A study of unequal task difficulty and unequal angles for simultaneous hand motion an a horizontal plane [microform].

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LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS RÉCU
A STUDY OF UNEQUAL TASK DIFFICULTY AND UNEQUAL ANGLES
FOR
SIMULTANEOUS HAND MOTION ON A HORIZONTAL PLANE

by

KAZUO TSUCHIYA

A Thesis
Submitted to the Faculty of Graduate Studies
through the Department of Industrial Engineering
in Partial Fulfillment for the
Degree of Master of Applied Science
at the University of Windsor

Faculty of Graduate Studies
University of Windsor
August, 1982
I wish to dedicate this work
to my parents and sister.
ABSTRACT.

It has been recognized that the amount of work done by workers using two hands simultaneously is greater than that of workers using one hand alone. However, it has also been reported that when a task is simultaneously performed the cycle time of such a task is higher than when it is performed single-handedly. Many attempts have been made to set the standard time for such tasks, but these motions are still handled differently in all available predetermined Motion Time Systems.

Simultaneous hand motions have been generally defined as the motions begun and completed by two hands in the same period of time either in a symmetrical or an asymmetrical way. Symmetrical simultaneous hand motions are those motions with identical angles and equal degrees of task difficulty; others are asymmetrical simultaneous motions. The task difficulty of manual tasks where "move" and "position" are involved has often been defined by the following relationship, $TD = \log_2(2D/C)$ bits, where $D$ is the distance moved and $C$ is the target diameter. Therefore, it seems that the task difficulty of simultaneous hand motion may also be defined by the above-mentioned relationship for given angles of hand motions.

The heart rate of workers performing a task have sometimes been used as a physiological measure to predict work-load and to rate worker performance and has proven to be
highly correlated with the physical load of various tasks. On the other hand, it has been found that the mental load of tasks may be measured by the amount of the fluctuations of Heart rate (Heart Rate Variability or HRV).

The effects of the task difficulty and the angle of hand movements along with the physical and the mental loads on simultaneous motions do not seem to have been adequately investigated. In this study, the simultaneity of a task involving "move" and "position" was investigated under three conditions, 1) symmetrical angles and symmetrical task difficulties, 2) symmetrical angles and asymmetrical task difficulties and 3) asymmetrical angles and symmetrical task difficulties.

The results for the first condition (symmetrical angles and symmetrical task difficulty) show that the effects of task difficulty and angle of move were significant on the performance time. However, heart rate was not significantly affected by both the above factors. Statistical tests for the entire study used a significance level of $\alpha=0.05$. The results for the second condition (symmetrical angles and asymmetrical task difficulty) show that performance time once again was significantly affected by the task difficulty as well as the angle of move. However, neither of the above factors do not affect the heart rate significantly. The results for the third condition (asymmetrical angles and symmetrical task difficulty) show that the effects of task difficulty, the angle of move of
left hand (AL), the angle of move of right hand (RH), and the interaction between the angle of move of left and right hand (AL*AR) significantly affected the performance time. Further, task difficulty significantly affected the heart rate while angle of move of left hand and angle of move of right hand had no effect on it. Within task difficulty it was seen that only distance of move had a significant effect on the heart rate while the lateral clearance of fit had no effect. It was also seen that task difficulty, angle of move of left hand, and angle of move of right hand have significant effects on the Heart Rate Variability Index. From these results it was concluded that as angle was seen to be a significant factor, PMTS's that do not incorporate angle effects (most of the available PMTS's do not) do not aid the design of such tasks in choosing the optimal direction of moves of simultaneous motion. Further, task difficulty was not found to be a preferable measure of physical load. Distance of move was found to be the better measure.
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CHAPTER 1

GENERAL INTRODUCTION

In industry it has been recognized that there are some situations where tasks are performed simultaneously by a worker using two hands (Raphael et al., 1952). For such tasks the amount of work done by the worker using two hands is greater than that of the worker using one hand alone (Barnes and Mackenzie, 1940). The idea of using two hands simultaneously to increase the productivity of such tasks was first documented in the 'Fundamental of Laws of Motion Economy' by Gilbreth (1923).

Simultaneous hand motions have been generally defined as the motions begun and completed by two hands in the same period of time either in a symmetrical or an asymmetrical way. Symmetrical simultaneous hand motions are those motions with identical angles and equal degrees of task difficulty; others are asymmetrical simultaneous motions. Although simultaneous motions have been studied by many researchers, these motions are still handled differently in all available Predetermined Motion Time Systems (PMTS's). In Method Time Measurement (MTM), for instance, there is no allowance in performance time for simultaneous motions unless the two motions are considered to be difficult to perform simultaneously. The time values for both motions are assigned to complete the simultaneous motions (i.e., twice the time value for an equivalent single handed
motion in the symmetrical case.

Simultaneous symmetrical and asymmetrical "reach" motion experiments were conducted recently (Racuf et al., 1978, Ito, 1979, Mak, 1978). Findings in these experiments confirmed that simultaneous motions require more time than single-handed motions for element reach. Although the mean performance times for single-handed motions generally agree with the values assigned by PMTS's, in the same-experimental conditions, it was found that the time values for simultaneous two-handed reach motions are always higher than those of PMTS's. For the motion employed in the previously cited experiments, PMTS's do not allow any extra time for simultaneously performed tasks. However, none of the motions required twice the time values which one PMTS assigns in some other cases. The largest percentage increase in performance time for symmetrical simultaneous motions over single-handed motions, in the same experimental conditions, was calculated to be 66.0%.

Another important result in these experiments is that the angle of the moves was found to be a significant factor (Racuf et al., 1978, Ito, 1979). In industry not only "reach" but also motion "move" and "position" are often performed simultaneously (Raphael et al., 1952). The time necessary to complete a task depends on its difficulty. This difficulty normally consists of more than one factor. Fitts (1954, 1964) introduced information theory, index of difficulty (task difficulty), in prediction of work performance of certain types of task, and found that performance time was well predicted by the following relationship.
Task difficulty (TD) = \log_2 (2D/C) \text{ bits},

where \( D \) is the distance of the hand movements and \( C \) is the tolerance range. Raouf et al., (1977) reported that many researchers have obtained high correlations between TD and the performance time of manual tasks.

It has been reported that when a task is performed simultaneously it requires somewhat more attention than when it is performed single-handedly. The results of symmetrical simultaneous reach experiments (Ito, 1979) show that the mean heart rate differences of subjects performing two-handed simultaneous tasks were higher than those performing single-handed tasks. It was also shown as the angle of hand motion from a central reference plane (12 o'clock) increased, performance time also increased and subject heart rate difference decreased. Since it is obvious that as the angle increases visual requirement to complete the task is increased, it may be said that the degree of difficulty of the task at a larger angle was somewhat greater than that at zero degrees (12 o'clock). Although the subjects were asked to perform the tasks as quickly as they could, it was not possible to perform the tasks at the larger angle as quickly as at zero degrees. Furthermore, the physical load of the task per hour was reduced because of lower performance; consequently heart rate differences were observed to be lower at larger angles than at zero degrees. From the above discussion one may feel that it is necessary to investigate this nonphysical load of the task, which can not be measured by Heart Rate (HR) alone and which may have an
important influence on simultaneous hand motion. As Macormick (1976) described, every kind of human activity is considered to involve physical acts and mental work.

The relationship between Heart Rate Variability (HRV) and Mental Load has been studied by many and proved to be highly correlated in some cases (Kalsbeek, 1973; Rohmert et al., 1973; Zwage, 1973). In the area of mental load study, bits of information have been used as a unit to express mental load or the rate of information processing. The difficulty of manual tasks such as "move" task and "position" task can also be expressed by the use of bits of information as discussed earlier. However, the relationship between such task difficulty of simultaneous motions (expressed in bits) and HRV does not seem to have been investigated in the past. In this study a task consisting of motions "move" and "position" is used to investigate the simultaneity under laboratory conditions. Independent variables to be included in the experiment are angle and task difficulty.
CHAPTER II

LITERATURE SURVEY

2.1 INTRODUCTION

The related literature on simultaneous hand motions and physiological measures is documented in this Chapter.

2.2 CHARACTERISTICS OF SIMULTANEOUS MOTIONS

Simultaneous motions are generally defined as motions begun and completed at the same time, in either a symmetrical or an asymmetrical way.

It was observed through a film analysis that when tasks are performed simultaneously, there is a tendency for one of the hands to limit the other. When two hands travel different distances, the hand which travels the shorter distance slows down and the other hand which travels the longer distance speeds up such that their time of travel is almost equivalent. Raphael et al., (1952) concluded that, in general, motions requiring more control will limit motions which need the same or a lesser amount of control. Later, Barnes (1968) found that symmetrical movement of arms tends to balance both arms, reducing the shock and jar on the body, thus allowing the worker to be able to perform the tasks with less mental and physical effort.

It has also been recognized that as the amount of control of one hand increases, the performance time of the other hand also increases. The amount of control required to perform such simultaneous motions
is considered to depend upon a worker’s biomechanical and visual controls. Furthermore, each type of control depends upon the type and degree of the difficulty of the task. The factors considered to be influencing the difficulty of the tasks involving simultaneous motions are the angle of movements, the separation distance of the two hands at starting points and the distance moved, and if a "position" task is to be executed with width of the target or clearance of fit.

The effects of angle on symmetrical simultaneous (SYMT SIMO) motions were investigated by Barnes and Mundel (1953). The results of a series of experiments indicate that although minimum performance time occurred at 30 degrees from the central reference plane the least number of mistakes was recorded at zero degrees. They also indicate that as the angle of the motions decreased, the number of errors decreased. Hassan and Block (1967) investigated the effects of separation distance and class of fit in positioning tasks. The results show that there is a linear relationship between performance time and separation distance in each class of fit. The results also indicate that the performance times for simultaneous positioning are greater than that for one-hand positioning. However, the results of simultaneous symmetrical positioning experiments using pegs and pegboards by Niel, Kassab and Noll (1972) show the existence of an exponential relationship between performance time and separation distance.

Ito (1979) compared the performance times of SYMT SIMO’s with
single handed motions under various conditions. His results show that minimum performance times for single handed motions occur between 30 degrees and 60 degrees from the central reference plane in most cases. However, minimum performance times for SYMT SIMO's occur at 0 degrees in most cases. Single hand motions require less visual control than SYMT SIMO's. These results indicate that when the visual requirements of a task are minimal, the most efficient direction of arm movements is determined by biomechanical factors, but when SYMT SIMO's are performed visual requirements are the predominant factors determining optimum conditions. Therefore it can be said that in this latter case there is a trade-off between the speed of moves and the accuracy of the moves.

2.3 HEART RATE AND HEART RATE VARIABILITY

Heart Rate (HR) and Heart Rate Variability (HRV) are often used to measure the workload of a task. MacCormick (1976) proposed that every kind of human activity involves some combination of physiological processes involving not only with physical acts but also with mental work and nonphysical acts.

The Heart Rate differences of a worker at rest and at work, or when he performs different types of work, have been used to measure physical workload (Brouha, 1954). Since high correlations have been obtained between the intensity of paced physical work and Heart Rate, it was suggested that Heart Rate may be used to rate operator performance (Young, 1956).

Kalsbeek, et al., (1964) reported that when the Heart Rate of
a man sitting at rest was measured continuously, it was observed that Heart Rate was irregular (sinus arrhythmia) and the fluctuations could be up to 20 beats per minute. On the other hand when the subjects were performing a binary choice-reaction task, Heart Rate rose to a certain level and the irregularity diminished. They also found that when subjects were performing this type of task, sinus arrhythmia was gradually suppressed as the rate of information processing was increased.

Many workers looked at the relationship between mental load and sinus arrhythmia under various conditions (Sayers, 1973; Rohmert et al., 1973; Zwaag, 1973; Mulder et al., 1973; Luczak et al., 1973; Kalsbeek, 1973; Ogmen, 1973). However, there is more than one method of expressing sinus arrhythmia in the literature. Kalsbeek (1973) mentioned that there are at least 30 different methods of scoring sinus arrhythmia and obtaining so-called Heart Rate Variability in the literature. As a result of the diversity of approaches, he was able to discern that "different scoring methods lead to different values calculated from the same heart rate data".

Luczak (1973) compared 8 different formulae of scoring HRV from the same HR of 12 subjects performing binary choice tasks. Some of the commonly used HRV scoring methods did not show consistent changes in the scored values with the changes in the difficulty of the task. One computational method of HRV which is the combination of 2 measures (those being the amplitude information of HR in the numerator and the frequency information of HR in the denominator) was proposed earlier.
By Laurig in 1971. In Luczak's study both terms, numerator and denominator, were found to be significant at \( \alpha = .05 \) on "mental load" and HRV score itself was significant at \( \alpha = .05 \). The formula to obtain HRV is given below.

\[
HRV = \frac{\sum (HR_i - HR_{i+1}) \text{ for } (HR_i - HR_{i+1}) > 0}{\text{Freq.}((HR_i > HR_{i-1})A(HR_i < HR_{i+1}))V((HR_i > HR_{i-1})A(HR_i > HR_{i+1})))}
\]

The numerator is the sum of difference of two successive beats when HR is decreasing. The denominator is the frequency of relative maxima and minima.

The effects of "mental load" under different physical load were studied by Boyce (1974). Ten subjects were used in mental arithmetic experiments and their HR's and standard deviations of HR's to score HRV were measured. It was reported that HR increased when both physical and mental load were increased. HRV was determined by using standard deviation and found to decrease when "mental load" increased; however, an increase in HRV (which does not agree with the results from others' studies) was observed when physical load increased. Because the standard deviation was used to score HRV, together with the fact that a steady increase in HR during the experiment due to the nature of the task was expected, seem to explain the above mentioned disagreement.

In 1979, Luczak carried out a series of 2 experiments using the previously mentioned HRV scoring method. In the first experiment 48 male subjects worked on a binary choice task. The results show that
the correlations between HR and HRV, physical stress and HR, and mental stress on HRV are significant. In the second experiment, 20 female subjects performed a multiple choice-reaction task with 5 levels of task difficulty. The task difficulty levels were defined by the number of alternatives to the subjects, i.e., 2, 4, 6, 8, 10. Subjects were asked to perform the task in a 5-minute rest-work-schedule. The levels of the task difficulty were intentionally not randomized, but were increased gradually from session to session.

It was observed that HR decreased significantly in dependence on the duration of the experiment and is independent of task difficulty. In other words, it was found that HR decreased as the experiment progressed, although task difficulty was increased from session to session as planned. HRV decreased when task difficulty was increased. It was also found that HRV in the rest periods increased with the duration of the experiment.

Wierwille (1979) carried out an extensive research on "Physiological Measures of Aircrew Mental Workload" and found out that some researchers have found "no systematic relationship between heart rate and task difficulty. ... no relationship between heart rate variability and task difficulty". Mulder (1973) and Sayers (1973) used the variance of inter-beat-interval and HR, respectively, to score HRV in their research and found out that HRV is not significant on "mental load". However, through a different approach than that used by previous studies, they found by the use of spectrum analysis that respiration affected
HR and suggested the use of respiration as a measure of "mental load". Other researchers also found that HRV is affected by changes in respiration rate (Hichen et al., 1980; Hyndman et al., 1974). It seems that there is evidence that HRV is affected by changes in respiration rate caused by "mental load". However, Kalsbeek (1973) has already reported "sinus arrhythmia occurs during rest, whereas recorded breathing pattern does not show marked abnormality".

The definition of "mental load" or the effect being measured by HR and HRV is somewhat different among researchers. Zwaga (1973) found a decrease in HR during mental arithmetic tasks over time. He concluded that this is because of a decrease in "mental effort" over time. Hyndman (1974) agreed with the suggestion made by Kalsbeek (1964) that sinus arrhythmia is a measure of "total mental load" rather than just the load resulting from the task. Later Kalsbeek (1973) defined sinus arrhythmia as "an indicator of the proportional occupation of an individual's single channel capacity during rest and work".

As one can see there are several interpretations on sinus arrhythmia or HRV. However, one may conclude that sinus arrhythmia does decrease when the mental load which may be demanded by the task an individual is performing increase. External stimuli and other factors in the environment may cause an increase in mental load during performance of the task. Therefore, it seems important to analyze the task and isolate undesired influences from other sources than the task (Kalsbeek, 1973). In this sense the use of HRV as a
measure of mental load on a task under laboratory conditions may be validated.

As a final note it is important to stress that the task in which the effects of mental load are to be measured should not involve heavy physical load. Excessive physical load would provoke unwanted increase in HR during the experiment and would invalidate the meaning of the data (Luczak, 1979).
CHAPTER III

EXPERIMENTAL SET UP

3.1 INTRODUCTION

Special simultaneous two-handed motion experimental equipment and performance-time recording equipment, as well as physiological study equipment are used in the study. In this Chapter these experimental apparatus are described and corresponding procedures for processing performance time and physiological measures are explained.

3.2 SIMULTANEOUS TWO-HANDED MOTION EXPERIMENTAL EQUIPMENT

The simultaneous two-handed motion experimental apparatus was designed and built for this study. The equipment consisted of three units: (1) a SIMO-PIN unit; (2) a time-measuring unit and (3) a recording unit (paper tape punch). A layout of the SIMO-PIN unit is shown in Figure 3.1.

The SIMO-PIN unit consists of a wooden box 1580 mm long, 760 mm wide, 180 mm high, and the top of the box being 720 mm from the floor. Two 550 mm long x 45 mm wide mechanical units are located in the box. These mechanical units have two pin sockets each 7 mm in diameter. These sockets on the near side of the mechanical unit are fixed and the other two can be moved at any desired distance from the fixed pin sockets in the range of 50 mm to 450 mm. The distances between the
Figure 3.1
Experimental Layout
fixed pin sockets and movable pin sockets can be varied independently so that symmetrical (SYMT) and asymmetrical (ASYM) conditions are obtained. Each pin socket has a photoelectric sensor to activate the time measuring device. There are two switches 25 mm in diameter, 50 mm away from the fixed pin sockets. On pressing these switches two pins each 32 mm long, 6.35 mm in diameter and weighing 8 grams apiece are pre-positioned in the fixed pin sockets.

The time-measuring unit measures the elapsed time between the removal of the pins from the fixed pin sockets and the insertion (positioning) of each pin in the movable pin sockets. For changing the clearance between the pins and the pin sockets, top covers having different size holes are used. The time taken by the left hand and the right hand is measured simultaneously and punched onto a paper tape.

3.3 THE PERFORMANCE TIME DATA PROCESSING PROCEDURES

The performance times for the left hand and the right hand are measured in milliseconds and these data are sent to the paper tape punch through a specially built interface. Then the data is punched onto a paper tape in IBM 8-digit code. The data on the paper can be transferred onto computer cards later and analyzed on an IBM 370/3031 computer. Graphical representation of the data processing procedures is shown in Figure 3.2

3.4 THE PHYSIOLOGICAL MEASURES PROCESSING PROCEDURES

The subject heart beats are monitored by a Polygraph (Grass Instrument, Model 7) which equips an EKG Tachograph Pre-Amplifier
Figure 3.2
Graphical Representation Of Performance
Time Data Processing Procedures
(Model 7P4P), four DC Pen Drive Amplifiers (two being used for this study, Model 7DAP), and a 4-channel chart recorder. Three Beckman electrodes are attached to the subject's skin surface and leads are connected to the EKG preamplifier. The potential differences between pairs of points on the skin surface due to cardiac activity are amplified by the EKG preamplifier. Then beat-to-beat (inter-beat) Heart Rate (beats/minute) is computed by the tachograph. This HR data is recorded by the chart recorder in analog form and is simultaneously supplied to a PDP-11/03 digital computer. The PDP-11/03 has a 16-channel Analog-to-Digital (A/D) converter, and is capable of real-time processing the HR data at desired intervals up to 60 times/second. The HR data input to the PDP-11/03 is then digitalized and each beat-to-beat HR is determined by a computer program and recorded on a magnetic disk. An average HR and a scored HRV are computed for each experimental condition for each subject upon completion of each experimental condition. The HR data recorded on the disk was subsequently transferred to the IBM/3031 through the WYLBUR (text editing system) by a specially written program on PDP-11/03. The diagrammatic representation of the procedures are shown in Figure 3.3.
Figure 3.3
Graphical Representation Of Physiological Data Processing Procedures
CHAPTER IV

THE DESIGN OF THE EXPERIMENT

4.1 INTRODUCTION

The task employed in this study, the objectives of the study, the experimental conditions, the statistical models developed and the results of pilot studies are described in this Chapter.

4.2 EXPERIMENTAL TASK

In this study each subject is asked to perform a simultaneous two-handed task under various conditions. The subject is asked to sit at the SIMO-PIN unit and not to shift his body or speak during the experiment. The task to be performed by the subject is shown diagramatically in Figure 4.1. On hearing an audio signal, the subject is required to press simultaneously two switches located near the end of the experimental units using his index fingers. This results in activation of the mechanical units that push up two pins in the fixed pin sockets. The subject is required to grasp the pins and move these pins to the movable-pin sockets and to position (insert) them in the respective holes of the pin sockets. Approximately two seconds after completion of the task, the audio signal is given again and the subject performs the next cycle of the task.
Figure 4.1 Diagramatic Layout of Subject's Task:
4.3 THE OBJECTIVES OF THIS STUDY

The following are the objectives of this study.

(1) To see if there is any systematic relationship between the performance time and the factors constituting the task, i.e., the angle of hand movements, the distance of hand movements and lateral clearance, on a horizontal plane.

(2) To see if there is any systematic relationship between the factors constituting the task and the physiological measures of subjects.

4.4 THE RESULTS OF PILOT STUDIES

Two pilot studies were carried out. The first pilot study was designed to determine appropriate levels of the factors. The second pilot study was designed to discover the relationship between the factors and the performance time under (1) symmetrical conditions and (2) a type of asymmetrical condition (symmetrical angle and asymmetrical TD). RR of subjects was monitored during the experiments in the second pilot study.

4.4.1 The First Pilot Study

Four right-handed male subjects between the age of 21-27 were used in the first study. The factors investigated in this study were:

(1) Subject $S_i$ $i=1,2,3,4$

(2) Distance $D_k$ $k=100,150,200,250,300$ (mm)

(3) Clearance $C_l$ $l=0.65,2,65,4.65,6.65,8.65,10.65,12.65$ (mm)

(4) Hand $H_m$ $m="right","left"$

(5) Angle $A_j$ $j=0,15,30,45,60$ (degrees)
4.4.1.1 Statistical Model

Three statistical models using a 3-way classification were used. Each model involved S and H, and A, D or C. The models are shown below.

\[
\begin{align*}
PT_{ijmn} &= S_i + A_j + H_m + (S.A)_{ij} + (S.H)_{im} + (A.H)_{jm} \\
&\quad + (S.A.H)_{ijm} + E_{ijmn} \\
PT_{ikmn} &= S_i + D_k + H_m + (S.D)_{ik} + (S.H)_{im} + (D.H)_{km} \\
&\quad + (S.D.H)_{ikm} + E_{ikmn} \\
PT_{ilmn} &= S_i + C_l + H_m + (S.C)_{il} + (S.H)_{im} + (C.H)_{lm} \\
&\quad + (S.C.H)_{ilm} + E_{ilmn}
\end{align*}
\]

4.4.1.2 Results

The factors, A, D, C were found to be significant at $\alpha = .05$. The results of ANOVA's are shown in Appendix A. A Duncan's Multiple Range Test was carried out for each factor. The results are summarized below.

\[\text{DUNCAN'S MULTIPLE RANGE TEST}\]

<table>
<thead>
<tr>
<th>Variable</th>
<th>A</th>
<th>(degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>0 15 30 45 60</td>
<td></td>
</tr>
<tr>
<td>Grouping</td>
<td>--------</td>
<td>-----------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>C</th>
<th>(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>.65 2.65 4.65 6.65 10.65 12.65 9.65</td>
<td></td>
</tr>
<tr>
<td>Grouping</td>
<td>--------</td>
<td>---------</td>
</tr>
</tbody>
</table>
Variable D
Levels 100 150 200 250 300 (mm)
Grouping — — — —

The results of Duncan's Multiple Range Test show that for the factor A, there is a significant difference between the mean performance time at 0 degrees and at the other angles. The mean performance times were significantly different from each other at all levels except 150 mm and 250 mm for the factor D. The significance of the mean performance times, when lateral clearance was varied, was tested at seven levels. At the higher levels of hole size, results did not show a significant difference, but when the hole size was relatively smaller the factor showed a significant difference in performance.

4.4.2 The Second Pilot Study

By making use of the results of the first pilot study, appropriate levels of the factors were chosen. The second pilot study involved varying both factors A and TD. In this study an interaction between A and TD was also tested. The study was carried out in two parts. In part I subjects performed the task simultaneously under symmetrical conditions and in part II under asymmetrical conditions, those being the asymmetrical distance of move and lateral clearance, and the symmetrical angle. Eight right-handed male subjects participated in these studies. All of them were university students between the age of 20-24 and were paid a minimum wage rate. The only dependent variable used in these studies was performance time for the limiting hand (greater
of two time values). For part I the following independent variables were studied:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>150, 250, 300  (mm)</td>
</tr>
<tr>
<td>Lateral Clearance</td>
<td>0.65, 4.65, 8.65 (mm)</td>
</tr>
<tr>
<td>Angle</td>
<td>0, 30, 60      (degrees)</td>
</tr>
</tbody>
</table>

The variables used in part II are:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance moved by:</td>
<td></td>
</tr>
<tr>
<td>right hand</td>
<td>250, 350, 150, 150 (mm)</td>
</tr>
<tr>
<td>left hand</td>
<td>150, 150, 250, 350 (mm)</td>
</tr>
<tr>
<td>Lateral Clearance</td>
<td>0.65, 4.65, 8.65 (mm)</td>
</tr>
<tr>
<td>Angle of Moves</td>
<td>0, 30, 60 (degrees)</td>
</tr>
</tbody>
</table>

For both studies subjects performed the task 35 times in each condition.

#### 4.4.2.1 Statistical Model

A statistical model was developed for each study. TD's were calculated for each of the combinations using the following relationship, \( TD = \log_2 \frac{2D}{C} \) bits. For analyzing the results of part I the following statistical model was used.

\[
P_{ijkn} = \mu + S_i + A_j + TD_k + (S.A)_{ij} + (S.TD)_{ij} \\
+ (A.TD)_{jk} + (S.A.TD)_{ijk} + E_{ijkn}
\]
where

\[ PT_{ijkn} = \text{MAX} [PTR_{ijkn}, PTL_{ijkn}] \]

PTR = PT for right hand

PTL = PT for left hand

μ = average PT

Si = ith subject

Aj = jth level of angle effect

TDk = kth level of task difficulty

n = nth observation

E_{ijkn} = experimental error.

The statistical model used in part II is:

\[ PT_{ijln} = \mu + S_i + A_j + TDLTG_{ij} + (S.A)_{ij} \]
\[ + (S.TDLTG)_{il} + (A.TDLTG)_{il} + (S.A.TDLTG)_{ijl} \]
\[ + E_{ijln} \]

where

TDLTG = MAX [TDR, TDL]

TDR = TD for right hand

TDL = TD for left hand.

4.4.2.2 Results

Analysis of collected data indicated that a logarithmic
transformation was required before the analysis of variance could be
carried out. ANOVA for part I and part II are shown in Appendix A.
It is observed that the following variables had significant effects
upon performance time at .05 level.

Part I  Part II
TD, A and S  TDLTG, A and S.

Duncan's Multiple Range Test was carried out for each of the above variables. The results are shown below.

**DUNCAN'S MULTIPLE RANGE TEST**

**PART I SYMMETRICAL SIMO**

<table>
<thead>
<tr>
<th>Variable</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>0 30 60 (degrees)</td>
</tr>
<tr>
<td>Grouping</td>
<td>— — —</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>5.11 6.01 5.85 6.33 6.74 8.65 9.58 7.23 10.07 (Ibits)</td>
</tr>
<tr>
<td>Grouping</td>
<td>— — — — — — — —</td>
</tr>
</tbody>
</table>

**DUNCAN'S MULTIPLE RANGE TEST**

**PART II ASYMMETRICAL SIMO**

<table>
<thead>
<tr>
<th>Variable</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>0 30 60 (degrees)</td>
</tr>
<tr>
<td>Grouping</td>
<td>— — —</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>5.85 6.33 6.74 7.23 9.58 10.07 (Ibits)</td>
</tr>
<tr>
<td>Grouping</td>
<td>— — — — — —</td>
</tr>
</tbody>
</table>

-26-
It was observed that as the angle increased mean performance time at each level increased significantly in both symmetrical and asymmetrical cases. For the factor TD in the symmetrical case, it seems that, as the task difficulty increased, PT increased and in the asymmetrical case, it is clear that all mean PT's are significantly different from each other and that PT increased when TD was increased.

4.5 HEART RATE

During the experiments the HR of each subject was monitored. For part I, the significance level of factor A was found to be .0542, and that of TD was .0893. Furthermore, a statistical model with A, C and D was developed and the effects of factors C and D were tested. The results of the ANOVA indicated that the factor C was not significant but the factor D was significant at α = .05. A mean HR was computed for each level of factors. It was observed that the mean of HR at each level was significantly different from all others for both the factors A and D. It was also found that HR increased when the distance of moves was increased and HR decreased when the angle was increased. These results agree with the ones in the literature and seem to indicate that HR may be used as a measure of the physiological cost of such tasks. For part II both factors A and TDLTG were insignificant, but the mean HR's showed similar trends as the results in part I did. The results of ANOVA and Duncan's Multiple Range Test for part I and part II are found in Appendix B.
4.6 SIMULTANEOUS MOTION WITH ASYMMETRICAL ANGLE OF MOVES

In pilot study #2, the task difficulties were defined for given angles of 0, 30 and 60 (degrees), and, in each case the angle of moves was kept symmetrical. However, simultaneous motion with an asymmetrical angle of moves has not been investigated. What was intended was a measure of the physiological load on TD by use of HR. However, results showed that the relationship between physiological load on TD and HR was not significant. It was therefore necessary to design a new set of experiments to find a better method of measuring physiological load on TD. The outline of this new set of experiments is found in section 4.6.1.

4.6.1 Experimental Conditions

The following conditions were used:

ANGLE (A) for Right Hand  AR  0  0  0  30  30  60  60  60 (degrees)
ANGLE (A) for Left Hand   AL  0  30  60  0  30  60  0  30  60 (degrees)
Resulting TD   5.11, 6.34, 8.85 and 10.07 (Ibits)

D  150  350 (mm)
C  .65  8.65 (mm)

The study was carried out in two parts, performance time study and physiological study.

4.6.2 Performance Time Study

Performance time was investigated under the experimental conditions.

The statistical model used in this study was:
\[ PT_{ijkn} = \mu + S_i + AR_j + AL_k + TD_l + (S.AR)_{ij} + (S.AL)_{ik} + (S.TD)_{il} + (AR.AL)_{jk} + (AR.TD)_{jl} + (AL.TD)_{kl} + (S.AR.AL)_{ijk} + (S.AR.AL.TD)_{ijkl} + E_{ijkl} \]

where

- \( PT_{ijkn} \) = Max \( P^{TR}_{ijkl}, P^{TL}_{ijkl} \)
- \( P^{TR} \) = PT for right hand
- \( P^{TL} \) = PT for left hand
- \( \mu \) = average PT
- \( S_i \) = ith level of subject \( i=1,9 \)
- \( AR_j \) = jth level of AR \( j=1,3 \)
- \( AL_k \) = kth level of AL \( k=1,3 \)
- \( TD_l \) = lth level of TD \( l=1,4 \)
- \( E_{ijkl} \) = experimental error \( n=1,30 \).

The task was replicated 15 times for each condition. The model can be expressed as 9 x 3 x 3 x 4 factorial with 15 replications.

4.6.3 Physiological Study

HR and HRV are used to measure physiological load of the task. To eliminate individual differences in HR and HRV, a "range correction" technique proposed by Luczak (1979) was used. The formulae are given below.
\[ \text{SHR} = \frac{\text{HR} - \text{HR}_{\text{min}}}{\text{HR}_{\text{max}} - \text{HR}_{\text{min}}} \]

where

- \( \text{SHR} = \) standardized mean HR.
- \( \text{HR} = \) the mean HR in the experimental condition.
- \( \text{HR}_{\text{min}} = \) min. HR for the subject during the experiments.
- \( \text{HR}_{\text{max}} = \) max. HR for the subject during the experiments.

\[ \text{SHRV} = \frac{\text{HRV} - \text{HRV}_{\text{min}}}{\text{HRV}_{\text{max}} - \text{HRV}_{\text{min}}} \]

where

- \( \text{SHRV} = \) standardized scored HRV.
- \( \text{HRV} = \) scored HRV in the experimental condition.
- \( \text{HRV}_{\text{min}} = \) min HRV for the subject during the experiments.
- \( \text{HRV}_{\text{max}} = \) max HRV for the subject during the experiments.

The SHRV values were then divided by the subject's mean PT for the experimental condition and a new measure of heart rate variability, Heart Rate Variability Index (HRVI) was developed. The definition of the HRVI is given below.

\[ \text{HRVI}_{ijkl} (\text{per unit time}) = \frac{\text{SHRV}_{ijkl} \ (\%)}{\text{mean PT}_{ijkl} \ (\text{sec})} \]

where

- \( i = \) ith subject.
- \( j = \) jth AL.
- \( k = \) kth AR.
- \( l = \) lth TD.
This new measure of HRV, HRVI provides that relative HRV for the subject per unit time. The same experimental conditions in the performance time study were used since HR and HRVI are measured throughout the experiments. The statistical models for this study are shown below.

\[
HR_{ijkl} = \mu + S_i + AR_j + AL_k + TD_l
+ (S,AR)_{ij} + (S,AL)_{ik} + (S,TD)_{il}
+ (AR,AL)_{jk} + (AR,TD)_{jl} + (AL,TD)_{kl}
+ (S,AR,AL)_{ijk} + (S,AR,TD)_{ijl} + (S,AL,TD)_{ikl}
+ (AR,AL,TD)_{jkl} + (S,AR,AL,TD)_{ijkl} + E_{ijkl}
\]

where

- \( HR_{ijkl} \) = standardized mean HR
- \( \mu \) = constant
- \( S_i \) = ith level of subject \( i=1,9 \)
- \( AR_j \) = jth level of AAR \( j=1,3 \)
- \( AL_k \) = kth level of AAL \( k=1,3 \)
- \( TD_l \) = lth level of TD \( l=1,4 \)
- \( E_{ijkl} \) = experimental error.

\[
HRVI_{ijkl} = \mu + S_i + AR_j + AL_k + TD_l
+ (S,AR)_{ij} + (S,AL)_{ik} + (S,TD)_{il}
+ (AR,AL)_{jk} + (AR,TD)_{jl} + (AL,TD)_{kl}
+ (S,AR,AL)_{ijk} + (S,AR,TD)_{ijl} + (S,AL,TD)_{ikl}
+ (AR,AL,TD)_{jkl} + (S,AR,AL,TD)_{ijkl} + E_{ijkl}
\]
where

\[ HRVT_{ijkl} = \text{heart rate variability index} \]
\[ \mu = \text{constant} \]
\[ S_i = \text{ith level of subject} \quad i=1,9 \]
\[ AR_j = \text{jth level of AR} \quad j=1,3 \]
\[ AL_k = \text{kth level of AL} \quad k=1,3 \]
\[ TD_l = \text{lth level of TD} \quad l=1,4 \]
\[ E_{ijkl} = \text{experimental error} \]

The statistical models have one observation per cell. The test statistics for ANOVA were chosen upon determination of the expected mean squares.
4.7 THE SUBJECTS

Nine subjects—volunteers for this study are chosen from among the students of the University of Windsor at the time that the experiments are carried out.

To be eligible to participate in the experiments, each subject must satisfy the following conditions:

1. to be a Canadian citizen or Landed Immigrant
2. to be a right-handed male between the age of 20–26
3. to have no physical disability
4. to have good vision (20/20)
5. to have knowledge about neither the characteristics of simultaneous motions nor the physiological load of the task.

It is estimated that the experiments take approximately five hours for a subject. The subjects are paid for participating in the experiments. The basic payment is $25.00, 70 cents per the experiment condition. This amount is equivalent to an hourly wage rate of $5.00. However, there was a penalty for making errors. If the subject fumbled the pin, he is penalized ten cents each time. After the experiments, a mean performance time for each condition is computed and if the time value exceeded 150% of what PMTS's assign, the subject is penalized 20 cents for the experimental condition.

To confirm these agreements with the subjects, they are asked to fill out a questionnaire. The form is given in Appendix C.
4.7.1 The Randomization of the Experimental Conditions

To eliminate or balance undesired influences to the experiments, such as boredom, fatigue and the effects of circadian rhythm, the sequence of the experiments is randomized for each subject. One set of random numbers, 1 to 36, has been generated by a computer. These numbers are divided into 9 groups, 4 numbers in one group. These 9 groups are rotated and randomized by Latin-Square-like randomization while 4 numbers in each group are randomized for each group and each subject. The results are given in Appendix C.
CHAPTER V

ANALYSIS, RESULTS AND DISCUSSION

5.1 INTRODUCTION
This chapter describes the analysis of the performance time
and physiological measures.

5.2 PERFORMANCE TIME ANALYSIS

5.2.1 Data Analysis
Nine subjects, each of them performed the task, using both
hands, twenty times under 36 experimental conditions so that a
total of 12960 data points of performance times was obtained.
The highest performance time, either of, right hand or left hand
was considered as a simultaneous two-handed performance time.
After filtering out the erroneous data due to machine error, in
order to obtain a balanced design, 15 observations per condition
for each subject were used for statistical analysis. Thus, out
of the total number of observations only 4860 were used in the
study. The normality of the performance time data was tested
before the analysis of variance was carried out. The data
showed a pattern of log-normal distribution. As such a
logarithmic transformation was made on the original data.

5.2.2 Results of Performance Time Analysis
The mean performance times of the fifteen cycles of all the
experimental conditions for all the subjects are shown in Table D.1 of Appendix D.1. The results of the analysis of variance of the performance time (PT) and Duncan's Multiple Range Test are shown in Appendix D.2.

The analysis of variance considering all the main effects and the interactions of the model (see 4.6.1) was carried out first. The model consisted of four main effects, six second order interactions, four third order interactions and one fourth order interaction. Three insignificant interaction terms were determined by the above analysis of variance: these were pooled and a new model was developed. This model consisted of four main effects, four second order interactions, three third order interactions and a fourth order interaction.

The analysis of variance (ANOVA) using the new model indicated that all the main effects (i.e. S, TD, AL and AR) had significant effects upon PT. An interaction term AL*AR was also found to be significant. The proposed ANOVA model involves both fixed effects and random effects. The Expected Mean Square (EMS) for all the terms in the model was determined and is shown in Appendix D.3.

The percentage contribution of variance component to the model was calculated for all the terms and is shown in Appendix D.6, and that for the significant effects are summarized in Table 5.1.

As shown in Table 5.1, the highest percentage contribution of variance component to the model was made by the effect TD followed by the effect S. However, the contribution made by
<table>
<thead>
<tr>
<th>Effect</th>
<th>% of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>7.29</td>
</tr>
<tr>
<td>TD</td>
<td>52.65</td>
</tr>
<tr>
<td>AL</td>
<td>1.15</td>
</tr>
<tr>
<td>AR</td>
<td>1.64</td>
</tr>
<tr>
<td>AL*AR</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table 5.1
Percentages of Variance Component of Significant Effects.

effects AL, AR and the interaction AL*AR to the model were found to be relatively small.

The results of the Duncan's Multiple Range Test for the mean performance times (MPT's) of each main effect are summarized in Table 5.2. The MPT's are then re-transformed and shown in milliseconds. The table shows that the MPT's were not significantly different when TD was equal to 6.85 and 6.33. However, MPT's at other levels were significantly different from each other, and it seems that there is a trend that the MPT was increased when the TD increased. The minimum MPT occurred when the TD was smallest (i.e. 5.116). For AL and AR, the MPT's were significantly different from each other at each level. The Maximum MPT's were observed at 60 degrees for both AL and AR. The minimum MPT's occurred at 0 degrees for both effects. It is clear that when the angle was widened more time was needed to
complete the task.

5.2.3 Prediction Model

In order to predict the simultaneous performance time for the task used in this study, a regression analysis was carried out. The model used in the regression analysis consisted of three main effects, TD, AL and AR, and a first-order interaction AL*AR. The results are given in Appendix D.4. The results show that the model had a significant level of fit (prob.>F = 0.01) and a correlation coefficient of 0.66. Table 5.3 shows a comparison between the predicted values calculated by the above-mentioned model and the actual mean performance time (WPT). An upper confidence limit and a lower confidence limit (both at $\alpha = 0.05$) are calculated for each experimental condition and are shown in the Table as well.

A series of plots were drawn to compare the predicted time values in this study and those given by some of the available Predetermined Motion Time systems (PMTS's). The graphs are given in Figure D.1 to D.9 in Appendix D.5. From the graphs it is observed that the values obtained from PMTS's are, in most cases, higher than those obtained by the prediction model developed in this study. It is also observed that time values for all the PMTS's do not follow a consistent trend of increasing as the TD increases.
DUNCAN'S MULTIPLE RANGE TEST

Dependent Variable PT

Variable TD
Levels  5.12  6.34  8.85  10.07 (Ibits)
Grouping  ----  ---------  ----

Variable AL
Levels  0  30  60 (degrees)
Grouping  ---  ---  ---

Variable AR
Levels  0  30  60 (degrees)
Grouping  ---  ---  ---

Table 5.2
Duncan's Multiple Range Test For Performance Time Data
<table>
<thead>
<tr>
<th>TD</th>
<th>AR</th>
<th>AL</th>
<th>MPT</th>
<th>PREDICTED VALUE</th>
<th>UPPER LIMIT</th>
<th>LOWER LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.116</td>
<td>0.</td>
<td>0</td>
<td>744</td>
<td>782</td>
<td>767</td>
<td>797</td>
</tr>
<tr>
<td>5.116</td>
<td>0.</td>
<td>30</td>
<td>769</td>
<td>821</td>
<td>801</td>
<td>841</td>
</tr>
<tr>
<td>5.116</td>
<td>0.</td>
<td>60</td>
<td>793</td>
<td>862</td>
<td>837</td>
<td>887</td>
</tr>
<tr>
<td>5.116</td>
<td>30.</td>
<td>0</td>
<td>795</td>
<td>825</td>
<td>806</td>
<td>846</td>
</tr>
<tr>
<td>5.116</td>
<td>30.</td>
<td>30.</td>
<td>830</td>
<td>851</td>
<td>823</td>
<td>880</td>
</tr>
<tr>
<td>5.116</td>
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<td>60</td>
<td>860</td>
<td>878</td>
<td>841</td>
<td>916</td>
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<tr>
<td>5.116</td>
<td>60.</td>
<td>0</td>
<td>829</td>
<td>871</td>
<td>846</td>
<td>897</td>
</tr>
<tr>
<td>5.116</td>
<td>60.</td>
<td>30</td>
<td>854</td>
<td>883</td>
<td>846</td>
<td>921</td>
</tr>
<tr>
<td>5.116</td>
<td>60.</td>
<td>60</td>
<td>818</td>
<td>894</td>
<td>846</td>
<td>945</td>
</tr>
<tr>
<td>6.339</td>
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<td>0</td>
<td>959</td>
<td>862</td>
<td>845</td>
<td>880</td>
</tr>
<tr>
<td>6.339</td>
<td>0.</td>
<td>30</td>
<td>1034</td>
<td>905</td>
<td>882</td>
<td>929</td>
</tr>
<tr>
<td>6.339</td>
<td>0.</td>
<td>60</td>
<td>1093</td>
<td>950</td>
<td>921</td>
<td>980</td>
</tr>
<tr>
<td>6.339</td>
<td>30.</td>
<td>0</td>
<td>1014</td>
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Table 5.3
A Comparison Between The Predicted Values And The Actual Mean Performance Times
5.3 HEART RATE ANALYSIS

5.3.1 Data Analysis

Subject's Heart Rate (HR) was measured by using the Polygraph throughout the experiment and was recorded on a magnetic disk. The computer program to collect HR data, to store it on the disk and to compute the Heart Rate Variability (described in later section) is listed in Appendix E.1. Another computer program which lets the PDP 11/03 computer to communicate with WYLBUR is given in Appendix E.2. The Mean Heart Rate (MHR) was then computed for each experimental condition for each subject. In order to eliminate the variation among the subjects, 'range correction' (described in section 4.6.3) was performed on the MHR. From this the standardised HR (SHR) was calculated. The results of the collection are given in Table F.1 in Appendix F.

The results of the analysis of variance using the model described before (4.6.3) are shown in Table F.2 in Appendix F. The results indicate that two of the main effects, SUB and TD were significant factors upon SHR at α = 0.05. The insignificant terms including AL and NR were then pooled into the error term and a new model considering only two of the main effects, SUB and TD was developed. The new model is defined below:

\[ \text{SHR}_{ij} = s_i + t_j + e_{ij} \]
The results of the analysis of variance and Duncan's Multiple Range Test for the SHR using the new model are given in Table F.3 in Appendix F. The results of the analysis of variance indicate that the effects SUB and TD were significant at α=0.05 level. However, the Duncan's test of means shows the mean SHR and TD's are not consistent.

The mean SHR's for TD=6.34 and TD=10.07 were found to be not significantly different and those for TD=5.12 and TD=8.85 were also found to be not significantly different from each other. Therefore it was considered necessary to use some other measure to investigate the characteristics of the SHR. Since the TD was calculated from two measures, namely the Distance of move (DIS) and Clearance of fit (CLE), it was decided to use these measures in place of TD in the analysis of variance. The statistical model employed using DIS and CLE is defined below:

\[
\text{SHR}_{iop} = \text{SUB}_i + \text{DIS}_o + \text{CLE}_p + \text{SUB}.\text{DIS}_{i0} + \text{SUB}.\text{CLE}_{ip} + \text{DIS}.\text{CLE}_{op} + \text{SUB}.\text{DIS}.\text{CLE}_{iop} + E_{iop}
\]

where

- \text{SUB}_i = i\text{th subject}
- \text{DIS}_o = o\text{th level of DIS. } o=1,2
- \text{CLE}_p = p\text{th level of CLE. } p=1,2
- E_{iop} = \text{Experimental ERROR.}

- \text{DIS1} = 150 \text{ mm}
- \text{DIS2} = 350 \text{ mm}
CLES1 = 0.65 mm  
CLES2 = 8.65 mm

The results of the analysis of the above model are given in Table F.4. The results show that the effects SUB and DIS were significant at $\alpha=0.05$. The insignificant terms found in the analysis of variance were then pooled and a model considering only the SUB and DIS was developed. The new model includes only SUB and DIS and is shown below:

$$SHR_{io} = SUB_i + DIS_o + E_{io}$$

The results of the analysis of variance and Duncan's test are given in Table F.5. The results show that the effect DIS was significant at $\alpha=0.05$ and the Duncan's test indicate that when the DIS was increased from 150 mm to 350 mm, the subject HR increased over 10% on the average.

5.4 HEART RATE VARIABILITY INDEX ANALYSIS

5.4.1 Data analysis

The Heart Rate Variability Index (HRVI) was computed from the HR data stored on the magnetic disk (described in 5.3.1). The analysis of variance for the HRVI using the full factorial model was carried out. The results are given in Appendix C.1. From the above analysis some insignificant terms were found. These insignificant terms were then pooled and a new analysis of
variance model was developed. The new model is defined below:

$$HRVI_{ijkl} = SUB_i + TD_j + AL_k + AR_l + SUB\cdot TD_{ij} + SUB\cdot AL_{ik} + SUB\cdot AR_{il} + E_{ijkl}$$

The results of the analysis of variance for HRVI using the new model are given in Appendix G.2. The results show that the significant variables, at $\alpha=0.05$ level were SUB, TD, AL and AR. The Duncan's Multiple Range Test was also performed on the HRVI data. The results are summarised below.

**Duncan's Multiple Range Test for Dependent Variable HRVI**

**Variable TD**

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For the variable TD, the results show that the mean HRVI's for TD=5.12 (Ibits) and TD=6.34 are not significantly different, and also those for TD=8.85 and TD=10.07 do not differ significantly from each other.

It was also found that the mean HRVI's for the variables AL are not significantly different when AL=0° and AL=30°. For AR, the results indicate that mean HRVI's are not significantly different from each other. All of the above Duncan’s tests were performed with the significant level of α=0.05.

A series of plots for the HRVI’s was drawn and is shown in Figure 5.1. The plots show that as AL increased from 30° to 60°, the HRVI decreased. Figure 5.1 shows that the HRVI values for AL=0° are somewhat higher than those for AL=30°, but Duncan’s test has proved that these values are not significantly different.

5.5 DISCUSSION

From the results of the analysis, some considerations on the design of the task which involves simultaneous motions are discussed here.

5.5.1 The Effects of the Angle

As it was shown that when the task is simultaneously performed by both the hands, the angles (i.e. AL and AR) affect the performance time (PT) significantly. A comparision of the mean performance times for the task in this study and predicted values in
Figure 5.1
A Series of Plots for HRVI vs. AL
PMTS's is shown in Figure 5.2. The figure shows that although most of the PMTS's (e.g. MTM and BMTS) allow sufficient time for the task, the time values are equal for all the angles. This means that PMTS's do not aid the designer of such tasks in choosing the optimal direction of moves of simultaneous motion.

Another important finding concerning the direction of moves was indicated by the HRVI analysis, i.e. as the angle of move (AL) increased from 30° to 60° the HRVI decreased significantly. It seems that when the angle of move becomes wider, the increase in visual requirement caused an increase in the mental load of the task.

5.5.2 The effects of the Task Difficulty

From the results of the analysis we have learnt that an increase in the TD of the task yields longer performance time and greater mental load. However, TD was not found to be a preferable measure for the physical load (expressed in subject's heart rate). The distance of move was found to be the better measure for the physical load. Further, in designing such tasks, care must be taken to incorporate an appropriate level of mental load. If the mental load is too low, the subject's attention is liable to be distracted from the task, resulting in an error. On the other hand if the mental load is set too high, then the subject is liable to be more error-prone due to high task difficulty and could be fatigued needlessly. Further, this would result in an unnecessary increase in performance time.
Figure 5.2
A Comparison of The Mean Performance Times and Predicted Time Values By Some of PMTS's
Figure 5.3 shows the super-imposition of percentage increase in PT with TD and the percentage decrease in HRVi (increase in mental load) with TD. The intersection of the two lines seems to suggest the value of TD which corresponds to an appropriate level of mental load.
Super-imposition of Percentage Increase in PT with TD and The Percentage Decrease in HRVI (increase in mental load) with TD.
CHAPTER VI

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

6.1 Performance Time

a) Performance Time (PT) is shown to increase significantly with task difficulty. This conclusion is based on studies involving both distance and hole size variations.

b) Performance Time also increases significantly with the angle of motion in the range of 0 to 60 degrees. It is further shown that the performance time increases if asymmetry is introduced in the angle motion. It is further shown that the interaction effect between the left side angle and also the right side angle is significant.

c) The performance time is shown to increase if asymmetry is introduced in the task difficulty.

6.2 Heart Rate and Heart Rate Index

a) The heart rate (HR) and heart rate variability index (HRVI) are shown to be functions of the task difficulty both for the symmetrical and the asymmetrical cases. However, the relationship is found to be non-linear in general.

b) On the basis of the experimental observations, it is felt that distance rather than task difficulty is a better
measure of physical load and hence heart rate will be affected more by the distance involved than the hole size. This could explain the non-linear effects observed.

c) In general, it was found that angle (symmetrical or asymmetrical) did not have any significant effect on the heart rate.

d) However, HRVI was found to be significantly affected by the asymmetrical angle for left hand (AL).

In summary it is concluded that an appropriate level of mental load may be obtained on the intersection of PT-TD and HRVI-TD curves (Figure 5.3).

6.3 SUGGESTIONS FOR FURTHER STUDIES

In order to make study more general and applicable to practical situations, the following are the suggestions for further studies.

1. The effect of sex and age on the performance of the same task needs to be studied.

2. The same experiment, under similar conditions should be conducted with tasks involving inward hand movements.

3. The same experiment should be repeated with different weight of pins.

4. The effect of different plane angles on the performance of such types of tasks needs to be investigated.
BIBLIOGRAPHY


-53-


VITA AUCTORIS

1953 Born in Tokyo, Japan, on March 10th.

1972 Completed Secondary education from Takanawa High School, Tokyo, Japan.

1977 Graduated with a Bachelor of Engineering from Tokai University, Kanagawa, Japan.

1977 Joined the Graduate School at the University of Windsor, Ontario, Canada.

1982 Currently a Candidate for the degree of M.A.Sc. in Industrial Engineering.
APPENDIX A

The Results of ANOVA for The Pilot Study #1
### ANOVA for Pilot study 1

#### Variable: Ankle

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**Significance level .01**

**Significance level .05**
APPENDIX B

The Results of ANOVA and Duncan's Multiple Range Test for The Pilot Study #2
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ANOVA Table for The Pilot Study #2 Part I

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The Results of Duncan's Multiple Range Test for The Pilot Study #2 Part I and Part II
APPENDIX C

The Questionnaire Form
University of Windsor
Department of Industrial Engineering
Simultaneous Motions Experiment
Questionnaire

Page 1 of 2 (Preliminary Questions)

Circle or fill in your answers.

1. Are you a Canadian citizen or a landed immigrant?  Yes. No.


3. How old are you?  __________ years old.

4. Do you have any physical disability?  Yes. No.

5. Do you have 20/20 vision?  Yes. No.

6. Are you a student of the University of Windsor?  Yes. No.

If Yes, please write faculty and year. __________ __________.

7. Are you on any medical treatment now?  Yes. No.

If Yes, are you taking any of the followings?

(1) antibiotics,
(2) tranquilizer,
(3) stimulants,
(4) anodynes (pain killer).  Yes. No.

8. Have you ever had any of the following problems or seen a doctor because of the problem(s)?

(1) high blood pressure,
(2) respiratory problems,
(3) heart problems,
(4) circulatory problems,
(5) diabetes,
(6) epilepsy,
(7) psychological problems,
(8) allergic to adhesive tape.  Yes. No.

Please, read the following and sign.

To the best of my knowledge, above answers are all true.

X______________

Date______________

Please hand this sheet to the interviewer once.
Please, read the following and sign.

The experiment consists of 36 conditions (sessions) and takes about 5 (five) hours. There will be a short break in between the sessions and two 15-minute breaks during the experiment.

I During the experiment you are asked to perform two simple and almost identical tasks by both the right and the left hands simultaneously. Each task involves moving a light metal pin from one place to another and dropping it in a hole. The direction of moving the pin and the size of the hole will be changed from session to session. Your performance will be measured and recorded for each cycle in each session.

II In addition to the performance time, your Heart Rate (Pulse rate) will also be observed throughout the experiment. For this purpose, three "electrodes" will be attached on your chest. When these electrodes are attached, it is necessary to remove a part of or all of your shirt(s) when you are asked to do so.

III When you have completed all 36 (thirty-six) sessions, you will be paid 7 (seventy) cents for a session or $25.2 for 36 sessions. However, there will be two types of penalty, 1) 1 (ten) cents for dropping the pin outside the hole and 2) 2 cents for taking too long for the session. The penalty for dropping the pin will be applied for each hand each time.

IV Since the experiment lasts for 5 (five) hours, you have to choose your "pace" so that you are able to maintain the accuracy and the speed of performing the tasks throughout the experiment. A practice session is provided at the beginning of the experiment and also, at the beginning of each session, there will be a practice period.

V Lastly, you may drop out from the experiment anytime, but you will be paid at rate of $3.3/hr. but the total will not be more than $5.

X

Date

NAME____________________ PHONE #____________________

ID____________________ S.I.N.____________________

MAILING ADDRESS____________________

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APPENDIX D.1

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Table D.1

The Mean Performance Times of The Fifteen Cycles of All The Experimental Conditions for All The Subject
APPENDIX D.2

The results of the Analysis of Variance of the Performance time and Duncan's Multiple Range Test
DATA;
  INPUT CNDTN SUB AL AR DIS CLE;
  X=2.*DIS/CLE;
  TD=LOG2(X);
  IF SUB EQ 1 THEN OHTS=LOG(801.);
  IF SUB EQ 2 THEN OHTS=LOG(902.);
  IF SUB EQ 3 THEN OHTS=LOG(1018.);
  IF SUB EQ 4 THEN OHTS=LOG(1168.);
  IF SUB EQ 5 THEN OHTS=LOG(970.);
  IF SUB EQ 6 THEN OHTS=LOG(906.);
  IF SUB EQ 7 THEN OHTS=LOG(814.);
  IF SUB EQ 8 THEN OHTS=LOG(777.);
  IF SUB EQ 9 THEN OHTS=LOG(832.);
  RETAIN SUB AL AR DIS CLE TD OHTS;
  DO I=1 TO 1;
  INPUT R L 88;
  R=R*100.0;
  L=L*100.0;
  IF L GE R THEN PT=L;
  IF L LT R THEN PT=R;
  PT=LOG(PT);
  OUTPUT;
END;
DROP I X L R;
CARDS;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
REACHED PAST THE END OF A LINE.

NOTE: DATA SET WORK.DAT1 HAS 4860 OBSERVATIONS AND 9 VARIABLES.

NOTE: THE DATA STATEMENT USED 5.31 SECONDS AND 160K.

1322 PROC ANOVA;
1323 CLASSES SUB TD AL AR;
1324 MODEL PT=SUB*TD*AL*AR;
1325 TEST H=T D E=SUB*TD;
1326 TEST H=AL E=SUB*AL;
1327 TEST H=AR E=SUB*AR;
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1330 TEST H=AL*AR E=SUB*AL*AR;
1331 TEST H=TD*AL*AR E=SUB*TD*AL*AR;
1332 MEANS TD AL AR/DUNCAN;

NOTE: THE PROCEDURE ANOVA USED 30.72 SECONDS AND 204K
AND PRINTED PAGES 1 TO 6.

1333 PROC SORT;
1334 BY SUB;

NOTE: DATA SET WORK.DAT1 HAS 4860 OBSERVATIONS AND 9 VARIABLES.

171 OBS/TRK

NOTE: THE PROCEDURE SORT USED 3.29 SECONDS AND 282K.

1335 PROC ANOVA;
1336 CLASSES TD AL AR;
1337 MODEL PT=TD*AL*AR;
1338 MEANS TD AL AR/DUNCAN;
STATISTICAL ANALYSIS SYSTEM
5:50 WEDNESDAY, JUNE 30, 1982

ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

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NUMBER OF OBSERVATIONS IN DATA SET = 4860
### Analysis of Variance Procedure

**Dependent Variable:** PT

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**Model F =** 40.65  
PR > F = 0.0001

**R-Square, C.V., Std Dev, PT Mean**

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**Tests of Hypotheses Using the ANOVA MS for SUB*TD as an Error Term**

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</tr>
</thead>
<tbody>
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<td>TD</td>
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<td>0.0001</td>
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**Tests of Hypotheses Using the ANOVA MS for SUB*AL as an Error Term**

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<td>0.0001</td>
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**Tests of Hypotheses Using the ANOVA MS for SUB*AR as an Error Term**

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<th>DF</th>
<th>ANOVA SS</th>
<th>F Value</th>
<th>PR &gt; F</th>
</tr>
</thead>
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**Tests of Hypotheses Using the ANOVA MS for SUB*TD*AL as an Error Term**

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STATISTICAL ANALYSIS SYSTEM 5:50 WEDNESDAY, JUNE 30, 1982

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB*TD*AR AS AN ERROR TERM

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<th>PR &gt; F</th>
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TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB*AL*AR AS AN ERROR TERM

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</thead>
<tbody>
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TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB*TD*AL*AR AS AN ERROR TERM

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<th>ANOVA SS</th>
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<th>PR &gt; F</th>
</tr>
</thead>
<tbody>
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<td>0.76353835</td>
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**ANALYSIS OF VARIANCE PROCEDURE**

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT**

Means with the same letter are not significantly different.

**ALPHA LEVEL=.05**  **DF=4536**  **MS=.0165862**

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<thead>
<tr>
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<th>TD^2</th>
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<td>10.0727</td>
</tr>
<tr>
<td>B</td>
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<td>1215</td>
<td>8.850307</td>
</tr>
<tr>
<td>B</td>
<td>6.960014</td>
<td>1215</td>
<td>6.338511</td>
</tr>
<tr>
<td>C</td>
<td>6.680127</td>
<td>1215</td>
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</tbody>
</table>
ANALYSIS OF VARIANCE PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

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<th>MEAN</th>
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<th>AL</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>6.974861</td>
<td>1620</td>
<td>60</td>
</tr>
<tr>
<td>B</td>
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<td>1620</td>
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</tr>
<tr>
<td>C</td>
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STATISTICAL ANALYSIS SYSTEM
5:50 WEDNESDAY, JUNE 30, 1982

ANALYSIS OF VARIANCE PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05        DF=4536        MS=.0165862

<table>
<thead>
<tr>
<th>GROUPING</th>
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<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
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<td>60</td>
</tr>
<tr>
<td>B</td>
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<td>30</td>
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<tr>
<td>C</td>
<td>6.905387</td>
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**STATISTICAL ANALYSIS SYSTEM**

5:50 WEDNESDAY, JUNE 30, 1982

SUB=1

**ANALYSIS OF VARIANCE PROCEDURE**

**CLASS LEVEL INFORMATION**

<table>
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<tr>
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<th>LEVELS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD</td>
<td>4</td>
<td>10.0727 5.116119 6.338511 8.850307</td>
</tr>
<tr>
<td>AL</td>
<td>3</td>
<td>0 30 60</td>
</tr>
<tr>
<td>AR</td>
<td>3</td>
<td>0 30 60</td>
</tr>
</tbody>
</table>

NUMBER OF OBSERVATIONS IN BY GROUP = 540
DATA:
  INPUT CNDTN SUB AL AR DIS CLE;
  TD=LOG2(X);
  DO I=1 TO 15;
    INPUT R L @@;
    L=L*100.0;
    IF L GE R THEN PT=L;
    IF L LT R THEN PT=R;
    END;
  OUTPUT;
  DROP I X L R;
END;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
REACHED PAST THE END OF A LINE.

NOTE: DATA SET WORK.DATAL HAS 4860 OBSERVATIONS AND 8 VARIABLES.

NOTE: THE DATA STATEMENT USED 5.24 SECONDS AND 160K.

PROC ANOVA;
  CLASSES SUB TD AL AR;
  MODEL PT = SUB*TD*AL*AR
         SUB*TD*SUB*AL*AR*AL*AR
         SUB*AL*AR
         SUB*TD*AL
         SUB*TD*AR
         SUB*TD*AL*AR;
  TEST H=TD E=SUB*TD;
  TEST H=AL E=SUB*AL;
  TEST H=AR E=SUB*AR;
  TEST H=AL*AR E=SUB*AL*AR;
  MEANS TD AL AR AL*AR / DUNCAN;

NOTE: THE PROCEDURE ANOVA USED 31.63 SECONDS AND 200K
AND PRINTED PAGES 1 TO 6.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
BOX 8000
CARY, N.C. 27511
### ANALYSIS OF VARIANCE PROCEDURE

#### CLASS LEVEL INFORMATION

<table>
<thead>
<tr>
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<tbody>
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<td>1 2 3 4 5 6 7 8 9</td>
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<td>AL</td>
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<td>0.30 60</td>
</tr>
<tr>
<td>AR</td>
<td>3</td>
<td>0 30 60</td>
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</tbody>
</table>

**NUMBER OF OBSERVATIONS IN DATA SET = 4860**
### Statistical Analysis System

**Analysis of Variance Procedure**

**Dependent Variable: PT**

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<th>Sum of Squares</th>
<th>Mean Square</th>
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<td>0.67416562</td>
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<tr>
<td>Error</td>
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<td>75.23522660</td>
<td>0.01658625</td>
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<tr>
<td>Corrected Total</td>
<td>4859</td>
<td>292.99072232</td>
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</table>

**Model F =** 40.65  
**PR > F = 0.0001**

<table>
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<tr>
<th>R-Square</th>
<th>C.V.</th>
<th>STD Dev</th>
<th>PT Mean</th>
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<td>1.8544</td>
<td>0.12878761</td>
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<table>
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<th>F Value</th>
<th>PR &gt; F</th>
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</tr>
<tr>
<td>TD</td>
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**Tests of Hypotheses Using the ANOVA MS for SUB*TD as an Error Term**

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<th>ANOVA SS</th>
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</tr>
</thead>
<tbody>
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**Tests of Hypotheses Using the ANOVA MS for SUB*AL as an Error Term**

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**Tests of Hypotheses Using the ANOVA MS for SUB*AR as an Error Term**

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<th>ANOVA SS</th>
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<tr>
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**Tests of Hypotheses Using the ANOVA MS for SUB*AL*AR as an Error Term**

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<th>F Value</th>
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</thead>
<tbody>
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META-ANALYSIS

ANALYSIS OF VARIANCE PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

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<tr>
<th>GROUPING</th>
<th>MEAN</th>
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<th>TD</th>
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<tbody>
<tr>
<td>A</td>
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<td>1215</td>
<td>10.0727</td>
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<tr>
<td>B</td>
<td>6.961866</td>
<td>1215</td>
<td>8.850307</td>
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<td>B</td>
<td>6.960014</td>
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<td>6.338511</td>
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<tr>
<td>C</td>
<td>6.680127</td>
<td>1215</td>
<td>5.116119</td>
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## Statistical Analysis System

6:16 Tuesday, July 20, 1982

### Analysis of Variance Procedure

**Duncan's Multiple Range Test for Variable PT**

Means with the same letter are not significantly different.

**Alpha Level = .05**  **DF = 4536**  **MS = .0165862**

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<tr>
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<td>B</td>
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<td>C</td>
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**Statistical Analysis System**

**Analysis of Variance Procedure**

Duncan's Multiple Range Test for Variable PT

Means with the same letter are not significantly different.

**Alpha Level** = .05  
**DF** = 4536  
**MS** = .0165862

<table>
<thead>
<tr>
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<td>C</td>
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## Analysis of Variance Procedure

### Means

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APPENDIX D.3

The expected Mean Square for The Analysis of Variance Model with All The Interaction Terms.
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<th>AR</th>
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<td>3</td>
<td>3</td>
<td>15</td>
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<tr>
<td></td>
<td>N</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>R</td>
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</tr>
<tr>
<td></td>
<td>1</td>
<td>J</td>
<td>k</td>
<td>l</td>
<td>m</td>
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<tr>
<td>(SUB)k</td>
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<td>3</td>
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<td>3</td>
<td>3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>3</td>
<td>3</td>
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<td></td>
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<td>(AL)k</td>
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<td>3</td>
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<td>15</td>
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<td>1</td>
<td>1</td>
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\( \sigma^2_{\text{sub}} = 540 \sigma^2 \)

\( \sigma^2_{\text{td}} = 135 \sigma^2_{\text{td,sub}} + 1215 \sigma^2_{\text{td}} \)

\( \sigma^2_{\text{al}} = 180 \sigma^2_{\text{al,sub}} + 1620 \sigma^2_{\text{al}} \)

\( \sigma^2_{\text{ar}} = 180 \sigma^2_{\text{ar,sub}} + 1620 \sigma^2_{\text{ar}} \)

\( \sigma^2_{\text{td,al}} = 45 \sigma^2_{\text{td,al,sub}} + 405 \sigma^2_{\text{td,al}} \)

\( \sigma^2_{\text{td,ar}} = 45 \sigma^2_{\text{td,ar,sub}} + 405 \sigma^2_{\text{td,ar}} \)

\( \sigma^2_{\text{al,ar}} = 45 \sigma^2_{\text{al,ar,sub}} + 405 \sigma^2_{\text{al,ar}} \)

\( \sigma^2_{\text{td,al,ar}} = 60 \sigma^2_{\text{td,al,ar,sub}} + 540 \sigma^2_{\text{td,al,ar}} \)

\( \sigma^2_{\text{al,ar,al}} = 15 \sigma^2_{\text{al,ar,al,sub}} + 135 \sigma^2_{\text{al,ar,al}} \)

\( \sigma^2_{\text{al,ar,al,ar}} = 15 \sigma^2_{\text{al,ar,al,ar,sub}} + 135 \sigma^2_{\text{al,ar,al,ar}} \)

\( \sigma^2 = \)
APPENDIX D.4

The results of Thr regression Analisis for The Simultaneous Performance Time When The Task difficulty is Symmetrical and The Angle is Asymmetrical
DATA;
  INPUT CNDTN SUB AL AR DIS CLE;
  X=2.*DIS/CLE;
  TD=LOG2(X);
  RETAIN SUB AL AR DIS CLE TD;
  DO I=1 TO 15;
    INPUT R L @@;
    R=R*100.0;
    L=L*100.0;
    IF L GE R THEN PT=L;
    IF L LT R THEN PT=R;
    PT=LOG10(PT);
    OUTPUT;
  END;
  DROP I X L R;
CARDS;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
REACHED PAST THE END OF A LINE.
NOTE: DATA SET WORK.DAT1 HAS 4860 OBSERVATIONS AND 8 VARIABLES.
191 OBS/TK
NOTE: THE DATA STATEMENT USED 5.86 SECONDS AND 160K.

PROC GLM;
  MODEL PT = TD AL AR AL*AR;

NOTE: THE PROCEDURE GLM USED 11.68 SECONDS AND 182K
AND PRINTED PAGE 1.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
BOX 8000
CARY, N.C. 27511
**STATISTICAL ANALYSIS SYSTEM**

**GENERAL LINEAR MODELS PROCEDURE**

**DEPENDENT VARIABLE:** PT

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
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**MODEL F =** 940.40 \( P R > F = 0.0001 \)

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<tr>
<th>R-SQUARE</th>
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<th>STD DEV</th>
<th>PT MEAN</th>
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<table>
<thead>
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<td>3526.25</td>
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<td>AL</td>
<td>1</td>
<td>3.05303555</td>
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<td>AL*AR</td>
<td>1</td>
<td>0.68413517</td>
<td>20.12</td>
<td>0.0001</td>
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<table>
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<table>
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<tr>
<th>PARAMETER</th>
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APPENDIX D.5

Figures for Comparing The Predicted Values in this Study and Those Given by PMTS's

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<td>D.6</td>
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<td>D.7</td>
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<td>D.9</td>
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<td>60</td>
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</table>
EXP #3 SYMT
AL=AR=0°

Figure D.1

-90-
EXP #3 SYMT
AL=AR=30°

PREDICTED VALUES <MS> *10^1

TD <IBITS>

MTM
BMTS
W.F.
THIS STUDY

Figure D.2
Figure D.3
EXP #3 ASYM. ANGLE
AL=30° AR=0°

PREDICTED VALUES, <MS> '10'

TD <IBITS>

MTM
BMTS
W.F.
THIS STUDY

Figure D.4

-93-
EXP #3 ASYM. ANGLE
AL=60° AR=0°

PREDICTED VALUES, CMS x 10^1

TD < IBITS >

MTM
BMTS
W.F.
THIS STUDY

Figure D.5
EXP #3 ASYM. ANGLE
AL = 0° AR = 30°

PREDICTED VALUES <MS> × 10^4

TD <IBITS>

MTM
BMTS
W.F.
THIS STUDY

Figure D.6

-95-
EXP #3 ASYM. ANGLE
AL=60° AR=30°

PREDICTED VALUES \( <MS> \times 10^{1} \)

TD (IBITS)

MTM
BMTS
W.F.
THIS STUDY

Figure D.7

-96-
EXP #3 ASYM. ANGLE
AL=0° AR=60°

PREDICTED VALUES <\langle MS \rangle > \times 10^1

TD <\langle IBITS \rangle >

MTM
BMTS
W.F.
THIS STUDY.

Figure D.8
EXP #3 ASYM. ANGLE
AL=30° AR=60°

PREDICTED VALUES, $\langle \text{MTS} \rangle \times 10^3$

TD $\langle \text{IBITS} \rangle$

- MTM
- BMTS
- W.F.
- THIS STUDY

Figure 5.9

-98-
APPENDIX D.6

The Percentage Contribution of Variance Component to the Model
### Percentage Variance

#### Main Effects

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Subtotal 62.72

#### Second Order Interactions

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Subtotal 5.20

#### Third Order Interactions

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Subtotal 5.23

#### Fourth Order Interaction and error term

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Subtotal 26.85

#### TOTAL

|   | 100.00 |

-100-

APPENDIX B.1

The Computer Program to Collect HR Data, To Store It on The Magnetic Disk and To compute The HRV.
INTEGER*2 IHR(2,1000), ITEMS(13)
LOGICAL*1 COND(6)
REAL*4 IHR, LHR, MPH, MVOL, LP, HRV(4,99)
COMMON UHR, LVOLT, LHR, LVOL, MPH, MVOL, IHR, COND,
ITICK, IREP, ICOND, IFLAGI, LS, US, ZERO, ITEMS, HRV,
ICHHR, ICHSE, ICHST, ICHPR, ICHR, ICHED, LUNCRT, LUNPRN
0005  DATA COND/'S', ' ', ' ', ' ', ' ', ' ', ' '/
0006  CALL START
0007  1  CALL LOOP(IBEAT)
0008  CALL OUTPUT(IBEAT)
0009  GO TO 1
0010  END
SUBROUTINE OUTPUT(IBAT)
INTEGER*2 IHR(2),1000),ITEMS(13),YESNO2
LOGICAL*1 COND(6)
REAL*4 LHR,IVOL,MR,MM,MR,MVOL,LS,MV(4,99)
COMMON UHR,UVOL,LHR,IVOL,MR,MM,MR,MVOL,LS,COND,
*ITICK,IPREP,ICOND,IFLAG,LS,LM,ZERO,ITEMS,HRV,
*ICH3R,ICHE,ICHT,ICHFR,ICHE,ICHED,LUNCRT,LUNCRT
CALL IEOAM(IBAT)
CALL ISTORE(IBAT)
CALL DEAM2(IBAT)
828 WRITE(LUNCRT,830)
830 FORMAT(1/A,'ARE THERE ANY CHANGES IN INPUT DATA SPEC?',
*1/YES NO')
831 IF(YESNO2(LUNCRT)) 828,690,840
840 CALL ISPEC2
841 CALL ISPEC3(I Cont,K)
842 GO TO 842
844 CALL ISPEC4(K)
846 GO TO 840
847 WRITE(LUNCRT,832)
832 FORMAT(1/A,'IS RECALIBRATION NECESSARY?  YES NO')
849 IF(YESNO2(LUNCRT)) 842,690,844
854 CALL CALSEC
690 RETURN
END
SUBROUTINE START

INTEGER*2 IHR(2,1000), ITEMS(13), YESNO2, ANS, YESNO
LOGICAL*1 COND(6)
REAL*4 LHR, LVOLT, MHR, MVOLT, IS, HRV(4,99)
COMMON UHR, LVOLT, LHR, LVOLT, MHR, MVOLT, IHR, COND,
    *TIX, IREP, ICOND, IFLAG, IS, US, ZER0, ITEMS, HRV,
    *ICHRI, ICHSE, ICHST, ICHPR, ICHRE, ICHED, LUNCRT, LUNPN

CALL CLEAR

100 FORMAT(' /* HR AND HRV DATA--SAMPLING PROGRAM*/')
500 TYPE 1000
1000 FORMAT(' DO YOU NEED ANY HELP? <TYPE YES OR NO>*/')

CALL YESNO(ANS)
112 IF(ANS)500,600,510 IF YES POOL-PROOF-MODE ENABLE

CALL INTRO0
114 CALL INTRO1
115 IPOOL=1

621 CALL YESNO(ANS)
620 IF(ANS)620,630,130
630 TYPE 121

121 FORMAT(' /* ASSIGN LOGICAL UNIT NUMBERS TO THE DEVICES. */
   *' *////.' BYE BYE!')

STOP

622 TYPE 122
122 FORMAT(' TRY AGAIN! */')

621 GO TO 621

600 IPOOL=0

130 CALL IASS

160 WRITE(LUNCRT,100)

IF(IPPOOL.EQ.0) GO TO 202

CALL INTRO2(LUNCRT)

200 CALL ISPEC1

204 WRITE(LUNCRT,204)

204 FORMAT(' /* DO YOU WANT TO VERIFY THE SPECIFICATION?*/
   *' *////.' <YES OR NO>*/')

IF(YESNO2(LUNCRT)) 202,212,214

212 CALL ISPEC2

CALL ISPEC3(ICONT,K)

IF(ICONT.EQ.0) GO TO 212

CALL ISPEC4(K)

214 GO TO 214

212 IF(IPPOOL.EQ.0) GO TO 300

CALL INTRO3(LUNCRT)

300 CALL CALSET

212 IF(IPPOOL.EQ.0) GO TO 690

690 CALL INTRO4(LUNCRT)

690 RETURN

END
SUBROUTINE IFILE
INTEGER*2 IHR(2,1000), ITEMS(13), YESNO2
LOGICAL*1 COND(6), EXTENT(4)
REAL*4 LHR, LVOLT, MHR, MVOLT, IS, HRV(4,99)
COMMON UHR, UVOIL, LHR, LVOLT, MHR, MVOLT, IHR, COND,
*ITICK, IREP, ICOND, IFLAG1, IS, US, ZER0, ITEMS, HRV,
*LOHR, LCHO, ICHET, ICHPR, ICORE, ICHED, LUNCRT, LUNPR;
DATA EXTENT/'', 'D', 'A', 'T'/
WRITE(LUNCRT, 691)
SUBJECT NUMBER ? "I2"/'
READ(LUNCRT, 692) (COND(I), I=2,3)
WRITE(LUNCRT, 693) (COND(I), I=2,3)
READ(LUNCRT, 694) (COND(I), I=4,6)
WRITE(LUNCRT, 695) (COND(I), I=4,6)
READ(LUNCRT, 696) (COND(I), I=1,6), (EXTENT(J), J=1,4)
WRITE(LUNCRT, 697)
WRITE(LUNCRT, 698)
IF(YESNO2(LUNCRT)) 696, 690, 700
RETURN
END
SUBROUTINE CALSEC
LOGICAL*1 QCND(6)
INTEGER*2 IHR(2,1000), ITEMS(13), YESNO2
REAL*4 LS, LHALF, LOWER, LHR, LVOLT, MER, MVOLT, HRV(4,99)
COMMON UHR, LVOLT, LHR, LVOLT, MER, MVOLT, IHR, QCND,
*TVICL, TREP, ICOND, IPLAGI, LS, US, ZERO, ITEMS, HRV,
*ICHHR, ICHE, ICIST, ICHPR, ICHE, ICHED, LUNCRT, LUNPRT
IBELL=8199
WRITE(LUNCRT,131)
FORMAT(112/ 'A/D CONVERTER CALIBRATION'/ 
* FILL THE INSTRUCTIONS BELOW'/)
WRITE(LUNCRT,132)IBELL
WRITE(LUNCRT,133)
FORMAT(112/ 'ARE YOU READY? <YES OR NO> ----> $'
IF(YESNO2(LUNCRT)) 21,22,23
WRITE(LUNCRT,20)
FORMAT(112/ 'WORKING!!'/)
CALL CAL(ZERO,ICHR)
CALL CLEAR
WRITE(LUNCRT,134)IBELL
WRITE(LUNCRT,135)
FORMAT(112/ 'SET TACH SCALE SWITCH TO -2CM.'
WRITE(LUNCRT,133)
IF(YESNO2(LUNCRT)) 25,24,26
WRITE(LUNCRT,20)
CALL CAL(LOWER,ICHR)
CALL CLEAR
WRITE(LUNCRT,135)IBELL
WRITE(LUNCRT,133)
IF(YESNO2(LUNCRT)) 27,28,29
WRITE(LUNCRT,20)
CALL CAL(UPPER,ICHR)
WRITE(LUNCRT,136)
FORMAT(112/ 'CALIBRATION COMPLETED'/)
UPHALF=UPPER-ZERO
LHALF=LOWER-ZERO
SCALE=(UPHALF-LHALF)/2.0
IF(UPHALF.NE.0.0) GO TO 200
US=0.0
GO TO 210
US=SCALE/UPHALF
IF(LHALF.NE.0.0) GO TO 220
LS=0.0
GO TO 230
LS=SCALE/LHALF
RETURN
END
SUBROUTINE CAL(AVE, ICHAN)

SUM=0.

DO 1 I=1, 30

J=ISLEEP(0, 0, 0, 10)

1 SUM=SUM+IADC(ICHAN)

CONTINUE

AVE=SUM/30.

RETURN

END
SUBROUTINE ISPECI
LOGICAL CARD(80), CHA(12), COND(6)
DATA CARD,'1','2','3','4','5','6','7','8','9',
*0', '1H,'/
INTEGER ITEMS(13), IHR(2,1000)
REAL LHR, LVOLT, MHR, MVOLT, LS, HRV(4,99)
COMMON UHR, UREP, ICOND, IFLAG1, LS, US, ZERO, ITEMS, HRV,
*ICHHR, ICHSE, ICHST, ICHPR, ICHRE, ICHED, LUNCRT, LUNPRN

INITIALIZATION OF THE VALUES.
TO CHANGE THE SPEC. PERMANENTLY, REPLACE THE VALUE BY USING
EDIT.

LHR=40.  IHR VALUE WHEN THE PEN IS AT -2 CM
LVOLT=-1.3  I CORRESPONDING VOLTAGE
MHR=60.  IHR VALUE WHEN THE PEN IS AT BASE LINE
MVOLT=0.0  I CORRESPONDING VOLTAGE
UHR=120. IHR VALUE WHEN THE PEN IS AT +2 CM
UVOLT=1.3  I CORRESPONDING VOLTAGE
ITICK=20  IHR SAMPLING INTERVAL
IREP=5  NUMBER OF REPLICATIONS IN THE EXP.
ICOND=1  NUMBER OF CONDITIONS IN THE EXPERIMENT
IFlag1=1  IF 1 STARTING/ENDING SIGNAL IS SUPPLIED, =0 NOT

PRESET CHANNEL NUMBERS
ICHHR=2  IHR DATA FROM POLIGRAPH <J6>
ICHRE=3  I STARTING/ENDING SIGNAL
ICHST=6  I START-STATE
ICHPR=7  I PAUSE/RESUME-STATE
ICHRE=10  IRESET-STATE
ICHED=11  I END-STATE
RETURN
END
SUBROUTINE ISPEC2
DATA CH,'1'..'2'..'3'..'4'..'5'..'6'..'7'..'8'..'9',
*0',LH,'/
INTEGER*2 ITEMS(13), IHR(2,1000)
REAL*4 LHR, LVOLT, MHR, MVOLT, LS, HRV(4,99)
COMMON UHR, UVOLT, LHR, LVOLT, MHR, MVOLT, IHR, COND,
*TTICK, IREP, ICOND, IFLAGL, LS, US, ZERO, ITEMS, HRV,
*ICHR, ICHSE, ICHST, ICHPR, ICHRE, ICHED, LUNCT, LUNFRN

PRINT OUT THE TABLE CONTAINS ABOVE INFORMATION

CALL CLEAR
WRITE(LUNCT, 90)
WRITE(LUNCT, 100) UHR, UVOLT, MHR, MVOLT, LHR, LVOLT,
*TTICK, IREP, IFLAGL, ICOND,
*ICHR, ICHSE, ICHST, ICHPR, ICHRE, ICHED

FORMAT( 100 fmt)
*HEART RATE VALUE WHEN THE PEN IS AT +20M', T60, F5.1,
**B/M'/
**HEART RATE VALUE WHEN THE PEN IS AT BASE LINE',
*T60, F5.1,' B/M'/
**HEART RATE VALUE WHEN THE PEN IS AT -20M', T60,
*F5.1,' B/M'/
**CORRESPONDING VOLTAGE', T60, F5.1,' DCV'/
**TICK'/
**HR-SAMPLING INTERVAL <1 TICK=1/60 SEC.'>, T62, I3,
**NUMBER OF REPLICATIOMS', T62, I3,' CYCLES'/
**STARTING/ENDING SIGNAL IS SUPPLIED YES=1 NO=0',
*T64, I1,'
**NUMBER OF EXPERIMENTAL CONDITIONS', T62, I3/
*/A/D CONVERTER CHANNEL ASSIGNMENT', T61, 'CHANNEL'/
**HR-DATA FROM POLYGRAPH <J6>', T63, I2/
**START-SWITCH', T63, I2/
**PAUSE/RESUME-SWITCH', T63, I2/
**RESET-SWITCH', T63, I2/
**END-SWITCH', T63, I2)

FORMAT( 90 fmt)
*HEART RATE VALUE WHEN THE PEN IS AT +20M', T60, F5.1,
**B/M'/
**HEART RATE VALUE WHEN THE PEN IS AT BASE LINE',
*T60, F5.1,' B/M'/
**HEART RATE VALUE WHEN THE PEN IS AT -20M', T60,
*F5.1,' B/M'/
**CORRESPONDING VOLTAGE', T60, F5.1,' DCV'/
**TICK'/
**HR-SAMPLING INTERVAL <1 TICK=1/60 SEC.'>, T62, I3,
**NUMBER OF REPLICATIOMS', T62, I3,' CYCLES'/
**STARTING/ENDING SIGNAL IS SUPPLIED YES=1 NO=0',
*T64, I1,'
**NUMBER OF EXPERIMENTAL CONDITIONS', T62, I3/
*/A/D CONVERTER CHANNEL ASSIGNMENT', T61, 'CHANNEL'/
**HR-DATA FROM POLYGRAPH <J6>', T63, I2/
**START-SWITCH', T63, I2/
**PAUSE/RESUME-SWITCH', T63, I2/
**RESET-SWITCH', T63, I2/
**END-SWITCH', T63, I2)

RETURN
END
SUBROUTINE ISPEC3 (ICONT, K)

LOGICAL*,1 CARD(60),CHA(12),COND(6)

IF (ISET(1), '11', '12', '13', '14', '15', '16', '17', '18', '9', '9', '9', '9')

INTEGER*,2 ITEMS, IHR(2,1000), YESNO2

REAL*4 LHR, LDOVLT, MHR, MUOVT, IS, HRV(4, 99)

COMMON LHR, LDOVLT, MHR, MUOVT, IS, HRV, COND

*ICHR, ICHF, ICHT, ICHPR, ICHRE, ICH00, LUNCRT, LUNPRN

WRITE(LUNCRT, 110)

WRITE(LUNCRT, 120) (CARD(I), I=1, 80)

READ(LUNCRT, 200) (CARD(I), I=1, 20)

FORMAT(10, )

FORMAT(10, )

DO 21 I=1, 80

DO 40 J=1, 12

IF (CARD(I), EQ, CHA(J)) GO TO 10

CONTINUE

WRITE(LUNCRT, 130) CARD(I)

FORMAT(10, )

FORMAT(10, )

GO TO 31

10 IF (J, GE, 11) GO TO 11

IFLAG=0

IF (J, EQ, 10) J=0

IF (ITEM, NE, 0) GO TO 12

IF (J, EQ, 0) IFLAG=-1

IF (ITEM, NE, 0) IFLAG=-2

ITEM=J

GO TO 13

12 IF (ITEM, EQ, ITEM*10+J)

IF (ITEM, GT, 13) OR (ITEM, LT, 1) GO TO 14

GO TO 13

IFLAG=1

13 IF (IFLAG, NE, 1) GO TO 21

IF (IFLAG, EQ, 1) GO TO 14

IF (ITEM, EQ, 0) GO TO 21

R=R+1

ITEM=K

IFLAG=0

ITEM=0

IF (R, GE, 13) GO TO 15

GO TO 21

WRITE(LUNCRT, 140) ITEM

FORMAT(10, )

ITEM=13

FORMAT(10, )

GO TO 21

WRITE(LUNCRT, 150) (CARD(L), L=I+1, 80)

FORMAT(10, )

GO TO 22
0064 21 CONTINUE
0065 22 CONTINUE
0066 WRITE(UNIT,159)
0067 159 FORMAT(' /* THE VALUES FOR THE ITEMS 1 - 3 ARE REAL
* NUMBERS, SUCH AS 12.3 /* I.E. MUST HAVE A DECIMAL POINT*/
* THE REST, ITEMS 4 - 13, ARE ALL INTEGER NUMBERS.*/
* I.E. MUST NOT HAVE "." */)
0068  NN=ISLEEP(0,0,5,0)
0069 IF(K.EQ.0) GO TO 91
0071  ICON=1
0072  RETURN
0073 30 ICON=0
0074  RETURN
0075  END
SUBROUTINE ISPEC4(K)
LOGICAL ISPEC(80), CHA(12), COND(6)
DATA CHA/"1", "2", "3", "4", "5", "6", "7", "8", "9",
          *0", "A", "B", "C", "D",
INTEGER ITEMS(13), IHR(2, 1000)
REAL UHR, LVOLT, MHR, MVOLT, LS, HRV(4, 99)
COMMON UHR, LVOLT, MHR, LVOLT, MHR, MVOLT, IHR, COND,
     *ITICK, IREP, ICOND, IFLAG1, LS, US, ZERO, ITEMS, HRV,
     *ICHHR, ICHEHR, ICHESE, ICHER, ICHEER, ICHED, LUNCRT, LUPRNR
تمع 0 TO 1 K
تمع 0 TO (301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313),
تمع ITEMS(I)

WRITE(LUNCRT, 160)
FORMAT(1020) UHR
GO TO 210
WRITE(LUNCRT, 161)
FORMAT(161) WHAT IS THE VOLTAGE THEN ?/
READ(LUNCRT, 210) LVOLT
GO TO 50
WRITE(LUNCRT, 162)
FORMAT(162) ENTER THE HR VALUE WHEN THE PEN IS AT BASE LINE'/
READ(LUNCRT, 210) MHR
GO TO 50
WRITE(LUNCRT, 163)
FORMAT(163) ENTER THE HR VALUE WHEN THE PEN IS AT -2CM'/
READ(LUNCRT, 210) MHR
WRITE(LUNCRT, 161)
READ(LUNCRT, 210) LVOLT
GO TO 50
WRITE(LUNCRT, 164)
FORMAT(164) ENTER THE DESIRED HR SAMPLING INTERVAL',
     *' IN TICKS <=1/60 SEC. >'/
READ(LUNCRT, 220) ITICK
GO TO 12
WRITE(LUNCRT, 165)
FORMAT(165) ENTER THE NO. OF REPLICATIONS IN AN',
     *EXPERIMENTAL CONDITION'/
READ(LUNCRT, 220) IREP
GO TO 50
WRITE(LUNCRT, 166)
FORMAT(166) TYPE 1 IF STARTING/ENDING SIGNAL IS SUPPLIED /
     *' OTHERWISE TYPE 0'/
READ(LUNCRT, 220) IFLAG1
GO TO 50
WRITE(LUNCRT, 167)
FORMAT(167) ENTER THE NO. OF EXPERIMENTAL CONDITIONS'/
READ(LUNCRT, 220) ICOND
GO TO 50
WRITE(LUNCRT, 168)
FORMAT(168) ENTER THE CHANNEL NO. FOR THE HR-INPUT'/
READ(LUNCRT, 220) ICHHR
GO TO 50
0050  309 WRITE(LUNIT,169)
0051  169 FORMAT( ' /' ENTER THE CHANNEL NO. FOR STARTING/ENDING',
0052  * SIGNAL/', )
0053      READ(LUNIT,220) ICHSE
0054  GO TO 50
0055  310 WRITE(LUNIT,170)
0056  170 FORMAT( ' /' ENTER THE CHANNEL NO. FOR START-SWITCH/', )
0057      READ(LUNIT,220) ICHST
0058  GO TO 50
0059  311 WRITE(LUNIT,171)
0060  171 FORMAT( ' /' ENTER THE CHANNEL NO. FOR PAUSE/RESUME-SWITCH/', )
0061      READ(LUNIT,220) ICHPR
0062  GO TO 50
0063  312 WRITE(LUNIT,172)
0064  172 FORMAT( ' /' ENTER THE CHANNEL NO. FOR RESET-SWITCH/', )
0065      READ(LUNIT,220) ICHR
0066  GO TO 50
0067  313 WRITE(LUNIT,173)
0068  173 FORMAT( ' /' ENTER THE CHANNEL NO. FOR END-SWITCH/', )
0069      READ(LUNIT,220) ICHED
0070  CONTINUE
0071  RETURN
0072  END
SUBROUTINE INTROO

1001 FORMAT(' THIS PROGRAM IS USED TO MEASURE HR AND HRV OF A',
* SUBJECT,
** IT IS ASSUMED THAT THE USER OF THIS PROGRAM IS FAMILIAR TO '/
** 1. HR AND HRV,'/
** 2. GRASS POLYGRAPH AND,'/
** 3. PDP-11/03 AND RT-11',/
** ' THIS PROGRAM CONSISTS OF THE FOLLOWING SECTIONS;' /
** ' INPUT-DATA SPECIFICATIONS SECTION'
** ' CALIBRATION SECTION'
** ' DATA-SAMPLING SECTION'
** ' IN THE FIRST SECTION, SPECIFICATIONS ON THE INPUT DATA',
** ' ARE DEFINED. IN CASE THE SPECIFICATIONS ARE DIFFERENT',
** ' FROM THE ONES YOU INTEND TO USE, YOU MUST REDEFINE THEM',
** ' IN THE SECOND SECTION, THE CALIBRATION OF THIS PROGRAM',
** ' IS PERFORMED. THE CALIBRATION OF GRASS POLYGRAPH IS A',
** ' PREREQUISITE FOR THIS SECTION',
** ' THE LAST SECTION IS FOR COLLECTING THE DATA. THIS IS',
** ' DONE BY USING THE INFORMATION WHICH HAS BEEN GIVEN IN THE',
** ' FIRST SECTION. THE PROGRAM CAN OBSERVE UP TO 1000 HEART',
** ' BEATS OR AT LEAST 8 MINUTES IN A CONTINUOUS RUN, WHEN THE',
** ' AVERAGE HEART RATE IS LESS THAN 120 BEATS PER MIN.' /
** ' IT WAS INTENDED TO WRITE THIS PROGRAM IN A STYLE, SO-CALLED',
** ' INTERACTIVE SYSTEM FOR USER CONVIENCE. ONCE THE PROGRAM',
** ' HAS BEEN STARTED TO EXECUTE, THE PROGRAM SHOULD BE CONTROLLED',
** ' BY THE CONTROLLER BUILT FOR THIS PROGRAM. THE USE OF KEY-BOARD',
** ' COMMANDS SUCH AS CTRL/C AND CTRL/A ETC. IS NOT RECOMMENDED',
** ' THE FUNCTION OF THE FOUR SWITCHES ON THE CONTROLLER IS',
** ' EXPLAIN BELOW', '/
1. START-SWITCH',
** ' ENABLES FOR THE PROGRAM TO START COLLECTING HR DATA',
** ' WHEN STARTING/ENDING SIGNAL IS SUPPOSED TO BE SUPPLIED',
** ' FROM ANOTHER SOURCE, PROGRAM WILL NOT START UNTIL THE',
** ' SIGNAL IS GIVEN. OTHERWISE PROGRAM',
** ' STARTS IMMEDIATELY', '/

RETURN

END
SUBROUTINE INTRO1

TYPE 120

FORMAT( ' 2. PAUSE/RESUME-SWITCH'
          ' WHEN THIS SWITCH IS AT THE PAUSE POSITION, THE'
          ' EXECUTION OF THE PROGRAM IS TEMPORARY HELD. WHEN THE '
          ' SWITCH IS REPOSITIONED, PROGRAM RESUMES ITS'
          ' EXECUTION. EXCESSIVE USE OF PAUSE CAUSES THE DIS-'
          ' CHARGE OF BATTERY.'//
          ' 3. RESET-SWITCH'
          ' IS TO DISCONTINUE THE EXECUTION OF THE PROGRAM FOR THE'
          ' RUN. THE DATA COLLECTED IN THE RUN WILL BE LOST.'//
          ' TO RE-START, PRESS THE START-SWITCH.'//
          ' 4. END-SWITCH'
          ' CAUSES TERMINATION FROM THE DATA-COLLECTION FOR THE'
          ' RUN. HR AND HRV FOR THE RUN WILL BE COMPUTED AND'
          ' STORED ON THE DISK. WHEN STARTING/ENDING SIGNAL IS '
          ' SUPPOSED TO BE SUPPLIED FROM ANOTHER SOURCE, PROGRAM'
          ' WILL NOT TERMINATES TILL THE SIGNAL IS GIVEN.'//
          ' TO USE THIS PROGRAM AS EFFECTIVE AS IT WAS DESIGNED'//
          ' THE FOLLOWING PROCEDURES MUST BE EXECUTED.'//
          ' 1. ASSIGN A NUMBER <LOGICAL UNIT NUMERR> TO THE CRT'
          ' TERMINAL AND ENTER THE NUMBER TO THIS PROGRAM AS LINCRT.'//
          ' 2. ASSIGN ANOTHER NUMBER <LOGICAL UNIT NUMBER> TO THE'
          ' PRINTER AND ENTER THIS NUMBER AS LUNPRN.'//
          ' HOWEVER, THESE LOGICAL UNIT NUMBERS MUST HAVE BEEN'
          ' ASSIGNED TO THE DEVICES <TT: AND LF:> BEFORE THEY ARE ENTERED '
          ' INTO THIS PROGRAM.'//
          ' IF YOU ARE READY TO ENTER THESE LINCRT AND LUNPRN'
          ' TYPE YES, IF NOT TYPE NO')

RETURN

END
SUBROUTINE INTRO2(LUNCRT)
WRITE(LUNCRT,162)
REWIND LUNCRT
END FILE LUNCRT
162 FORMAT(//' INPUT-DATA SPECIFICATIONS SECTION'/
     // ALL THE SPECIFICATIONS ARE PRESET IN THIS /
     // PROGRAM. HOWEVER, THEY MAY NOT BE SUITABLE FOR THE PURPOSE OF /
     // YOUR STUDY. IF THIS IS THE CASE, THEN YOU MUST REDEFINE /
     // THE SPECIFICATIONS. // /
     // SOMETIMES, DURING THE EXPERIMENT, IT MAY HAPPEN /
     // THAT IT IS NECESSARY TO CHANGE SOME OF THE SPECIFICATIONS. // /
     // IN SUCH A CASE, PROGRAM PROMPTS TO MAKE SUCH A REQUEST /
     // BETWEEN THE RUNS //)
RETURN
END
0001  SUBROUTINE INTRO3(LINCRT)
0002      WRITE(LINCRT,302)
0003      REWIND LINCRT
0004  END FILE LINCRT
0005  FORMAT('  */' 'CALIBRATION SECTION' '/
0006 * THIS SECTION IS FOR CALIBRATING THE SCALE FACTORS IN THE'
0007 * PROGRAM LOGIC WHICH CONVERTS INPUT ANALOG HR DATA IN TO'
0008 * DIGITAL HR VALUE. THIS PROCEDURE MUST BE PERFORMED AT THE'
0009 * BEGINNING OF THE EXPERIMENT AND WHENEVER THE GRASS POLYGRAPH'
0010 * HAS BEEN RECALIBRATED.' /
0011  RETURN
0012  END
SUBROUTINE INTRO4(RUNCRT)
WRITE(RUNCRT,140)

140 FORMAT(' /// DATA-SAMPLING SECTION''/
* /// IN THIS SECTION THE HR DATA IS ACTUALLY''/
* /// COLLECTED. AT THE BEGINNING OF EACH RUN <EXPERIMENTAL''/
* /// CONDITION, PROGRAM PROMPTS TO INPUT SUBJECT NUMBER AND''/
* /// RUN NUMBER. SUBJECT NUMBER IS USE TO IDENTIFY THE SUBJECTS''/
* /// AND THE NUMBER CAN BE 00 TO 99 INCLUSIVE. THE RUN NUMBER IS''/
* /// FOR RECORDING THE EXPERIMENTAL CONDITION. THE FORMAT FOR''/
* /// THE RUN NUMBER IS "AA", THEREFORE EXPERIMENTS WITH UP TO''/
* /// 999 CONDITIONS CAN BE HANDLED BY THIS PROGRAM. HOWEVER, WHEN''/
* /// THE NUMBER OF CONDITIONS IS LESS THAN 99, THE THIRD DIGIT''/
* /// CAN BE LEFT BLANK OR CAN BE FILLED WITH YOUR INITIAL. ''/
* /// THE DATA WILL BE STORED ON THE DISK WITH FILE NAME''/
* /// SXXXYY.DAT, WHEN THE RUN HAS BEEN COMPLETED. THESE''/
* /// X'S INDICATE THE SUBJECT NUMBER AND YY IS FOR THE RUN NUMBER''/
* /// EACH RUN <CONDITION> NUMBER MUST BE DIFFERENT FOR A SUBJECT''/
* /// GIVING <USING> THE SAME RUN NUMBER WILL RESULT''/
* /// IN Deleting THE DATA-FILE ON THE DISK WITH THE SAME FILE NAME''/
* /// TO AVOID THIS INCONVENIENCE <LOSING THE DATA FOR A CONDITION''/
* /// THE SIXTH COL. OF THE FILE NAME <THIRD "Y"> SHOULD BE CHANGED''/
* /// WHEN AN EXPERIMENTAL CONDITION IS REPEATED, OR WHEN A FILE''/
* /// WITH THE SAME FILE NAME IS ALREADY STORED ON THE DISK''/
* /// <AFTER THE EXPERIMENT, THE EXTENTION OF THE FILE''/
* /// NAMES "DAT" SHOULD BE CHANGED TO A UNIQUE EXTENTION NAME''/
* /// TO AVOID DELETING A FILE "ACCIDENTALLY''/
* /// AFTER THIS MESSAGE, THE PROGRAM SHOULD ONLY BE CONTROLLED''/
* /// BY THE CONTROLLER. AN ATTEMPT TO TERMINATE FROM THE RUN''/
* /// BY USING CTRL/C WILL RESULT IN LOSING THE DATA FOR THE RUN''/
* /// AND YOU WILL HAVE TO REDEFINE THE SPEC.'')
RETURN
END
SUBROUTINE ISTORE(IBEAT)
LOGICAL*1 COND(6)
INTEGER*2 GSIGN, GOLID, GOLHR, IHR(2,1000), ITEMS(13)
REAL*4 HRV(4,99), LHV, LVOLT, MHR, MVOLT, LS
COMMON LHRV, LHV, LVOLT, MHR, MVOLT, LS, COND,
*TRICK, IREP, ICOND, IFLAG1, RS, US, ZERO, ITEMS, HRV,
*IHR, ICHSR, ICHST, ICHPR, ICHRE, ICHED, LUNCR, LUNPRN
WRITE(LUNPRN,1100) (COND(I), I=1,6)
1100   10(' BEAT CYC BR'),/}
DO 1110 I=1,IBEAT,10
IF(I+9.LE.IBEAT) GO TO 1111
1111   II=I+9
WRITE(LUNPRN,1113) (J,HRV(1,J),IHR(2,J),J=I,II)
1113   CONTINUE
REINDEX LUNPRN
WRITE(LUNPRN,1120)
1120   'ITEM',5(' CYC. VALUE '//' )
DO 1122 I=1,IREP,5
IF(I+4.LE.IREP) GO TO 1122
II=IREP
GO TO 1114
1122   II=I+4
CONTINUE
WRITE(LUNPRN,1118) (J,HRV(1,J),J=I,II)
WRITE(LUNPRN,1124) (J,HRV(4,J),J=I,II)
WRITE(LUNPRN,1126) (J,HRV(4,J),J=I,II)
1118   FORMAT(' NEUM',5(4,IX,F16.2))
1124   FORMAT(' HRD',5(4,IX,F16.0))
1126   FORMAT(' HR ',5(4,IX,F16.2))
WRITE(LUNPRN,1119)
REINDEX LUNPRN
SUBROUTINE IEXAM(IBAT)
  LOGICAL*1 COND(6)
  INTEGER*2 OSIGN,OLDHR,IHR(2,1000),ITEMS(13)
  REAL*4 HRV(4,99),LHR,LVOLT,MR,NUVOLT,LS
  COMMON UHR,LVOLT,LIR,LVOLT,MIR,NUVOLT,THR,COND,
     *TICK, IREP, ICOND, IFLAG, LS, LS, ZERO, ITEMS, HRV,
     *ICHHR, ICSE, ICST, ICHPR, ICHRE, ICRED, LUNCAT, LUNFRN

  ICYC=0
  IB=0
  DO 999 I=1,IBAT
     IB=IB+1
  999 IF(IHR(1,I).EQ.ICYC) GO TO 900
  ICYC=ICYC+1
  OLDHR=IHR(2,I)
  OSIGN=0
  HR=OLHR*0.1
  HRD=HR
  IFLAG=0
  GO TO 960
  900 NEWHR=IHR(2,I)
  HRD=HR-NEWHR
  IF(ILAG.EQ.1) GO TO 920
  HRD=HRD-910,960,910
  IF(ILAG.EQ.1) GO TO 910
  910 IF(HRD)*930,960,940
  920 IF(HRD)*930,960,940
  930 NSIGN=-1
  HRV(1,ICYC)=HRV(1,ICYC)-HRD
  GO TO 960
  940 NSIGN=1
  950 IF(OSIGN.EQ.0) GO TO 952
  952 HRV(2,ICYC)=HRV(2,ICYC)+HRD
  OSIGN=NSIGN
  960 HRV(4,ICYC)=HRV(4,ICYC)+HR
  IF(I.EQ.IBAT) GO TO 970
  IF(IHR(1,I).EQ.IHR(1,I+1)) GO TO 999
  970 IF(HRV(2,ICYC).EQ.0.0) GO TO 980
  980 HRV(4,ICYC)=HRV(4,ICYC)/IB
  IB=0
  999 CONTINUE
  RETURN
END
SUBROUTINE JEXAM2 (IBEAT)

INTEGER*2 OSDI, OLDHR, IHR(2,1000), ITEMS(13)
REAL*4 HRV(4,99), LHR, LVOLT, MHR, MVOLT, IS
COMMON UHR, UVOLT, LHR, LVOLT, MHR, MVOLT, IHR, COND,
* ICYC, IREP, ICOND, IFLAG, IS, US, ZERO, ITEMS, HRV,
* IHRS, IHRE, IHSE, ICHS, ICPR, ICHE, IHOD, LUNIT, LUNFN

ICYC = 0
IBE = 0
HRV(1,1) = 0.
HRV(2,1) = 0.
HRV(3,1) = 0.
HRV(4,1) = 0.
DO 999 I = 1, IBEAT
IBE = IBE + 1
999 IF (ICYC.EQ.1) GO TO 900
ICYC = ICYC + 1
OLDHR = IHR(2,I)
OSIGN = 0
HR = OLDHR * 0.1
HR = HR
IFLAG = 0
960 GO TO 960
900 NEWHR = IHR(2,I)
HR = NEWHR * 0.1
HR = HR + HR
IF (IFLAG.EQ.1) GO TO 920
IF (HRD) 910,960,910
910 HRD = 910, 960, 910
920 IFLAG = IFLAG + 1
930 IF (HRD) 930, 960, 940
930 NSIGN = 1
HRV(1, ICYC) = HRV(1, ICYC) - HRQ
933 GO TO 950
934 NSIGN = -1
950 IF (OSIGN .NE. NSIGN) HRV(2, ICYC) = HRV(2, ICYC) + 1.
939 OSIGN = NSIGN
940 OLDHR = NEWHR
941 HR = HR
960 HRV(4, ICYC) = HRV(4, ICYC) + HR
943 IF (IBEAT .EQ. 1) GO TO 970
945 GO TO 999
970 IF (HRV(2, ICYC).EQ.0.0) GO TO 980
970 HRV(3, ICYC) = HRV(1, ICYC) / HRV(2, ICYC)
948 HRV(4, ICYC) = HRV(4, ICYC) / LBN
950 CONTINUE
951 WRITE (LUNFN, 1) (HRV(I, ICYC), I = 1, 4)
1 FORMAT ('', 'OVERALL NELM. ', T20, F16.2/
*** DENO. ', T20, F16.0/
*** HR. ', T20, F16.5/
*** HR ', T20, F16.4)
953 REWIND LUNFN
954 RETURN
955 END
SUBROUTINE LOOP(IBEAT)
INTEGER*4 JTIME
INTEGER*2 IHR(2,1000), ITEMS(13), YESNO2, ON, OFF,
*SWITCH, OLDHR
LOGICAL*1 COND(6)
REAL*4 IHR, UVOLT, MHR, MVOLT, LS, HRV(4,99)
COMMON IHR, UVOLT, IHR, MVOLT, MHR, IHR, COND,
*ITICK, IREP, ICOND, IFLAG1, LS, US, ZERO, ITEMS, HRV,
*ICHR, ICHRE, ICHST, ICHPR, ICHRE, ICHED, LUNCRT, LUNPRN

CALL IFILE
WRITE(LUNCRT,701)
FORMAT('""') TO START SAMPLING PRESS START SWITCH"")
CALL INITIA
ON=1
OFF=1
IFLAG=0
IFLAGS=0
IFLAGE=0
IFLAGS=0
LASTSE=OFF
IBEAT=0
OLDH=0
ID=0
IHR=0
ISTAP=0
IF(IFLAG1.EQ.0) ID=1
CALL NAP (ICHST, ZERO)
IF(IFLAG1.EQ.1) GO TO 720
IF(IFLAGS.EQ.1) GO TO 708
IFLAGS=1
CALL NAP (ICHST, ZERO)
IF((SWITCH(ICHST, ZERO),EQ.OFF) GO TO 710
IF(LASTSE.EQ.ON) GO TO 720
LASTSE=ON
ID=ID+1
IF(ID.GT.IREP) GO TO 900
IF(IFLAG-EQ.1) GO TO 900
GO TO 720
LASTSE=OFF
GO TO 720
IFLAG=0
IF((SWITCH(ICHST, ZERO).EQ.ON) GO TO 718
IF((SWITCH(ICHST, ZERO).EQ.OFF) GO TO 730
WRITE(LUNCRT,200)
FORMAT("A RESET REQUEST HAS BEEN ACCEPTED")
WRITE(LUNCRT,201)
FORMAT("SAME EXPERIMENTAL CONDITION? <YES OR NO>")
IF(YESNO2(LUNCRT)) 722,690,725
WRITE(LUNCRT,203)
FORMAT("" TO RESTART, PRESS START-SWITCH")
GO TO 700
IF((SWITCH(ICHST, ZERO).EQ.ON) IFLAG=1
IF(IFLAG.EQ.1) AND (IFLAG1.EQ.0) GO TO 900
IF(IFLAG.EQ.1) GO TO 750
IFLAG=1
CALL GTIM(JTIME)
CALL CVTIM(JTIME, IH, IM, IS, IT)
    790 IF(IT=IT+ITICK)
    069 IF(IT.LE.59) GO TO 800
    071 IT=IT+60
    072 IS=IS+1
    073 IF(IS.LE.59) GO TO 800
    075 IS=0
    076 IM=IM+1
    077 IF(IM.LE.59) GO TO 800
    079 IH=IH+1
    080 IT=0
    081 IF(IT.LE.23) GO TO 800
    083 IH=0
    084 800 JTIME=JTIME+1
    085 DIFF=IAAC(ICHRR)-ZERD
    086 IF(DIFF)804,803,802
    087 802 HR=HR-DIFF*DS
    088 GO TO 805
    089 803 HR=HR
    090 GO TO 805
    091 804 HR=HR+DIFF*US
    092 805 NEWHR=(HR+0.05)*10.0
    093 IF(IABS(OLDHR-NEWHR).GT.90) GO TO 812
    095 811 ICOUNT=ICOUNT+1
    096 IAHR=IAHR+NEWHR
    097 NEWHR=IAHR/ICOUNT
    098 ELAPSD=(TICK+1.5)*ICOUNT/60.
    099 CHR=CHR+0.1
    100 LIMIT=60./CHR
    101 IF(ELAPSD.LE.XLIMIT) GO TO 705
    102 812 IBEAT=IBEAT+1
    103 IF(IBEAT.LE.999) ISTOP=1
    105 IAHR=0
    107 ICOUNT=0
    108 ISTOP=0
    109 820 IHR(IHR,IHR)=ID
    110 IHR(2,IHR)=NEWHR
    111 OLDHR=NEWHR
    112 WRITE(LUNCRT,1) ID,IBEAT,HR
    113 1 FORMAT(' ',2I4,4F8.0)
    114 IF(ISTOP.EQ.1) GO TO 850
    116 GO TO 705
    117 850 IBEAT=IBEAT+1
    118 WRITE(LUNCRT,860)IBEAT
    119 860 FORMAT(' "AI", NO. OF BEATS HAS REACHED TO 999."
    120 * PROGRAM STOPED COLLECTING DATA. */
    120 900 RETURN
    121 END
```
FUNCTION SWITCH(ICHAN, ZERO)
INTEGER*2 SWITCH
SWITCH=-1
IF(IAEC(ICHAN).GE.ZERO+500.) SWITCH=1
RETURN
END
```
0001 SUBROUTINE IASS
0002 INTEGER*2 IHR(2, 1000), ITEMS(13)
0003 LOGICAL*1 COND(6), EXTENT(4)
0004 REAL*4 LHR, HRV(4, 99), LVOLT, MVOLT, LS
0005 COMMON UHR, UVOLT, LHR, LVOLT, MHR, MVOLT, IHR, COND,
0006 TTRACK, TREP, ICOND, IFLAG1, LS, US, ZERO, ITEMS, HRV,
0007 IOHR, IOISE, IOISE, IOHPR, IOHRE, IOHRED, LUNCRT, LUNPRN
0008 TYPE 131
0009 131 FORMAT (' /' ENTER LUNCRT')
0010 132 FORMAT(12)
0011 133 FORMAT (' /' ENTER LUNPRN')
0012 ACCEPT 134, LUNPRN
0013 134 FORMAT(12)
0014 TYPE 135
0015 135 FORMAT (' /' AFTER THIS MESSAGE THE CONTROL OF THIS',
0016 PROGRAM IS MOVED TO THE CRT. '/' BYE' //')
0017 RETURN
0018 END
SUBROUTINE NAP(ICHAN, ZERO)
IF(IADC(ICHAN) .LT. ZERO .AND. 000.) GO TO 1
RETURN
END
SUBROUTINE YESNO(ANSWER)
ANSWER=1 WHEN ANSWER IS YES
ANSWER=0 WHEN ANSWER IS NO
ANSWER=-1 WHEN ANSWER IS INVALID

INTEGER*2 ANSWER,YESNO
LOGICAL*1 ANS(I),Y,E,S,N,O,BLANK
DATA Y,'Y'/,E,'E'/,S,'S'/,N,'N'/,O,'O'/,BLANK/' ','IBELL/9199/
ANS(I)=BLANK
ACCEPT 201,(ANS(I),I=1,10)

FORMAT(10A1)
DO 1 I=1,10
IF(ANS(I).EQ.BLANK) GO TO 1
* GO TO 2
* .AND.(ANS(I+3).EQ.BLANK)) GO TO 3
GO TO 200
CONTINUE

TYPE 102,IBELL,(ANS(I),I=1,10)
FORMAT(' ',A1/,',10A1,':INVALID')
ANSWER=-1.
RETURN
2 ANSWER=0.
RETURN
3 ANSWER=1.
RETURN
END
FUNCTION YESNO2(LINECRT) 
INTEGER*2 YESNO2  
LOGICAL*1 ANS(11),Y,E,S,N,O,BLANK  
DINP Y/Y',E/E',S/S',N/N',O/O',BLANK/ ';' ,IBELL/8199/  
ANS(11)=BLANK  
READ(LINECRT,201) (ANS(I),I=1,10)  
201 FORMAT(10A1)  
DO 1 I=1,10  
1 IF(ANS(I).EQ.BLANK) GO TO 1  
* ) GO TO 2  
* .AND.(ANS(I+3).EQ.BLANK)) GO TO 3  
GO TO 200 
1 CONTINUE  
200 TYPE 102,IBELL,(ANS(I1),I=1,10)  
102 FORMAT(' ',A1/1', ' ,IOAL,' : 'INVALID')  
YESNO2=-1.  
RETURN 
2 YESNO2=0.  
RETURN 
3 YESNO2=1.  
RETURN 
END
SUBROUTINE INITMA

INTEGER*2 IHR(2,1000), ITEMS(13), YESNO2, ON, OFF, YESNO, ANS,
*SWITCH, OLDHR

LOGICAL*1 COND(6), EXIST(4)

REAL*4 LHR, LVOLT, MHR, MVOLT, LS, HRV(4,99)

COMMON UHR, UVOLT, LHR, LVOLT, MHR, MVOLT, IHR, COND,
*TICK, IREP, ICOND, IFLAG1, LS, US, ZERO, ITEMS, HRV,
*ICHR, ICHE, ICHST, ICHPR, ICHR, ICHED, LUNCRT, LUNPRN

DO 2 J=1, 99
HRV(I,J)=0.0
2 CONTINUE

DO 3 I=1, 2
3 CONTINUE

RETURN
END
APPENDIX E.2

The Computer Program for The PDP 11/03 To
Communicate with WYLBUR
PROGRAM WILBUR
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1,RBUF1,XCSR1,XBUF1,RCSR2,RBUF2,XCSR2,XBUF2,READY,
*NEWCHA,
LOGICAL*1 WHAT(18),WNAME(20),FET(10)
COMMON/BIG/ FILE
DATA FET/'F','E','T','r','a','r','r','C','O','i','y','e','u','m','e','a','n','f','?'/
*WHAT/'w','w','a','s','m','o','c','i','y','e','u','m','e','a','n','f','?'/
C
CALL COMDAT
900 TESCS=0
100 CALL WILLOOP(IGOTO)
101 GO TO(1100,1050,3000,4000,5000,6000,1010,1200) IGOTO
110 DO 1015 I=1,18
115 NEWCHA=WNAME(I)
120 CALL SNDCRT
125 CONTINUE
130 NEWCHA="7"
135 CALL SNDCRT
140 NEWCHA="215"
145 CALL SNDWL
150 GO TO 900
155 TESCS=1
160 NEWCHA="012"
170 CALL SNDCRT
175 NEWCHA="215"
180 CALL SNDCRT
185 CALL IPOKER(RCSR1,"100")
190 CALL IASSIGN(1,-1)
200 CALL IPOKER(RCSR1,0)
IF(TESCS.NE.0) GO TO 2000
210 CALL RCV
220 GO TO 900
C
230 CALL SEND
240 GO TO 900
C
250 CALL ACC
260 GO TO 900
C
270 GO TO 3010 I=1,10
280 NEWCHA=FET(I)
290 CALL SNDWL
300 CALL SNDCRT
310 CONTINUE
320 I=I+1
330 CALL FMWL
340 CALL SNDCRT
350 IF(NEWCHA.EQ."21") GO TO 3030
360 I=I+1
370 GO TO 3020
380 IF(I.GT.6) GO TO 900
390 NEWCHA="314"
CALL SNDCRT
CALL SNDWYL
NEWCHA="215"
CALL SNDCRT
CALL SNDWYL
GO TO 900

C
4000 IF(NOCHA.EQ.0) CALL VNAM(WNAME, 20, NOCHA)
CALL G0(WNAME, 20, NOCHA)
GO TO 3000

C
5000 CALL VNAM(WNAME, 20, NOCHA)
GO TO 900

C
6000 IF(NOCHA.EQ.0) CALL VNAM(WNAME, 20, NOCHA)
CALL USE(WNAME, 20, NOCHA)
GO TO 900
END
C
0001 SUBROUTINE NAP
0002 IMPLICIT INTEGER (R,X)
0003 COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
0004 , NEMOF
0005 1 CALL FRMNL
0006 IF (NEXCHX.EQ. "21") GO TO 2
0007 CALL SNDCRT
0008 GO TO 1
0009 2 RETURN
0010 END
SUBROUTINE SMDCRT

IMPLICIT INTEGER (R,X)

COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,

*NEWCPA

IF (IPEEKB(XCSR1).LT.READY) GO TO 10

CALL IPOKEB(XBUF1, NEWCPA)

RETURN

END
SUBROUTINE SNDWYL
IMPLICIT INTEGER (R,X)
COMMON RCSR1,RBUF1,XCSR1,XBUMP1,RCSP2,RBUF2,XCSR2,XBUF2,READY,
*NEWCHA

IF(IPEEK(XCSR2).LT.READY) GO TO 60  ! IF WYL NOT READY LOOP
CALL IPOKEB(XBUF2,NEWCHA)  ! SEND THE CHAR. TO WYL.
RETURN
END
SUBROUTINE FRMVL
IMPLICIT INTEGER (R,X)
COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
*NEWCHA
IF (IPEEKB(RCSR2).LT.READY) GO TO 10 IF WYL HAS NOT SENT
NEWCHA=IPEEKB(RBUF2) YES THEN READ IT
RETURN
END
SUBROUTINE WYLOOP (IGOTO)
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSRI, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
* NEWCHA
LOGICAL *1 ESC(4)
DATA ESC/ 'E', 'S', 'C', ' ' /
CTRL=/ '023'
CTRLL='004'
LP='012'
CR='215'
ESC='233'
A='301'
F='306'
G='307'
L='314'
N='316'
R='322'
S='323'
U='325'
C
CALL IPOKE(RCSR1, 0)
900 IF (IPEEK(RCSR1).LT.READY) GO TO 950
922 NEWCHA = IPEEK(RBUF1)
923 IF (NEWCHA .EQ. CTRL) CALL EXIT
925 IF (NEWCHA .EQ. CTRLL) GO TO 990
927 IF (NEWCHA .EQ. ESC) GO TO 1000
929 IF (NEWCHA .EQ. *377) NEWCHA='210
331 CALL SNDCRT
332 CALL SNDWYL
933 IF (IPEEK(RCSR2).LT.READY) GO TO 900
935 NEWCHA = IPEEK(RBUF2)
336 CALL SNDCRT
937 GO TO 900
C
990 NEWCHA = CTRLL
992 DO 995 I=1, 5
994 CALL SNDWYL
995 CONTINUE
997 GO TO 900
C
1000 IF (IPEEK(RCSR1).LT.READY) GO TO 1000
1002 NEWCHA = IPEEK(RBUF1)
1004 IF (NEWCHA .EQ. A) GO TO 1200
1006 LSTCHA = NEWCHA
1008 DO 1005 I=1, 4
1010 NEWCHA = ESC(I)
1012 CALL SNDCRT
1014 CONTINUE
1016 LSTCHA = NEWCHA
1018 CONTINUE
1020 CALL SNDCRT
1022 NEWCHA = LF
1024 CALL SNDCRT
1026 NEWCHA = CR
1028 CALL SNDCRT
1030 NEWCHA = LSTCHA
-137-
0060  IGOTO=0
0061  IF(NEWCHA.EQ.R) IGOTO=1
0063  IF(NEWCHA.EQ.S) IGOTO=2
0065  IF(NEWCHA.EQ.F) IGOTO=3
0067  IF(NEWCHA.EQ.Q) IGOTO=4
0069  IF(NEWCHA.EQ.N) IGOTO=5
0071  IF(NEWCHA.EQ.U) IGOTO=6
0073  IF(IGOTO.EQ.0) IGOTO=7
0075  RETURN
0076   1200  IGOTO=8
0077  RETURN
0078  END
SUBROUTINE COMDAT
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
*NEQCHR
RCSR1='177560
RBUF1='177564
XCSR1='177564
XBUF1='177566
RCSR2='175610
RBUF2='175612
XCSR2='175614
XBUF2='175616
READY='200
RETURN
END
SUBROUTINE GD(WNAME, I1, NOCHA)

IMPLICIT INTEGER (C,N,R,X,Q,S)

COMMON RCSR1, RBUF1, RCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
*NEWCHA

LOGICAL*1 WNAME(I1), RUN(8), SAV(4), REP(5)

DATA RUN/ 'R', 'U', 'Q', 'O', 'H', 'O', 'L', '215/,
*SAV/ 'S', 'A', 'V', 'O', 'P', '215/
*REP/ 'R', 'E', 'P', '215/

DO 4010 I=1,8

NEWCHA=RUN(I)

CALL SNDCRT

CALL SNDWYL

4010 CONTINUE

CALL NAP

DO 4020 I=1,4

NEWCHA=SAV(I)

CALL SNDCRT

CALL SNDWYL

4020 CONTINUE

DO 4030 I=1,NOCHA

NEWCHA=WNAME(I)

CALL SNDCRT

CALL SNDWYL

4030 CONTINUE

DO 4040 I=1,5

NEWCHA=REP(I)

CALL SNDCRT

CALL SNDWYL

4040 CONTINUE

CALL NAP

RETURN

END
SUBROUTINE USEWNAME(I2,NOCHA)

IMPLICIT INTEGER (C,N,R,X,Q,S)

COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,

*NEWCHA

LOGICAL*1 WNAME(I2), U(4), CLE(4)

DATA U/*'U', 'S', 'E', 'E'/,

*CLE/*'C', 'L', 'E', '215'/

DO 6010 I = 1, 4

NEWCHA = U(I)

CALL SNDWR

6010 CONTINUE

DO 6020 I = 1, NOCHA

NEWCHA = WNAME(I)

CALL SNDWR

6020 CONTINUE

DO 6030 I = 1, 4

NEWCHA = CLE(I)

CALL SNDWR

6030 CONTINUE

CALL NAP

NEWCHA = "114"

CALL SNDWR

NEWCHA = "215"

CALL SNDWR

RETURN

END
SUBROUTINE WMAM(WNAME, I2, NOCHA)
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY, *NEWCHA
LOGICAL*1 NAME(I8), WNAME(I2)
                 'Y', 'A', 'M', 'F', 'L', 'H', 'I', 'C', 'N', 'H', 'E',
                 'Y', 'A', 'M', 'F', 'L', 'H', 'I', 'C', 'N', 'H', 'E',
                 'Y', 'A', 'M', 'F', 'L', 'H', 'I', 'C', 'N', 'H', 'E',
                 'Y', 'A', 'M', 'F', 'L', 'H', 'I', 'C', 'N', 'H', 'E',
                 'Y', 'A', 'M', 'F', 'L', 'H', 'I', 'C', 'N', 'H', 'E'
NEWCHA = '212
CALL SNDCRT
NEWCHA = '215
CALL SNDCRT
DD 5010 I = i, 18
NEWCHA = NAME(I)
CALL SNDCRT
CONTINUE
5010 CONTINUE
5020 IF (IPEEKB(RCSR1).LT.READY) GO TO 5020
NEWCHA = IPEEKB(RBUF1)
IF (NEWCHA .EQ. '215) GO TO 5030
WNAME(NOCHA) = NEWCHA
NOCHA = NOCHA + 1
CALL SNDCRT
5030 WNAME(NOCHA) = '240
NEWCHA = '212
CALL SNDCRT
NEWCHA = '215
CALL SNDCRT
CALL SNDWYL
CALL SNAP
RETURN
END
SUBROUTINE SEND
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
*NEWCH

IWORD=0
IADDR=IADDR(IWORD)
IADDR=IADDR+1
IRBC=1
NEWCH='103
CALL SNDCRT
NEWCH='215
CALL SNDWYL
CALL NAP
DO 2100 I=1, 11000
READ(1,IREC) IWORD
IF(IWORD.EQ.0) GO TO 2200
NEWCH=IPEEK(IADDR)
CALL SNDCRT
CALL SNDWYL
IF(NEWCH.EQ."12") CALL NAP
NEWCH=IPEEK(IADDR)
IF(NEWCH.EQ.0) GO TO 2200
CALL SNDCRT
CALL SNDWYL
IF(NEWCH.EQ."12") CALL NAP
2100 CONTINUE
2200 NEWCH='215
CALL SNDWYL
CALL SNDCRT
CALL NAP
CALL CLOSE(1)
NEWCH='4
CALL SNDWYL
RETURN
END
SUBROUTINE RCV
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1,RBUF1,XCSR1,XBUF1,RCSR2,RRBUF2,XCSR2,XXBUF2,READY,
    *NEWCHA
INTEGER*2 FILE(10500)
COMMON/BIG/FILE
LOGICAL*1 MESSG1(6)
IZERO=0
IWORD=0
IADRSW=IADDR(IWORD)
IADRSB=IADRSW+1
DO 1 I=1,6
    NEWCHA=MESSG1(I)
1 CONTINUE
C
LREC=1
ICOUNT=1
CALL FRMWHL
IF(NEWCHA.EQ."215") GO TO 3
IF(NEWCHA.EQ."012") GO TO 3
GO TO 110
CALL SNDCRT
GO TO 2
GO TO 300
CALL FRMWHL
IF(LSTCHA.EQ."012.AND.NEWCHA.EQ."077") GO TO 300
ICOUNT=ICOUNT-1
IF(ICOUNT.EQ.-1) GO TO 200
CALL IPOKE(IADRSW,LSTCHA)
CALL IPOKE(IADRSB,LSTCHA)
FILE(IREC)=IWORD
LREC=LREC+1
LSTCHA=NEWCHA
CALL SNDCRT
GO TO 100
IEVEN=0
IF(ICOUNT.EQ.1) GO TO 310
CALL IPOKE(IADRSW,LSTCHA)
CALL IPOKE(IADRSB,0)
FILE(IREC)=IWORD
LREC=LREC+1
IEVEN=1
310 IREC=1
KREC=LREC-1
KKREC=KREC+256
DEFINE FILE 1 (KKREC,1,U,IREC)
DO 350 I=1,KREC
WRITE(*,1)IREC FILE(I)
CONTINUE
NOC=KKREC+2
IF(IEVEN.EQ.1) NOC=NOC-1
350 TYPE=300,NOC
FORMAT("0","NO. OF CHARACTERS TRANSFERRED : ",I5,
     *<includes CR and LF>")
IREST = 257 - MOD (IREC, 256)
DO 400 I = 1, IREST
WRITE (1, *IREC*) IZERO
CONTINUE
CALL CLOSE (1)
NEWCHA = "212"
CALL SNDCHR
NEWCHA = "215"
CALL SNDCHR
NEWCHA = "215"
CALL SNDWYL
CALL NAP
RETURN
END
SUBROUTINE ACC
IMPLICIT INTEGER (C,N,R,X,Q,S)
COMMON RCSR1, RBUF1, XCSR1, XBUF1, RCSR2, RBUF2, XCSR2, XBUF2, READY,
* NEWCHA
DATA ACC, KEY(4), VOL(15), TER(4), TIM(10),
*TER/, 13, 60, 60, 015/,
*VOL/, S, E, T, O, N, I, M, S, K, 60, 63, 015/,
*TIM/, S, E, T, O, N, I, M, 015/,
NEWCHA=ACC(I)
DO 1210 I=1,11
CONTINUE
CALL SNDWL
1200 DO 1230 I=1,4
NEWCHA=KEY(I)
CALL SNDWL
1230 CONTINUE
CALL NAP
DO 1240 I=1,4
NEWCHA=TER(I)
CALL SNDWL
CALL SNDCRT
1240 CONTINUE
CALL NAP
DO 1250 I=1,15
NEWCHA=VOL(I)
CALL SNDWL
CALL SNDCRT
1250 CONTINUE
CALL NAP
DO 1260 I=1,10
NEWCHA=TIM(I)
CALL SNDWL
CALL SNDCRT
1260 CONTINUE
RETURN
END
APPENDIX F

Tables for The Heart Rate analysis

1. Standardized Heart Rate Data
2. The Results of The Analysis of Variance for HR
3. The Results of The analysis of variance for HR After insignificant factors have been pooled
4. The Results of The Analysis of Variance Using Factors DIS and CLE
5. The Results of The Analysis of Variance for The model with SUB AND DIS
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ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS LEVELS VALUES
SUB 9 1 2 3 4 5 6 7 8 9
TD 4 10.0727 5.116119 6.338511 8.850307
AL 3 0 30 60
AR 3 0 30 60

NUMBER OF OBSERVATIONS IN DATA SET = 324

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: HR

SOURCE DF SUM OF SQUARES MEAN SQUARE
MODEL 71 59272.43006174 834.82295862
ERROR 252 163362.31833333 648.26316799
CORRECTED TOTAL 323 222634.74839507

MODEL F = 1.29 PR > F = 0.0815

R-SQUARE C.V. STD DEV HR MEAN
0.266232 50.2287 25.46101271 50.69012346

SOURCE DF ANOVA SS F VALUE PR > F
SUB 8 23231.11672840 4.48 0.0001
TD 3 9855.76469137 5.07 0.0022
SUB*TD 24 13459.84930863 0.87 0.6499
AL 7 155.60598766 0.12 0.8870
SUB*AL 16 7500.93234567 0.72 0.7695
AR 2 290.42302470 0.22 0.7995
SUB*AR 16 4779.34697530 0.46 0.9632
ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

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NUMBER OF OBSERVATIONS IN DATA SET = 324

STATISTICAL ANALYSIS SYSTEM

0:55 SATURDAY, JUNE 12, 1982

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: HR

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MODEL F = 4.95
PR > F = 0.0001

R-SQUARE      C.V.         STD DEV   HR MEAN
0.148615      48.6249      24.64802659 50.69012346

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<td>TD</td>
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<td>9855.76469137</td>
<td>5.41 0.0014</td>
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**STATISTICAL ANALYSIS SYSTEM**

0:55 SATURDAY, JUNE 12, 1982

**ANALYSIS OF VARIANCE PROCEDURE**

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE HR**

Means with the same letter are not significantly different.

**ALPHA LEVEL=.05**

**DF=312**

**MS=607.525**

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ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

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<td>CLE</td>
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NUMBER OF OBSERVATIONS IN DATA SET = 324

STATISTICAL ANALYSIS SYSTEM 2
1:04 SATURDAY, JUNE 12, 1982

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: HR

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MODEL F = 2.18  PR > F' = 0.0003

R-SQUARE 0.209072  C.V. 48.7804  STD DEV 24.72684289  HR MEAN 50.69012346

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ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

CLASS LEVELS VALUES
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DIS 2 150 350

NUMBER OF OBSERVATIONS IN DATA SET = 324

STATISTICAL ANALYSIS SYSTEM 2
1:15 SATURDAY, JUNE 12, 1982

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: HR

SOURCE DF SUM OF SQUARES MEAN SQUARE
MODEL 9 32657.36907408 3628.59656379
ERRQR 314 189977.37932098 605.02350102
CORRECTED TOTAL 323 222634.74839507

MODEL F = 6.00 PR > F = 0.0001

R-SQUARE C.V. STD DEV HR MEAN
0.146686 48.5247 24.59722547 50.69012346

SOURCE DF ANOVA SS F VALUE PR > F
SUB 8 23231.11672840 4.80 0.0001
DIS 1 9426.25234568 15.58 0.0001

-153-
ANALYSIS OF VARIANCE PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE HR

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

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ALPHA LEVEL = .05       DF = 314       MS = 605.024
APPENDIX G.1

The Results of The Analysis of Variance for The HRVI
with All The Main Effects
DATA;
  INPUT CNDTN SUB AL AR DIS CLE;
    X=2.*DIS/CLE;  
    TD=LOG2(X);
  RETAIN SUB' AL AR DIS CLE TD;
  DO I=1 TO 15;
    INPUT R L @@;
    R=L*100.0;
    IF L GE R THEN PT=L;
    IF L LT R THEN PT=R;
  OUTPUT;
  END;
  DROP I X L'R;
CARDS;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
      REACHED PAST THE END OF A LINE.
NOTE: DATA SET WORK.DATA1 HAS 4860 OBSERVATIONS AND 8 VARIABLES.
519 OBS/TRK
NOTE: THE DATA STATEMENT USED 4.53 SECONDS AND 160K.

PROC SORT;
  BY SUB AL AR DIS CLE;
NOTE: DATA SET WORK.DATA1 HAS 4860 OBSERVATIONS AND 8 VARIABLES.
519 OBS/TRK
NOTE: THE PROCEDURE SORT USED 3.85 SECONDS AND 282K.

PROC MEANS NOPRINT;
  VAR PT;
  BY SUB AL AR DIS CLE;
  OUTPUT OUT=DATA2
  MEAN=MEANPT;
  ID SUB AL AR DIS CLE;
NOTE: DATA SET WORK.DATA2 HAS 324 OBSERVATIONS AND 11 VARIABLES.
141 OBS/TRK
NOTE: THE PROCEDURE MEANS USED 3.00 SECONDS AND 164K.

PROC SORT;
  BY SUB AL AR DIS CLE;
NOTE: DATA SET WORK.DATA2 HAS 324 OBSERVATIONS AND 11 VARIABLES.
141 OBS/TRK
NOTE: THE PROCEDURE SORT USED 0.75 SECONDS AND 282K.

DATA DATA3;
  INPUT CNDTN AL AR DIS CLE;
  TD=LOG2(2.0*DIS/CLE);
  DO SUB=1 TO 9;
    INPUT HRV @@;
  OUTPUT;
  END;
CARDS;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
      REACHED PAST THE END OF A LINE.
NOTE: DATA SET WORK.DATA3 HAS 324 OBSERVATIONS AND 8 VARIABLES.
  91 OBS/TRK
NOTE: THE DATA STATEMENT USED 0.42 SECONDS AND 162K.

PROC SORT;
  BY SUB AL AR DIS CLE;
NOTE: DATA SET WORK.DATA3 HAS 324 OBSERVATIONS AND 8 VARIABLES.
  91 OBS/TRK
NOTE: THE PROCEDURE SORT USED 0.72 SECONDS AND 282K.
DATA DATA4;
MERGE DATA2 DATA3;
BY SUB AL AR DIS CLE;
NEWHRV=HRV/MEANPT*100.0;
DROP CNDTN;

NOTE: DATA SET WORK.DATA4 HAS 324 OBSERVATIONS AND 9 VARIABLES. 1
71 OBS/TRK
NOTE: THE DATA STATEMENT USED 0.60 SECONDS AND 162K.

PROC ANOVA;
CLASSES SUB TD;
MODEL NEWHRV=SUB TD ;
MEANS TD/DUNCAN;

NOTE: THE PROCEDURE ANOVA USED 1.30 SECONDS AND 182K
AND PRINTED PAGES 1 TO 3.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
BOX 8000
CARY, N.C. 27511
STATISTICAL ANALYSIS SYSTEM
5:16 WEDNESDAY, JUNE 30, 1982

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

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NUMBER OF OBSERVATIONS IN DATA SET = 324
**Analysis of Variance Procedure**

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Model $F = 7.25$, $\text{PR} > F = 0.0001$

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**Source**

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DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE NEWHRV

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

**ALPHA LEVEL** = .05  **DP** = 312  **MS** = 5.25237

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APPENDIX G.2

The results of the Analysis of Variance Using New Model
DATA;
  INPUT QND AL AR DIS CLE;
  TD = LOG2(2.0*DIS/CLE);
  DO SUB = 1 TO 9;
  INPUT HRV @@;
  OUTPUT;
END;
CARDS;

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT REACHED THE END OF A LINE.
NOTE: DATA SET WORK.DATA1 HAS 324 OBSERVATIONS AND 8 VARIABLES. 191 OBS/ERK.
NOTE: THE DATA STATEMENT USED 0.43 SECONDS AND 160K.

PROC ANOVA;
CLASSES SUB TD AL AR;
MODEL HRV = SUB TD AL AR SUB*TD SUB*AL SUB*AR;
MEANS TD AL AR DUNCAN;
TEST H = TD E = SUB*TD;
TEST H = AL E = SUB*AL;
TEST H = AR E = SUB*AR;

NOTE: THE PROCEDURE ANOVA USED 2.28 SECONDS AND 168K
AND PRINTED PAGES 1 TO 9.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
BOX 8000
CARY, N.C. 27511

STATISTICAL ANALYSIS SYSTEM
9:41 WEDNESDAY, JUNE 9, 1982
ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

   CLASS LEVELS   VALUES
SUB    9   1 2 3 4 5 6 7 8 9
TD     4   10.0727 5.116119 6.338511 8.850307
AL     3   0 30 60
AR     3   0 30 60

NUMBER OF OBSERVATIONS IN DATA SET = 324
**Statistical Analysis System**

*Analysis of Variance Procedure*

**Dependent Variable: Hrv**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>71</td>
<td>64537.09750001</td>
<td>908.97320423</td>
</tr>
<tr>
<td>Error</td>
<td>252</td>
<td>129090.87888889</td>
<td>512.26539242</td>
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<tr>
<td>Corrected Total</td>
<td>323</td>
<td>193627.97638889</td>
<td></td>
</tr>
</tbody>
</table>

**Model F =** 1.77

<table>
<thead>
<tr>
<th>R-Square</th>
<th>C.V.</th>
<th>Std Dev</th>
<th>Hrv Mean</th>
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<tbody>
<tr>
<td>0.333305</td>
<td>50.5845</td>
<td>22.6328064</td>
<td>44.74351852</td>
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<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Anova SS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub</td>
<td>8</td>
<td>23094.91500001</td>
<td>5.64</td>
<td>0.0001</td>
</tr>
<tr>
<td>TD</td>
<td>7</td>
<td>7943.01935186</td>
<td>5.17</td>
<td>0.0019</td>
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<tr>
<td>AL</td>
<td>22</td>
<td>3161.19685186</td>
<td>2.09</td>
<td>0.0844</td>
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<tr>
<td>AR</td>
<td>22</td>
<td>533.82907408</td>
<td>0.52</td>
<td>0.5845</td>
</tr>
<tr>
<td>Sub*TD</td>
<td>24</td>
<td>17136.52870370</td>
<td>1.39</td>
<td>0.1092</td>
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<tr>
<td>Sub*AL</td>
<td>16</td>
<td>8554.19037036</td>
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<tr>
<td>Sub*AR</td>
<td>16</td>
<td>4110.61814814</td>
<td>0.50</td>
<td>0.9453</td>
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</table>

**Tests of Hypotheses Using the Anova MS for Sub*TD as the Error Term**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Anova SS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD</td>
<td>3</td>
<td>7943.01935186</td>
<td>3.71</td>
<td>0.0253</td>
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**Tests of Hypotheses Using the Anova MS for Sub*AL as the Error Term**

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<th>Pr &gt; F</th>
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</thead>
<tbody>
<tr>
<td>AL</td>
<td>2</td>
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**Tests of Hypotheses Using the Anova MS for Sub*AR as the Error Term**

<table>
<thead>
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<th>Source</th>
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<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>2</td>
<td>533.82907408</td>
<td>1.04</td>
<td>0.3765</td>
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</table>
**ANALYSIS OF VARIANCE PROCEDURE**

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE HRV**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL = .05**

<table>
<thead>
<tr>
<th>GROUPING</th>
<th>MEAN</th>
<th>N</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>51.664198</td>
<td>81</td>
<td>6.338511</td>
</tr>
<tr>
<td>A</td>
<td>47.190123</td>
<td>81</td>
<td>10.0727</td>
</tr>
<tr>
<td>B</td>
<td>40.451852</td>
<td>81</td>
<td>8.850307</td>
</tr>
<tr>
<td>C</td>
<td>39.667901</td>
<td>81</td>
<td>5.116119</td>
</tr>
</tbody>
</table>

---

**ANALYSIS OF VARIANCE PROCEDURE**

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE HRV**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL = .05**

<table>
<thead>
<tr>
<th>GROUPING</th>
<th>MEAN</th>
<th>N</th>
<th>AL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>47.742593</td>
<td>108</td>
<td>30</td>
</tr>
<tr>
<td>A</td>
<td>46.052778</td>
<td>108</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>40.435185</td>
<td>108</td>
<td>60</td>
</tr>
</tbody>
</table>
ANALYSIS OF VARIANCE PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE H RV

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.
ALPHA LEVEL = 0.05

<table>
<thead>
<tr>
<th>GROUPING</th>
<th>MEAN</th>
<th>N</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>45.953704</td>
<td>108</td>
<td>30</td>
</tr>
<tr>
<td>A</td>
<td>45.310185</td>
<td>108</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>42.966667</td>
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<td>60</td>
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