times and the sequence of produced units; R^2. However, no attempt has been made to run any sort of analysis on this variable, which is thought of as an aid in analyzing the relationship between the fitted curve and the produced units.

Another variable obtained from the computer programs is the number of iterations taken to find the solution of a certain subject, K. This variable gives an indication about the efficiency of the program in dealing with the given data.

A summary of the programs output is listed in Tables C-1 through C-6 in Appendix C where the results of the exponential function, the first version of the power function and the second version, are tabulated, respectively, for all subjects for DAY1 and DAY2.

At the bottom of each table, simple calculations are done such as the total, mean, standard derivation and sum of squares to give an idea of the performance ob subjects as a whole. It is to be noted that the variable SSE enables the experimenter to compare the fit of data on a specific curve for different subjects while the variable R^2 measures the relationship between two variables for a specific subject. Therefore, they are not directly proportional to each other.

Preliminary Discussion

After inspecting the programs' output, unusually large SSE values are found for subjects number 10 and 16 in DAY1 for both the exponential and the power curve fits. The raw data was examined.

With regard to the data of subject #10, unit #2 and #4 were done with relatively high assemble time. The remarks in the data sheet suggest that a partial unit had been assembled, then left aside, may be due to confusion, and another trial was given to produce unit #2. However, failure to find a legitimate reason to dispense with the data for unit #4 is encountered. In fact, discarding this data point would not endanger the results but on the contrary would reduce the SSE value appreciatively and make the results plausable. A satisfactory reason to excuse doing so is the apparent long time consumed (239 seconds) which does not fall in the context of the preceding, nor the subsequent unit times. The fact of having such an observation raises the suspicion that something wrong had occurred and the observer failed to report it.

The same reasoning could be applied to unit #3 time (243 seconds) which belongs to subject #16 in DAY1. The observer succeeded in recording the fumbles commited and corrected by the same subject during unit #8 assembly, which accordingly reckoned an undesirable unit and the associated time (261 seconds) could be eliminated. A computer rerun for both subjects and recalculation for the items at the bottom of the tables in Appendix C were performed with these four data points omitted.

Curve Fitting

A certain curve fits data better if the associated SSE value is less provided that proper procedures have been followed in finding the independent variables. Looking to the mean across subjects SSE of the exponential function and comparing it to that of the power function in its two forms, it is clear how much the former outweighs the latter under the light of the rule of thumb mentioned above. However, subjective decisions should not be made until after statistical tests are performed. The following are six trials to determine the superior curve in fitting the data.

Paired t-test on power (A=0) vs. exponential function for SSE values in DAY1.

The dependent variable, ΔSSE, comprises the difference between both functions SSE values for all 20 subjects, i.e.

$$\Delta SSE = (SSE)_{pow} - (SSE)_{exp} .$$

The null hypothesis suggests that the population ΔSSE values are zero while the alternative hypothesis suggests a non-zero value. This statement is abbreviated as follows:

H_0: $\mu_{\Delta SSE} = \mu_{pow} - \mu_{exp} = 0$, and

H_a: $\mu_{\Delta SSE} \neq 0$

The values of ΔSSE variable for all subjects together with the basic calculations are listed in Table D-1 in Appendix D. The calculated t value, denoted by t(cal.), comes out equal to 2.42 as opposed to a tabulated t value, denoted by t(table), equals to ± 2.09 for a two-sided test, .05 level of confidence and 19 degrees of freedom, i.e. $t(table) = t_{\alpha, df} = t_{.05,19} = \pm 2.09$; thus the null hypothesis is rejected.

It may thus be concluded, the values of ΔSSE are significant, which implies that the exponential function fits the data of DAY1 better than the power function with A=0.

<u>Paired t-test on power (A=0) vs. exponential function for SSE values in DAY2.</u>

The dependent variable definition and hypothesis are exactly like those above. The figures needed for the test are calculated from concerned data in DAY2 and listed with minor calculation in Table D-2. The calculated t value, t(cal.) equals 3.42, compared to 2.09 for tabulated t, again calling for the rejection of the null hypothesis.

<u>Paired t-test on power (A≠0) vs. exponential function for SSE values in DAY1</u>

Because the first version of the power curve with A=0 contains only two parameters (B_0 and B_1), whereas the exponential curve contains three (B_0, B_1, and α), it may be conjectured the better fit of the exponential function is simply due to the larger number of parameters and not the form of the model. The current test involves the second version of the power function with A≠0 which comprises as many independent variables (B_0, B_1, and A) as the exponential function does. In this case, one can be assured of non-biased results due to variation in the number of parameters. The dependent variable and hypothesis are again as before. The required data are presented in Table D-3 with calculation results. The calculated t value becomes insignificant, t(cal.) = .88, versus 2.09 for t(table), thus H_0 cannot be rejected. The ΔSSE values are not significantly different, implying no superiority in fitting has been shown for either the exponential nor the second model of the power function in DAY1.

Paired t-test on power (A≠0) vs. exponential function for SSE values in DAY2

For the same reason stated in the foregoing test, it is complementary to perform the test in DAY2. The dependent variable definition and hypothesis remain unchanged. The needed figures for the test are listed in Table D-4. The calculated t values, t(cal.) = 2.89, is greater than the tabulated t value, t(table) = 2.09, by a small margin, calling for rejection of H_0. The values of ΔSSE are significant, which implies that the exponential function fits the data of DAY2 better than the power function (A≠0) significantly at the .05 level of confidence.

The results of the previous four tests are summarized in the table on the following page.

	DAY1	DAY2
EXP. vs. POW (A=0)	reject H_0	reject H_0
EXP. vs. POW.(A≠0)	accept H_0	reject H_0

According to the contents of the table, it is not clear which model fits the data better since the exponential function had not fitted the data better in all test, but only three out of four. Generally, the judgment should not be based only on the number of times a certain function fits a historical data better but equal, if not more, consideration should be given to the prediction of future performance and the mean error produced by each function as will be discussed in the subsequent tests.

A quick look to the mean SSE values, tabulated in the table below, shows the exponential function fits better than the power

	DAY1	DAY2
Exponential	3194.61	1062.30
POW. (A=0)	3407.82	1148.93
POW. (A≠0)	3249.05	1117.06

function in its two models for both DAY1 and DAY2. However, when looking thoroughly at the figures, our conjecture indicates small differences among the figures in the table. For example, the maximum difference in SSE values in DAY1 is between the first two functions (i.e., 3194.61 against 3407.82), which amounts to about 200. Recalling the number is squared, the square root is about 14 second distributed among all 20 participant subjects, which leaves each subject with almost negligible contribution (fraction of a second) to the available difference in the associated SSE values. In fact, this very pair of functions (exponential vs. power (A=0)) were significantly different with respect to their SSE values in the paired t-test done earlier, which takes the data on an individual basis, i.e. a pair of data for each individual is considered, while what has just been shown takes the data as a whole based on the mean SSE values. But, after all, for proper scientific work, the statistical tests are taken into account above any other consideration.

<u>Paired t-test on power (A=0) vs. exponential function for SSE values belonging to units 21 through 40</u>

One of the most important reasons for fitting laboratory or real life data to a specific function is to use the history of operators' performances as a mean to forecast their future behavior under the same or similar conditions.

To see which function, the power (A=0) or the exponential, predicts the future task best, a small computer program was prepared to calculate the sum of squared errors (SSE) between the observed times and the predicted times for the units 21 through 40, i.e. for G3 (40,1) and G4 (40,3) as they completed 40 units in DAY1. The basic formula used in the program (listed in Appendix F) is,

$SSE = \sum_{X=21}^{40} \frac{(Y_X - P_X)^2}{20}$ where Y_X is the actual times for units X = 21 through 40 and P_X is the predicted times for the same units. As far as the SSE formula is concerned, the P_X variable may take the exponential form ($P_X = B_0 + B_1 \alpha^X$) or the power form ($P_X = B_0 X^{B_1}$). The output of the computer program is shown in Table D-5, in Appendix D.

Surprisingly, the power function predicts better than the exponential function for eight of the ten subjects.

Let us recall one characteristic for both models in which their behavior was different. In the case of the power function, the cumulative average time continued to decrease as the cumulative number of units increased. Time reduction in this regard is an indication that the learning process is still going on. On the other hand, the nature of the exponential function is to level out to the asymptotic cycle time after a certain number of units have been produced. The portion of the curve where the asymptotic time follows a constant value is an indication of learning process termination. Having these features in mind and remembering that the power function has predicted the production time for units 21 through 40 better, it is possible to say that the subjects in G3 (40,1) and G4 (40,3) were on the learning process up to and including the assembly of the 40th unit.

The significance of the better fit can be tested by running a paired t-test on the SSE values for both functions. The dependent variable definition and proposed hypothesis are the same as in the first test. The calculated t value, t(cal.) = -.059, falls in the acceptance region of t(table) = $t_{.05,9} = \pm 2.26$, therefore H_0 cannot be rejected.

As a result, the difference in prediction power of both functions is not significant.

t-test on the mean error for both the exponential and power function

To close the section, it is convenient to discuss the error involved for both functions. The mean error formula is $\bar{e} = \frac{\sum_{X=21}^{40} (Y_X - P_X)}{20}$ where Y_X and P_X are as defined earlier. The calculated t value is obtained from the formula $t(cal.) = \frac{\bar{e}}{\left(\frac{SSE - 20*\bar{e}^2}{19}\right)/20}$

The statistical hypothesis are,

H_0: $\bar{e} = 0$

H_a: $\bar{e} \neq 0$

The dependent variable ($\bar{e}$) and the associated calculated t values are presented in Table D-6. The summary table below shows that two out of ten subjects support H_0 in the exponential case while four students out of ten suggest that H_0 cannot be rejected in the power case basing the results on a tabled t value of ± 2.26.

Function	Below lower t-limit (predicted higher than actual)	Acceptance Region	Above upper t-limit (predicted lower than actual)
Exponential	6	2	2
Power (A=0)	2	4	4

This finding simply says that the cumulative error committed by using the power function is less, and therefore fits better.

An important observation from the above table is that the exponential function has overestimated six out of ten subjects while the case with the power function is two subjects. The meaning of this note contends that the exponential function levels out sooner than the actual times, which have been in continuous, but slower decrease. On the opposite side, the power function has underestimated four out of ten subjects, whereas the case is two in the exponential function. In fact, this note confirms the disadvantage of the power function since the actual unit times were beginning to reach the saturation level, but the power curve continues to drop at a rate faster than the actual data.

Finally, the outcomes of the six foregoing tests lead to say that the exponential function fits the data better than the power function with its two forms; in the sense that it was better in three tests, no difference at two tests, and fits worse in one test. However, caution should be taken not to generalize this conclusion and should only be considered for the specified or a similar task. Had the experiment been run with a different apparatus or different design, the better fit decision would have probably been changed.

For example, if a complex task is to be learned by subjects, the power curve may fit the data better because complex tasks take more trials to completely be learned, which means the production times per trial continue to decrease for a relatively large amount of trials. The data of such tasks may be better fitted by the power curve because it also continues to decrease as the number of trials increase. This situation may not be necessarily true for all complex tasks, but it alerts the experimenter to carefully draw conclusions.

Analysis for the Exponential Function

Although subjects reported similar experiences on similar tasks and were randomly assigned to groups, an analysis of the learning parameters for DAY1 was performed to ensure no initial inter-group differences. This analysis included a one-way analysis of variance for the estimated time of the first unit, the asymptotic cycle time, and the learning rate parameter for DAY1.

A one-way analysis of variance will first be performed on Y_1 (the dependent variable) which represents the fitted time to produce the first unit in DAY1. The values of Y_1 are calculated from the exponential function with X = 1, i.e. from $Y_1 = B_0 + B_1 \alpha^1$, and shown in Table D-7. The ANOVA table is shown in Table 4-1 where the TOTAL, MEAN, and TOT/ADJ values are omitted. The analysis indicates there is no significant difference among Y_1 values due to the amount of prior experience $(.11 < 4.49)$, the duration of interruption $(.11 < 4.49)$, and the interaction effect $(.34 < 4.49)$ for the 0.05 level of confidence. $F_{0.05} = 4.49$.

Table 4-1

ANOVA Table for Production Times of First Unit in DAY1 (using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN				
TOT/ADJ				
E	1	428.74	428.73	.34
I	1	139.39	139.39	.11
EI	1	430.59	430.59	.34
ERROR	16	20,091.74	1,255.73	

where,

E = amount of prior experience factor

I = duration of interruption factor

The results are as expected since subjects were randomly assigned to groups.

Proceeding in the same line of matching the subjects with respect to the ability to perform the task, similar work was done on the B_0 variable which was previously defined as the fitted asymptotic cycle time of DAY1 and represents the dependent variable in the current design; the data is contained in Table C-1 in the Appendix. The results of the analysis are contained in Table 4-2.

Table 4-2

ANOVA Table for Asymptotic Cycle Times in DAY1 (using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN				
TOT/ADJ				
E	1	82.50	82.50	.18
I	1	210.21	210.21	.45
EI	1	303.73	303.73	.65
ERROR	16	7495.55	468.47	

The results of the analysis are best interpreted the same way as above, which could be summarized by saying equality among subjects initially do exist based upon 0.05 type I error. Therefore, the evidence of subject matching became stronger when, not only the initial performance but also the ultimate performance of subjects do not differ significantly.

To finish up the effort to prove equality of initial conditions among all 20 subjects, a final test was done on α (the learning rate parameter in the exponential function during DAY1) which represents the dependent variable in the current test. The data was provided in one of the columns given in Table C-1 in the Appendix, where the results of the analysis are tabulated in Table 4-3.

Table 4-3

ANOVA Table for Learning Rate Values in DAY1 (using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN				
TOT/ADJ				
E	1	.0014	.0014	.22
I	1	.0480	.0480	7.47
EI	1	.0026	.0026	.40
ERROR	16	.1028	.0064	

The outcome of this analysis does not totally agree with the preceeding work in the sense that the I factor becomes significant (7.47 > 4.49). An examination of the data did not suggest any systematic cause for this significance. When nine tests are being performed at an $\alpha = 0.05$ level, there is a 37% chance one null hypothesis will be rejected even though all are true. This was apparently what happened.

The results of the previous three tests contends the proper matching of subjects, which together with the fact that the subjects have been gathered and assigned randomly, lead us to infer there were no systematic differences between groups.

The first question to be addressed in the analysis is, "Does forgetting result from interrupting a repetitive motor task?" The performance after interrupting any type of job can take one of the following possibilities:

1) Performance is reduced to a lower level where some or all of the experience is lost; in this case, the performance has been affected negatively and the term forgetting emerges.

2) There is an insignificant change in performance, which means the operator resumes the task after the interruption period at the same level as before.

3) Performance after the interruption is improved. In the latter case, the performance has been affected positively and the term reminiscence emerges. Reminiscence may be defined as the increase in skill proficiency attributed to a rest period. This phenomenon is observed in the data of subjects 1, 3, 11, 15, and 17, where forgetting (F) values are negative and shown in Table D-8 in the Appendix.

To answer the original question, the dependent variable, the amount of forgetting (F) measured in time units, is defined as the difference between Y_2 and Y_f. The variable Y_2 represents the predicted assembly time of the first unit produced after the rest period, while the variable Y_f represents the predicted assembly time of the unit sequent to the last unit produced prior to the rest period, that is, Y_f = time for unit #21 in G1 (20,1) and G2 (20,3) or the time for unit #41 in G3 (40,1) and G4 (40,3). Both variables and the F variable as well are clarified in Figure 4-1.

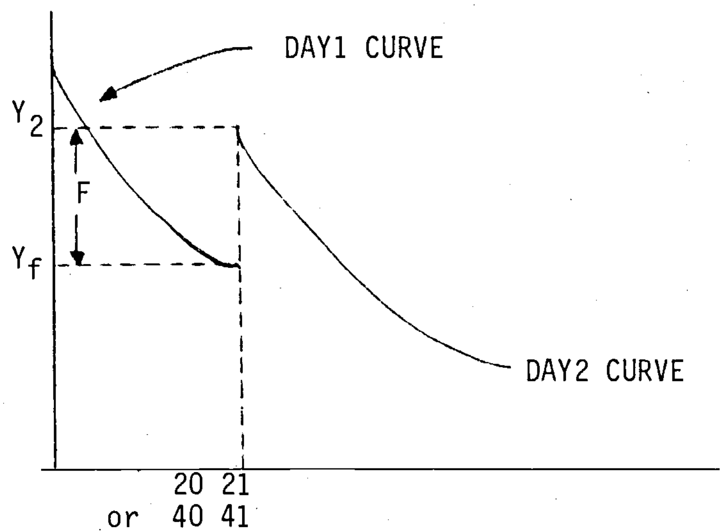

Figure 4-1. The amount of forgetting ($F = Y_2 - Y_f$) using the exponential function

There are other measures of the amount of forgetting, like the one measured in units which will be mentioned when discussing the retention section. The reason for choosing Y_f as such, is when visualizing it as the time for the first unit done in DAY2 without interrupting the job. Meantime, Y_2 is the time consumed in the same unit after the interruption period which is expected to be larger than Y_f for most subjects. Therefore, the difference between Y_f and Y_2 represents a time increase in assembling the same unit due to forgetting phenomenon. The values of Y_2, Y_f, and F are summarized in Table D-8 in Appendix D.

Two additional questions are, "Is forgetting influenced by the amount of prior experience?", and "Is forgetting influenced by the length of interruption period?" To answer these questions statistically, a CRF-22 design was conducted on the forgetting (F) variable.

Results

By referring to Table 4-4, the forgetting variable (MEAN value) has shown significance for a type one error of .05, $(11.11 > 4.49)$. However, neither the effect of prior experience nor the effect of length of interruption was significant $(.034 < 4.49$ and $3.80 < 4.49$, respectively).

Table 4-4

ANOVA Table for the Forgetting Values
(using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL	20	5095.45		
MEAN	1	1827.30	1827.30	11.11
TOT/ADJ	19	3268.15		
E	1	5.67	5.67	0.034
I	1	624.63	624.63	3.80
EI	1	5.48	5.48	0.033
ERROR	16	2632.39	164.52	

The value of F (calculated) = 3.80 associated with the I factor is significant for a type one error of 0.10 where F (table) = 3.05. Therefore, it can be concluded that forgetting has been influenced significantly by the duration of the rest period.

Discussion

The fact that the effect of rest period was significant and the effect of prior experience was not, does not rule out the role of experience. In retrospect, it appears that for the task selected most of the skill needed could be learned by practicing 20 trials. Therefore, there was very little to be gained in practicing an extra 20 units. If the experiment had been designed such that G1 (20,1) and G2 (20,3) produce lesser number of units, say 10, in DAY1, then the amount of experience factor would probably be significant. Let us now draw more inference from the group means plotted in Figure 4-2.

Both sketches in (a) and (b) of Figure 4-2 support the statistical results obtained from the ANOVA table in the sense that the lines in each sketch tend to be parallel, therefore, the interaction effect (EI) is not significant. The gap created between the lines in (a) is greater than that in (b). The technical interpretation of the previous statement is to say that the duration of the interruption period is more powerful than the amount of experience in causing forgetting, at least for this specific task. This finding cannot be generalized to all real life cases for three reasons. First, different tasks are learned and forgotten differently; hence, the factors' effectiveness on both variables takes different degrees.

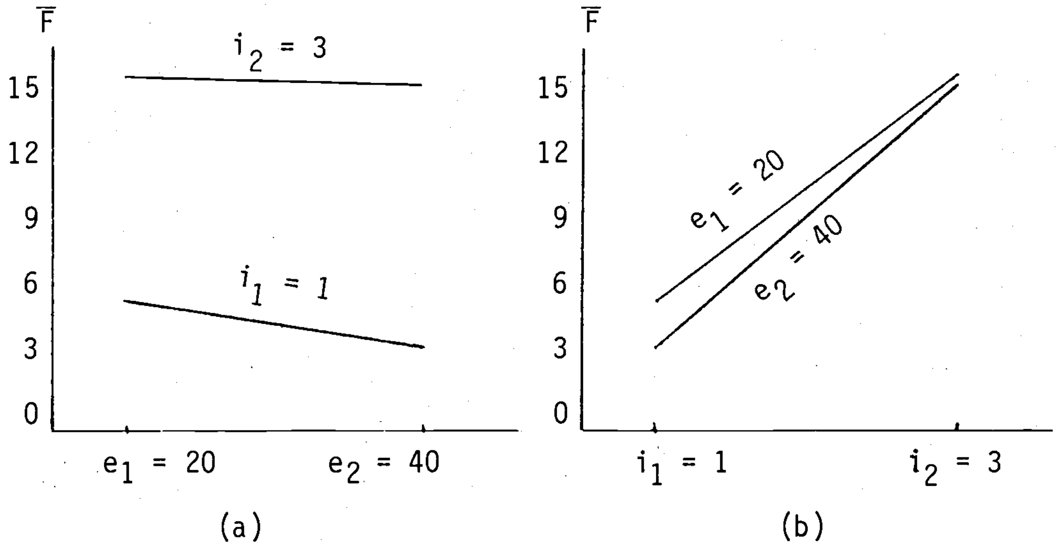

Figure 4-2. Illustration of mean forgetting ($\overline{F}$) vs.
(a) the amount of experience levels (e_1 = 20 units and e_2 = 40 units)
(b) the length of interruption levels (i_1 = 1 day and i_2 = 3 days)
(using the exponential function)

Secondly, the unavailability of multiple levels, say 5, for each factor in the experiment. Doing the experiment with such number of levels and having the gap in (a) consistently greater than the gap in (b) still does not confirm the above mentioned conclusion because, thirdly, the ratios of the factors' levels are not equal, i.e. the level ratio for E = 20 units/40 units = 1:2, while the level ratio for I = 1 day/3 days = 1:3.

The notion that I affects forgetting more than E is also clear from the slope of lines. While the lines in (a) are approximately horizontal, the other lines in (b) have a sharp inclination upward. In such figures, a horizontal line indicates the lack of influence of the factor under consideration because the mean values of the dependent variable have not been affected significantly by changing the levels. On the other hand, an effective factor shows the degree of power by how large is the angle confined between the concerned line and the abscissa.

Line $i_2 = 3$ represents the mean amount of forgetting for G2 (20,3) and G4 (40,3). The difference between the respective forgettings equals 15.16 - 15.14 = 0.02. Both groups had three rest days, but despite the fact that G4 had 20 units more experience in DAY1 than G2, the change in forgetting is almost negligible, which indicates that the 20 more units done by G4 has not influenced the results.

Line $i_1 = 1$ is a comparison between G1 (20,1) and G3 (40,1). The difference between their respective forgetting means is 5.03 - 2.91 = 2.12. It is clear that one day of rest is not enough to bring the amount of forgetting for both groups to the same level. However, an intuitive remark should be made, which says that increasing the amount of experience decreases the amount of forgetting, something could have been observed from Figure 4-2 (b) by having the line $e_1 = 20$ above the line $e_2 = 40$. In the previous two cases, the decrease was 0.02 and 2.12 due to experience, respectively.

Line $e_1 = 20$ compares G2 (20,3) with G1 (20,1). The difference between the respective forgetting means is 15.16 - 5.03 = 10.13.

Line $e_2 = 40$ compares G4 (40,3) and G3 (40,1). The difference between the respective means is 15.14 - 2.91 = 12.23. The latter two figures are appreciatively greater than those calculated earlier, this matter contends the expectation that the duration of rest is more influential than experience.

Again, an intuitive remark about Figure 4-2 (b) suggests increasing the length of interruption would increase the amount of forgetting, something could have been noticed from Figures 4-2 (a) by having line $i_1 = 1$ below line $i_2 = 3$. The increase in the latter two cases takes the values 10.13 and 12.23, respectively.

Generally speaking, it is expected that G2, the group with the lowest amount of experience (20 units) and with the largest duration of rest (3 days) will experience the greatest amount of forgetting among the groups, which is consistent with the experimental results. On the opposite side, it is expected that G3, the group with the highest amount of experience (40 units) and with the shortest length of interruption (1 day) will experience the lowest amount of forgetting, this too is confirmed by the results.

A related question is to what extent retention (R) is influenced by interrupting a repetitive motor task? The dependent variable is the amount retained after the interruption period denoted by R and measured by number of units. To know how R is found, see Figure 4-3.

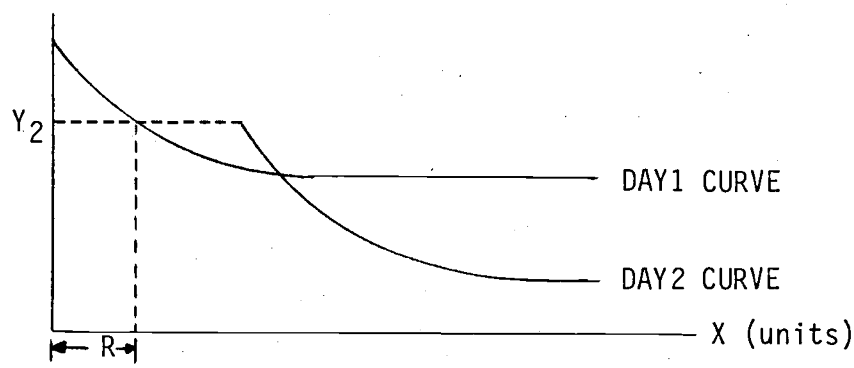

Figure 4-3. The amount retained (R) after interruption (using the exponential function)

Suppose the exponential formula for DAY1 is, $Y_E = B_0 + B_1 \alpha^X$. Let Y_2 be the predicted time to produce the first unit after the rest period. By projecting the value of Y_2 on the DAY1 curve, it is possible to know the retention (R) in units. The level of Y_2 is achieved in DAY1 also when R units have been completed. If the amount of forgetting (F) is desired in units as well, the value of R would have to be subtracted from the cumulative units accomplished in DAY1, i.e. either F = 20 - R for G1 (20,1) and G2 (20,3) or F = 40 - R for G3 (40,1) and G4 (40,3). Mathematically, the value of Y_2 is substituted in DAY1 formula as $Y_2 = B_0 + B_1 \alpha^X$. Rearranging terms in order to find the value of X, the following expression is found, $X = \log (\frac{Y_2 - B_0}{B_1})/\log \alpha$ where X is the amount of experience retained (R) measured in units. In case the value of B_0 happens to be greater than the value of Y_2 (this situation occurs when performance in DAY2 starts below the asymptotic cycle time of DAY1), it means retention is a hundred percent preserved. Because lograthims are not applied to negative numbers, then X (or R) is assigned the cumulative number of units done in DAY1, i.e. R = 20 for G1 (20,1) and G2 (20,3), or R = 40 for G3 (40,1) and G4 (40,3) as shown in Table D-9 in the Appendix, where the R values are listed for all subjects. The denominator of the X formula ($\log \alpha$) is always negative (unless when no learning takes place where α takes the extreme values, zero or one), therefore; X may take a negative value when the numerator is positive (Y_2 is larger than B_0 by an amount greater than B_1). According to this, the initial performance in DAY2 must be worse than the initial performance in DAY1. This situation is clarified in Figure 4-4 when imagining the value of $B_1\alpha$ is normally less than the value of B_1, therefore the value of Y_2 must be somewhere larger than the value of Y_1 in order to have a time difference (between Y_2 and B_0) larger than B_1.

Fortunately, not a single case has been encountered in this experiment.

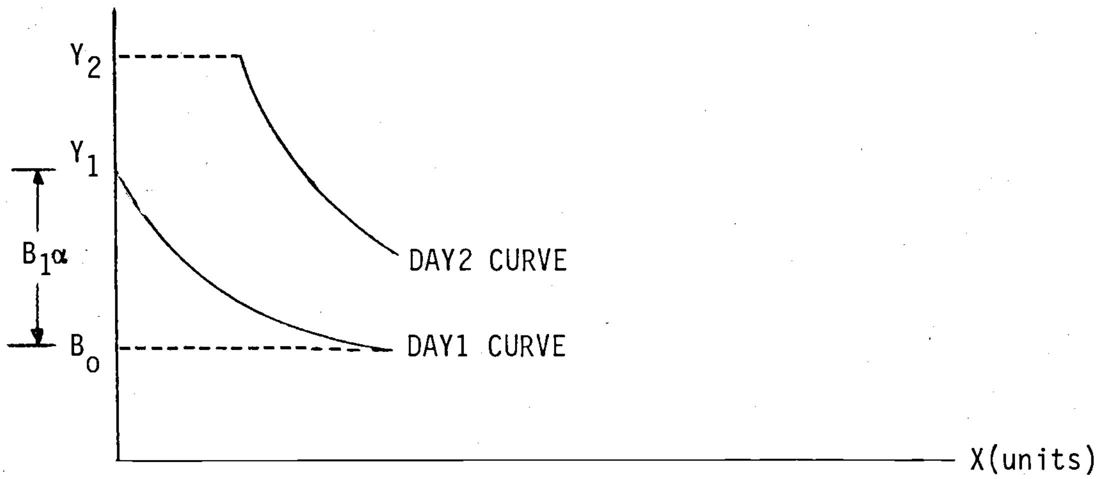

Figure 4-4. Illustration of how initial worse performance in DAY2 than in DAY1 causes negative retention value

Two additional questions of interest are, "Is retention influenced by the amount of prior experience?", and "Is retention influenced by the length of interruption period?" An analysis of variance is performed to answer those three questions.

Results

The results of the CRF-22 design are summarized in Table 4-5. Retention (MEAN value) seems to be significant (38.72 >4.49) for the

Table 4-5

ANOVA Table for the Retention Values
(using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL	20	7418.26		
MEAN	1	5024.45	5024.45	38.72
TOT/ADJ	19	2393.81		
E	1	243.61	243.61	1.88
I	1	70.99	70.99	0.55
EI	1	2.82	2.82	0.02
ERROR	16	2076.39	129.77	

.05 level of confidence; however, E and I factors are not. These results are similar to the results obtained from the forgetting analysis.

Discussion

For the first look, one would think that the result of the current analysis contradicts the result of the previous analysis. In other words, how come both forgetting and retention are found to be statistically significant variables? The answer is simple. The subjects as a whole have forgotten something and at the same time have retained something, too. To make the picture clear, let's have a look at the table of mean retention on the following page. The cumulative mean retention is 63.40 units out of 120 units done in DAY1, which

	$i_1 = 1$	$i_2 = 3$	marginal means of I
$e_1 = 20$	14.62	10.10	24.72
$e_2 = 40$	20.85	17.83	38.68
marginal means of E	35.47	27.93	

amounts to 52.8% of learning being preserved and 47.2% being lost. The percentage values for retention and forgetting are close enough to let both have the same status, i.e. both are significant variables.

As far as the E and I factors are concerned, they still maintain the same position of insignificance even with the 0.1 level of confidence (F = 3.05).

More explanation about retention could be pinpointed from Figure 4-5. Both sketches in (a) and (b) interpret the results of the ANOVA table regarding the lack of interaction effect due to lines parallelism.

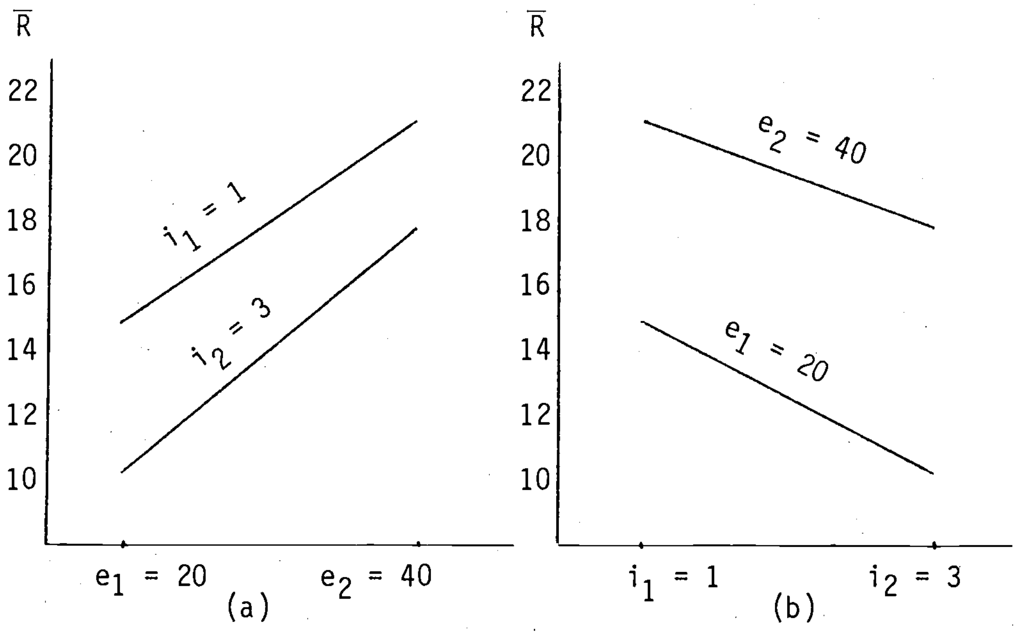

Figure 4-5. Illustration of mean retention ($\bar{R}$) vs.
(a) the amount of experience levels (e_1 and e_2)
(b) the length of interruption levels (i_1 and i_2)

On the contrary the analysis of the forgetting variable, the gap between the lines in (a) is smaller than that in (b). This finding is supported from the F (calculated) value of E which happens to be greater than the corresponding I value (1.88 > 0.55).

Line i_2 = 3 represents the mean retention for G2 (20,3) and G4 (40,3). Retention has risen from 10.10 to as high as 17.83, a change of 7.73 units. Line i_1 = 1 represents the mean retention for G1 (20,1) and G3 (40,1). Retention has risen from 14.62 to 20.85, a change of 6.23 units. Even though the factors roles were insignificant, it is suitable to mention a complementary statement to the intuitive remarks made in the analysis of forgetting which suggests that increasing the amount of prior experience would increase the amount of retention. This observation can be detected from Figure 4-5 (b) by having line e_2 = 40 above line e_1 = 20. The increase takes the values 7.73 and 6.23 for both lines, respectively. Line e_1 = 20 represents the mean retention for G1 (20,1) and G2 (20,3). Retention has dropped from 14.62 to 10.10, a change of 4.52 units. Line e_2 = 40 represents the mean retention for G3 (40,1) and G4 (40,3). Retention has dropped from 20.85 to 17.83, a change of 3.02 units.

The figures found in the former two lines are higher than those found in the latter two lines, a finding contending that the amount of prior experience is more influential in maintaining retention than the length of rest period. This finding differs from the one obtained from the forgetting analysis where the factors have switched positions. Again, the conjecture here says that lengthening the rest period would depress the amount of retention. This remark can be observed from Figure 4-5 (b) by having line $i_2 = 3$ below line $i_1 = 1$. The depression takes the values 4.52 and 3.02 for the later two cases, respectively.

Taking the marginal means into consideration, it is clear which factor is more efficient by observing the absolute difference due to the increase in the amount of experience (38.68 - 24.72 = 13.97) as opposed to the difference due to the duration of rest (35.47 - 27.93 = 7.54).

As explained previously, G3 (40,1) is expected to maintain the lowest forgetting and highest retention and it does with $\overline{R}$ = 20.85. Also, G2 (20,3) is expected to have the highest forgetting and lowest retention and it did with $\overline{R}$ = 10.10. For the remaining two groups, the one with higher experience (according to the feeling shown above) should occupy the second position in preserving retention, namely G4 (40,3), and it does with $\overline{R}$ = 17.83. The third position goes to G1 (20,1) with $\overline{R}$ = 14.62. In summary, the rank of groups in descending order is G3, G2, G4, and G1 concerning the amount of retention.

It is worthwhile at this point to mention that the groups who have been trained more (G3 and G4) are also the ones who lost more. By referring to the total amount of retention, let us divide all the groups into two parties based on the amount of experience given. The party with less experience (G1 and G2) have retained 123.60 units out of 200, i.e. 61.8%, while the party with more experience (G3 and G4) have retained 193.40 units out of 400, i.e. 48.35%. So, although the more trained groups have accumulated more experience after the interruption period, they also have lost more than the less trained groups.

As a comment on the current and previous analysis, it appears the forgetting is probably controlled by the duration of interruption more than the amount of experience, while the control is reversed for retention. Since, both forgetting and retention are very much related (one is the opposite of the other), then the obtained results, although insignificant, suggest that both factors E and I have an impact on forgetting or retention. Unfortunately, having insignificant results limits the ability to draw solid conclusions, but subjective observations may be constructive tools leading to extraction of facts with further experimentation.

Other questions to be examined in this analysis are, "Is learning rate influenced by interrupting a repetitive motor task?", and if so, how is it influenced by the amount of prior experience and the duration of interruption? In order to see how the learning rate behaves before and after an interruption, it is suitable to utilize the concept of transformation for the concerned variables into a different form. In the CRF-22 design here, the variables α (DAY1) and α (DAY2) will be transformed into the dependent variable $\Delta\alpha = \alpha(\text{DAY1}) - \alpha(\text{DAY2})$ whose points are listed in Table D-10 in Appendix D.

Results

The results obtained from the ANOVA table, shown in Table 4-6, suggest none of the factors were significant at a type one error of

Table 4-6

ANOVA Table for Learning Rate Difference
($\Delta\alpha = \alpha$ (DAY1) - α (DAY2)
(using the exponential function)

Source	df	SS	MF	F (Calculated)
TOTAL	20	1.43		
MEAN	1	0.24	0.25	4.17
TOT/ADJ	19	1.18		
E	1	0.003	0.003	.05
I	1	0.13	0.13	2.17
EI	1	0.090	0.090	1.50
ERROR	16	0.95	0.06	

.05 where F (table) = 4.49. However, with a type one error of 0.10, the dependent variable $\Delta\alpha$ (MEAN) becomes significant (4.27 > F (table) = 3.05) meaning there exists a significant different between α (DAY1) and α (DAY2) at the indicated level of confidence.

Discussion

One issue of great importance is whether the subjects acquired their skill faster, during prerest period of postrest period? The answer to the question is dependent on the learning rate of both periods. The overall average of all 20 subjects of α (DAY1) = 0.8066 is greater than the corresponding α (DAY2) = 0.6942. The meaning of this is that the learning process in DAY2 is faster than that in DAY1 since the right-hand term of the exponential formula $B_1 \alpha^X$ vanishes faster in DAY2. In mathematical terms, "faster" means leveling out sooner for the exponential curve. To clarify this point more, Table 4-7 is constructed where the mean values of variables (B_0, B_1, and α) for both days are used to calculate the mean assembly times (Y_E) for several units enabling this to establish the general shape of the curves shown in Figure 4-6. It is evident from Table 4-7 that the right-hand term of DAY2 function reaches a zero value at unit #25 while the corresponding term of DAY1 function still non-zero (0.45), this in turn explains the leveling out which occurred in DAY2 before DAY1, which leads to the conclusion that the learning process in DAY2 is faster than DAY1, according to this definition. The term "faster" could also describe the day at which a shorter time is consumed to produce a certain amount of units. By referring to Figure 4-6, DAY1 curve happens to be above DAY2 curve, which means more time is predicted to be spent in DAY1 than DAY2 to produce units. Therefore, the learning process in DAY2 is faster than DAY1, according to the second definition, too.

Unfortunately, the mean value of the dependent variable ($\Delta \alpha$'s) do not contribute much because, as shown in Figure 4-7, the lines in (a) and (b) do not follow an expected pattern in the sense that they converge in (a) and intersect each other in (b). This kind of behavior is difficult to understand or to extract conclusions, therefore, the problem should be approached from a different angle.

TABLE 4-7

Predicted Assembly Times (Y_E) Using Mean B_0, B_1, and α for DAY1 and DAY2 of the exponential function

UNIT # OR X	DAY1 $Y_E = 88.73 + 96.09\ (.8066)^X$	DAY2 $Y_E = 72.28 + 52.07\ (.6942)^X$
1	166.24 = 88.73 + 77.51	108.43 = 72.28 + 36.15
5	121.54 = 88.73 + 32.81	80.67 = 72.28 + 8.39
10	99.93 = 88.73 + 11.20	73.63 = 72.28 + 1.35
15	92.55 = 88.73 + 3.82	72.50 = 72.28 + 0.22
20	90.04 = 88.73 + 1.31	72.32 = 72.28 + 0.04
25	89.18 = 88.73 + 0.45	72.28 = 72.28 + 0.00

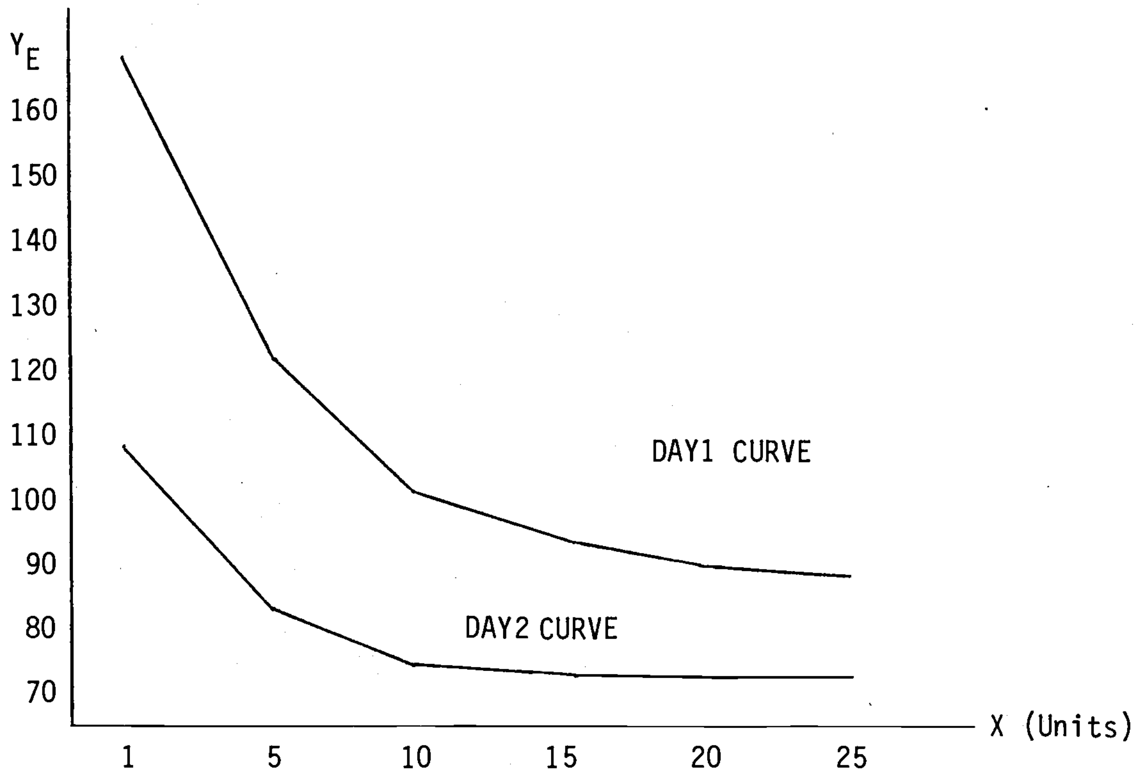

Figure 4-6. Learning curves for DAY1 and DAY2 using the exponential function plotted from Table 4-7.

A try to explain the behavior of the learning rate is done by establishing a correlation between the learning rate difference ($\Delta\alpha$) itself and the amount of forgetting (F) and also the amount of retention (R).

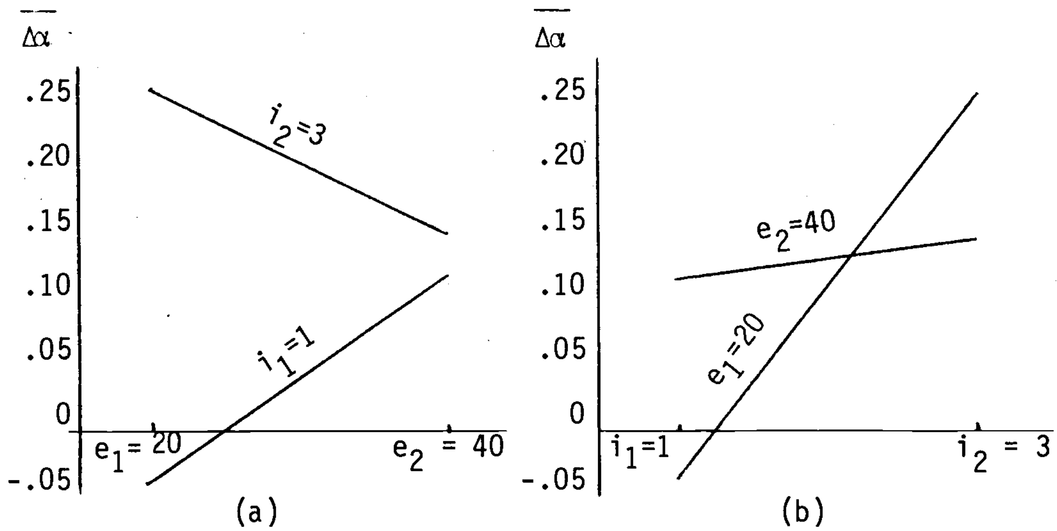

Figure 4-7. Illustration of mean $\Delta\alpha$ vs.
(a) the amount of experience levels
(b) the length of interruption levels
(using the exponential function)

The required data for the correlation process is contained in Tables D-8, D-9, and D-10 in Appendix D. The limits of the acceptance region are found by equating the t (table) value ($t_{.05,18} = 2.1$ for a two-sided test) with the expression $r_c\sqrt{n-2}/\sqrt{1-r_c^2}$ which come to be (-0.44, 0.44) or $r_c = \pm 0.44$. Running the same calculation for t (table) = $t_{.1,18} = 1.73$, the critical values of r become 0.37, i.e. $r_c = \pm 0.37$. Now is the time to calculate the correlation coefficient between F and $\Delta\alpha$. It is found to be r = 0.40, which is significant with 0.1 type one error; consequently the null hypothesis (assumes the population correlation coefficient equals to zero) is rejected. Putting it in other words, there is a direct correlation between F and $\Delta\alpha$ for 0.1 level of confidence. Therefore, the group which is expected to experience the most amount of forgetting, G2 (20,3), is also expected to have the highest $\Delta\alpha$ value and will be the fastest group to learn in DAY2. On the opposite side, G3 (40,1), is expected to lose the least amount of units and should be the slowest to learn in DAY2.

Going back to Table 4-6, it is noted that the length of interruption factor is more powerful than the amount of prior experience factor ($2.27 > 0.05$), a feature also occurring in the forgetting analysis ($3.80 > 0.34$). Putting things together, it is possible to say that the effect of extending the rest period forces $\Delta\alpha$ and F to rise, while decreasing the prior experience would cause $\Delta\alpha$ and F to fall.

A similar correlation test was performed between $\Delta\alpha$ and R values, but the r value came out -0.30, which is not significant even for the 0.1 level.

The final questions to be asked in this phase of the analysis investigates the influence of interrupting a repetitive motor task on the asymptotic cycle time (B_0) and how the prior experience and length of interruption factors take part in that influence?

The general feeling about the behavior of B_0 is that it tends to decrease as the amount of experience increases until its value reaches the population asymptotic cycle time. The same feeling indicates that if the learning process has been stopped before the population B_0 has been achieved then the B_0 value will tend to increase in a direct proportion with the length of interruption. To see whether these conjectures are correct or false, simple calculations were performed.

The effect of experience was tested by comparing the mean B_0 values for G1 (20,1) and G2 (20,3) against the more trained groups G3 (40,1) and G4 (40,3) in DAY1. The means were found to be 90.8 and 86.70, respectively; which advocate the first feeling. The effect of duration of rest is tested by comparing the mean B_0 values for G1 (20,1) and G3 (40,1) against the groups who interrupted the task longer G2 (20,3) and G4 (40,3) in DAY2. The means are found to be 70.7 and 89.9, respectively; which again advocates the second feeling. It should be pointed out that the agreement of the figures with the subjective feelings may be incidental and cannot be verified without statistical significance.

For more investigation, a CRF-22 design will be used with utilization of the transformation idea to obtain the values of the dependent variable, presented in Table D-12 in Appendix D, much in the same manner as before, that is $\Delta B_0 = B_0(DAY1) - B_0(DAY2)$.

Results

The results of the analysis of variance are listed in Table 4-8. The dependent variable (ΔB_0) is significant, hence reject the null hypothesis; while E, I, and EI are not, hence accept the null hypothesis. Since both E and I influences were insiginificant, it is appropriate

Table 4-8

ANOVA Table for the Differences in Asymptotic Cycle Times (ΔB_0) (using the exponential function)

Source	df	SS	MS	F (Calculated)
TOTAL	20	15,169.65		
MEAN	1	5,388.06	5,388.06	9.51
TOT/ADJ	19	9,781.59		
E	1	214.45	214.45	0.38
I	1	471.32	471.32	0.83
EI	1	27.50	27.50	0.05
ERROR	16	9,068.32	566.77	

to use other channels to know about the behavior of the asymptotic cycle time, e.g. the mean differences of B_0 ($\overline{\Delta B_0}$).

Discussion

The mean ΔB_0 values are plotted in Figure 4-8 to enhance the understanding of the variable in hand. It seems that the area confined between the lines in (a) is larger than that in (b) by a tiny amount, which points out the superiority of E to I in relative, but not significant terms. This observation is supported by the results of the ANOVA table ($0.83 > 0.38$).

The sketch in (a) shows how the length of interruption affects ΔB_0. As the length of interruptions increases, ΔB_0 decreases. This phenomenon leads the suggestion that if the period of interruption is long enough to cause total forgetting, then ΔB_0 would disappear and the prospective performance would likely follow the original learning.

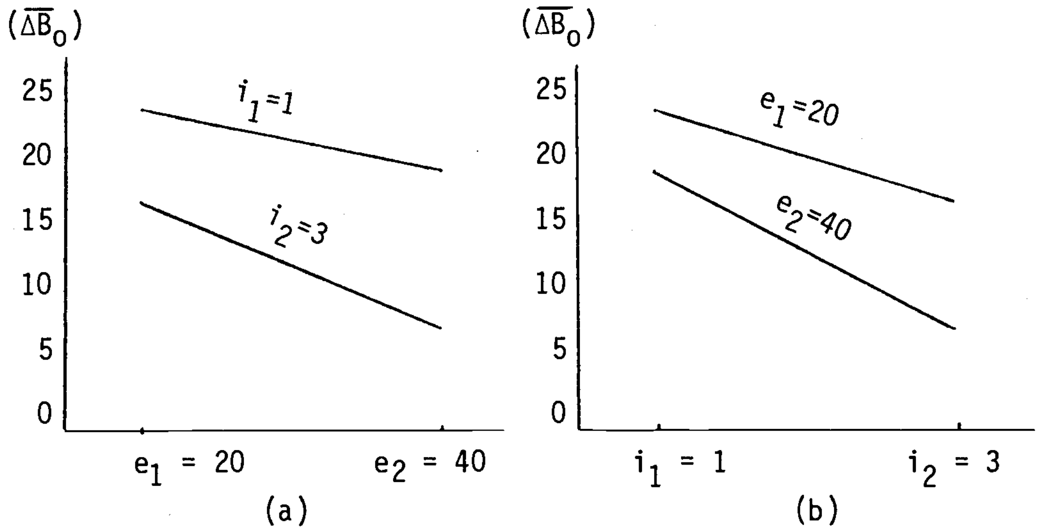

Figure 4-8. Illustration of mean change of B_0 vs.
(a) the amount of experience levels
(b) the length of interruption levels
(using the exponential function)

The diagram in (b) shows the effect of the amount of prior experience on ΔB_0. As the experience increases, ΔB_0 decreases. A long the same line of thinking, it would be easy to comprehend the behavior of the asymptotic cycle time by noting which line is above the other and what would happen by adding more levels to the E and I factors. For example, if the experiment had been designed to handle a third level of prior experience, say $e_3 = 60$, then $\Delta\overline{B}_0$ would be expected to fall even more.

By recalling the effect of prior experience and length of interruption period on forgetting and learning rate; then, although effects were insignificant, it is possible to present our personal feeling by saying that the effect of giving more practice is to decrease forgetting, the difference in learning rates and the difference in asymptotic cycle time between DAY1 and DAY2. The effect of lengthening the interruption period is the opposite except for ΔB_0.

Analysis for the Power Function

As in the previous analysis, this analysis will begin by comparing the subjects' initial performance on the first day. The purpose of this comparison is to establish the initial equivalence of groups.

A one-way analysis of variance will first be performed on B_0 (the estimate for first trial time on DAY1). The values are listed in Table C-3 in Appendix C. The ANOVA table is shown in Table 4-9. As expected, the E and I factors are not significant in affecting the B_0 values.

Table 4-9

ANOVA Table for B_0 (DAY1) Values
Using the Power Function

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN				
TOT/ADJ				
E	1	135.72	135.72	0.12
I	1	1,259.29	1259.29	1.13
EI	1	314.42	314.42	0.28
ERROR	16	17,846.31	1115.39	

A similar analysis was performed on B_1, the learning parameter for DAY1 whose values are listed in Table C-3 in Appendix C. The ANOVA table of the analysis is shown in Table 4-10. The results obtained also indicate the lack of significance produced by the E and I factors.

Table 4-10

ANOVA Table for B_1 (DAY1) Values
Using the Power Function

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN				
TOT/ADJ				
E	1	0.0004	0.0004	0.14
I	1	0.0000	0.0000	0.00
EI	1	0.001	0.001	0.36
ERROR	16	0.0448	0.0028	

The outcomes of the foregoing analysis suggest equal capabilities initially for all subjects ensuring us that they have been drawn from the same population.

Now it is possible to test some of the basic variables involved, such as forgetting, retention, and the parameters of the model, B_0 and B_1. The same questions raised earlier about forgetting will be answered by using the power function instead of the exponential.

The dependent variable is again the amount of forgetting, which is obtained in much the same manner as was done previously. The definition of the variables F, Y_2 and Y_F as shown in Figure 4-9 are as follows,

$F = Y_2 - Y_f$

$Y_2 = B_0$ (DAY2)

$Y_f = B_0 (21)^{B_1}$ DAY1 for lower experience groups

$B_0 (41)^{B_1}$ DAY1 for higher experience groups

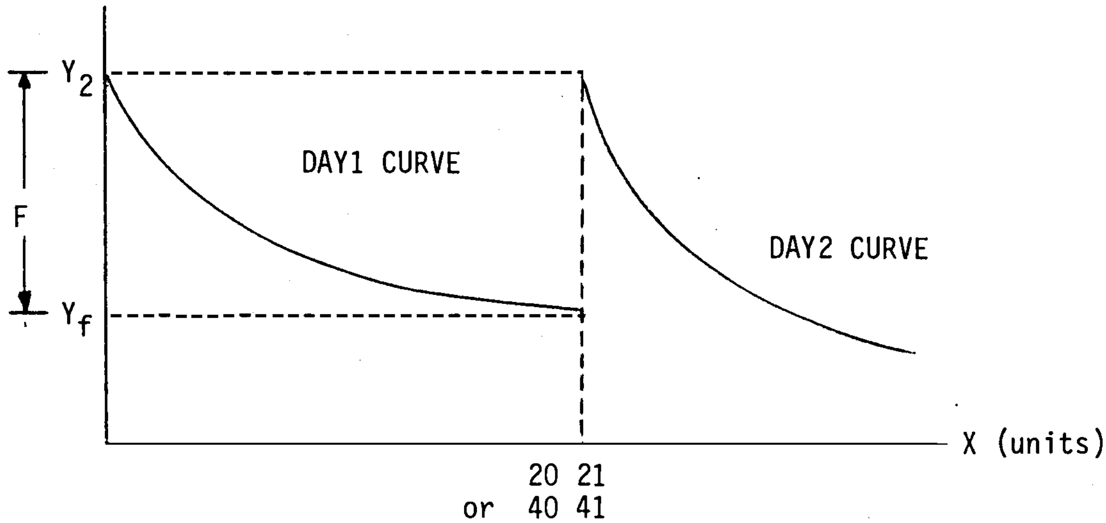

Figure 4-9. The amount of forgetting ($F = Y_2 - Y_f$) using the power function

The values for these variables for all subjects are listed in Table D-13 in Appendix D.

Results

The results of the analysis of variance are tabulated in Table 4-11, which shows a significant forgetting existed ($23.89 > 4.49$) for the 0.05 type one error. However, neither the E nor the I factors show significance.

Table 4-11

ANOVA Table for Forgetting Values
(Using the power function)

Source	df	SS	MS	F (Calculated)
TOTAL	20	5837.99		
MEAN	1	3387.28	3387.28	23.89
TOT/ADJ	19	2450.71		
E	1	178.21	178.21	1.26
I	1	0.22	0.22	.002
EI	1	3.49	3.49	.02
ERROR	16	2268.79	141.80	

Discussion

Although, both E and I factors have shown their weakness of influencing the significant amount of forgetting, it is appropriate to speculate regarding the reasons for such results. The reasoning for the E factor is still the same as before; i.e. the designed levels of experience (20 and 40 units in DAY1) have almost the same effect. As far as the I factor is concerned, it seems that the interruption periods selected (1 day and 3 days) are not quite enough to cause forgetting, and that whatever has been lost was due to one or several factors not included in the experiment.

The mean forgetting values ($\overline{F}$) are plotted in Figure 4-10. Unfortunately, Figure 4-10 does not offer fruitfull information in the

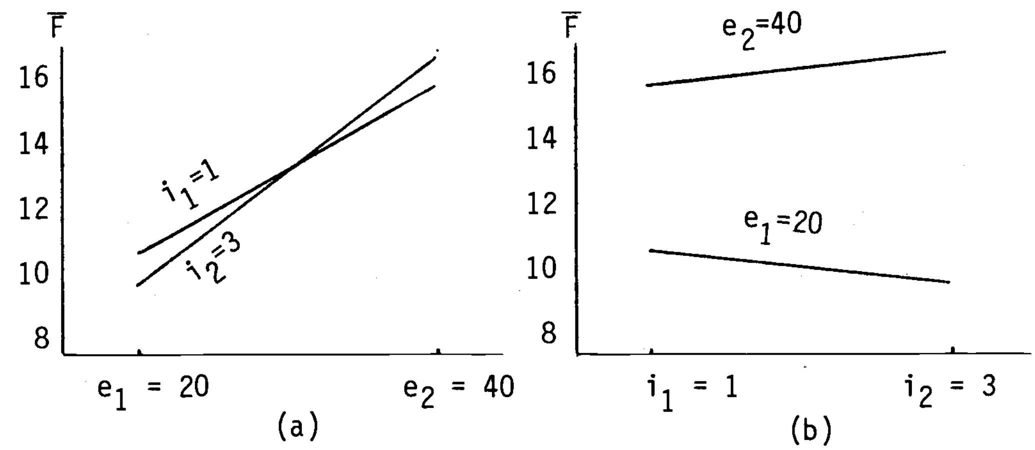

Figure 4-10. Illustration of mean forgetting values using the power function vs.
(a) The amount of prior experience levels
(b) The length of interruption levels

sense that the lines are intersected in (a) and diverged in (b). Therefore, it is unwise to speculate.

The questions concerning retention are repeated here. The idea of obtaining the retention values is exactly the same as explained in the exponential function case with the exception of replacing formulas. The situation is sketched in Figure 4-11, where

$Y_2 = B_0$ of DAY2

$Y_p = B_0 X^{B_1}$ for DAY1

Substituting Y_2 in place of Y_p gives the following equation, $Y_2 = B_0 X^{B_1}$. By taking logarithms of both sides and rearranging terms, the following expression is found, $\log X = \dfrac{\log B_0 - \log Y_2}{B_1}$.

Now, let $R = \min\{X,Z\}$ where Z = 20 for G1 and G2, and 40 for G3 and G4.

When the value of X exceeds the actual units produced, Z will be assigned to R and the subjects are described as experiencing

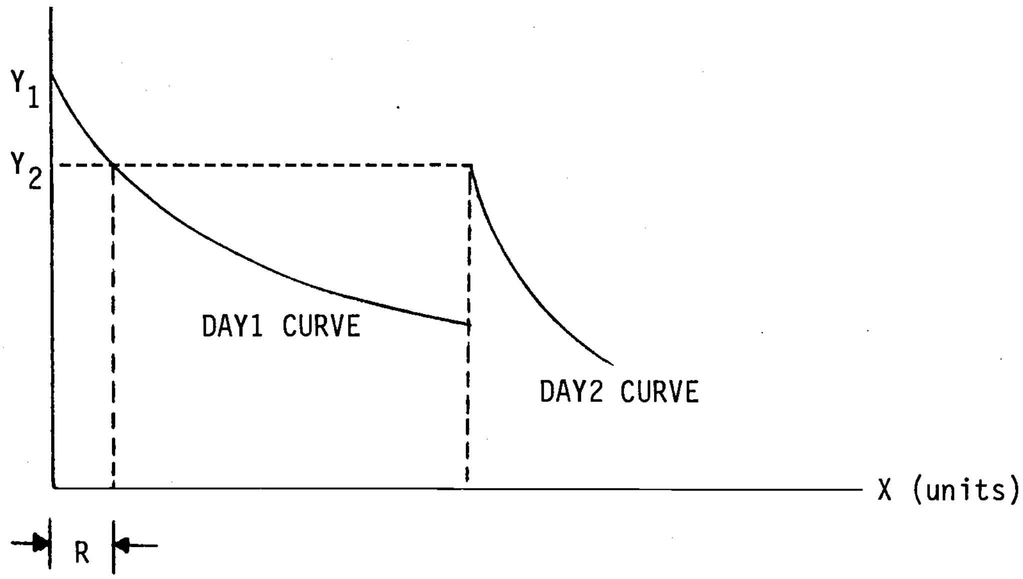

Figure 4-11. The amount retained (R) after interruption using the power function

reminiscence as happened for data of subjects #5, 7, and 11. The calculated R values are contained in Table D-14, in Appendix D.

Results

The results of the analysis of variance are summarized in Table 4-12. It seems that retention of subjects is highly significant (96.40 > 4.40). Similar to the retention results obtained by the exponential function; the E and I factors are both not significant.

Discussion

If the question of contradiction between forgetting and retention is raised again, i.e. how come both variables were significant? The answer would be the same as said before when this situation was encountered with the exponential function. The subjects as a whole have partially forgotten the learned experience, and at the

Table 4-12

ANOVA Table for Retention Values
Using the Power Function

Source	df	SS	MS	F (Calculated)
TOTAL	20	6427.48		
MEAN	1	5353.32	5353.32	96.40
TOT/ADJ	19	1074.16		
E	1	128.68	128.68	2.31
I	1	34.88	34.88	0.63
EI	1	22.23	22.23	0.40
ERROR	16	888.48	55.53	

same time have maintained some. Talking in numerical terms, the grand total of units retained is 65.44 out of 120 units practiced in DAY1, which is interpreted as 54.53% preserved, and 45.47% lost.

Further analysis shows that G1 (20,1) and G2 (20,3) have retained 27.65 units out of 40 units, i.e. 69.13% retention, while G3 (40,1) and G4 (40,3) have retained 37.79 out of 80 units, i.e. 47.24% retention. This means that the latter groups have contributed to the bulk forgetting more than the former groups. Even though G3 and G4 have done double the amount of units done by G1 and G2, it is obvious which party has suffered the most, on the contrary to our expectations.

The interaction effect (EI) obtained in the ANOVA table is not significant at all; however, both lines in each sketch of Figure 4-12 are more inclined than parallel. The area confined between the lines in (b) is greater than that in (a), indicating that factor E is more influential than I; the ANOVA table results back up this observation (2.31 > 0.63). Our conjecture that increasing I would decrease R, and increasing E would increase R is supported by having line $i_2 = 3$ below line $i_1 = 1$ and line $e_2 = 40$ above line $e_1 = 20$, respectively. This remark should not be confused with the finding found earlier which says the more experience gained the more the forgetting occurs in case of interruption. All the remark is saying here is that the amount retained by the lower experienced groups cannot be in any way more than the retention of the more experienced groups.

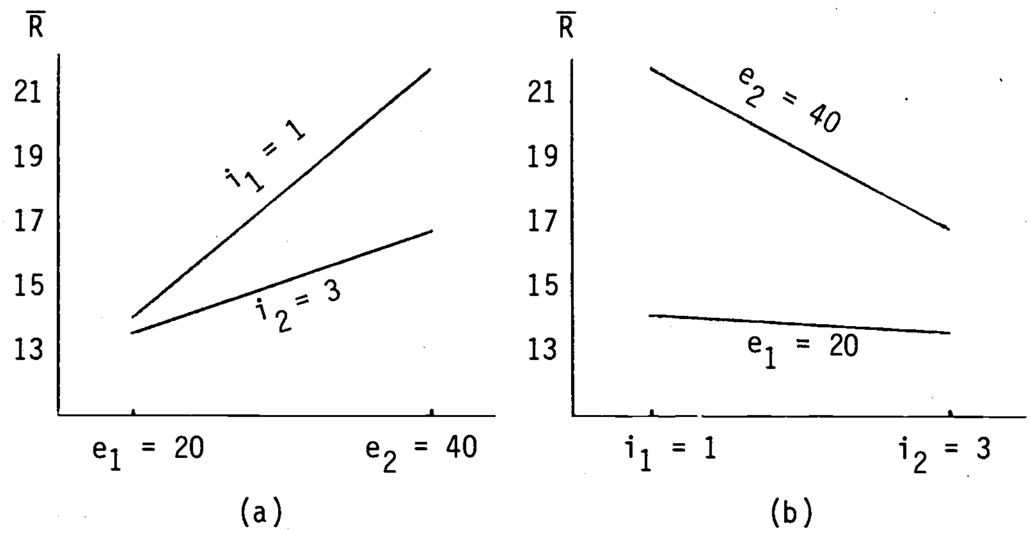

Figure 4-12. Illustration of mean retention using the power function vs.
(a) the amount of prior experience
(b) the length of retention

In addition to the forgetting and retention analysis, the learning rate will also have a turn. Converting the learning rate parameter

(B_1) into the percentage form is more common for better understanding. The percentage learning rate (%) is found from the formula, $\log \% = B_1 \log 2$. The dependent variable ($\Delta\%$) in this section will be also in a transformed form and represents the percentage learning rate difference between DAY1 and DAY2, i.e. $\Delta\% = \%\ (DAY2) - \%\ (DAY1)$ where its values are listed in Table D-15 in Appendix D.

Results

The results of the CRF-22 design for the learning rate difference are tabulated in Table 4-13. It shows a substantial significance for the change in learning rates between DAY1 and DAY2 ($70.68 > 4.49$). Unfortunately, the E or I factors are not significant in causing the immense change.

Table 4-13

ANOVA Table for the Change in Percentage Learning Rates Using the Power Function

Source	df	SS	MS	F (Calculated)
TOTAL				
MEAN	1	1076.78	1076.78	70.68
TOT/ADJ				
E	1	2.2	2.2	0.14
I	1	0.22	0.22	0.014
EI	1	8.83	8.83	0.58
ERROR	16	243.76	15.24	

Discussion

It is to be noted that all the dependent variable values are positive numbers, indicating the increase of the % (DAY2) over % (DAY1) values. This means the subjects learned more rapidly in DAY2 than in DAY1. In other words, most of the skill needed to learn the task have been acquired in DAY1 and subjects have picked up less in DAY2.

In order to know in which day the learning process was faster, simple calculations will be performed. The overall means for the B_0 parameter were 168.6 and 99.17; and the overall means for the B_1 parameter were -0.19731 and -0.08044 for DAY1 and DAY2, respectively.

Now let's establish a small table showing the predicted assembly times (Y_p) for several units using the mean values as shown in Table 4-14, which are plotted in Figure 4-13. If you consider the day at which the drop in assembly times are larger as a faster learning day, then it would be DAY1. However, if you consider the day at which the assembly times are less as a faster learning day, then it would be DAY2. So, it depends on the definition of the term "faster".

The mean change in percentage rates ($\overline{\Delta\%}$) are plotted in Figure 4-14. The sketch suggests a strong interaction between factors E and I. Let's analyze each line at a time. Line $i_1 = 1$ represents G1 (20,1) and G3 (40,1) data. While $\overline{\Delta\%}$ for G1 is small (6.24), it

Table 4-14

Predicted Assembly Times Using Mean B_0 and B_1 of the Power Function

Unit #	DAY1	DAY2
	$Y_p = 168.6\ X^{-0.1973}$	$Y_p = 99.17\ X^{-0.08044}$
1	168.6	99.17
5	122.7	87.1
10	107.0	82.4
15	98.9	79.8
20	93.4	77.9

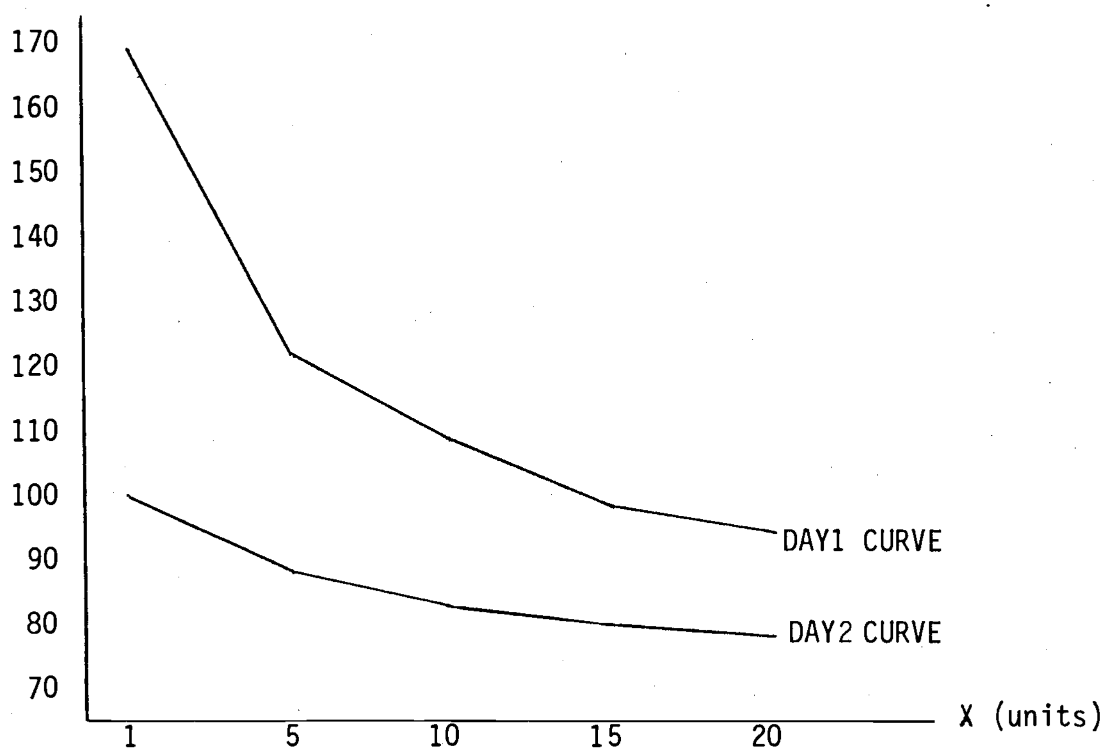

Figure 4-13. Learning curves for DAY1 and DAY2 using the power function plotted from Table 4-14

jumped to a relatively high value (8.23) when the amount of experience has increased to 40 units.

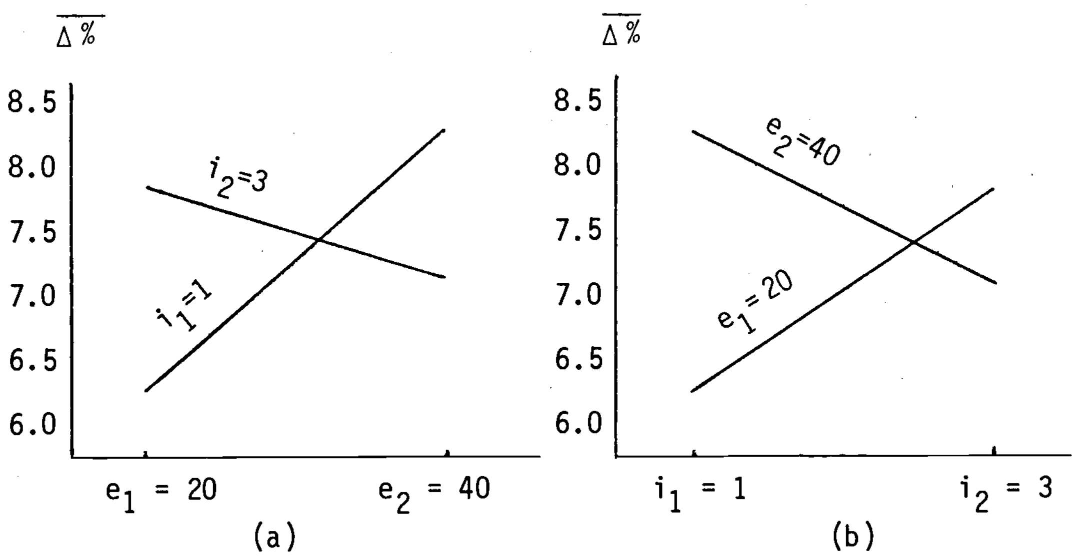

Figure 4-14. Illustration of mean learning rate difference $\overline{\Delta\%}$ using the power function vs.
(a) the amount of prior experience levels
(b) the length of interruption levels

The meaning of this increase is to say that more experience tends to increase the percentage learning rate. When the percentage value comes close to 100%, then little room for learning is left and the process of learning is described slow as far as the former definition is concerned. Line i_2 = 3 represents G2 (20,3) and G4 (40,3) data. This line behaves strangely because the point (e_1 = 20, i_2 = 3) should be below the point (e_1 = 20, i_1 = 1) in (a). The case should be so because G2 (20,3) is the group expected to have the greatest amount of forgetting, which leads Δ% to be the smallest. Line e_1 = 20 represents G1 (20,1) and G2 (20,3) data. Once the modification suggested above is implemented, then point

(e_1 = 20, i_2 = 3) would also be below the point (e_2 = 40, i_2 = 3) in (b). Having this visualization in mind, it is possible to say that:

a) Increasing the length of interruption period would tend to decrease Δ% as the amount of forgetting increased. This in turn suggests the disappearance of the difference between percentage learning rates, i.e. Δ% = 0, when experiencing a total forgetting.

b) Increasing the amount of experience tends to increase Δ%. Line e_2 = 40 represents G3 (40,1) and G4 (40,3) data. The Δ% for G3 (e_2 = 40, i_1 = 1) is greater than that for G4 (e_2 = 40, i_2 = 3) as the former group retained more units because of shorter rest period and therefore has a greater increase in percentage learning rate.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The objective of this research was to examine the effect of job interruption on motor task learning with special consideration to the influence of the degree of prior learning and the length of the interruption period on forgetting. An experiment was conducted to achieve this objective where its data was the source for statistical inferences.

Conclusions Related to Better Fit

Six different statistical tests were performed involving different data in order to determine which function, the exponential or the power, would fit the available data better. The number of occurrences in which the exponential function showed a significantly better fit was three, whereas the power function showed only one occurrence; the remaining two cases showed no significant difference between the two functions. According to this result, one would gather that the exponential function fit the data better.

Generally, the importance of learning curves is concentrated on the prediction of future performance. In contrast to the above finding, the power function predicted the future learning, based on experimental data, better than the exponential function in one of the foregoing mentioned tests. Despite the fact that no significant difference was found in this particular test, one would lean to consider the power function as a better prediction curve. On the other hand, the exponential function should be used to fit historical data because it showed a significantly better fit in three of the four cases. It should be emphasized at this point that these findings are restricted to the reported task or a very similar assembly task taking into account the conditions of the experiment. Any failure to control a certain source of variations may cause a dramatic change in results.

Conclusions Related to Forgetting

The measure of the amount of forgetting for each subject was the time difference between the first unit produced after the interruption period and a corresponding imaginary unit which could have been produced immediately after original learning as if no interruption had yet occurred. The forgetting effect was significant using both functions, power and exponential; however, neither the amount of original experience nor the duration of interruption period showed significance. It appears that the lower level of original learning (20 trials) is enough to learn the described task. Therefore, practicing more than that much (40 trials) would result in little gain. This may be the reason for having insignificant effects by the amount of original learning factor.

There is no doubt that forgetting would not exist if the job had not been interrupted, but how do we explain the current situation with significant amounts of forgetting resulting from interrupting the job wherein the duration of the interruption period is not significant? One explanation may be the levels of the rest interval (one and three days) were not long enough to cause the reported forgetting and there may be other factors, not included in the analysis, enhanced in losing experience. The other explanation, which sounds more logical, could be the indifferentiability between the selected levels of rest, therefore the effect of both levels in producing forgetting were possibly the same.

Conclusions Related to Retention

The amount of retention was measured by the number of units completed prior to the interruption period where the performance is equivalent to the initial performance after the interruption period. The amount of units retained by subjects was found significant using both the power and the exponential function; however, the amount of prior experience and duration of interruption factors were not significant. Almost 50 percent of learning skills had been retained using both functions. Therefore, on the basis of having 50 percent retention and 50 percent forgetting, it is logical to obtain significant results for both variables as had happened.

Based on the mean retention of groups; it was found that the larger the prior experience, the more loss of learning. But the amount of experience retained by the more experienced groups was consistently greater than that of the less experienced groups. Consistency also was found for a drop in retention when the duration of interruption period increases.

These findings are confirmed by the fact that the greatest retention belongs to the more experienced group with shorter rest periods. On the other hand, the less experienced and longer rest period group demonstrated the least retention.

Conclusions Related to the Learning Rate

The learning rate has not changed significantly from postrest to prerest periods when using the exponential function. A decrease in the overall average learning rate occurred after the interruption period; this means faster learning proceeded during resumption of learning. Relearning (the performance level achieved in the last trial before the interruption period) was generally fast. It can be shown from Figure 4-6 that relearning has been obtained by practicing only three trials.

A marginal significant increase in learning rate resulted from the interruption period when using the power function. In fact, this result supports our conjecture before performing the research which proves that interrupting the job must have an effect on the course of learning.

In support of the findings above, faster learning is accomplished after the no-practice period and relearning is possible by practicing three trials, from Figure 4-14.

Actually, it was intended, not only to prove a change in learning rate occurs due to a job interruption, but as well, study its behavior under the assumed influence of the degree of original learning and the length of the retention interval. The results obtained by using the power function suggest the change in learning rates due to job interruption period increases with increasing original learning at the shorter interruption period; whereas it decreases with increasing original learning at the longer interruption period. Putting it from the length of the interruption period perspective, it is possible to say that the change in learning rates due to job interruption increases with longer interruption period at lower original experience level, whereas it decreases with longer interruption period at the higher original experience level. It is important to mention that the interaction between the factors described above was not found significant but we felt reporting this observation may help in further analysis. The results obtained by using the exponential function almost support the previous findings.

Relationships with Previous Research

The amount of prior experience was found insignificant in causing forgetting or maintaining retention. Also found, the more experience gained prior to the interruption period the more the learning loss. This finding is in general agreement with the finding by Ammons, Farr, Bloch, Neumann, Dey, Marion, and Ammons (1958). This agreement implicitly contradicts the finding of Jahnke (1958) which states that the degree of prior learning is associated with increases in performance at postrest practice. High performance means fewer trials to relearn the job or, more precisely, less forgetting. Although the degree of original learning is described as the major influential factor on retention [Carison and Rowe (1976); Fleishman and Parker (1962); Naylor, Briggs, and Reed (1968); finally Schendel, Shields, and Katz (1978)], the results of this research does not consistently appear to support the previous description. In fact, Bell (1949) encountered the same insignificance of the level of prior experience but over one year of interruption period which, certainly, is much longer than the periods given to our subjects.

In a slightly different situation, Roehrig's (1964) study showed high retention irrespective of the number of trials before the break.

The length of the interruption period is also found to be insignificant, but consistency exists for drop in retention when the duration of interruption increases. This finding again was in consonance with the finding of Ammons, Farr, Bloch, Newmann, Dey, Marion, and Ammons (1958) regarding the consistency between retention (or forgetting) and the rest period. Newmann and Ammons'(1955) finding conveys essentially the same meaning when their subjects took longer to relearn the longer the retention interval. As far as consistency is concerned, Naylor, Briggs, and Reed's (1968) study resulted in finding the effect of retention intervals less consistent than the amount of prior practice. The length of the rest period factor was also found insignificant by Bell (1949) prior to the one year interruption. In support to the above discussion, Fleishman and Parker (1962) found variations in retention interval from 1 to 14 months were unrelated to retention performance. Meyer's experiment in 1967 (Marx, 1977) contends the minor role of the no-practice interval, too.

Like the above mentioned factors, the results concerning the amount of retention (or forgetting) vary from one study to another. The finding of this research shows about 50 percent of the original learning has been retained by subjects.

Carison and Rowe (1976) have suggested some forgetting is always to be expected, but total forgetting does not occur within short periods of interruption. Therefore, our finding may be considered to confirm their suggestion since the interruption periods involved were relatively short (one and three days). In relation to this discussion, the finding of Newmann and Ammons (1955) does not seem to completely confirm the above suggestion because forgetting was substantial after as little as two days, and after one year it was almost complete. On the contrary, high retention was found after 13 weeks of interruption (Meyer, 1967 in Marx, 1977), one year (Fleishman and Parker, 1962; and Roehrig, 1964), and even after two years of interruption (Smith, 1971). The general idea is the decrease in retention with time (Schendel, Shields, and Katz, 1978) depending on several variables including the amount of original training, the duration of the no-practice interval and the type of task involved. It is our belief that the nature of the job, continuous or discrete, and its complexity, difficult or simple, may be as important as the other two variables in determining the amount of retention.

With regard to the learning rate after cease of practice, it is found significantly different from the initial learning rate. The reason of such difference may depend on the experience retained by subjects at the moment of job resumption which definitely was absent at the moment prior to original learning. Actually, the learning rate formula developed by Hoffman (1968) adopts the concept that the learning rate is associated with prior experience. However, Carison and Rowe (1976) expected the performance rate would maintain the same level after the interruption period.

Finally, relearning the forgotten experience was fast nearly in three trials. The phenomena of rapid relearning (reaching the performance level at the last trial before the interruption) occurred also after eight trials in the Bell study (1949) and after the first few minutes of repractice in the Fleishman and Parker study (1962).

Recommended Future Research

The conduct of the examination of the amount of retention maintained at the end of a job interruption and the possibility that the learning rate initially differs from the relearning rate; associated with the influence of the amount of prior experience and the duration of interruption period imposed on retention and learning rates has opened the door for further investigations that could be the potential basis for a comprehensive model in this area of research. Specifically, the relearning rate should be worked upon to know more about the hidden characteristics. This could be accomplished by running an extensive experiment including several levels of original learning and multiple retention intervals.

The task should at least contain two different apparatus, one of continuous type and the other discrete. Probably no response is totally one or the other, but a continuous response can be defined as involving the repetition of a movement pattern that does not have a discernible beginning or end, such as tracking tasks. A response is discrete if it has a definite beginning and end and, typically, is quite brief in duration. Procedural tasks typically are composed of a series of discrete motor responses such as the assembly process task used in this research. The reason for adding the nature of response factor to the previous two rests on the factuality of industrial life which does not lend itself to one task. Further, procedural tasks are believed to be forgotten in days, weeks, or months, whereas continuous tasks are remembered for months, or years (Shendel, Shields, and Katz, 1978).

Of course, the forgetting curve can be constructed from the experimental data. The ordinate may serve as the time for the first trial after the retention interval and the abssica represents the retention interval itself. The shape of the curve is expected to be initially concave, then levels off at complete forgetting. One great benefit of the forgetting curve, once fitted to a mathematical function, is to be able to predict the time consumed in the first trial after a certain no-practice interval.

Once the major ingredients of the relearning function are known; namely the relearning rate and the first trial time in relearning, then prediction of relearning performance would be possible taking into consideration the amount of prior learning, the duration of interruption period and the type of task as possible influential factors on the relearning process.

At this stage, learning, forgetting, and relearning functions are obtainable, which consistutes the comprehensive model mentioned in the beginning of the section. Naturally, the proposed model would not be applicable to all situations, but it could be utilized in the context of the stated conditions.

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APPENDICES

APPENDIX A

Observed Assembly Times for G1 (20,1)

	DAY1					DAY2				
U/S	1	2	3	4	5	1	2	3	4	5
1	156	169	134	189	122	106	111	94	94	82
2	158	127	125	137	123	93	114	84	87	80
3	132	141	112	153	120	93	111	77	101	69
4	133	106	111	151	106	91	104	77	86	73
5	114	100	117	122	97	96	100	84	74	69
6	121	101	102	108	103	78	101	72	83	64
7	119	124	105	148	116	83	88	84	90	60
8	102	100	84	113	95	92	95	79	78	60
9	106	90	97	93	87	97	82	84	80	61
10	105	110	92	93	87	101	92	85	83	76
11	100	93	83	96	87	89	89	77	75	65
12	94	104	108	85	85	86	76	76	87	66
13	101	112	89	106	85	76	80	83	66	56
14	109	88	90	100	85	70	85	72	87	67
15	89	97	86	79	89	86	84	70	77	69
16	106	86	103	90	80	86	87	77	78	59
17	123	85	81	86	76	80	90	74	73	63
18	135	90	84	87	83	92	93	78	80	62
19	110	85	93	90	86	81	76	69	65	71
20	95	87	88	90	81	90	74	71	73	61

S = Subject no., U = Unit no.

Appendix A (Cont.)

Observed Assembly Times for G2 (20,3)

	DAY 1					DAY2				
U/S	6	7	8	9	10	6	7	8	9	10
1	226	145	126	148	215	144	114	78	98	129
2	147	148	131	124	325*	118	95	73	81	147
3	197	153	111	126	144	123	74	86	94	89
4	210	153	85	144	239*	118	83	86	67	99
5	157	147	78	118	162	115	91	85	81	86
6	186	126	104	97	114	111	103	75	68	99
7	148	106	99	105	168	120	89	86	86	84
8	178	96	90	99	136	117	99	80	67	103
9	169	118	101	90	149	115	92	77	72	86
10	136	103	81	101	101	100	76	71	72	107
11	146	113	73	99	170	118	100	81	77	118
12	113	150	93	77	129	95	80	88	66	92
13	97	109	82	77	127	116	100	65	82	111
14	148	118	70	86	125	112	85	69	72	81
15	104	95	72	87	150	96	83	71	75	75
16	129	101	72	84	135	91	88	68	116	112
17	116	92	90	74	118	108	86	68	67	96
18	120	103	79	81	112	108	108	73	70	86
19	146	101	74	72	110	96	79	77	76	76
20	120	94	70	87	102	96	76	75	74	86

*Points eliminated from analysis

Appendix A (Cont.)

Observed Assembly Times for G3 (40,1)

	DAY1					DAY2				
U/S	11	12	13	14	15	11	12	13	14	15
1	142	182	246	171	157	67	117	123	100	76
2	134	136	164	140	111	74	102	111	84	79
3	118	142	147	118	176	65	100	91	78	72
4	104	134	135	120	99	64	92	89	83	78
5	105	115	198	105	101	58	95	95	74	66
6	100	126	122	128	98	69	87	96	84	68
7	96	124	111	98	100	63	97	80	70	67
8	116	118	108	114	88	65	104	83	72	72
9	92	126	94	99	89	59	98	80	71	71
10	95	122	100	112	90	65	92	89	71	60
11	101	115	94	102	85	60	97	80	66	68
12	94	102	106	100	74	56	92	78	75	64
13	83	111	106	101	81	62	104	75	73	70
14	76	111	107	98	103	63	100	79	69	66
15	74	99	109	94	81	54	84	75	65	89
16	69	110	95	86	85	62	101	77	75	71
17	90	112	109	84	76	73	85	84	80	69
18	92	127	94	85	79	59	94	82	73	70
19	93	120	96	86	82	60	87	73	67	71
21	70	113	90	87	89					

Observed Assembly Times for G3 (40,1) (Cont.)

22	80	101	89	89	80
23	68	98	97	85	97
24	71	108	97	84	75
25	67	100	88	77	80
26	66	110	85	83	87
27	68	117	95	81	87
28	68	106	90	74	80
29	68	106	99	100	76
30	69	92	81	80	74
31	66	105	85	88	85
32	70	98	84	82	73
33	71	91	97	84	75
34	67	101	83	71	74
35	64	102	89	70	87
36	63	108	91	74	79
37	59	101	105	79	71
38	70	104	82	82	83
39	63	118	92	72	71
40	55	104	97	76	73

Appendix A (Cont.)

Observed Assembly Times for G4 (40,3)

	DAY1					DAY2				
U/S	16	17	18	19	20	16	17	18	19	20
1	160	257	181	135	149	107	104	103	85	109
2	122	193	151	116	125	103	95	92	107	90
3	243*	152	150	102	133	123	92	90	82	82
4	148	180	134	134	150	91	103	78	82	87
5	140	192	104	132	112	100	88	86	80	87
6	116	181	112	96	112	88	98	82	74	77
7	121	130	111	111	131	87	95	80	82	83
8	261*	115	110	148	99	85	92	75	74	77
9	113	118	105	102	113	90	90	88	71	82
10	119	133	106	104	104	90	103	90	62	82
11	101	106	97	109	101	76	86	77	69	71
12	115	101	123	96	84	88	83	71	71	80
13	125	105	128	112	96	109	90	102	72	74
14	101	87	101	94	93	105	100	87	71	82
15	123	100	100	95	85	81	111	73	70	75
16	107	108	88	90	95	85	92	78	72	75
17	103	108	89	98	90	85	79	82	64	76
18	118	104	84	97	95	86	92	77	72	83
19	97	139	99	85	77	74	82	98	77	82
20	102	127	99	91	82	83	89	79	65	68

Observed Assembly Times for G4 (40,3) (Cont.)

21	99	103	109	89	83
22	95	108	113	87	84
23	116	110	77	88	92
24	114	108	93	81	88
25	100	104	93	88	76
26	84	137	74	87	78
27	92	126	88	82	88
28	90	131	90	84	87
29	88	102	78	84	87
30	87	91	79	87	77
31	101	120	99	78	81
32	91	131	82	79	85
33	94	99	82	80	78
34	90	116	82	83	82
35	85	105	80	86	79
36	96	94	93	77	80
37	84	108	80	72	82
38	100	109	92	98	74
39	107	91	80	92	81
40	82	95	69	80	78

* Points eliminated from analysis

APPENDIX B

Program Listings to Fit the Data

A listing of a program* to optimize the learning rate parameter (α) of the exponential function by using Powel's Search as determined by minimizing the sum of squared errors (SSE) is as follows:

```
10 DIM Y(20)
20 N=20
30 FOR I=1 TO N
40 INPUT "Y",Y(I)
50 NEXT I
60 INPUT "TOLERANCE",D
70 X1=.6:X2=.7:X3=.8
80 K=0
90 A=X1
100 GOSUB 620
110 Y1=S6
120 A=X2
130 GOSUB 620
140 Y2=S6
150 A=X3
160 GOSUB 620
170 Y3=S6
```

```
180 K=K+1
190 X4=((X2↑2-X3↑2)*Y1+(X3↑2-X1↑2)*Y2+(X1↑2-X2↑2)*Y3)/(2*((X2-X3)
      *Y1+(X3-X1)*Y2+(X1-X2)*Y3))
200 IF X4>.999 THEN 230
210 IF X4<.001 THEN 250
220 GOTO 260
230 X4=.999
240 GOTO 260
250 X4=.001
260 A=X4
270 GOSUB 620
280 K=K+1
290 Y4=S6
300 IF Y3<Y2 THEN 360
310 IF Y2<Y1 THEN 330
320 GOTO 380
330 X1=X2
340 Y1=Y2
350 GOTO 380
360 X1=X3
370 Y1=Y3
280 X2=X4
390 Y2=Y4
400 IF ABS(X1-X2)<D THEN 540
410 IF K>10 THEN 540
```

```
420 IF Y2<Y1 THEN 460
430 X3=X1:Y3=Y1
440 X1=X2:Y1=Y2
450 X2=X3:Y2=Y3
460 X3=2*X2-X1
470 IF X3>.999 THEN 500
480 IF X3<.001 THEN 520
490 GOTO 530
500 X3=.999
510 GOTO 530
520 X3=.001
530 GOTO 150
540 A=X2
550 GOSUB 620
560 PRINT "A",A,"SSE",S6,"B0",B0,"B1",B1,"R2",R2,"K",K
570 SELECT PRINT 215
580 PRINT "A",A,"SSE",S6,"B0",B0,"B1",B1,"R2",R2,"K",K
590 SELECT PRINT 005
600 STOP
610 GOTO 20
620 REM SUBROUTINE SUM OF SQUARES
630 S1=9:S2=0:S3=0:S4=0:S5=0
640 FOR I=1 TO N
650 S1=S1+Y(I)
660 S2=S2+Y(I)↑2
```

```
670 S3=S3+A↑I
680 S4=S4+Y(I)*A↑I
690 S5=S5+A↑(2*I)
700 NEXT I
710 B1=(N*S4-S1*S3)/(N*S5-S3↑2)
720 B0 = (S1-B1*S3)/N
730 S6=S2-B0*S1-B1*S4
740 R1=S2-S1↑2/N
750 R2=(R1-S6)/R1
760 PRINT"A",A,"SSE",S6,"K",K
770 RETURN
780 END
```

A listing of a program* to find the parameters of the first form of the power function (A=0), B_0 and B_1, by using regression analysis. Then the parameters of the second form (A≠0) are found by using the Golden Section Method on A as determined by minimizing SSE.

```
10  DIM Y(20)
20  N=20
30  F=.618
40  FOR I=1 TO N
50  INPUT "Y",Y(I)
60  NEXT I
70  INPUT "TOLERANCE",D
80  X1=0:X4=40
90  K=0
```

```
100 GOSUB 580
120 PRINT"A",A,"SSE",S6,"BO",BO,"B1",B1,"R2",R2,"K",K
125 SELECT PRINT 215
130 PRINT "A",A,"SSE",S6,"BO",BO,"B1",B1",R2,"R2,"K",K
140 SELECT PRINT 005
150 Y1=S6
160 X3=X1+F*(X4-X1)
170 X2=X1+(X4-X3)
180 IF ABS(X4-X1)<D THEN 330
185 PRINT"(X4-X1)",X4-X1
190 IF K>10 THEN 330
200 A=X2
210 GOSUB 580
220 Y2=S6
230 A=X3
240 GOSUB 580
250 Y3=S6
260 K=K+1
270 IF Y2<Y3 THEN 310
280 X1=X2
300 GOTO 160
310 X4=X3
320 GOTO 160
```

```
330 A=X1
340 GOSUB 580
350 Y1=S6
360 A=X2
370 GOSUB 580
380 Y2=S6
390 A=X3
400 GOSUB 580
410 Y3=S6
420 A=X4
430 GOSUB 580
440 Y4=S6
450 IF Y1>Y2 THEN 480
460 A=X1
470 GOTO 529
480 IF Y2>Y3 THEN 505
490 A=X2
500 GOTO 529
505 IF Y3>Y4 THEN 520
510 A=X3
515 GOTO 529
520 A=X4
529 GOSUB 580
530 PRINT "A",A,"SSE",S6,"B0",B0,"B1",B1,"R2",R2,"K",K
535 SELECT PRINT 215
```

```
540 PRINT "A",A,"SSE",S6,"BO",BO,"B1",B1,"R2",R2,"K",K
550 SELECT PRINT 005
560 STOP
570 GOTO 20
580 REM SUBROUTINE SUM OF SQUARES
590 S1=0:S2=0:S3=0:S4=0:S5=0
600 FOR I=1 TO N
610 S1=S1+LOG(Y(I))
620 S2=S2+Y(I)↑2
630 S3=S3+LOG(I+A)
640 S4=S4+LOG(Y(I))*LOG(I+A)
650 S5=S5+(LOG(I+A))↑2
660 NEXT I
670 B1=(N*S4-S1*S3)/(N*S5-S3↑2)
680 BO=(S1-B1*S3)/N
690 BO=EXP(BO)
700 S6=0
710 FOR I=1 TO N
720 S6=S6+(Y(I)-BO*(I+A)↑B1)↑2
730 NEXT I
740 R1=S2-S1↑2/N
750 R2=(R1-S6)/R1
760 PRINT "A",A,"SSE",S6,"K",K
770 SELECT PRINT 005
```

```
780 RETURN

780 END
```

*BASIC language run in WANG 2200 microcomputer

APPENDIX C

Summary Output of the Fitting Programs

Summary output of the programs listed in Appendix B. The functions used are:

(1) Exponential, $Y_x = B_0 + B_1 \alpha^x$ where,

Y_x = Individual production time of the x-th unit.

B_0 = Asymptotic cycle time

B_1 = Coefficient of learning rate term (α^x).

α = Learning rate parameter.

x = Cumulative production of units.

(2) Power, $Y_x = B_0 (A + x)^{B_1}$ where,

Y_x = Cumulative average time to produce the x-th unit.

B_0 = Production time of the first unit.

B_1 = Learning rate parameter.

A = Amount of retention in units.

x = Cumulative production of units.

The power function is used in two versions, one with setting the A parameter to zero (A = 0) and the other does not require this assumption but depends on the program, in Appendix B, to determine the value of A.

Other variables calculated by the programs are,

SSE = Sum of squared errors

R^2 = Correlation coefficient

K = Number of iterations to reach solution.

The results for subjects number 10 and 16 are repeated twice in DAY1 of the tables in Appendix C. One result is based on all the first 20 units produced, which is the same thing done with the rest of the subjects. The other result is based on 18 units where 2 undesired data were eliminated from consideration.

Table C-1

Summary output of DAY1 using the exponential function

Group No.	Subject No.	α	B_o	B_1	SSE	R^2	K
G1	1	0.7156	105.2	81.03	2,269.73	0.6797	6
	2	0.7030	93.19	97.72	2,148.74	0.7561	4
	3	0.7977	88.02	57.32	1,019.17	0.7613	4
	4	0.7985	87.70	117.9	3,085.79	0.8171	4
	5	0.8724	76.41	57.06	622.42	0.8553	8
G2	6	0.9061	100.4	118.6	9,271.16	0.6138	8
	7	0.9118	85.60	75.72	3,710.52	0.6113	8
	8	0.8083	75.60	64.75	1,957.05	0.6861	6
	9	0.8715	71.82	84.96	1,437.37	0.8502	8
	10	0.7653	123.65	104.14	7,097.80	0.5001	6
	10*	0.8029	116.0	176.7	24,347.42	0.5630	4
G3	11	0.8043	83.23	71.84	1,404.73	0.7875	4
	12	0.6209	113.92	98.67	1,326.60	0.7836	6
	13	0.6954	101.0	185.6	6,438.92	0.7835	2
	14	0.7982	89.89	85.14	1,498.22	0.8273	2
	15	0.7704	81.14	96.25	4,311.48	0.6600	6
G4	16	0.8952	99.22	52.31	1,798.77	0.5960	
	16*	0.9704	3.06	173.76	27,334.73	0.2652	12
	17	0.7818	106.1	172.6	7,519.08	0.7882	6
	18	0.7231	99.20	110.5	2,179.18	0.8090	6
	19	0.9756	25.61	104.84	3,072.91	0.4671	8
	20	0.9171	67.66	84.89	1,722.62	0.8044	6
	TOTAL	16.1322	1774.56	1921.84	63,892.26	14.4376	
	MEAN	0.8066	88.73	96.09	3,194.61	0.7219	
	S.D.	0.0903	20.64	34.59	2,466.20	0.1144	
	VAR.	0.00815	425.89	1196.36	6082,139.1	0.01309	

TOTAL*	16.25	1670.75	2115.81	106,677.84	14.17
MEAN*	0.8123	83.54	105.8	5,333.89	0.7085
S.D.*	0.09499	27.44	40.65	7,387.88	0.1475
VAR.*	0.009025	752.99	1652.49	54,580,715.6	0.02178

*Results of all first 20 units completed in DAY1. Those results are not included in the analysis because the raw data contains an undesired points.

Table C-2

Summary output of DAY2 using the exponential function

Group No.	Subject No.	α	B_0	B_1	SSE	R^2	K
G1	1	0.7253	85.16	23.77	1,019.40	0.2971	6
	2	0.8579	79.06	43.55	614.17	0.7766	8
	3	0.9835	37.23	48.72	453.45	0.4053	12
	4	0.9200	68.34	26.81	829.30	0.4546	8
	5	0.6455	63.88	30.47	437.28	0.5380	4
G2	6	0.8853	96.56	40.59	1,185.57	0.6080	12
	7	0.1119	88.61	228.78	1,771.25	0.2598	10
	8	0.9891	22.28	60.82	697.67	0.2521	8
	9	0.4653	76.05	46.03	2,501.80	0.1680	6
	10	0.5637	92.94	79.89	3,990.06	0.3794	6
G3	11	0.8161	60.11	11.67	412.54	0.2561	6
	12	0.3247	94.41	70.40	625.03	0.4573	6
	13	0.7041	78.61	60.90	442.75	0.8544	2
	14	0.6786	70.37	39.09	497.01	0.6598	6
	15	0.6165	69.85	13.65	634.77	0.1244	4
G4	16	0.8224	84.55	31.98	1,776.11	0.3788	6
	17	0.9887	48.86	49.84	1,086.99	0.1340	12
	18	0.4389	82.55	47.35	1,166.52	0.2856	6
	19	0.8037	68.34	33.46	700.73	0.6166	
	20	0.5416	77.93	53.66	403.55	0.7113	8
	TOTAL	13.88	1445.69	1041.43	21,245.95	8.6172	
	MEAN	0.6942	72.28	52.07	1,062.30	0.4309	
	S.D.	0.2360	19.01	45.13	885.50	0.2172	
	VAR.	0.0557	361.22	2037.10	784,118.3	0.04718	

Table C-3

Summary output of DAY1 using the first form of the power function (A = 0)

Group No.	Subject No.	B_o	B_1	SSE	R^2	K
	1	154.9	-0.1449	2,878.00	0.5939	0
	2	156.1	-0.1967	1,981.97	0.7750	0
G1	3	135.1	-0.1059	1,068.79	0.7497	0
	4	190.6	-0.2706	3,106.40	0.8159	0
	5	133.9	-0.1690	825.51	0.8080	0
	6	228.8	-0.2130	10,333.83	0.5696	0
	7	167.5	-0.1711	4,363.83	0.5428	0
	8	131.1	-0.1913	1,918.07	0.6924	0
G2	9	160.0	-0.2383	1,882.28	0.8038	0
	10	202.2	-0.1825	6,447.0	0.5459	0
	10*	258.9	-0.2752	26,526.61	0.5239	0
	11	145.1	-0.1941	1,393.17	0.7893	0
	12	161.1	-0.1371	1,650.46	0.7308	0
	13	215.0	-0.2851	6,706.92	0.7745	0
G3	14	162.6	-0.2077	1,078.99	0.8757	0
	15	152.0	-0.2236	4,661.18	0.6324	0
	16	155.3	-0.1288	1,894.5	0.6137	0
	16*	185.0	-0.1790	30,137.62	0.1898	0
	17	245.5	-0.2956	7,899.15	0.7775	0
	18	174.7	-0.2126	2,186.04	0.8084	0
G4	19	138.0	-0.1242	3,523.02	0.3891	0
	20	162.5	-0.2091	2,357.72	0.7323	0
	TOTAL	3372.45	-3.9462	68,156.33	14.0207	
	MEAN	168.6	-0.1973	3,407.82	0.7010	
	S.D.	32.08	0.04929	2,588.52	0.1243	
	VAR.	1029.32	0.00243	6,700,435.80	0.01545	

TOTAL*	3458.9	-4.0891	116,479.06	13.5748
MEAN*	172.9	-0.2045	5,823.95	0.6787
S.D.*	37.20	0.04954	8,104.54	0.1693
VAR.*	1383.97	0.00245	65,683,592.0	0.02867

*Results of all 20 units completed in DAY1. Those results are not included in the analysis because the raw data contains undesired points.

Table C-4

Summary output of DAY2 using the first form of the power function (A = 0)

Group No.	Subject No.	B_1	B_1	SSE	R^2	K
	1	100.9	-0.06522	1,011.39	0.3026	0
	2	120.8	-0.1346	738.56	0.7313	0
G1	3	89.40	-0.06392	427.08	0.4399	0
	4	97.14	-0.08945	850.43	0.4403	0
	5	78.93	-0.08230	514.44	0.4565	0
	6	138.5	-0.1082	1,088.01	0.6402	0
	7	99.03	-0.04834	2,119.24	0.1144	0
G2	8	84.06	-0.04577	790.03	0.1531	0
	9	87.33	-0.05821	2,738.19	0.08938	0
	10	124.4	-0.1196	4,307.53	0.3301	0
	11	69.81	-0.05274	417.29	0.2475	0
	12	107.70	-0.05529	756.44	0.3433	0
G3	13	116.8	-0.1496	486.33	0.8401	0
	14	93.07	-0.1080	519.63	0.6443	0
	15	74.76	-0.02631	682.10	0.5911	0
	16	111.9	-0.09731	1,807.10	0.3680	0
	17	101.3	-0.04127	1,081.35	0.13850	0
G4	18	94.07	-0.05385	1,352.61	0.1716	0
	19	94.68	-0.1129	799.43	0.5626	0
	20	98.88	-0.09594	491.47	0.6484	0
	TOTAL	1983.46	-1.6088	22,978.65	7.7216	
	MEAN	99.17	-0.08044	1,148.93	0.3861	
	S.D.	17.20	0.03422	961.16	0.2327	
	VAR.	295.97	0.00117	92,381.4	0.05417	

Table C-5

Summary output of DAY1 using the second form of the power function (A ≠ 0)

Group No.	Subject No.	A	B_0	B_1	SSE	R^2	K
G1	1	0	154.9	-0.1449	2,878.01	0.5939	12
	2	0	156.1	-0.1967	1,981.97	0.7750	12
	3	0.08	136.2	-0.1537	1,068.43	0.7497	12
	4	0.80	220.0	-0.3193	3,024.63	0.8207	12
	5	3.28	188.2	-0.2776	655.17	0.8453	12
G2	6	8.79	699.9	-0.5389	9,458.48	0.6060	12
	7	9.16	432.1	-0.4467	3,733.91	0.6088	12
	8	0.33	136.8	-0.2060	1,909.56	0.6937	12
	9	3.88	280.8	-0.4152	1,513.78	0.8422	12
	10	0	202.2	-0.1825	6,447.0	0.5459	12
	10*	1.45	334.0	-0.3599	25,578.54	0.5409	12
G3	11	0.20	149.0	-0.2035	1,389.04	0.7899	12
	12	0	161.6	-0.1371	1,650.46	0.7308	12
	13	0	215.0	-0.2851	6,706.92	0.7745	12
	14	0	162.6	-0.2077	1,078.99	0.8757	12
	15	0	152.0	-0.2236	4,661.18	0.6324	12
G4	16	0.53	162.8	-0.1451	1,891.62	0.6143	12
	16*	40.0	23,798.6	-1.3373	27,771.41	0.2535	12
	17	0	245.5	-0.2960	7,899.15	0.7775	12
	18	0	174.7	-0.2126	2,186.04	0.8084	12
	19	40.0	3,909.0	-0.9211	3,106.77	0.4612	12
	20	12.0	737.7	-0.6353	1,739.89	0.8024	12
	TOTAL	79.05	8,677.1	-6.1486	64,981.0	14.3483	
	MEAN	3.95	433.86	-0.3074	3,249.05	0.7174	
	S.D.	9.23	836.25	0.1988	2,499.16	0.1153	
	VAR.	85.24	699,316.1	0.03951	6,245,807.0	0.0133	

TOTAL*	119.97	32,444.4	-7.5182	109,992.3	13.9825
MEAN*	6.00	1,622.22	-0.3759	5,499.62	0.6991
S.D.*	12.17	5,285.72	0.2972	7,627.00	0.1543
VAR.*	148.1	27,938.792.	0.08833	58,171,163.8	0.02381

*Results of all 20 units completed in DAY1. Those results are not included in the analysis because the raw data contains undesired points.

Table C-6

Summary output of DAY2 using the second form of the power function (A ≠ 0)

Group No.	Subject No.	A	B_0	B_1	SSE	R^2	K
	1	0	100.9	-0.06522	1,011.39	0.3026	12
	2	2.7	151.3	-0.2072	655.26	0.7616	12
G1	3	0	89.43	-0.06392	427.08	0.4399	12
	4	4.3	122.7	-0.1623	824.79	0.4576	12
	5	0	78.93	-0.08230	514.45	0.4564	12
	6	0	138.5	-0.1082	1,088.01	0.6403	12
	7	0	99.03	-0.04834	2,119.24	0.1144	12
G2	8	40.0	348.1	-0.3876	702.27	0.2471	12
	9	0	87.33	-0.05821	2,738.19	0.08937	12
	10	0	124.4	-0.1196	4,307.53	0.3301	12
	11	0.72	71.62	-0.06152	416.05	0.2497	12
	12	0	107.7	-0.05529	756.44	0.3433	12
G3	13	0	116.8	-0.1496	486.33	0.8401	12
	14	0	93.07	-0.1080	519.63	0.6443	12
	15	0	74.76	-0.02631	682.10	0.05911	12
	16	1.25	121.1	-0.1237	1,789.19	0.3742	12
	17	0	101.3	-0.04125	1,081.35	0.1385	12
G4	18	0	94.07	-0.05385	1,352.61	0.1716	12
	19	1.1	102.7	-0.1402	777.78	0.5745	12
	20	0	98.88	-0.09594	491.47	0.6484	12
	TOTAL	59.96	2322.62	-2.1586	22,341.16	7.88318	
	MEAN	3.00	116.13	-0.1079	1,117.06	0.3942	
	S.D.	9.09	58.32	0.08070	976.24	0.2318	
	VAR.	82.57	3400.77	0.00651	953,035.9	0.05371	

APPENDIX D

Data Tables for Statistical Tests

Reference to the following tables were made in Chapter IV.

Table D-1. The difference in SSE values between the power (A = 0) and the exponential functions for DAY1, i.e. $\Delta SSE = (SSE)_{Pow(A=0)} - (SSE)_{Exp}$ for DAY1.

$$SSE = \sum_{x=1}^{20} (Y_x - P_x)^2 \quad \text{where}$$

Y_x = observed time for unit x

P_x = predicted time for unit x

Group No.	Subject No.	ΔSSE
G1	1	608.27
	2	-166.77
	3	49.62
	4	20.61
	5	203.09
G2	6	1062.67
	7	653.31
	8	-38.98
	9	444.91
	10	-650.80
G3	11	-11.56
	12	323.86
	13	268.00
	14	-419.23
	15	349.70
G4	16	95.73
	17	380.07
	18	6.86
	19	450.11
	20	634.60

G1 = (20,1) G2 = (20,3)

G3 = (40,1) G4 = (40,3)

Table D-2

The difference in SSE values between the power (A = 0) and the exponential functions for DAY2, i.e. $\Delta SSE = (SSE)_{Pow(A=0)} - (SSE)_{Exp}$ for DAY2

Group No.	Subject No.	ΔSSE
G1	1	-8.01
	2	124.39
	3	-26.37
	4	21.13
	5	77.16
G2	6	-97.56
	7	347.99
	8	92.36
	9	236.39
	10	317.47
G3	11	4.75
	12	131.41
	13	43.58
	14	22.62
	15	47.33
G4	16	30.99
	17	-5.64
	18	186.09
	19	98.70
	20	87.92

Table D-3

The difference in SSE values between the power ($A \neq 0$) and the exponential functions for DAY1, i.e. $\Delta SSE = (SSE)_{Pow(A \neq 0)} - (SSE)_{Exp}$ for DAY1

Group No.	Subject No.	ΔSSE
G1	1	608.28
	2	-166.77
	3	49.26
	4	-61.16
	5	32.75
G2	6	187.32
	7	23.39
	8	-47.49
	9	76.41
	10	-650.80
G3	11	-15.69
	12	323.86
	13	268.00
	14	-419.23
	15	349.70
G4	16	92.85
	17	380.07
	18	6.86
	19	33.86
	20	17.27

Table D-4

The differene in SSE values between the poer ($A \neq 0$)
and the exponential functions for DAY2, i.e.
$\Delta SSE = (SSE)_{Pow(A \neq 0)} - (SSE)_{Exp}$ for DAY2

Group No.	Subject No.	ΔSSE
G1	1	-8.01
	2	41.09
	3	-26.37
	4	-4.51
	5	77.17
G2	6	-97.56
	7	347.99
	8	4.6
	9	236.39
	10	317.47
G3	11	3.51
	12	131.41
	13	43.58
	14	22.62
	15	47.33
G4	16	13.08
	17	-5.64
	18	186.09
	19	77.05
	20	87.92

Table D-5

The difference in SSE values between the power (A = 0) and the exponential functions for units X = 21 through 40 (output of the program in Appendix G), i.e.

$\Delta SSE = (SSE)_{Pow(A=0)} - (SSE)_{Exp}$ for X = 21 through 40

$$\text{and } SSE = \sum_{x=21}^{40} (Y_x - P_x)^2 \quad \text{where}$$

Y_x = observed times for units X = 21 through 40

P_x = predicted times for the same units

Group No.	Subject No.	ΔSSE
	11	-4218.81
	12	-1667.72
G3	13	-11.91
	14	-1898.08
	15	1203.24
	16	-337.93
	17	7125.83
G4	18	-3652.93
	19	-1375.45
	20	-1047.30

Table D-6

Average error ($\bar{e}$) for both the power (A=0) and the exponential functions

$$\bar{e} = \frac{\sum_{x=21}^{40} (Y_x - P_x)}{20}$$

Group No.	Subject No.	Exponential		Power (A=0)	
		$\bar{e}$	t(Cal.)	$\bar{e}$	t (Cal.)
	11	-16.27	-14.72	-7.91	-9.14
	12	-9.77	-6.16	2.71	1.63
G3	13	-10.22	-7.02	9.10	5.07
	14	-9.17	-5.74	0.58	0.41
	15	-1.43	-0.91	8.65	6.47
	16	-6.64	-3.26	-5.49	2.74
	17	3.08	1.01	19.37	6.56
G4	18	-12.57	-5.01	1.77	0.80
	19	8.63	4.58	-6.40	-4.91
	20	7.5	7.77	2.10	2.22

Table D-7

Production times of first unit (Y_1) for DAY1 using the exponential function

Group No.	Subject No.	Y_1
G1	1	163.2
	2	161.9
	3	133.7
	4	181.8
	5	126.2
G2	6	207.9
	7	154.6
	8	127.9
	9	145.9
	10	203.3
G3	11	141.0
	12	175.2
	13	230.1
	14	157.9
	15	155.3
G4	16	146.0
	17	241.0
	18	179.1
	19	127.9
	20	145.5

Table D-8

Amount of forgetting (F) measured in seconds using the exponential function, $F = Y_2 - Y_f$ where,
Y_2 = production time of first unit in DAY2
Y_f = production time of unit following DAY1 production i.e., Y_{21} or Y_{41}

Group No.	Subject No.	Y_2	Y_f	F
	1	102.4	105.3	-2.87
	2	116.4	93.20	23.20
G1	3	85.15	88.50	-3.35
	4	93.01	88.74	4.26
	5	83.55	79.66	3.89
	6	132.5	115.35	17.15
	7	114.2	96.49	17.71
G2	8	82.4	76.34	6.06
	9	97.47	76.55	20.92
	10	137.97	124.03	13.94
	11	69.63	83.24	-13.41
	12	117.27	113.92	3.35
G3	13	121.5	101.0	20.50
	14	96.90	89.90	7.00
	15	78.27	81.14	-2.87
	16	110.9	99.78	11.12
	17	98.14	106.1	-7.96
G4	18	103.3	99.20	4.10
	19	95.23	63.69	31.54
	20	106.99	70.10	36.89

Table D-9

The amount of retention (R) measured in units
using the exponential function

$$R = \log\left(\frac{Y_2 - B_o}{B_1}\right)/\log \alpha \text{ where}$$

Y_2 = production time of first unit for DAY2, and
the parameters B_o, B_1, and α belong to DAY1 performance

Group No.	Subject No.	R	Remarks
G1	1	20.00	$Y_2 < B_o$
	2	4.08	
	3	20.00	
	4	13.78	
	5	15.23	
G2	6	13.25	
	7	10.54	
	8	10.59	
	9	8.71	
	10	7.42	
G3	11	40.00	$Y_2 < B_o$
	12	7.10	
	13	6.06	
	14	11.08	
	15	40.00	$Y_2 < B_o$
G4	16	13.54	
	17	40.00	
	18	10.16	
	19	16.57	
	20	8.89	

Table D-10

The difference in learning rate parameters ($\Delta\alpha$) between DAY1 and DAY2, i.e.
$\Delta\alpha = \alpha(DAY1) - \alpha(DAY2)$

Group No.	Subject No.	$\Delta\alpha$
G1	1	-0.0097
	2	-0.1549
	3	-0.1858
	4	-0.1215
	5	0.2269
G2	6	0.0208
	7	0.7999
	8	-0.1808
	9	0.4062
	10	0.2016
G3	11	-0.0118
	12	0.2962
	13	-0.0087
	14	0.1196
	15	0.1539
G4	16	0.0728
	17	-0.2069
	18	0.2842
	19	0.1719
	20	0.3755

Table D-11

The difference in asymptotic cycle times (ΔB_o)
between DAY1 and DAY2, i.e.
$\Delta B_o = B_o(\text{DAY1}) - B_o(\text{DAY2})$

Group No.	Subject No.	ΔB_o
	1	20.04
	2	14.13
G1	3	50.79
	4	19.36
	5	12.53
	6	3.84
	7	-3.61
G2	8	53.32
	9	-4.23
	10	30.71
	11	23.12
	12	19.51
G3	13	22.39
	14	19.52
	15	11.29
	16	14.67
	17	57.24
G4	18	16.65
	19	-42.73
	20	-10.27

Table D-12

The amount of forgetting (F) measured in seconds using the power (A=0) function
$F = Y_2 - Y_f$ where Y_2 and Y_f are as defined in Table D-8

Group No.	Subject No.	Y_2	Y_f	F
G1	1	100.9	99.65	1.25
	2	120.8	85.77	35.03
	3	89.4	85.34	4.06
	4	97.14	83.62	13.52
	5	78.93	80.04	-1.11
G2	6	138.5	119.6	18.9
	7	99.03	99.5	-0.47
	8	84.06	73.23	10.83
	9	87.33	77.45	9.88
	10	124.2	116.0	8.40
G3	11	69.81	70.57	-0.76
	12	107.7	97.12	10.58
	13	116.8	74.58	42.22
	14	93.07	75.19	17.88
	15	74.76	66.26	8.50
G4	16	111.9	96.26	15.64
	17	101.3	81.91	19.39
	18	94.07	79.33	14.74
	19	94.68	87.01	7.67
	20	98.88	74.75	24.13

Table D-13

The amount of retention (R) measured in units using the power (A=0) function. The values of R are found from the formula $\log R = (\log B_0 - \log Y_2)/B_1$. The parameters B_0 and B_1 belong to DAY1 performance

Group No.	Subject No.	R	Remarks
G1	1	19.27	
	2	3.68	
	3	15.43	
	4	12.07	
	5	20.00	R comes out 22.81
G2	6	10.56	
	7	20.00	R comes out 21.58
	8	10.21	
	9	12.69	
	10	14.33	
G3	11	40.00	R comes out 43.36
	12	19.29	
	13	8.50	
	14	14.68	
	15	23.89	
G4	16	12.71	
	17	19.98	
	18	18.39	
	19	20.77	
	20	10.76	

Table D-14

The difference in learning percentage rates (Δ%) between DAY2 and DAY1, i.e.
Δ% = %(DAY2) - %(DAY1)

Group No.	Subject No.	Δ%
G1	1	5.14
	2	3.84
	3	5.60
	4	11.09
	5	5.51
G2	6	6.50
	7	7.88
	8	9.30
	9	11.28
	10	3.92
G3	11	9.00
	12	5.31
	13	8.08
	14	6.20
	15	12.55
G4	16	2.02
	17	15.71
	18	10.04
	19	0.72
	20	7.06

APPENDIX E

Instructions to Subjects and the Data Sheet

Instructions to Subjects

The experiment you are about to conduct is related to the Learning-Forgetting principle. Job learning occurs due to continuously practicing the assigned task. However, job forgetting will occur in case the job is interrupted for a certain period of time. Consequently, the learning after the interruption period is expected to be slightly different from that before the interruption period.

Your job constitutes assembling the toy shown in the Instructional Sheet in step no. 7. Try to assemble as many units as you can until you are asked to stop the process. The time consumed to assemble each unit will be recorded by an observer to the nearest second.

Now, read the following instructions carefully:

1. You will construct an untimed unit, with the help of the observer for practice and to give you the feeling of the job.
2. Give the observer the audible signal "NOW" when you intend to move your hands to start assembling the first timed unit. When a unit is completed, put it on the lid of the can to inform the observer of recording the time. Immediately, start to assemble the second unit, the third, ... etc. If you need a small break (e.g., few seconds), tell the observer after completing the unit in hand.
3. Press on the parts provided until they stick together to produce good quality. No need to apply unnecessary pressure. Do not use

your teeth or any other tool.

4. Do not busy yourself with anything (e.g., talking) other than your job. Leave the parts dropped on the floor, the observer will take care of them.

5. Use the Instructional Sheet to help you. It is not necessary to exactly follow the same steps. In fact, you are encouraged to develop your own procedure, which will come automatically in time. Please feel free to ask any questions.

The Data Sheet

SUBJECT#:

GROUP #:

DAY #:

DATE:

SLEEPINT HOURS:

HEAVY ACTIVITIES:

SEX:

SIMILAR EXPERIENCE:

UNIT #	STARTING TIME	FINISH TIME	ELAPSED TIME (Y_O) M:S.	ELAPSED TIME (Y_O) SEC.	MISSING PARTS
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

REMARKS:

APPENDIX F

Program to calculate the sum of squared errors for units 21 through 40

A listing of a computer program* written to calculate the sum of squared errors (SSE) using the formula, $SSE = \frac{\sum_{x=21}^{40} (Y_x - P_x)^2}{20}$ where

Y_x = Observed production time

P_x = Predicted production time

The value of the exponential function parameters (B_0, B_1, and A) and the power function parameters (A1 and A2) should be changed for each subject.

*BASIC language program run in WANG 2200 microcomputer

```
20 PRINT "INPUT B0,B1,A"
21 INPUT B0,B1,A
25 PRINT "INPUT A1,A2"
26 INPUT A1,A2
29 S1=0:S2=0:S3=0:S4=0
30 FOR I=21 TO 40
40 PRINT "Y(",I,")=?"
50 INPUT Y
60 F1 = B0+B1*A↑I
70 F2 = A1*(I)↑A2
80 S1=S1+Y-F1
90 S2=S2+(Y-F1)↑2
100 S3=S3+Y-F2
```

```
110 S4=S4+(Y-F2)↑2
120 NEXT I
130 PRINT"S1",S1/20,"S2",S2/20,"S3",S3/20,"S4",S4/20
140 GO TO 20
150 END
```