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A PRIORI PREDICTION OF AN INDIVIDUAL'S HEART RATE RESPONSE TO A SERIES OF PHYSICAL TASKS OF VARYING LEVELS OF WORK LOAD

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BY

LARRY E. LONG

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A PRIORI PREDICTION OF AN INDIVIDUAL'S HEART RATE RESPONSE

TO A SERIES OF PHYSICAL TASKS OF VARYING

LEVELS OF WORK LOAD

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ABSTRACT

A PRIORI PREDICTION OF AN INDIVIDUAL'S HEART RATE RESPONSE TO A SERIES OF PHYSICAL TASKS OF VARYING LEVELS OF WORK LOAD

By: Larry E. Long
Chairman: LaVerne L. Hoag

This dissertation presents the development of a predictive model for depicting an individual's cardiac response to a series of adjacent fixed intensity tasks. The emphasis is on predicting cardiac response to exercises of no more than four minutes duration.

The most apparent deterrent to predicting heart rate patterns, caused by work onset or stoppage, is the extreme variation in absolute heart rate between individuals. However, this variation can be substantially reduced by translating heart rate in beats/minute to a percent of an individual's average resting heart rate (%RHR). The translation provides a common denominator and thereby a common origin for heart rate patterns produced by different individuals.

It was determined that cardiac responses in terms of percent of resting heart rate were similar for selected subject categories. The subject categories of this study are defined by two levels each of sex and physical fitness. A highly correlated linear relationship between work load and steady state %RHR was developed for each of the four subject categories. Cardiac responses in terms of %RHR were empirically derived for set levels of %RHR. The linear relationships and responses in %RHR constitute the foundation of the predictive model. The predictive model functions by extrapolating a heart rate response to exercise from empirically derived data. The only required inputs are sex, physical fitness, and resting heart rate. The output of the model includes the predicted %RHR and the predicted heart rate. The model will predict the cardiac response to a series of step changes in work load within the limits of 100 to 160 %RHR. Ninety percent of the time, the predictive model was shown to be within 5 to 10% of the observed heart rate pattern.

ACKNOWLEDGEMENTS

I would like to express gratitude to the professors on my doctoral committee for their contribution towards the successful completion of this dissertation, which would have not been possible without their able direction. Dr. Arnold Parr served as a personally interested and constructively critical committee member from outside the Department of Industrial Engineering. The observations of Dr. Hillel Kumin and Dr. B. L. Foote supplied needed insight into the interdisciplinary ramifications of this study. Dr. Jerry Purswell worked very closely with my chairman in defining the scope of the study and rendered invaluable expertise throughout the course of the investigation. I am especially appreciative of the technical assistance and guidance of my committee chairman, Dr. LaVerne L. Hoag. He gave willingly of his time and offered continual encouragement and moral support.

I would like to thank all of the people who served as subjects. Everyone was a willing participant and devoted long hours during the testing phase. Also, I am grateful for the administrative and financial assistance afforded by the School of Industrial Engineering. Ms. Marty Peters deserves a special thanks for typing the manuscript.

I met my wife, Nancy, on the day that I began work towards a doctorate. Since that day, she has been the perpetuant behind my pursuance of this objective. I wish to thank her. Nancy has also contributed directly in the completion of this study by serving as experimental and administrative assistant, subject, typist and editor.

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CHAPTER I

INTRODUCTION

The introductory chapter contains definitions of the terminology unique to this study, illustrations and examples of the problem and the predictive model of this investigation, a discussion of the relevance and contribution of this study, and a discussion of the uses of heart rate patterns.

Statement of Problem

The purpose of this study was to develop a predictive model of an individual's heart rate response over time as he performs physical tasks of fixed intensity for varying levels of work load. The emphasis is on short-range patterns of no more than four minutes for tasks of light to moderate intensity (less than 220 watts). The tasks are of a constant mechanical power. As long as the work load or power output requires less than approximately 50 percent of an individual's aerobic capacity, the heart rate will reach a steady state (SS) (Vogt, 1973, p. 46).

The intensity of the work loads of all tasks are such that the heart rate will reach a steady state in aerobic metabolism.

It is difficult to predict an individual's cardiac response to physical stress in terms of heart rate (heart rate pattern) because individuals have such disparate heart rate patterns for any given work load. For example, given a work load (task) of 50 watts, one individual's heart rate may reach a steady state of 80 beats/minute in 10 seconds while another individual may take 30 seconds and steady state at 100 beats/minute. These patterns can be studied universally by introducing compensatory variables and by the reduction of heart rate to a common denominator. This common denominator is percent of resting heart rate (%RHR) and is a function of each individual's resting heart rate (RHR) and his heart rate under physical stress.

For the purposes of this study, a person's resting heart rate is determined after he has been seated for at least 15 minutes. Resting heart rate is determined by counting the number of beats/minute during a 5-minute period following 15 minutes of rest to determine the average beats/minute at rest or the resting heart rate. When determining a subject's resting heart rate the subject should not eat nor exercise for at least one hour prior to testing. An unofficial study was conducted for the purpose of establishing resting heart rate as a physiological index with perennial stability. The medical records of twenty Air National Guard flying personnel, selected at random, were examined. The selected resting heart rate was recorded for each individual on a yearly basis during routine medical examinations performed by National Guard physicians for five to fifteen years depending upon the history of their individual medical records. It was determined that the resting heart rate exhibited perennial stability. The average standard deviation for all persons examined was approximately four beats/minute. This difference could very easily be attributed to variations in the clinical procedures used to determine resting heart rate.

It is expected that there are several variables which affect the increase or decrease, rate of increase or decrease, and/or level of heart rate. The extent of the effect of any given variable is unknown. Also, it is probable that as the level of one variable is changed in combination with another variable, that variable may have an altogether different effect on an individual's cardiac response to exercise (i.e., interaction effect). Environmental variables which might be considered to have an effect on cardiac response to exercise are:

1. temperature
2. humidity
3. noise level.

Human variables which might be considered to have an effect on cardiac response to exercise are:

1. somatotypes
2. extent of body movement
3. endurance capabilities
4. psychological stress
5. maximum heart rate level
6. maximum oxygen uptake
7. muscle mass
8. heart rate variability
9. body temperature
10. stroke-volume
11. age
12. resting heart rate
13. physical fitness
14. sex.

The latter three, resting heart rate, physical fitness, and sex, were examined for this study. These were chosen because persons can be classified by sex,and resting heart rate can be measured easily. As discussed in a later section under subject variables, an individual classified into an appropriate level of physical fitness. Also, it is known that all three variables have a considerable effect on heart rate patterns. During testing, controls were established to minimize variation within all other variables listed above. The subjects were limited to the age group of 20 to 30 years of age. Studies have shown that some of the above environmental and human variables listed have an effect on heart rate, and it is hypothesized that others may have an effect on heart rate. However, the extent of this study is to develop a model by which heart rate patterns can be predicted given only levels of sex, physical fitness and resting heart rate. There are two levels of sex and physical fitness. The levels of sex are male (M) and female (F). The levels of physical fitness are good physical fitness (G) and sedentary (S). Resting heart rate is not a factor in defining subject categories. Consequently, there are four subject categories. Those categories are male of good physical fitness (MG), sedentary male (MS), female of good physical fitness (FG), and sedentary female (FS). The levels of the variables and the subject categories are discussed in detail in Chapter III.

This study is limited in scope to examining only aerobic tasks for all subjects. Åstrand (1970, p. 283) states that exercises requiring an anaerobic energy contribution are those that demand more than 50 percent of an individual's maximal aerobic power. He also presented the steady state heart rate for different age groups for 50 percent of maximal aerobic power for both males and females (Åstrand, 1971, p. 312). These maximum heart rate values for aerobic exercise for the age group of this study were 134 and 138 beats/minute for males and females, respectively. The limits of this study are from 100 to 160 %RHR; therefore, the maximum allowable resting heart rate for subjects was 84 beats/minute for males and 86 beats/minute for females in order that no task would require an anaerobic contribution and that a steady state heart rate could be achieved for all tasks performed by all subjects.

It was shown (in this study) that individuals of similar characteristics (e.g., males of good physical fitness) have similar heart rate patterns when presented as %RHR versus time. It was also apparent that although a specific heart rate pattern can be produced by persons of all subject categories, the actual mechanical work necessary to produce this pattern varies for each subject category. There is little value in predicting a heart rate pattern if it is necessary to supply the expected steady state heart rate as input to the model. If this were the case, it would be necessary to empirically determine the steady state heart rate for a given task for any given individual. Upon considering this need, it becomes apparent that in order to make heart rate patterns a useful tool for industrial use, any given heart rate pattern must be equated with a work load. It was hypothesized at the onset and later determined experimentally that the relationship between work load and steady state %RHR is linear and unique for each subject category over the range of this study (100 %RHR to 160 %RHR).

The immediate problem in predicting heart rate patterns is the extreme variation in absolute heart rate (HR), even for persons of similar characteristics (same subject category). A relationship between work load and steady state heart rate such as shown in Figure 1 can be developed. However, the only way to develop this relationship is to record steady state heart rate at different levels of work loads for each individual separately. A similar relationship could be developed by using averaged data supplied by a group of subjects. However, one standard deviation about the regression line may be as much as 15 beats/minute. Therefore, it is difficult to draw conclusions about individuals from relationships developed from averaged data because of the individual variations attained in absolute heart rate. There is also a need to eliminate the requirement to empirically determine the work load versus steady state heart rate relationship for each individual. Perhaps the key to examining this relationship is to reduce all relationships to intercept at a common point. This can be accomplished by using percent of resting heart rate (%RHR) instead of heart rate. Regressions for work load versus steady state %RHR were computed for all subject categories from empirical data. These relationships serve as input to the model. Therefore, given a work load and category of subject, the expected steady state %RHR can be determined.

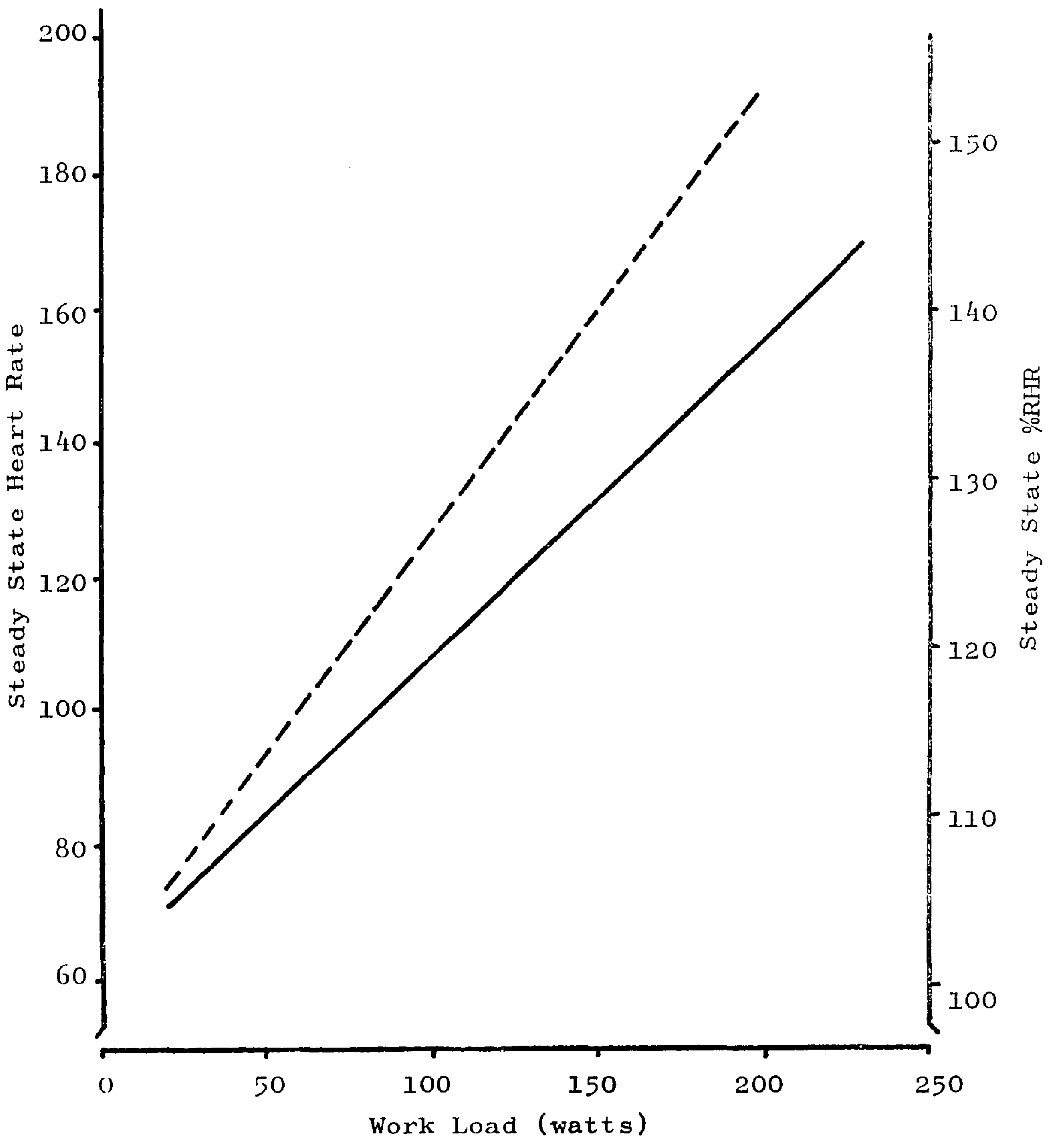

Figure 1. Example of relationships between steady state heart rate and work load (solid line--left ordinate) and between steady state %RHR and work load (dotted line--right ordinate).

Figure 1 also illustrates the relationship between work load and steady state %RHR.

The heart rate pattern is defined, for the purposes of this study, as an individual's heart rate over time from the instant he begins performing a physically demanding task of fixed intensity (including the resting state) until the termination of the task. The instant the individual stops performing a task of fixed intensity and begins a different level of fixed intensity (could be a resting state), another heart rate pattern is realized. In this case, a step change in work load or task intensity is realized. Figure 2 illustrates graphically what is meant by a heart rate pattern. Shown are the resultant heart rate patterns of two subjects who each performed a light work task. Subject A is of the sedentary male subject category and Subject B is of the sedentary female subject category. The task intensity was not the same. It can be noted that there was a 10 beat/minute difference in the initial heart rate values (in this case resting heart rate) at time zero. Subject A realized a steady state heart rate at 93 beats/minute after 48 seconds and Subject B at 80 beats/minute after 53 seconds. It would be difficult to predict these heart rate patterns since it is possible and probable that another subject of Subject A's characteristics (sedentary male--MS) could have produced Subject B's (sedentary female--FS) heart rate pattern and vice versa.

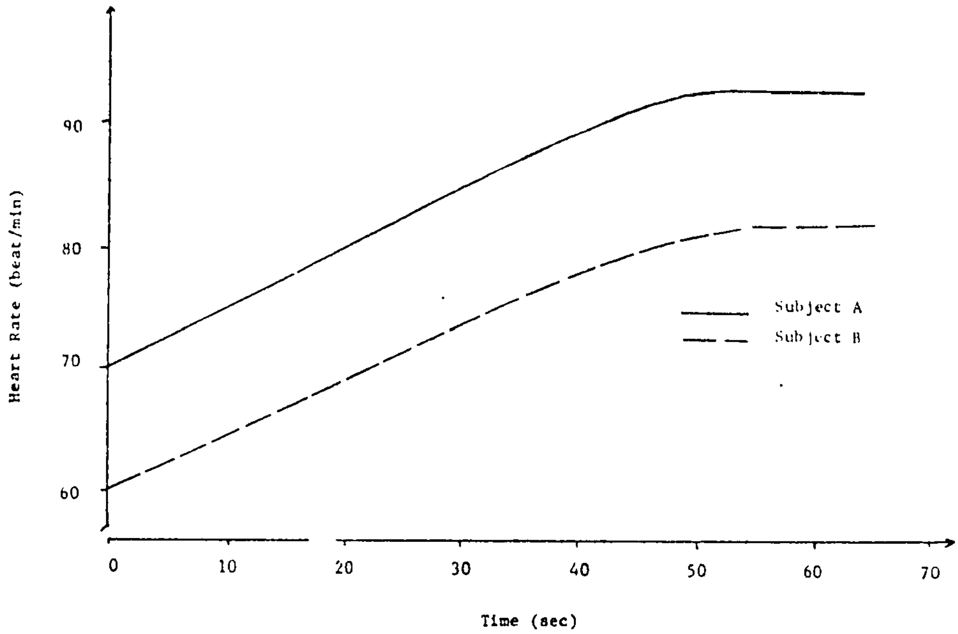

Figure 2. HR patterns (HR versus time) for two subjects performing tasks of light intensity.

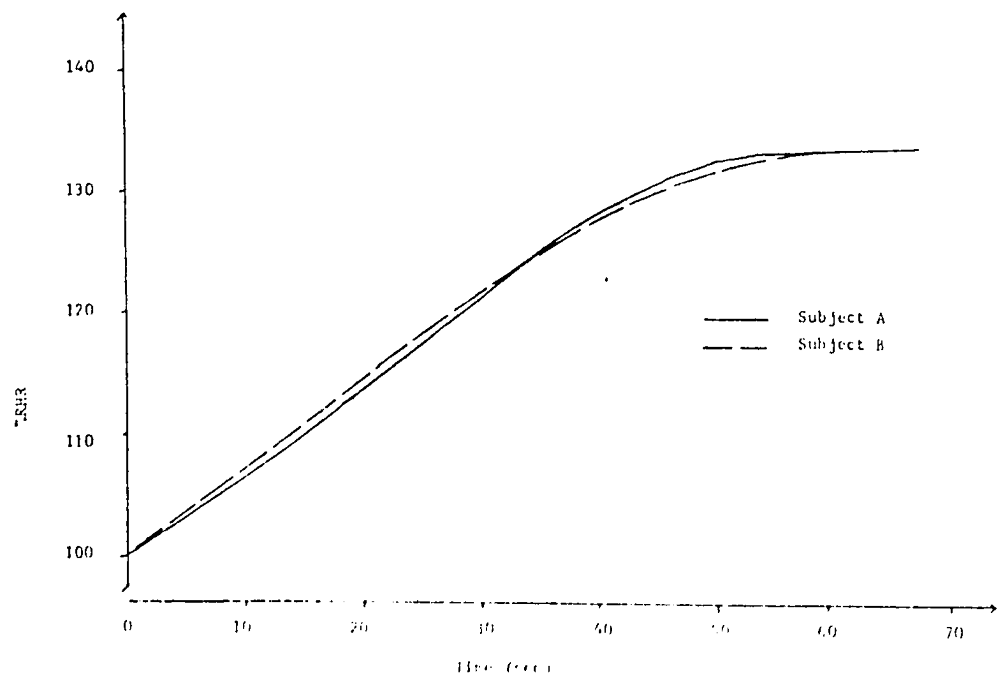

Figure 3. HR patterns (%RHR vs time) for two subjects performing tasks of light intensity.

Figure 3 illustrates the graphic representation when %RHR is used instead of heart rate to indicate heart rate patterns. Note that although the heart rate patterns are similar, the level of work load or task intensity at a steady state of 133 %RHR is not necessarily the same. The task intensities were 125 watts and 70 watts for Subjects A and B, respectively. Figure 4 illustrates, again, the disparity in heart rate patterns for tasks of moderate intensity (versus light intensity for Figure 2). The heart rates of both subjects reach a steady state at 160 %RHR as shown in Figure 5. However, again the task intensities required for like levels of steady state %RHR were different. The task intensities were 220 watts and 130 watts for Subjects A and B, respectively.

In order to illustrate the method by which the predictive model of this study compensates for the disparity in work load for similar patterns (of %RHR), the following example is presented. An individual is selected from one of the four subject categories. The individual is a sedentary male (MS) and his seated resting heart rate is 76 beats/minute. The intensities and durations of the tasks must be supplied. For example, the model will predict the heart rate response for a series of tasks of 110 watts for 60 seconds, 175 watts for 70 seconds and zero watts for 110 seconds. By using Figure 1 as the steady state %RHR to work load relationship for sedentary males,

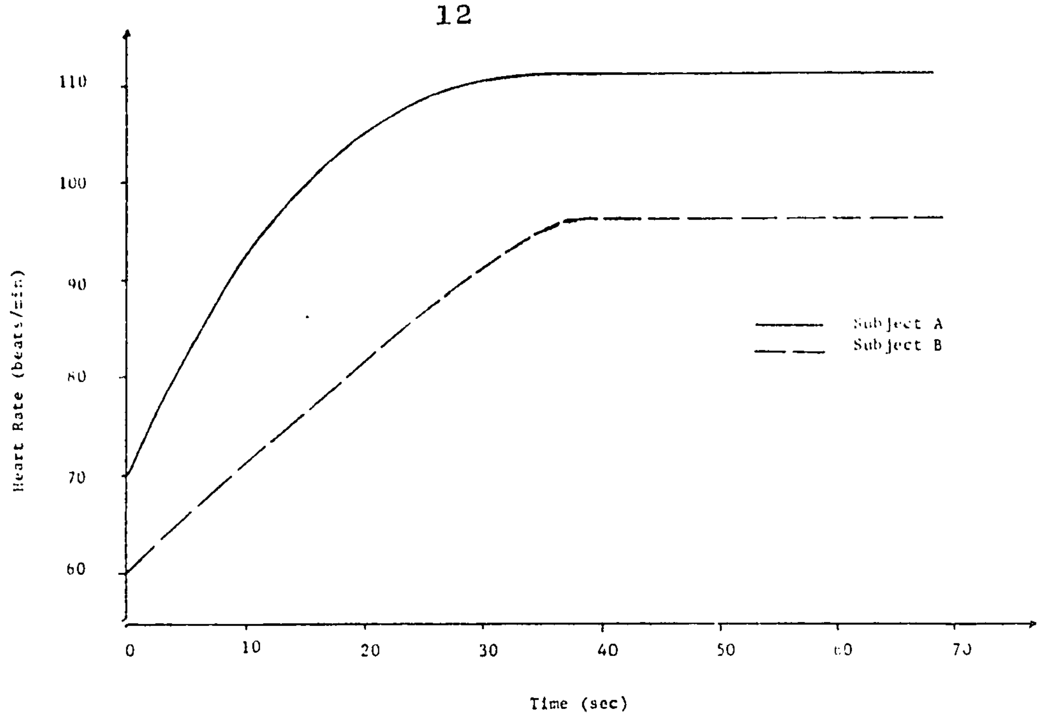

Figure 4. HR patterns (HR versus time) for two subjects performing tasks of moderate intensity.

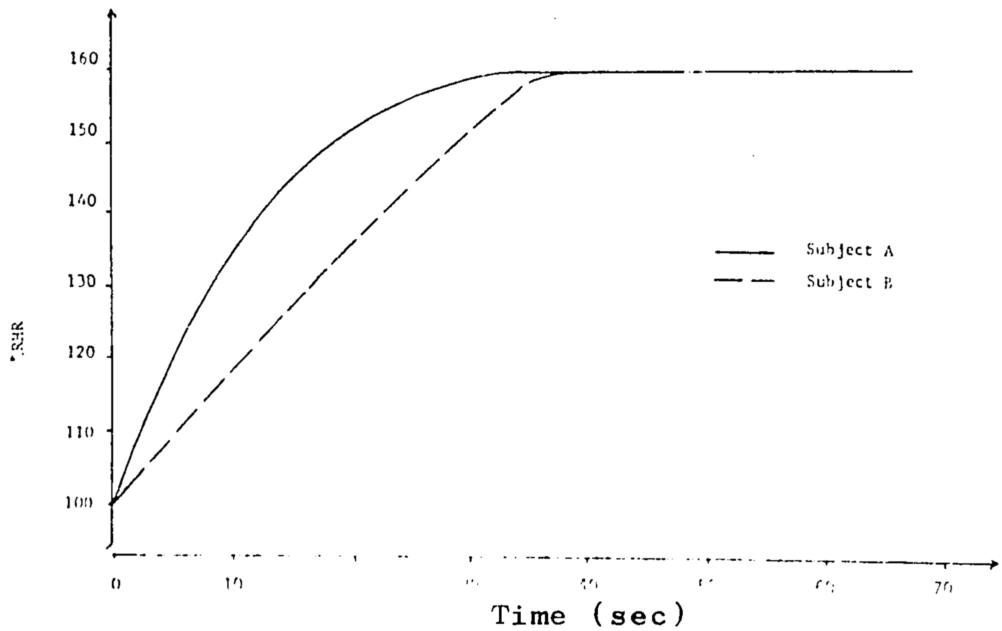

Figure 5. HR patterns (%RHR vs time) for two subjects performing tasks of moderate intensity.

it can be determined that there are steady state %RHR's of 130, 147, and 100 for work loads of 110, 175, and zero watts, respectively. The model supplies all transient responses between step changes in task intensity. This procedure is explained in detail in Chapter IV. The model predicts in terms of %RHR and then %RHR is translated to heart rate, since the individual's resting heart rate is given. The results of the predictive model for the subject and series of tasks previously defined are shown in Appendix 7 under series 1-MS.

Relevance and Contribution

Upon reviewing the papers presented at a symposium on heart rate variability, Rolfe (1973, p. 2) stated:

> It will be widely acknowledged for those who have measured heart rate variability that an anomaly frequently presents itself; namely that while a recorded trace of HR often shows clearly the suppression of variability in the work condition, it is difficult to quantify the change in cardiac response and relate it to the task. This theme is apparent throughout the papers which follow. The study of HR variability is at the stage where the problem is no longer one of getting effective electrodes and portable cardiac recording apparatus; rather it is in the development of techniques to process and analyze the data.

At present, no one has developed a predictive model which reflects cardiac response to stimuli on an individual basis.

Aberg, Elgstrand, Magnus and Lindholm (1968, p. 189) collaborated in an attempt to build a model to predict energy expenditures. (HR has been shown to be an effective predictor of energy expenditure (LeBlanc, 1957, p. 275).)

Their rationale for building this model merits repeating.

> The accuracy of physiological work studies depends only in part on the measuring instrument itself. If the measurement is performed on work which is insufficiently described, the total accuracy of the measurement is decreased. A proper selection of description variables increases the accuracy of physiological work measurement and makes a fairly general prediction of the energy expenditure possible. A model for prediction of energy expenditure from physical data is proposed and has been tested in a number of industrial cases. The accuracy of the result is of the same order of magnitude as a good work study.

They indicate that a good predictive model can produce results which are as accurate, in many cases, as if actual measurements were taken. The advantages of predictive models becomes readily apparent when it is recognized that it is possible to produce a heart rate pattern of the same order of accuracy as that of an empirical investigation. The predictive model of this study has the potential to produce the heart rate pattern for any individual which fits a combination of the levels of the two variables investigated (e.g., female of good physical fitness). An individual's cardiac response to tasks requiring certain steady state %RHRs can be depicted without actual measurement of heart rate while performing these tasks. This could result in savings in time and resources to industrial and government organizations.

Lucien Brouha (1960, p. 15), who was an established authority in physiological stress in industry, stated:

> In man, research is limited by the methods that can be used without impairing the subject's health or his performance. This consideration reduces substantially

> the kind of measurements that can be made directly during muscular activity. Fortunately, because of its close relationship to cardiac output and oxygen consumption, heart rate can be utilized to evaluate stress imposed by muscular activity with a minimum amount of interference with the subject's freedom of motion and performance ability. As a single factor, it can quite accurately depict the adjustment of the individual to muscular work and can be used conveniently as an index for evaluating the overall adaptation to muscular activity.

As Brouha indicated, heart rate is a viable tool for measuring muscular activity. However, interpretation of individual heart rate patterns is difficult with the present knowledge. Heart rate and heart rate patterns may vary greatly between sex, physical fitness, etc.; however, the predictive modeling technique developed within this study aids in transforming disparate heart rate patterns into comparable terms.

Man has physical limitations such as endurance and strength which are approached and sometimes surpassed in his working environment. These limitations must be recognized as critical when establishing criteria for work standards. An individual's heart rate could be a valuable tool when correlated with other limited physical capacities (e.g., endurance capabilities, blood pressure, work capacity, etc.). An investigation of heart rate patterns could provide the necessary information required to depict why and how an individual's heart rate varies. If so, then standards could be established for undue stress to not only the individual's cardiovascular system, but also other limited physical capabilities.

Uses of Heart Rate Patterns

The predictive model utilizes heart rate patterns to depict the expected cardiac response of an individual to physical work tasks of varying intensity. By accurately predicting the cardiac response to work tasks the need for actual measurement of an individual's heart rate under physical stress would be eliminated.

At this time specific guidelines have not been established to set critical limits of heart rate for individuals of specific categories with respect to %RHR. At present, heart rate and/or oxygen consumption are used for industrial guidelines to measure physiological cost. However, only unofficial guidelines exist, and then, only average values are presented. For example, gross unofficial guidelines are that a worker not be required to work on a continuous basis at a rate of over 4.5-5 kcal/min for metabolic energy expenditure and/or 120-125 beats/minute for heart rate. It is difficult to apply such guidelines since energy expenditure and heart rate vary so greatly between individuals. Murrell (1965, p. 375) compared two men of different size to illustrate this difference. A 144-pound male expended 4.0 kcal/min of work where a 200-pound male expended 5.3 kcal/min of work while walking at a rate of 3 mph. The former was within the unofficial guidelines and the latter was above, yet both were accomplishing the same task. This illustration points out the need for individualizing guidelines for energy expenditure and heart rate.

Future guidelines might reflect critical limits for %RHR for particular categories of individuals. From this study, and under the restrictive conditions of this study, a task requiring a particular physical work output could be applied to each subject category (within this study). Then the task could be related to a steady state %RHR for each subject category. For example, a steady state of 150 %RHR might be the standard maximum allowed for an 80 watt task of 5 minutes duration. (These criteria will have to be determined in a subsequent study.) It could also be true that only males of good physical fitness between the ages of 20 and 30 can maintain a steady state %RHR of less than 150 %RHR for that task. In this case, only persons of that category would be allowed to perform this task. All other tasks could be evaluated in a similar manner; therefore, the proper worker would be placed in the proper working environment.

In summary, this model allows for the collection and evaluation of heart rate data in comparable forms (%RHR). A national program to develop a historical data bank of cardiac responses (in terms of %RHR) of individuals of various personal characteristics for various task intensities could result in work standards. These standards could be effectively used for personnel selection and task evaluation.

CHAPTER II

RELATED INVESTIGATIONS AND RESEARCH

This investigation encompasses an attempt to develop a predictive model for cardiac response to fixed intensity tasks which can be related to the individual. There are many research efforts which have supplied direction and foundation for this examination. Of particular importance are the past attempts to develop predictive models. Research efforts pertinent to the development and evaluation of this model are presented in this chapter.

General Background

LeBlanc (1957, p. 275) indicates that heart rate can be an effective tool in the measurement of work activities. It had been determined by several experimenters that there is a definite correlation between heart rate and oxygen consumption within a limited range. LeBlanc extended his studies to investigate work and recovery heart rates of individuals while exercising at different levels of activity. He was concerned with curves which showed the heart rate pattern for one particular exercise. First, he illustrated graphically the pattern from resting heart rate to termination of a one mile run while varying the intensity (speed of runner). Second, he illustrated the pattern from resting heart rate to termination of a run which extended for varying lengths of time. The heart rate pattern showed an upward trend as intensity and/or duration was increased. It was apparent that the body experienced fatigue, therefore the heart rate increased to exhaustion at high levels of intensity and duration.

LeBlanc also viewed the associated recovery patterns. Since the body seemed to fatigue, he suggested that heart rate be used as an index of level of fatigue. Although it is not within the scope of this study to investigate fatigue, the results do indicate that the transient heart rate response to a step increase in work load as well as the recovery heart rate patterns are good indicators of physical fitness.

Brouha (1960, pp. 15-17) depicted the types of heart rate patterns (he used the term heart rate curves) for exercise situations into three categories. The first is where an individual is subjected to light exercise. The cardiac reaction to this light exercise is exaggerated at first but then gradually decreases to a steady state which is above the normal resting heart rate. The second curve involves a more intense exercise during which the heart rate increases to a steady state. The third curve is when the exercise intensity is such that the heart rate does not reach a steady state but continues to increase until the individual is exhausted. Figure 6 illustrates Brouha's "three typical curves."

Empirical results collected by this writer indicate

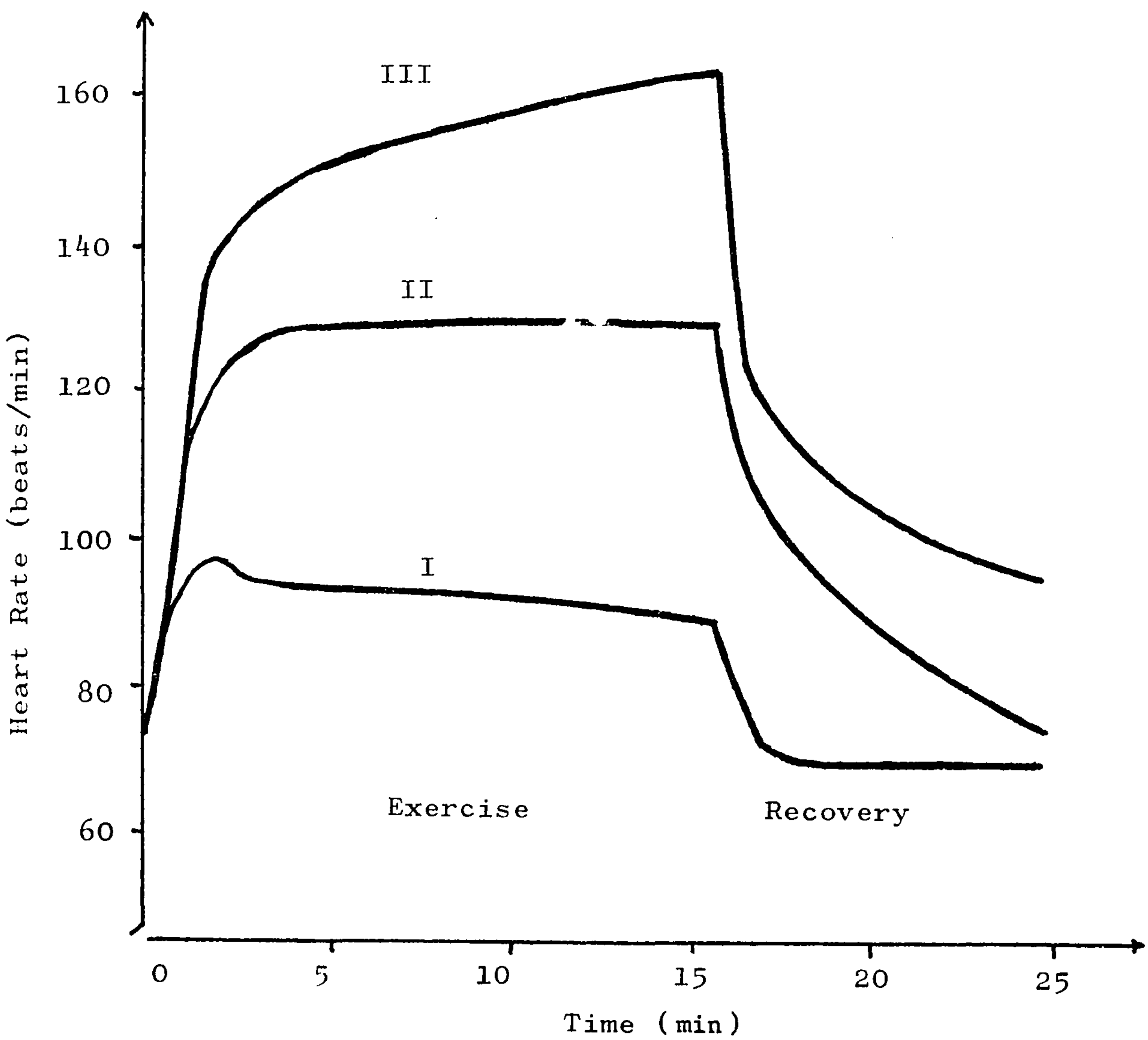

Figure 6. Heart rate curves during exercise and recovery for increasing work intensities. (Brouha, 1960, p. 16)

a deviation from these typical curves. With respect to the first curve, there was not so much increase above steady state heart rate at the start of the task. There was, instead, a gradual increase in heart rate to steady state. The second curve can also be challenged as to its general validity and application to any given individual. The graph of Figure 6 indicates that an individual with a resting heart rate of 75 beats/minute will maintain a heart rate of 130 beats/minute for an exercise of sufficient intensity to cause the cardiac effect of Curve II, for 15 minutes or longer. Fifteen minutes is a very long time to maintain a steady state for such an intense exercise. The results of experiments conducted by this writer indicated a very gradual increase after approximately three to four minutes for heart rates of 130 beats/minute as body fatigue became a factor. The 130 beats/minute is the approximate maximum heart rate of all subjects attained during experimentation (maximum 134 beats/minute). The third curve indicates an increase to exhaustion. An individual may reach a steady state (maximum attainable heart rate) prior to exhaustion and continue the exercise. Exercise of this intensity could be harmful to certain individuals' health and should be avoided.

Authorities such as Brouha (1960, pp. 17, 19, 89, 111) and Murrell (1965, p. 376) have tended to study heart rate patterns in a gross form utilizing heart rate averages of many persons to display results and depict transient responses.

It is common among researchers to display heart rate patterns graphically by plotting average heart rate against time; however, much information is lost when averaging the heart rates of many persons. For example, it is possible that the resting heart rates of a group may range from 56 to 90 beats/minute with an average of 78 beats/minute. The individual with a resting heart rate of 56 beats/minute may never exceed the average of 78 beats/minute for a light work task. This information is lost in the average.

An alternative to displaying heart rate patterns was shown by Schilpp (1951, p. 441). He utilizes beats/minute above resting heart rate in order to represent a general heart rate pattern. The assumption which is implied, but is not noted by Schilpp, is that each individual engaged in muscular activity will have the same increase in heart rate and the increase is independent of an individual's resting heart rate. As Brouha (1960, p. 22) notes, the resting heart rate is an indication of physical fitness, and therefore the heart rate displacement (beats/minute above resting heart rate) can be expected to be less for an individual with a lower resting heart rate.

The results of this dissertation indicate that heart rate patterns produced by dynamic muscular activity of fixed intensity can be reproduced as the individual repeats the exercise. However, the repetition of a pattern is dependent on the intensity of work and the duration of the preceding rest period. Approximately the same heart rate pattern can be obtained from an individual performing successive trials of the same task if the rest period is of sufficient duration. Rest periods are, in practice, not long enough for any individual to completely recover from an intense work task (20 minutes to over an hour). There is an accumulative effect which causes dissimilar heart rate patterns to occur when an individual is subjected to a task without sufficient rest. For light and moderate work loads the heart rate pattern can be repeated with accuracy. Even though a subject may be a little fatigued, an approximate replica of the heart rate pattern will still be produced when the task is light to moderate.

One objective of this study was to isolate and describe the effects which certain variables (sex and physical fitness) have on the heart rate of an individual under a controlled environment. It has been established that humidity and temperature do appreciably affect the heart rate during exercise (Brouha, Smith, DeLanne, Maxfield, 1960, p. 137). These two factors will not be examined. In the same study, the authors did pinpoint sex as a definite variable to be examined. They determined the reactions of females to be similar but at a statistically significant higher level than men. Under exercise conditions in a controlled environment the average female subject's heart rate is 6 to 8 beats/minute higher than a male's. This deviation in heart rate between the sexes is considerable; therefore, sex i included as a variable in the predictive model of this study.

Related, perhaps, to studying the heart rate pattern is the study of heart rate variability. Malmo and Shagass (1949, pp. 181-184) conducted a study to observe the correlation between age and heart rate variability. Heart rate variability was determined, in this case, by measuring the heart rate on three beat intervals taken before, during and after pain stimulation (thermal stimulation) and before and after standard questioning. For 12 pain stimulations there were 60 measurements taken. Heart rate variability was then calculated by determining the standard deviation of the 60 measurements. The findings indicate that the heart rate variability decreases with age in a linear fashion. They found no significant correlation between heart rate and heart rate variability. The females' heart rate variability was significantly higher than the males'. The explanation for the decrease of heart rate variability with age offered by the authors was the diminishing autonomic nervous system influences with increasing age.

Heart rate variability was said to be "a superimposition of different sources of variation which are systemized" (Rohmert, Laurig, Philipp, Luczak, 1973, pp. 33, 38-40). Theirs was an attempt to classify, in order of affect on heart rate variability, different categories of internal or external causes of variation. They found high correlations to heart rate variability for muscular work and weak correlations for that of non-muscular work. There are many methods of measuring heart rate variability. Their data were constructed by examining 50 beat intervals during 500 beats at a steady state heart rate.

The response of the cardiovascular system to non-muscular activities is difficult to interpret and explain. Kalsbeek (1973, p. 99) discussed sinus arrhythmia and likened it to heart rate irregularity. In his study, he stated that there are 30 different methods for scoring sinus arrhythmia, and in some cases different scoring methods indicate opposite results for the same data. Firth (1973, p. 7) quoted Kalsbeek as suggesting that instantaneous heart rate can be related to mental load. Within the same article Firth (1973, pp. 13 and 14) indicated that both heart rate and heart rate variability need further study in order to become useful research tools, and indicated that the cardiovascular response to any stimulus is unpredictable. It is recognized that non-muscular activities can have an effect on the heart rate. However, all non-muscular variations in heart rate are ignored for the purposes of this investigation.

The gross changes in heart rate resulting from static or dynamic muscular loading dominate other physiological and/or psychological causes of variability in heart rate. Rohmert and his colleagues (1973, p. 43) attest to this fact. It is for these reasons that this study includes only that variation in heart rate which is induced by muscular activity.

Greene, Morris and Wiebers (1959, pp. 182 and 183) described a relationship that may exist between the initial response to exercise from a resting state and the recovery to a resting state in terms of physiological cost of work. They plotted metabolic cost over time during response to exercise and recovery. The plot is similar in form to that of %RHR over time for the same activity (see Figure 7).

There have been no studies which address %RHR as a measure of metabolic cost. Although, this type of examination is not within the scope of this study, the analogy of %RHR to metabolic cost was helpful in explaining certain results.

Initial Value of Heart Rate Consideration

In an industrial environment, many times workers are not allowed to complete a task of a certain intensity and then rest or recover before the next task. As is more often the case, workers move from one physically demanding task to another without having an opportunity to allow their heart rate to return to a resting steady state. For this reason there can be any number of heart rate patterns for a task of a certain intensity. A worker's heart rate at the start of a task would be dependent upon the activity performed immediately prior to the start of the task. To illustrate the effect of the initial value of the heart rate on the heart rate pattern, Figure 8 shows five heart rate patterns which might have all been produced by one individual performing the same task five times but having five different initial values

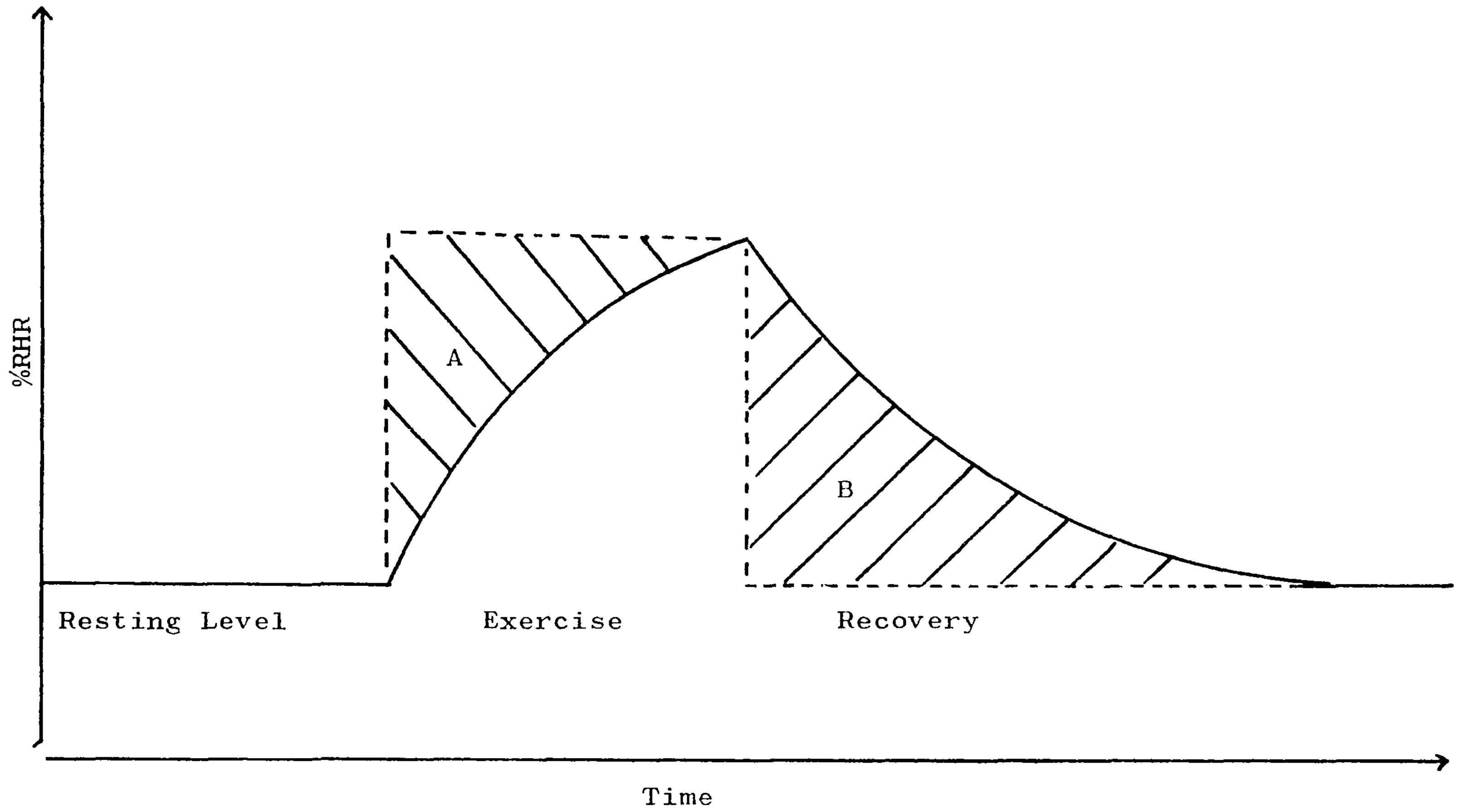

Figure 7. Expected area relationship between response and recovery to exercise (solid line). Area A represents oxygen debt and area B represents oxygen payback.

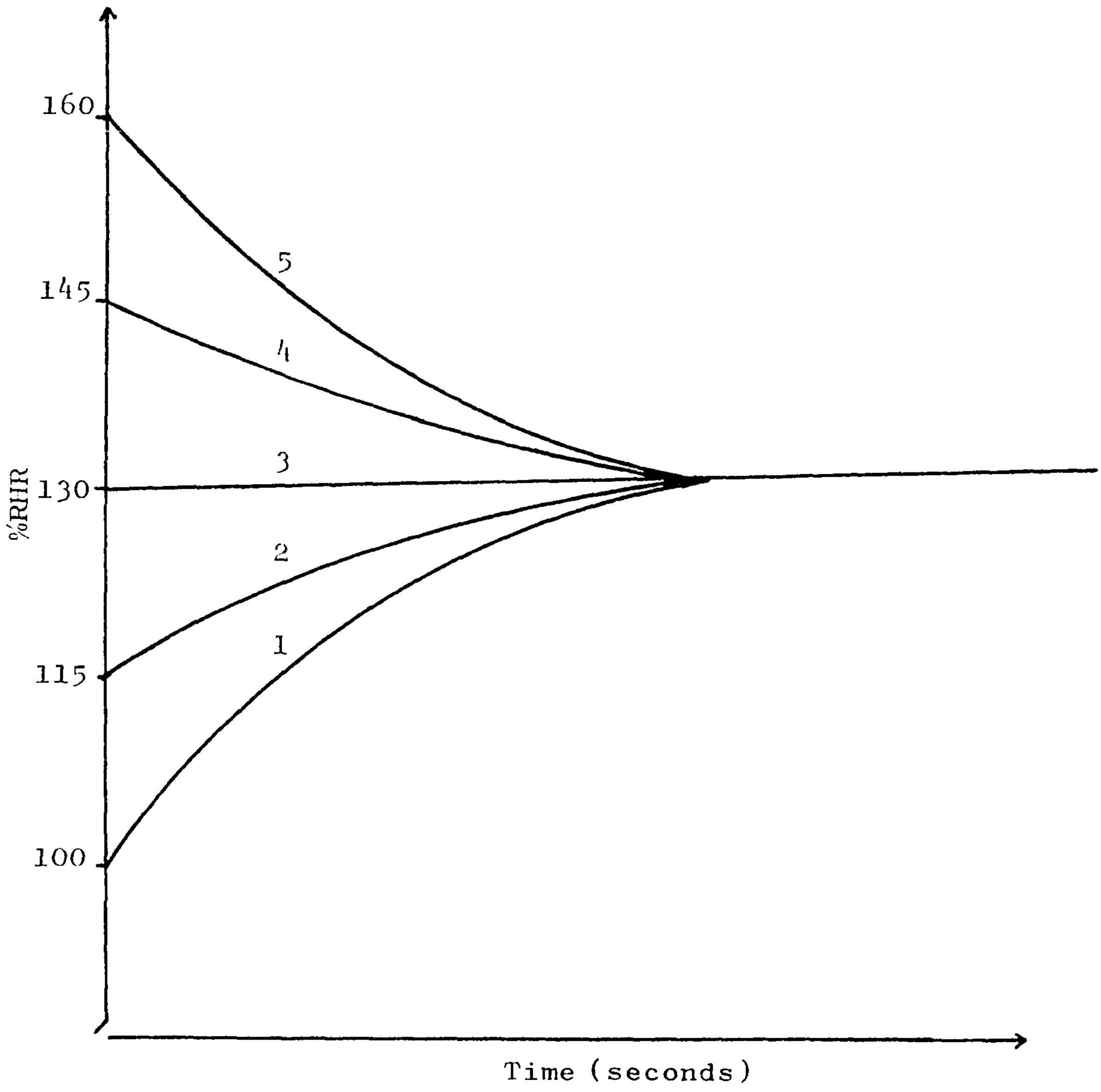

Figure 8. Example HR patterns for varying initial HR values for a task of fixed intensity.

of heart rate at the start of the task. For example, heart rate pattern 2 of Figure 8 increases from 115 %RHR to a steady state 130 %RHR.

Wilder's (1950, p. 392) Law of Initial Value states that:

> . . . the response to agents stimulating the function under investigation depends to a large extent on the initial level of that function. If that level is low there is a tendency to a marked increase; if that value is average this tendency is less marked; if the initial value is high we shall often find minimal or no increase and quite often a paradoxical drop. . . . The exact opposite is true for inhibitory agents.

Wilder intended his law to apply to psychophysical responses to stimuli. It can, however, be applied to cardiac response to muscular activity as well. As the absolute difference between the initial and the steady state heart rate required to accomplish the task becomes greater, the more rapid the rate of change of cardiac response. The rate of cardiac response becomes less as heart rate approaches the value required for the task.

Training and Its Effect

Under a controlled environment, the cardiovascular response to a task of a given intensity can be altered considerably through the effect of training (Brouha, 1960, p. 27). Brouha (1960, p. 29) stated his results that the resting heart rate decreases with training. The stroke volume also increases with training, thereby allowing the heart to function more effectively by circulating more blood per beat. Since resting heart rate is effected by training, caution was taken during this investigation to insure that a subject's resting heart rate was not affected by repeated trials during experimentation. The controls are detailed in the procedures section. By utilizing these controls, the effect of training was of no consequence.

Predictive Models for Heart Rate

Dahl and Spence (1971, pp. 369-376) undertook a study to predict heart rate by task demand characteristics. Nine questions were asked about the task. Then each task was rated according to frequency and complexity with 1 (least frequent and complex), 2, or 3 for each question. The tasks which were expected to have the least effect on heart rate increase would have a rating of 9 (sum of 9 ratings of 1) and those tasks expected to have the greatest effect on heart rate increase would have a rating of 27 (sum of 9 ratings of 3). Correlations between task demand scale figures and experimental heart rate were .86 to .90. The above study was not concerned with physical tasks of appreciable intensity. The range of heart rate deviation was small compared to the gross variations in heart rate expected in even light physical work tasks. The heart rates were averaged over all subjects.

Schilpp (1951, pp. 434-445) suggested a mathematical description of the heart rate response to exercise. His model was derived from 20 subjects who accomplished the same exercise (36 step-ups on a one foot platform/minute for 2 minutes). The model reflects only an average response and then only for one exercise. He used beats/minute above resting heart rate for ordinate values. However, he rendered no formal definition of resting heart rate. The exercise performed would be considered heavy exercise at an expected average heart rate of approximately 200 %RHR after two minutes. The exercises for this study required no more than 160 %RHR for any exercise.

Essentially, Schilpp's model describes only the transient response of the heart rate pattern. The expected steady state heart rate is not included in the mathematical model for any task intensity other than the one previously described which was for the only exercise investigated. In order to predict cardiac responses at different levels of work load, it would be necessary to empirically develop a new set of time constants since steady state is achieved more quickly for tasks of lesser intensities. Also, it would be necessary to determine how many beats/minute increase should be attributed to the fast component (A_1 below) and how many beats/minute increase should be attributed to the slow component (A_2 below).

Schilpp's model has two mathematical components. The first is used to define the heart rate during the first 10 to 15 seconds of exercise, and the second during the remainder of the exercise. The form is as follows:

First component, $A_1(1-e^{-K_1 t})$

Second component, $A_2(1-e^{-K_2 t})$

resulting in, $Y = A_1(1-e^{-K_1 t}) + A_2(1-e^{-K_2 t})$

where, Y = heart rate at time t

t = time in seconds

A_1 = 19 beats/minute

A_2 = 61 beats/minute

$A_o = A_1 + A_2 = 80$

$K_1 = .385$

$K_2 = .0233.$

Both components approach their respective limits of A_1 and A_2 over time. Since K_1 is much larger than K_2, the first component approaches its limit (A_1) much more rapidly. The effect of the first component is 90% complete within the first 7 seconds. The effect of the second component is of longer duration with half of its effect complete within 30 seconds and 90% complete within 90 seconds. Steady state is reached at about 4 minutes.

Schilpp indicated that the recovery is not begun until about 10 seconds after the rest period has begun. It is interesting to note that other studies (Brouha, Smith, Delanne, Maxfield, 1960, p. 135) indicated an abrupt deceleration in heart rate when exercise is stopped. However, Schilpp admits that "the first 30 seconds of recovery have not been studied carefully. . . ." The recovery formula was as follows:

$$Y = A_o' e^{-K_3 t'}$$

where $A_o' = 76$

$t' = t_R - 10$ (R for recovery)

$$K_3 = .0260.$$

Note that K_3 and K_2 are approximately equal indicating that the rate of increase is equivalent to the rate of decrease. Schilpp's colleague expected a continued steady state heart rate after the start of recovery for about 15 seconds and then rapid drop according to the "fast" component. He then suggested the recovery formula to be

$$Y = A_1 e^{-K_1 t} + A_2 e^{-K_2 t}.$$

After referencing Schilpp's "description" of the heart rate response to exercise, Suggs (1967, pp. 195-205) used a different approach to develop a model for heart rate response to exercise. He relied heavily on the many studies (including his own) that indicate oxygen consumption is linearly related to heart rate during both steady state and the transition period after exercise starts or stops. His model is "based on the more macroscopic physiological responses and will require no explicit reference to specific biochemical changes taking place at the cellular level." In order to develop a model to predict heart rate which can be applicable to industry, a researcher must subscribe to this type of examination. An examination at the cellular level would encompass many generalities and assumptions thereby making it difficult to produce a viable model.

The derivation of Suggs' model will not be discussed in detail here as it is tedious and involved and not directly related to the model for this thesis. Essentially, Suggs used the equation that oxygen intake is equal to external respiration of oxygen plus oxygen consumed to produce body energy. Using previously developed relationships between oxygen consumption and heart rate, he transformed the equation to include only heart rate as the variable. Then he empirically established constants for the equation. He developed two equations, one for exercise response and one for recovery. His equations are as follows:

H = heart rate

H_o = Initial heart rate

H_e = Final heart rate (steady state)

$A = H_e - H_o$

$K_1 = .693$, for light exercise

$K_2 = .499$, for light exercise

Exercise $\quad H = H_e - Ae^{-K_1 t}$

Recovery $\quad H = H_e + Ae^{-K_2 t}$.

Suggs concerned himself with heart rate responses to a step change in exercise level. The model was developed using averaged data from similar trials. Suggs stated that "it is not expected that the results will be useful for predicting heart rate. . . ."

The mechanism that Suggs used to determine an expected steady state heart rate was to convert steady state oxygen consumption to steady state heart rate. He presented a graphic display, complete with data points, but did not supply the regression equation. The regression was determined from graphic display to be

$$H_e = 60L + 78$$

where L = steady state O_2 consumption in liters/minute. The relationship of O_2 consumption to work load (Åstrand, 1971, p. 352) is

$$L = .014W$$

where W = work load in watts.

By incorporating the above relationships into Suggs' model, steady state heart rate could then be determined and the model could be used to predict heart rate. The above two equations were not presented by Suggs, but are suggested by the author of this thesis to complement the usefulness of Suggs' model.

Vogt, Meyer-Schwertz, Metz, and Foehr (1973, p. 45) conducted experiments to extract indirect estimates of muscular work stress and environmental heat stress from heart rate variations (heart rate patterns). A product of their experiment was a two part model which could be used to predict heart rate at any period of exercise. Vogt (et al.) stated that as long as other influencing factors are removed, the heart rate depends on mechanical work performed and environmental heat stress imposed. The experimenters are optimistic about the usefulness of heart rate. They stated:

> Even though heart rate itself is not a straight forward measure of cardiac cost, the finding of some precise laws of action and interaction of the factors involved in

> its combined responses to muscular work and environmental heat should enhance their value for practical purposes.

They also agree that there is a need to quantify heart rate patterns.

> All (researchers in physiology) agree on the clear cut differences between the respective patterns of initial acceleration and final deceleration of the heart rate. There is, however, no agreement on the quantitative form of the transfer function relating the heart rate "output" to the mechanical power "input" for even the simplest cases of positive (work onset) or negative (work stoppage) transient inputs.

In order to predict heart rate Vogt also detailed the circumstances required. The heart rate must realize a steady state and to do so the mechanical work (work load) must be submaximal and the work must be performed in the thermal comfort zone. Specifically, the lack of steady state occurs when the mechanical power exceeds the endurance limit, which is defined as "the maximal energy expenditure covered exclusively by aerobic metabolic processes, amounting to approximately 4 kcal/min (279 watts)." The greatest power requirement for the experiment of this dissertation was 220 watts, which is in the aerobic range. Also, all experiments were conducted in the thermal comfort zone (72^{o}F).

Vogt found two different stages of heart rate variation which appeared in sequence for both increases and decreases in mechanical power. The first stage is called the fast variation stage and is of two to five minutes duration. The second stage is the slow variation stage.

The former is the concern of this dissertation. Vogt's model is not an attempt to predict heart rate response to exercise during the slow variation stage, but is intended to relate heart rate, heat stress, and work load over time and during fixed intensity tasks. Essentially, work load and standard heart rate at rest are given inputs. Rectal temperature and mean skin temperature (taken at four locations) must be measured dynamically as the task is being performed; therefore, the model cannot be considered a predictive model for the slow variation stage. The work load is considered by translating mechanical power to beats/minute increase above resting heart rate to a steady state level. The conversion is:

$$C = bW$$

where C = beats/minute above RHR at steady state

b = .4 beats/minute/watt

W = mechanical power in watts.

The heart rate at period j (during the slow variation stage) is then determined by the following equation:

$$N_j = N_o + C + 21(T_{r,j} - 37.0) - 3(\Delta_j - 4.00)$$

where N_j = heart rate at period j

N_o = standard heart rate at rest

$T_{r,j}$ = rectal temperature at period j

Δ_j = difference $(T_r - T_s)$ between rectal and mean skin temperature at period j.

The change in heart rate at period j, during the fast variation stage (concern of this dissertation) is determined by the following equation:

$$D = A(1 - e^{-(Kt-p)})$$

where D = beats per minute change in heart rate

A = steady state value

K = reciprocal of time constant = 1/T

t = time measured from instant of step change of mechanical power

p = pure time delay.

The constant K is a function of the initial value of the heart rate and C for heart rate acceleration.

$$K = -1.35 - .0078\ (I + C)$$

where I = heart rate at the time of the step change of mechanical power.

For heart rate deceleration

$$K = -.712 - .0069C.$$

The heart rate is determined for the fast variation stage by two formulas. For step changes of increasing task intensity the following equation is applicable:

$$N_j = D + N_o.$$

For step changes of decreasing task intensity the following equation is applicable:

$$N_j = I - D.$$

In comparison, Schilpp, Suggs and Vogt utilized mathematical equations to predict heart rate patterns. Schilpp used two exponential components versus one for Suggs and Vogt. The time constants were set for Schilpp's model, making prediction of light tasks erroneous. Suggs and Vogt allowed for changes in the time constants dependent upon the intensity of the task. Suggs suggested three constants for three general levels of task intensity. The time constants of Vogt's model were a function of resting heart rate and work load. Unlike Vogt, neither Schilpp nor Suggs presented a definitive method for deriving the steady state heart rate to be achieved for any given work load. The models of Suggs and Vogt allowed for step increases and decreases in task intensity where Schilpp considered only increase and recovery to a resting state. The models of Schilpp and Vogt required a knowledge of resting heart rate but did not define the mechanism for determining resting heart rate. The models, as presented for all three, made no allowance for variations in sex, physical fitness or any other human variable. The predicted heart rate patterns are assumed to apply to all persons, and, therefore, only one pattern is predicted for each work load and duration for each model. In the results sections a comparison is made of selected heart rate patterns predicted by the three aforementioned mathematical models, the model of this study and the actual observed heart rate patterns.

CHAPTER III

THE EXPERIMENT

This chapter is a discussion of the experimental equipment, subjects, and the experimental procedures. It is prefaced by a general description of the experiment and an analysis of the industrial applicability of this technique for heart rate measurement.

General Description of Experiments

There were three experimental testing sessions. The first two, referred to as phase one and two of testing, were conducted for the purpose of quantifying the relationships between work load and steady state %RHR for each subject category and, also, to supply the required empirical data for the predictive model. Phases one and two related to each subject; therefore, it was not necessary to complete phase one for all subjects before beginning phase two. The third testing session, referred to as validation testing, was conducted for the purpose of evaluating the accuracy and validity of the predictive model. During all three experimental testing sessions, subjects were asked to exercise at a constant rate on a bicycle ergometer for varying task intensities while their heart rate response was recorded. Resting heart rate was determined at the onset of each testing session.

During phase one, all subjects were screened according to physical fitness. This was accomplished by interviewing each subject. Next, those subjects selected were asked to perform fixed intensity tasks, and the steady state heart rate pattern was recorded. Finally, the subjects performed tasks which ultimately required a fixed steady state %RHR. In this case, a trial and error technique was employed by varying the intensity of the task in order to find the proper work load for each subject.

In order to continue with phase two for a given subject, it was necessary to have completed phase one, since the method of testing in phase two depends on the results of phase one. The subjects performed tasks at the levels of intensity determined in phase one. All tasks resulted in a steady state heart rate but required varying initial values of heart rate.

The validation testing consisted of one subject from each of the four subject categories performing a series of step changes in task intensity (2 or 3 step changes). The heart rate patterns produced were then compared with the predicted heart rate patterns in order to evaluate the validity of the predictive model.

Industrial Applicability of Experiment

Corlett (1973) states that any technique for the measure of heart rate for industrial use should meet certain criteria. These criteria are:

1. acceptable to subject population
2. standardized (give results which may be judged against defined standards)
3. repeatable
4. readily teachable
5. readily interpretable.

Any study concerned with measuring, analyzing, or predicting heart rate should be conducted in a manner such that the above guidelines will be accomplished completely, or if that is not possible, in part.

By discussing each of the above criteria separately, the measurement and consequently the analysis of heart rate data in an industrial environment can be placed into its proper perspective. Fortunately, the state-of-the-art will allow experimenters to monitor and record heart rate via telemetry units with little, if any, inconvenience to the subjects. This was shown during a previous study (Purswell, Krenek, Long, 1972), in which subjects were required to exert themselves beyond that required of the normal industrial environment. Also, they were required to accomplish movements as quickly as possible. These movements consisted of considerable body movement in almost every possible body attitude. Without exception, the subjects indicated that the monitoring apparatus in no way hindered their efforts to perform the assigned tasks. It can be assumed, then, that the heart rate measurements will be acceptable to the subjects in an industrial as well as an experimental environment.

The predictive model of this study depicts cardiac response in terms of %RHR as well as heart rate. The %RHR index serves as a common denominator which substantially reduces the interpersonal variations in cardiac responses to exercise. Therefore, by using %RHR as an index, the results obtained from experimentation and prediction can be judged against defined standards.

The results of this study have indicated that heart rate patterns are repeated for individuals accomplishing tasks of similar intensity as long as fatigue does not become a factor. However, fatigue does become a factor under many industrial working conditions. This study was designed to eliminate fatigue as a variable, but it is recognized that a future study should include fatigue as a variable.

The instructions to experimenters for readying a subject in an industrial environment for heart rate measurements are minimal and should require no more than one to two hours of instruction. In order to obtain predicted heart rate values, the use of a computer is required; however, the only knowledge required to run the program is a knowledge of how to complete the input data cards. The analysis of results can again be easily taught to trained personnel working in the area of human factors engineering since each output will be compared to predefined standards. Moreover, there should be no interpretation problems since all data and norms will be standardized.

By the preceding logic, the predictive model of this study should be a technique with potential for industrial use. However, further and broader studies are required to encompass the spectrum of the industrial population in order to formalize standards and to set work task criteria.

Experimental Apparatus

Description and Use

The only physiological variable measured in this study is that of heart rate. The subject's heart rate was measured over time under varying intensities of physical stress. The range of heart rate investigated was limited to those rates between the lowest steady state heart rate (RHR) to 160 %RHR (32 to 50 beats/minute above RHR). Most persons can maintain a steady state heart rate of 160 %RHR for short periods of time (1 to 5 minutes). For heart rates much above 160 %RHR, the heart rate increases steadily to exhaustion or maximum attainable heart rate, whichever comes first. It is expected that most industrial tasks will require much less than 160 %RHR on a continuous basis.

In order to collect physiological data which exhibited clearly defined trends, the equipment selected for the subjects to use was the bicycle ergometer (see Figure 10). The intensity of the physiological tasks can be increased or decreased on a continuous scale on the bicycle ergometer. Similar cranking tasks using the upper limbs result in noticeable body fatigue after 30 to 60 seconds at heart rates of approximately 120 %RHR. Since tasks requiring a much greater heart rate can be sustained for longer periods of time with less fatigue using the lower limbs, the bicycle ergometer was selected for this study. As Åstrand (1970, p. 283) indicates, the use of large muscle groups for exercise is necessary for tasks which exceed three minutes in order to minimize fatigue.

Recording Instruments

The actual measurement of heart rate was accomplished by equipment manufactured by Narco Bio-Systems, Inc. The Desk Model Physiograph, DMP-4A, is a strip chart recorder with four recording channels and an event marker. Two channels and the event marker were used for monitoring subjects during experiments. The CA-200 and the Type 7070 channel amplifiers were used in conjunction with the pen motor on the physiograph. The Type 7171 High Gain Coupler was used to receive the heart rate signals from the subjects. The BT-1200 Biotachometer was utilized to transpose elapsed time for inter-beat intervals to heart rate.

To summarize, the Narco Bio-System components used were as listed below:

1. DMP-4A Desk Model Physiograph
2. CA-200 Channel Amplifier
3. Type 7070 Channel Amplifier
4. Type 7171 High Gain Coupler
5. BT-1200 Biotachometer

Figure 9 illustrates the recording equipment configuration.

Exercise Equipment

The Monark Bicycle Ergometer (Åstrand, 1973) shown in Figure 10 was the exercise equipment used for this experiment. In order for the subject to exercise in a consistent manner, a speedometer was used so that the subject could accelerate to a reference point (50 rpm). The subject was asked to maintain a certain power output which could be set on the ergometer on a scale graduated in kiloponds (one Kp is the force acting on the mass of one kilogram at normal acceleration of gravity). By maintaining exercise at a set level of energy (kp) over time, power expended can be determined. For example, at 50 rpm a reading of 1 kp = 300 kp-meters/minute, and at a two kp setting the power produced is 600 kp meters/minute, and so on. The unit of power used in this study is watts, where 100 kpm/min = 16.35 watts.

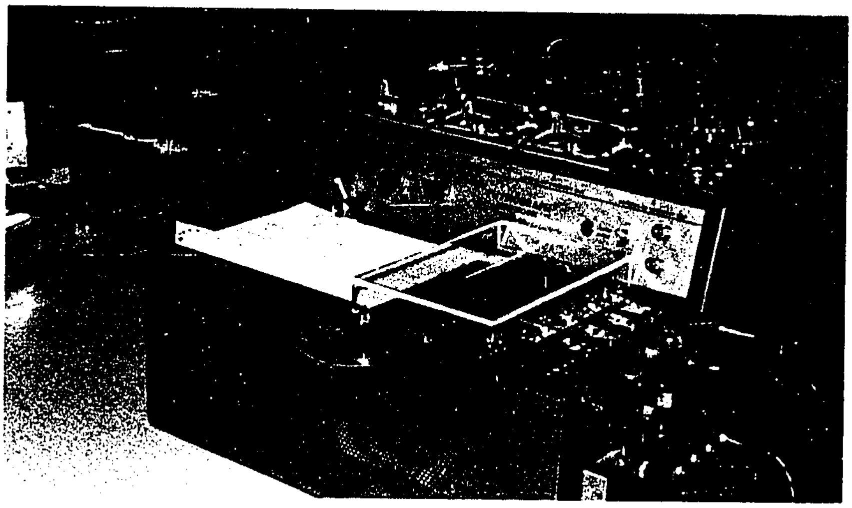

Figure 9. Recording Equipment.

Figure 10. Subject exercising on bicycle ergometer.

Subjects

The subjects varied in physical fitness and sex. There were a total of eight subjects (two in each of four subject categories) tested to collect data for development of the predictive model. There were a total of four subjects (one in each of four subject categories) tested to collect data to evaluate the model. The total number of subjects was twelve. The subjects were initially selected by somatotype and weight. The somatotyping system used to classify subjects utilizes a combination of endormorphic, mesomorphic and ectomorphic (order of ratings) components to categorize humans. In this system, an individual is assigned a value on a seven-point scale (7 being most characteristic) for the relationship to each of the three forms. This somatotyping system is discussed in detail in Croney's (1971) text on anthropometry. Subjects selected were predominantly mesomorphic and had at least a rating of 4 in this category and no more than 3 in the endomorphic and ectomorphic forms. The weight tolerance was 105 to 120 pounds for females and 145 to 160 pounds for males. The height tolerance was 5'2" to 5'5" for females and 5'9" to 5'11" for males.

Physical Fitness

As an individual improves his physical fitness, he also lowers his resting heart rate (Brouha, 1960, p. 27). Also, there are fewer beats/minute displacement from resting heart rate under physical stress and the speed of heart rate recovery to a resting state is increased (Brouha, 1960, p. 27). Brouha also indicates physical conditioning allows persons to attain "higher levels of performance." Certain physiological changes take place in persons who are committed to training and thereby causing the cardiac responses to be different from untrained individuals. There is greater strength in the muscles, improved coordination, and a more developed cardiovascular and respiratory system. All of these changes combine to aid individuals in accomplishing physical tasks.

General physical training, which results in improved physical fitness, provides an individual with an increased capacity to perform physically demanding tasks of moderate intensity (Brouha, 1960, p. 32). However, for heavier tasks, the person trained specifically for accomplishing a given task will perform it more efficiently than the person with a commensurate amount of general physical training. This study examined individuals of varying states of physical fitness performing tasks of light to moderate intensity. It was expected that those of good physical fitness could accomplish tasks with less expenditure of effort than those whose level of physical fitness was low.

Selecting subjects by physical fitness is a difficult task. Tests of physical fitness are awkward to administer and even more difficult to interpret. The Harvard Step Test which requires a maximal effort on the part of the subject is unreliable as are all tests which require maximal efforts.

The experimenter can never fully determine whether the subject was exhausted at termination or just unwilling to exert himself further (Åstrand, 1970, p. 350). Any test for physical fitness requiring a maximal effort is susceptible to erroneous results.

A maximal effort was not used for this experiment. According to data gathered on subjects who exercised to attain a maximum heart rate, the recovery period to resting heart rate is at least 30 minutes and could be more than one hour (Brouha, 1960, p. 17). An exercise of this intensity could cause a considerable oxygen debt and therefore increase the time to full recovery and/or bias results. Any exercise performed subsequent to execution of a maximal effort would be effected. A maximal effort for sedentary persons could delay testing for days and could possibly be harmful to their health. It should also be noted that tasks requiring a maximal effort are seldom found in industry.

As for sub-maximal work test to measure physical fitness, Åstrand (1970, pp. 358-359) states that there are two situations in which they can be used. First, they can be used in clinical examinations in order to examine the cardiovascular system under functional stress. And second, they can be used to evaluate the effectiveness of a training program. In the first situation the test is for reliability of the cardiovascular system, and in the second situation the test is used to examine relative changes in an individual's heart rate. In neither situation can an experimenter draw conclusions about an individual's level of physical fitness.

For the above reasons subjects were selected and placed in one of two levels of physical fitness according to a five point classification scheme for state of training or physical fitness suggested by Åstrand (1973, p. 32). Åstrand's five level classification system is as follows:

1. Completely untrained
2. Sporadic muscular activity--a few times per month
3. Regular but light exercise--once to twice per month
4. Rather intensive training one or more times per week
5. Hard training for competition several times per week.

There are only two levels of physical fitness for this study. In order to assure a definite distinction between these two levels, persons of level three above were not accepted as subjects. An extensive interview was conducted with each subject in order to determine if they could be classified in levels one, two, four or five above (see Appendix 2 for a brief description of each subject's state of physical fitness and exercise frequency). If a subject was of level one or two then he was classified as being sedentary (S). If a subject was of level four or five he was classified as being of good physical fitness (G).

Sex

The other subject variable was sex, male (M) and female (F). The subject categories are as shown in Table 1. Appendix 2 contains a descriptive summary of subjects tested for this study.

TABLE 1

SUBJECT CATEGORIES

	Male	Female
Good Physical Fitness	MG	FG
Sedentary	MS	FS

Experimental Procedures

Controls

Environmental

All testing was accomplished in a controlled environment with a temperature of $72^{\circ}F \pm 2^{\circ}$ and a relative humidity of $45\% \pm 5\%$. These conditions were held constant so that temperature and humidity would not be factors. The time of testing was from 10:00 hours to 16:00 hours. The considerable time span was necessary because of the length of each experimental session per subject. The time of day had little noticeable effect on the heart rate patterns or the resting heart rate since this experiment was focused on gross changes not often realized in time-of-day changes in physiological processes.

Subject

Subjects were asked in advance to adhere strictly to good eating (three well-balanced meals/day) and sleeping practices (approximately eight hours/day) for three days prior to testing. The nutritional problem of one's diet is of importance and must be considered. A quantity deficiency could result in a caloric consumption that is less than adequate for the work to be accomplished and thereby result in a reduced efficiency of the worker (Brouha, 1960, p. 25). Qualitatively, Vitamin A and Vitamin D are not essential for producing physical work, but Vitamin C has been shown helpful to those working under heat stress. Another study proved that Vitamin B is imperative for good physical efficiency. Brouha (1960, p. 25) cites Wald, Johnson, and Weaver to state these reactions to Vitamin A, B, C, and D. Consequently, certain nutritional imbalances could cause a physical inefficiency. Insufficient rest could also result in physical inefficiencies.

Caution was taken to insure that the subject's performance was not affected by training. Subjects were tested on two days only. The testing sessions were one week apart and no exercise was in excess of 240 seconds. The subjects exercised no more than 10% of the time thereby allowing 90% of the testing time for rest and recovery. No exercise was so intense as to require a maximal effort, or even close to it.

Testing Procedures

The actual testing sessions for phases one and two were scheduled on two separate days and one week apart for each individual. It was necessary to schedule rest periods between trials so as to eliminate an overall fatigue effect. Although the tasks were of varying intensities, the subjects were required to maintain a resting heart rate for five minutes prior to each trial, thereby making the minimum rest period between each exercise at least five minutes.

As the subjects arrived at the testing center, each was prepared by the experimenter for recording of heart beats. There are several methods for placing surface electrodes on subjects, but the only acceptable method for subjects engaged in exercise is a chest cluster. In any other arrangements, to include limbs, noise is generated in the signal by the muscles in the limbs.

Phase One of Testing

The subject, although interviewed briefly prior to the testing session, was again interviewed to assure proper placement in the appropriate subject category. If the subject did not fit into the subject categories of this study, then experimentation was discontinued and another subject was engaged. In order to acclimatize the subject to the experimental environment and to the bicycle ergometer, the bicycle ergometer was adjusted to adhere to the subject's arthropometric dimensions, and then the subject was allowed to exercise at will. Once the subject felt familiar with the bicycle ergometer, he was then asked to practice maintaining 50 rpm. The subject was then seated for fifteen minutes. His resting heart rate was then recorded for five minutes. The average resting heart rate was determined by counting the number of heart beats in this five minute period to determine the average beats per minute at rest (RHR).

In order to determine the work load to steady state %RHR relationship, each subject performed three tasks of which one was of light intensity, one of moderately heavy intensity, and the intensity of the third task was approximately midway between that of the former and the latter tasks. All tasks were performed on the bicycle ergometer until a steady state heart rate was attained. This first task was of sufficient intensity to raise the heart rate of the subject from 8 to 15 beats/minute above resting heart rate. The second task required an increase in heart rate of 15 to 25 beats/minute. The third task required an increase in heart rate from 25 to 40 beats/minute. In each case steady state was maintained for 30 seconds. The experimenter was then able to proceed to part two of phase one with an idea of the steady state heart rate to work load relationship for each subject.

The purpose of the second part of phase one of testing was to determine the work loads required for a particular subject's heart rate to steady state at %RHR levels of 120 %RHR, 140 %RHR and 160 %RHR. Conversion tables for translating heart rate to %RHR and %RHR to heart rate aided the experimenter in dealing with the two measures of cardiac response. (Conversion tables shown, in part, in Appendix 14). The testing included a trial and error technique. The experimenter could estimate the required work load from the results of part one. The experimenter set the bicycle ergometer at the work load level that he thought might require a steady state of 120 %RHR and asked the subject to exercise. If the steady state heart rate was not within ± 2% of 120 %RHR, fine adjustments in work load were made by the experimenter, and the above procedure was repeated until the subject's heart rate pattern was repeatable to a predetermined 120 %RHR. This was accomplished for the three levels of %RHR and phase one was then completed and the subject was scheduled to return one week later for phase two.

Phase one instructions to subjects are presented in Appendix 1.

Phase Two of Testing

The second phase was conducted one week after the completion of the first phase. The objective was to examine each subject's response to all combinations of step changes in task intensities of exercise for 100 %RHR, 120 %RHR, 140 %RHR and 160 %RHR. That is, the initial value could be any of the four levels of %RHR and the task could require a steady state %RHR at any of the four levels of %RHR. The step task matrix is shown in Table 2.

After the subject had been prepared by the experimenter for recording of heart rate, he was asked to accomplish a few light tasks which required an increase of fifteen to thirty beats/minute in heart rate. This exercise was intended to acclimatize the subject to the experimental environment. The subject's resting heart rate was recorded in the manner described in phase one. If the subject's resting heart rate was not within $\pm$ 2 beats/minute of that resting heart rate recorded for phase one, testing was postponed until a later date. The experiment proceeded to include all tasks noted in Table 2 for each subject. The intensity

TABLE 2

MATRIX OF EXPERIMENTAL STEP CHANGES IN TASK INTENSITY

Initial Value of %RHR	Steady State Value of %RHR			
	160	140	120	100
160	–	D'	C'	A'
140	D	–	B'	E'
120	C	B	–	F'
100	A	E	F	–

of each task was preset according to data gathered in phase one of testing.

The tasks represented by the cells in Table 2 were combined in pairs in order to expedite test procedures. The tasks were completed for each continuous exercise on the bicycle ergometer. For example, Task B and B' were completed during one continuous exercise on the bicycle ergometer. The task intensity was set at the onset of the exercise such that the subject would realize a steady state of 120 %RHR. This was the initial value (IV) for task B. The intensity was then adjusted such that the subject would realize a steady state of 140 %RHR. After a 30 second steady state period the task intensity was adjusted such that the subject would realize a steady state of 120 %RHR. Thus, 140 %RHR was the initial value for task B'. All tasks denoted by a prime (e.g., A') are recovery states. That is, the task is of lesser intensity than the preceding task. There were six trials (a trial being one continuous exercise) which each subject performed. The exercises were AA', BB', CC', DD', EE' and FF'. Once these experiments had been performed and the data recorded for all eight subjects twice, the testing required to furnish hard data (empirically derived data) for the predictive model was complete.

Phase two instructions to subjects are presented in Appendix 1.

Validation Testing

In order to validate the experiment, four subjects were selected such that each of the four subject categories were represented. Subjects used in phases one and two for for data development were not included. Each subject performed six series of tasks. A series is defined as a combination of adjacent step changes in task intensity. The duration of each series was 240 seconds and each series consisted of either 2 or 3 step changes in task intensity. The subject was at rest at the start of each series.

The step changes in task intensities and associated durations were selected at random for each series for one subject category. Then the step changes for the series of the other three subject categories were chosen such that all like series would require approximately the same steady state %RHRs for all subject categories. That is, the predicted heart rate patterns for series one would be approximately the same in terms of %RHR, and those for series two would be approximately the same, and so on. This procedure was followed so that there would be a similarity in the cardiac response for each series between subject categories; therefore, the subject category responses could be compared in terms of %RHR.

All series (step changes and durations) for all subject categories are presented in Chapter V.

The subject was introduced to the bicycle ergometer and his resting heart rate was determined according to the procedures detailed in phase one. Each subject was given a twenty minute rest period prior to each of the six series of step changes. The subject's heart rate was recorded throughout each series. The step changes in task intensity and durations, subject category, and resting heart rate were input into the predictive model. Utilizing the predictive model, the heart rate responses were predicted and then compared to the observed heart rate responses in order to evaluate the validity of the model.

Instructions to subjects for the validation testing are presented in Appendix 1.

<u>Collection of Heart Rate Data from Recorded Output</u>

The individual heart beats and the heart rate based on the inter-beat interval were recorded continuously on the strip chart recorder during rest and exercise.

The heart beat data were necessary for determining the resting heart rate as described in phase one of testing. The heart rate data were used to determine the empirically derived hard data patterns of 20 %RHR step changes used in the predictive model and to evaluate the predictive model.

Figure 11 presents an actual recorded response of a sedentary female while performing tasks AA' (100 to 160 to 100 %RHR). From the calibrated output of the strip chart recorder, the data were transferred to Form 3 (see Appendix 6) at 10 second intervals in discrete heart

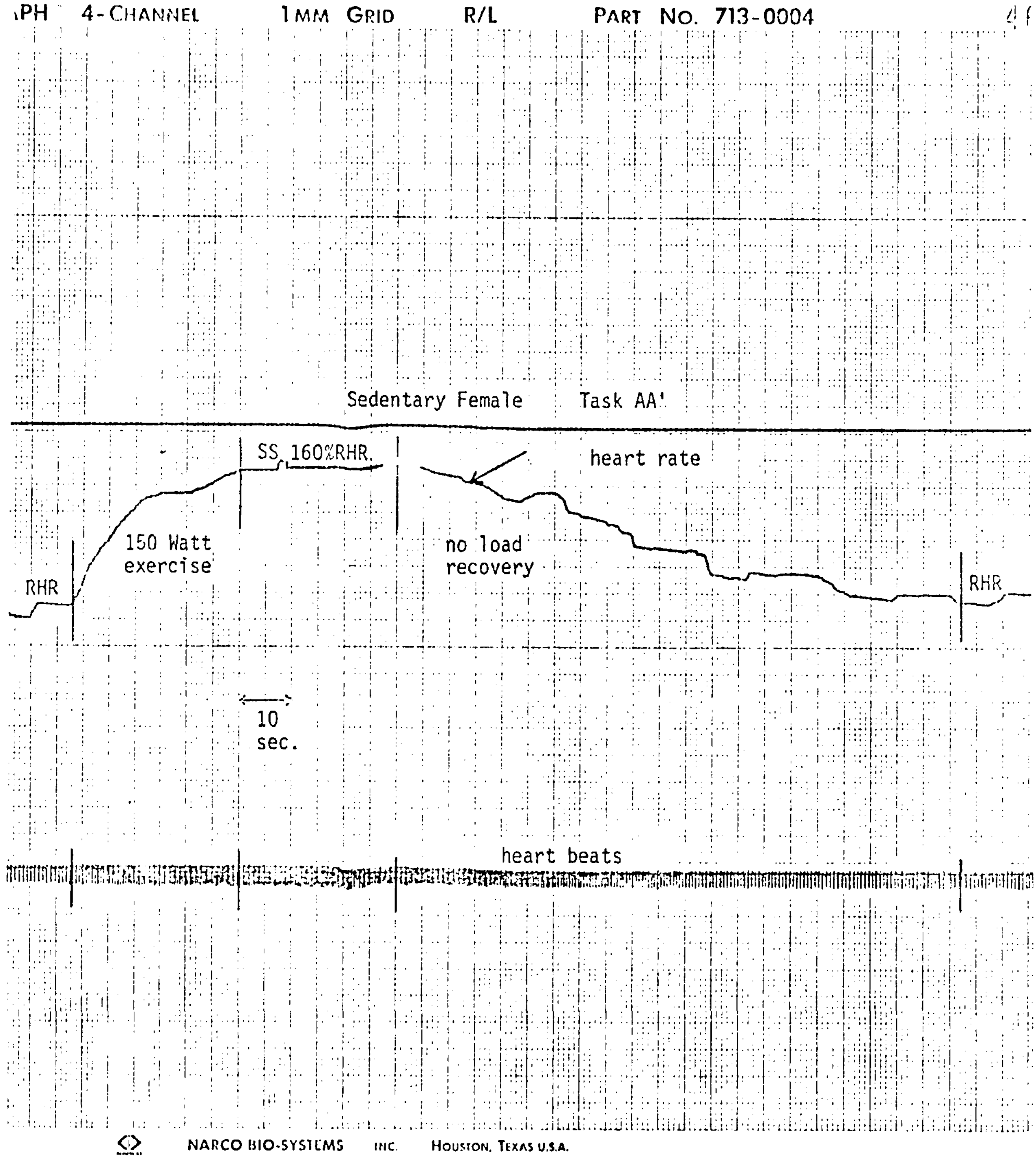

Figure 11. Strip chart recorder output during exercise AA' for sedentary female.

rate values. In some cases, equipment artifacts caused discontinuities in the recorded heart rate patterns. In these cases the closest, most representative point was selected as the data point transferred to Form 3. After the data had been collected in discrete heart rate values, the conversion tables (shown, in part, in Appendix 14) were used to transform all heart rate data to %RHR. These data were recorded on Form 2 of Appendix 6.

The heart rate data for validation testing were taken directly from the calibrated strip chart recorder output at 10 second intervals. It was not necessary to convert the heart rate data to %RHR since the predictive model was evaluated in terms of heart rate.

CHAPTER IV

THE EXPERIMENTAL DESIGN AND PREDICTIVE MODEL

The contents of this chapter include a discussion of the experimental design which was used for the collection and evaluation of the heart rate data necessary for the development of the predictive model. Also, the methodology of the predictive model is presented in detail. A numeric example is used to illustrate the logic and computational procedures of the predictive model.

The Experimental Design for Data Collection

The experimental design of this study was not established to evaluate the results of the model but rather to form a basis by which to collect and evaluate the data (hard data patterns) which constitute the foundation of the predictive model.

The main effects of sex and physical fitness were discussed in detail in the preceding chapter. There are two levels of sex, male and female. There are two levels of physical fitness, good and sedentary. Consequently, there are four subject categories.

The other main effects are time and subjects. The data (heart rate) for each heart rate pattern were collected at ten second intervals at time 0, 10, 20, etc. (nine levels of time). The ten second interval provides a reasonable balance between the sensitivity of the data and elapsed time. There were a total of eight subjects tested to supply empirical data for the predictive model (two subjects from each of the four subject categories). There was one replication for each trial; consequently, there are four data points for each time period for each hard data pattern for each subject category.

The experimental design is for a nested-factorial experiment with the main effects of sex, physical fitness, time periods and subjects. The subject factor is nested under sex and physical fitness. This analysis of variance model is applicable for investigating one heart rate pattern (e.g., 100 to 140 %RHR). There are twelve step changes in all and therefore twelve ANOVAs. The ANOVAs serve a two fold purpose in that the results indicate the significance of the main effects and as a by-product, the cell means by time period and by subject category provide the hard data patterns for the predictive model.

In the analysis of variance model, sex is denoted by "S," physical fitness by "P," subjects by "V," and time periods by "T." Levels 1 and 2 of sex are male and female, respectively. Levels 1 and 2 of physical fitness are good physical fitness and sedentary, respectively. Each level for subjects represents one subject. Levels 1 through 9 of the time periods are 0, 10, 20, through 80 seconds, respectively. The mathematical model is a mixed model.

$$X_{ijklm} = u + S_j + P_k + T_l + SP_{jk} + ST_{jl} + PT_{kl} + V_{i(jk)} + SPT_{jkl} + VT_{il(jk)} + e_{m(ijkl)}$$

where,

u = grand mean

V_i = subjects $i = 1,2, \ldots, 8$

S_j = sex $j = 1,2$

P_k = physical fitness $k = 1,2$

T_l = time period $l = 1,2, \ldots, 9$

e_m = experimental error $m = 1,2.$

Table 3 shows the sources of variation and associated degrees of freedom as well as the appropriate denominator for the F-Ratio for testing the significance of the associated main effect or interaction. Table 4 shows the experimental design.

The Predictive Model

Introduction

The predictive model of this study, referred to as the predictive model, was conceived and developed to make allowances for variations in an individual's state of physical fitness, sex and resting heart rate. This prediction process is accomplished by extrapolating cardiac responses to exercise from empirically derived heart rate patterns, referred to as hard data patterns, for various subject categories.

TABLE 3

SOURCES OF VARIATION, ASSOCIATED DEGREES OF FREEDOM, AND DENOMINATOR OF F-RATIO FOR ANOVA

Source of Variation	Degrees of Freedom	Denominator of F-Ratio
μ	1	
S - sex	1	V
P - physical fitness	1	V
T - time	8	VT
SP	1	V
ST	8	VT
PT	8	VT
V - subjects	4	
SPT	8	VT
VT	32	
Error	72	
	144	

TABLE 4

FORMAT OF DATA COLLECTION SCHEME

Time Periods (sec)		Sex							
		Male				Female			
		Physical Fitness				Physical Fitness			
		Sedentary		Good		Sedentary		Good	
	Subject →	1	2	3	4	5	6	7	8
0									
10									
20									
30									
40									
50									
60									
70									
80									

This approach differs from that of previous models in that previously, allowances were made only for resting heart rate and all previous models were stated in terms of mathematical equations. By categorizing subjects into two levels of physical fitness and sex, between subject variations in heart rate response to exercise can be reduced considerably by using percent of resting heart rate (%RHR) as a base. The rationale for this approach was predicated on four basic assumptions. First, individuals of a particular category adhere to a linear relationship between work load and steady state %RHR. Second, the heart rate patterns produced for any given work load by individuals of the same subject category are similar in form when presented as a function of %RHR. Third, heart rate patterns for any step change in work load can be extrapolated from hard data patterns, and these patterns can be shifted along the "time" axis. Fourth, it is reasonable that the individual's resting heart rate is relatively stable from year to year, except for instances when the individual changes his exercise habits.

Hard Data Patterns

Empirical data were collected for each subject category according to the experimental procedures set forth in the preceding chapter. The empirical data which are values of %RHR at 10 second intervals, are the basis for the hard data patterns of 180 seconds duration to include all possible combinations of step changes of task intensity for 100 %RHR, 120 %RHR, 140 %RHR, and 160 %RHR. There are sixteen in all for each subject category. Twelve were derived through experimentation, and the other four are steady state with no change in task intensity (e.g., 120 %RHR to 120 %RHR, 140 %RHR to 140 %RHR).

The hard data patterns were coded for future reference. The coded symbols are two character designators where the first character is alphabetic and the second numeric. The alphabetic character refers to the initial value of the pattern, where:

A is 100 %RHR.
B is 120 %RHR.
C is 140 %RHR.
D is 160 %RHR.

The numeric character refers to the steady state value of the pattern, where:

1 is 100 %RHR.
2 is 120 %RHR.
3 is 140 %RHR.
4 is 160 %RHR.

Table 5 presents a list of hard data patterns and the associated symbols.

The hard data patterns are presented by subject category in Appendix 3. Each data point is the result of an average of four instantaneous heart rate values at time t. The average was a result of two trials each for two subjects.

Other experimenters (Vogt, 1973; Schilpp, 1951; Suggs, 1967) have presented heart rate patterns as either monotically

TABLE 5

NOMENCLATURE FOR HARD DATA PATTERNS

Symbol	Initial Value (%RHR)	Steady State (%RHR)
A1	100	100
A2	100	120
A3	100	140
A4	100	160
B1	120	100
B2	120	120
B3	120	140
B4	120	160
C1	140	100
C2	140	120
C3	140	140
C4	140	160
D1	160	100
D2	160	120
D3	160	140
D4	160	160

increasing or decreasing depending on the direction of the step change of task intensity. The predicted results of previous models were not consistent with the hard data patterns of this study. Patterns produced by these models do not exhibit points of inflection or linear trends for any step change in task intensity. However, both points of inflection and linear trends were found during the data collection phase of this experiment. The points of inflection during the transient responses were expected since there is a lag in cardiac response to any step change in task intensity. Well defined linear trends were found in patterns produced by the sedentary groups. Only one point of inflection was allowed in a hard data pattern. For the time period after the point of inflection, it was expected that the patterns increased and decreased at a zero or decreasing rate. To obtain this feature, it was necessary to smooth several data points to assure only one point of inflection. Only 30 of 1152 (less than 3%) hard data points were adjusted and then by no more than 2 %RHR. No one heart rate pattern required an adjustment for more than two data points. The method used to adjust data points was straight forward. Any point of inflection for either increasing or decreasing heart rate patterns was adjusted up or down such that the slope relative to the two adjacent data points was either zero or decreasing. It was not necessary to adjust any data points in the time period just prior to the point of inflection.

Figures 24 through 35 on pages 115 through 120 display the hard data patterns for all subject categories and the overall average.

The relationship between power and steady state %RHR for each subject group was determined to be linear for each subject category. These relationships served as the basis for determining at what level of work a particular subject's heart rate could be expected to reach a specified steady state level. Figure 15 on page 96 of Chapter V illustrates the relative slopes and intercepts of each of the regression equations. These are discussed further in the results section.

General Discussion of Methodology

This section is a general discussion of the methodology that is used by the predictive model. The following section presents a numeric illustration with an example of inputs, calculations, and outputs.

Required Input

The input required in order to predict an individual's cardiac response to a series of fixed intensity tasks can be obtained easily by an interview and by measuring one physiological variable. An interview is necessary to determine the subject's state of physical fitness (good or sedentary) and the resting heart rate can be obtained by using the procedures set forth in the experimental procedures section. Other inputs include the duration and intensity of each of the tasks and the number of tasks. There can be either two or three adjacent tasks with an accumulative duration of no more than 240 seconds. If the initial value of the heart rate at work onset is other than resting heart rate, the initial value, in %RHR, is an input. This enables the prediction of heart rate responses for an ongoing exercise. To summarize the input required for predicting the cardiac response to a series of tasks, the following is required:

1. Subject category (MG, MS, FG, FS),
2. Resting heart rate (beats/minute),
3. Number of tasks (2 or 3),
4. Initial value of heart rate as %RHR (100 if resting at work onset),
5. Work load (in watts) and duration (in seconds) of each task.

Derivation of Step Change in %RHR

In order to predict a heart rate pattern, it is necessary to determine the expected step change in %RHR. The initial value is either given at work onset or is the value at the time of the step change. The expected steady state %RHR is then derived from the linear relationship of work load to steady state %RHR for the appropriate subject category. (See Figure 15 on page 96.) The initial value and the expected steady state %RHR depict the direction and magnitude of the step change in %RHR. For example, given an initial value of 100 %RHR and an expected steady state %RHR of 140 %RHR, the expected cardiac response is an increasing step change of 40 %RHR.

Selection of Appropriate Hard Data Patterns

It is apparent that a heart rate pattern for a step change of 100 to 130 %RHR is not available in the hard data patterns. However, this pattern can be accurately extrapolated from the hard data patterns which form the core of the predictive model. Given any step change in task intensity for any subject category, the step change in %RHR can be derived, thereby yielding the initial value and the steady state %RHR, 100 and 130 %RHR, respectively, in the above example. For each heart rate pattern to be predicted (P) the predictive model requires two hard data patterns which encompass P. The initial value of P is numerically within or equal to the initial value of the two hard data patterns (e.g., 100 %RHR $\leq$ IV $<$ 120 %RHR). The steady state %RHR of P is within or equal to the steady state %RHR (SS) values of the hard data patterns (e.g., 120 %RHR $\leq$ SS $<$ 140 %RHR). These hard data patterns which encompass P will hereafter be referred to as high and low patterns.

The high (H) and low (L) patterns are selected such that the absolute difference, $|H_t - L_t|$ is no greater than 20 %RHR at time t equal zero and at times when both patterns are at steady state. This means that there can be a difference of no more than 10 %RHR between P and H, or between P and L at IV and SS. The initial value (IV) of P will be within one of the three following limits:

$$100 \text{ \%RHR} \leq \text{IV} < 120 \text{ \%RHR},$$
or
$$120 \text{ \%RHR} \leq \text{IV} < 140 \text{ \%RHR},$$
or
$$140 \text{ \%RHR} \leq \text{IV} \leq 160 \text{ \%RHR}.$$

The steady state (SS) of P will be within one of the three following limits:

$$100\ \%RHR \le SS < 120\ \%RHR,$$
or
$$120\ \%RHR \le SS < 140\ \%RHR,$$
or
$$140\ \%RHR \le SS \le 160\ \%RHR.$$

Therefore, P can be within any combination shown in Table 6 . As noted in the table, a decreasing step change from an IV of more than 140 %RHR for the sedentary subject categories is not included in the predictive model. (This omission is explained in detail in the results section of Chapter V.) Therefore, the decreasing step changes for combination (9) and combination (8) are permitted for subject categories of good physical fitness only.

The low and high patterns are unique for combinations (2), (3), and (6) of Table 6 , (increasing) and for combination (8) (decreasing). However, for combinations (1), (5), and (9), P can either be increasing or decreasing since the initial value and steady state %RHR intervals are the same. Therefore, each of these combinations has a pair of low and high patterns. The selection of the appropriate low and high patterns are dependent upon the IV to SS relationship. There is also a pair of low and high patterns for combinations (4) and (7) of Table 6 . For combinations 4) and 7), if the decrease is to a resting state (to 100 %RHR), both the high and the low patterns decrease to a resting state. Otherwise, only the low decreases to a resting state.

There are sixteen hard data patterns of 180 seconds duration which contain 19 data points each at 10 second intervals for each of the four subject categories. Appendix

TABLE 6

COMBINATIONS OF POSSIBLE STEP CHANGES IN %RHR FOR P

Steady State %RHR	Initial Value 100 to 120 %RHR	Initial Value 120 to 140 %RHR	Initial Value 140 to 160 %RHR
100 to 120 %RHR	(1)	(4)	(7)[1]
120 to 140 %RHR	(2)	(5)	(8)[2]
140 to 160 %RHR	(3)	(6)	(9)[3]

[1]To RHR only, for S

[2]For G only

[3]Increase only, for S

3 contains all hard data patterns. Figure 12 presents a flowchart of the decision process for selection of the high and low patterns.

<u>The Predicted Heart Rate Pattern Not Adjusted for Time</u>

After the appropriate high and low patterns are selected, a heart rate pattern with the same steady state %RHR (SS) of the pattern to be predicted can be extrapolated from the high and the low. This is accomplished by linear interpolation. The ratio (R1) is derived from the following equation:

$$R1 = \frac{SS - LSS}{HSS - LSS}$$

where:

LSS = steady state of the low pattern

HSS = steady state of the high pattern

This ratio is multiplied times the difference of the high and the low patterns at time t (for 10 second intervals). The results are then added at the appropriate time period to the low heart rate pattern. The predicted heart rate pattern not adjusted for time (Z) is derived by the following equation:

$$Z_t = (H_t - L_t)R1 + L_t$$

where:

Z_t = point on P not adjusted for time at time t

H_t = point on H at time t

L_t = point on L at time t

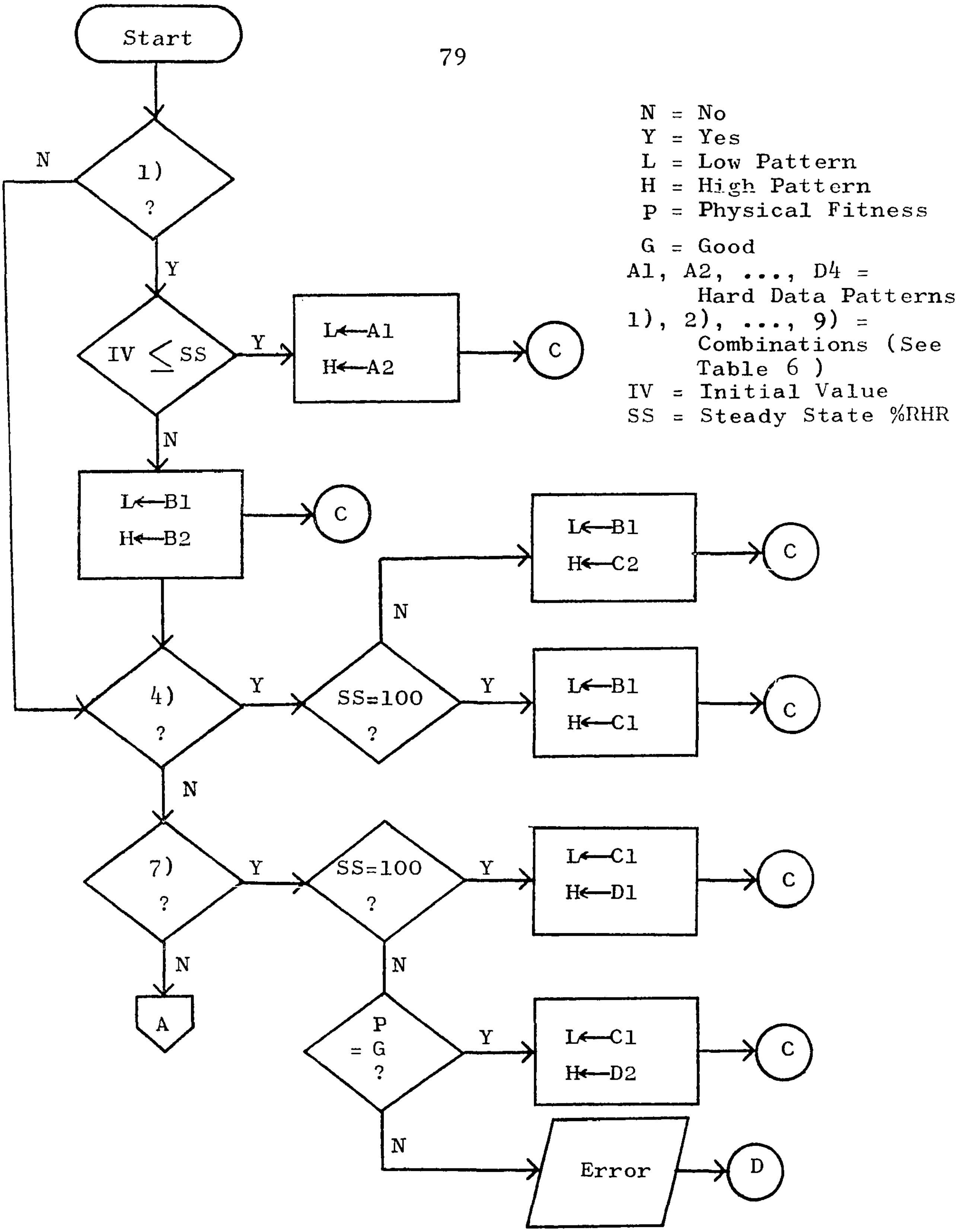

Figure 12. Selection process for high and low heart rate patterns.

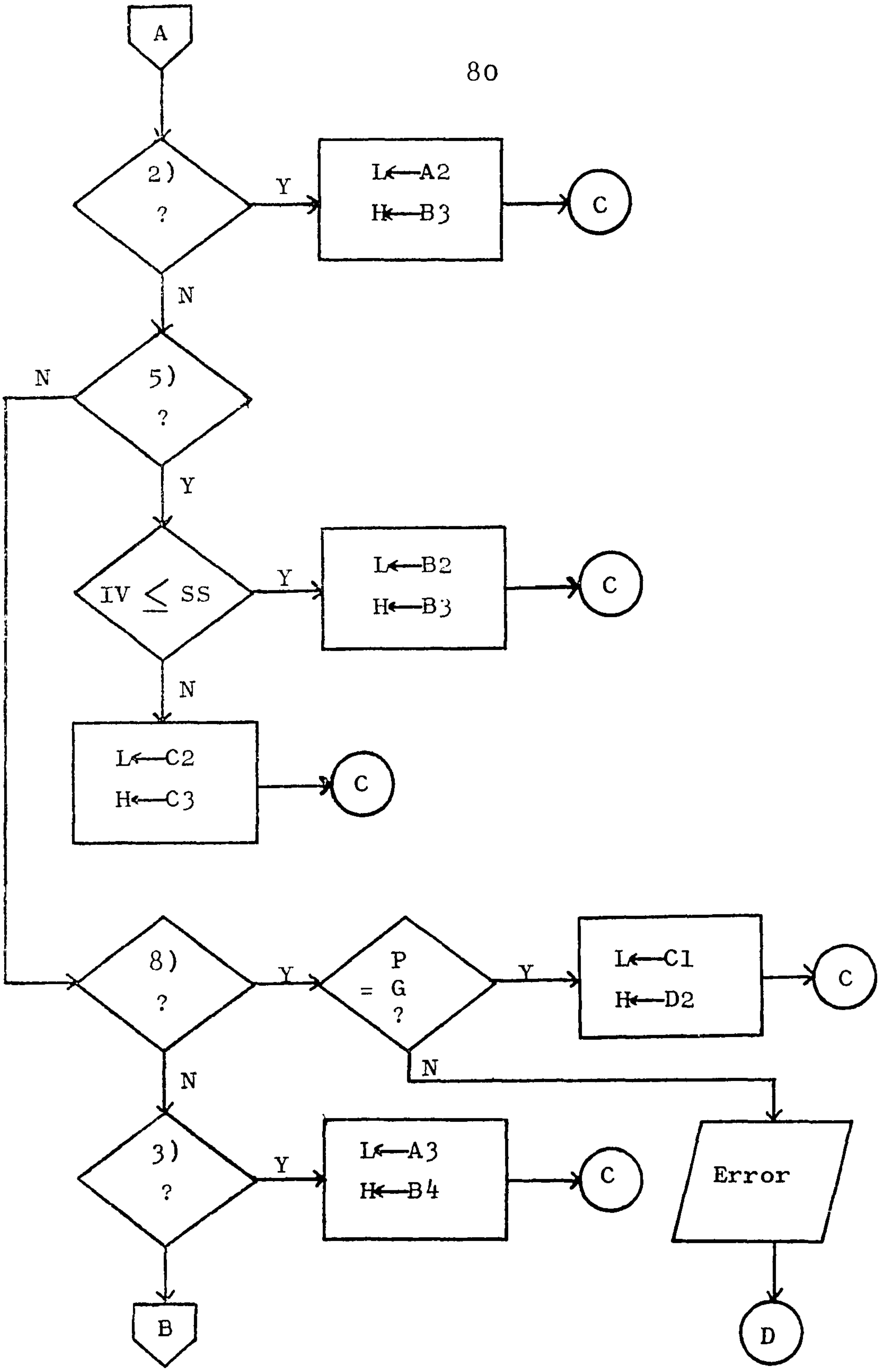

Figure 12. <u>Continued</u>.

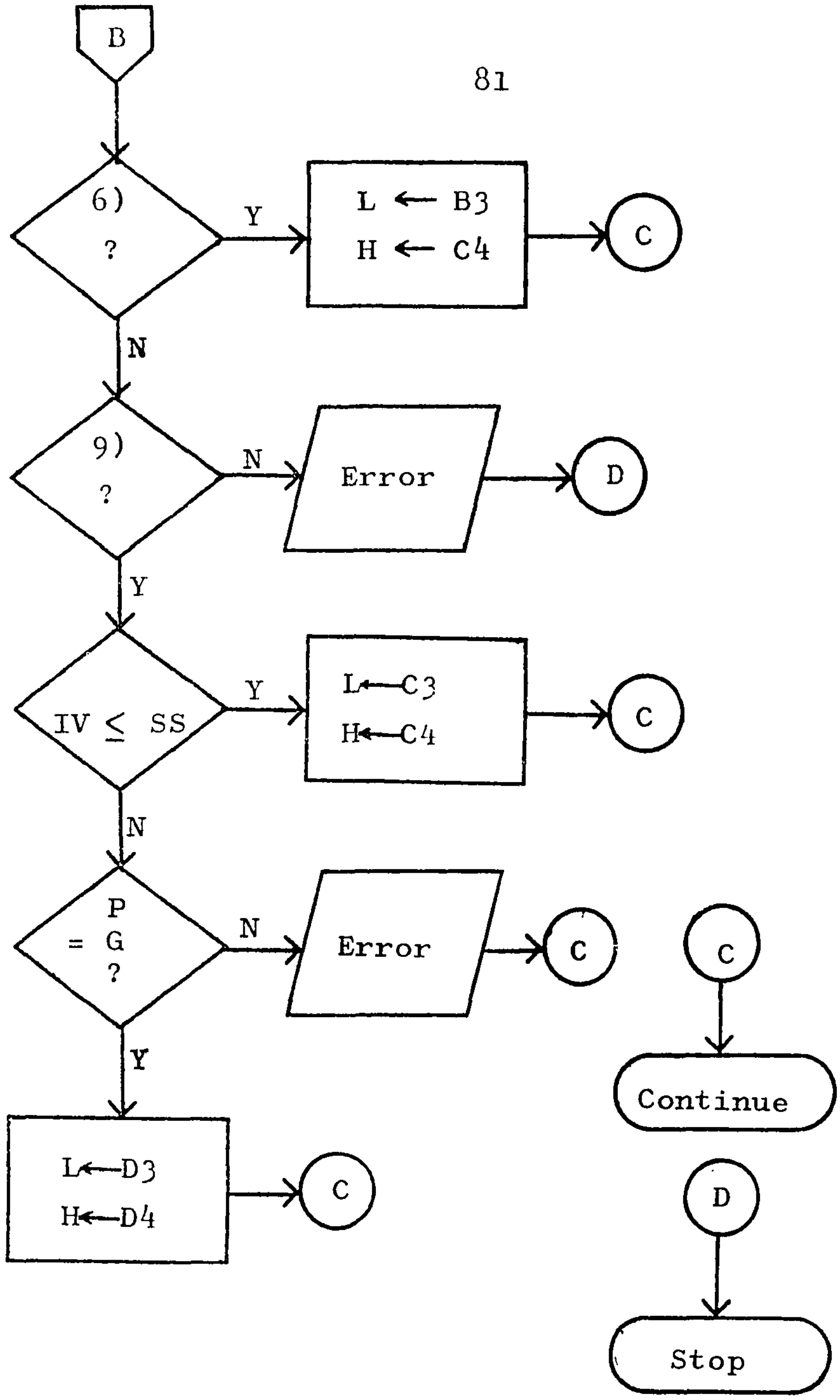

Figure 12. <u>Continued</u>.

$t = 0, 10, 20, \ldots, 180$.

Since the initial value of Z may or may not be equivalent to that of P, Z is said to be not adjusted for time. Z can be shifted along the time axis such that the intercept will be equivalent to the IV of P.

There are two circumstances in which P can be calculated directly without having to adjust for time. This occurs for combinations (4) and (7) of Table 6, when the step change is to a resting state. In these cases, both the high and the low patterns decrease to a resting state or to 100 %RHR; therefore, the ratio used to calculate P directly is derived from IV as follows:

$$R3 = \frac{IV - L_o}{H_o - L_o}$$

where:

L_o = value of low pattern at time zero

H_o = value of high pattern at time zero.

Pattern P is then derived as follows:

$$P_t = (H_t - L_t)R3 + L_t.$$

All other combinations must be adjusted for time as discussed in the following section.

The Predicted Heart Rate Pattern Adjusted for Time

The steady state of pattern Z is the same as that of Pattern P; however, the initial value of Z (Z_o) is dependent upon R1 and may or may not be equivalent to IV. In order to derive a heart rate pattern with the required IV and SS, it is then necessary to adjust Z by shifting Z along the time axis to a point where the intercept with the y axis (time = 0) is equal to IV. This heart rate pattern is adjusted for time and is equivalent to P.

The direction of the shift of Z along the time axis to derive P is dependent on the relation of IV to Z_o. If Z_o is greater than IV then Z is shifted to the right. If Z_o is less than IV then Z is shifted to the left. If Z_o is equal to IV then Z is equal to P. To summarize,

If $Z_o > IV$, $t \leftarrow t + T$

$Z_o < IV$, $t \leftarrow t - T$

$Z_o = IV$, $Z = P$

where:

T = shift in time (seconds).

In order to determine T, the amount of shift in time, the 10 second interval of Z in which IV is contained must be determined ($Z_t \leq IV < Z_{t+10}$). Since the data points of Z are at 10 second intervals, it is likely that the IV will not be equal to some Z_t. Having selected the appropriate 10 second interval in Z (Z_a to Z_{a+10}), it is then necessary to determine the ratio of the difference between IV and Z_a and the difference between Z_{a+10} and Z_a. The resultant ratio, R2, is shown below.

$$R_2 = \frac{|IV - Z_a|}{|Z_{a+10} - Z_a|}$$

The ratio R2 is then multiplied times each interval difference, $|Z_t - Z_{t+10}|$, and the result is either added to or subtracted from Z_t, depending on whether the heart rate is increasing or decreasing during the interval. The resultant heart rate pattern is P. The calculation is performed according to the following equation:

$$P_t = Z_t \pm (|Z_{t+10} - Z_t|) \times R2$$

Add, if $Z_{t+10} > Z_t$

Subtract, if $Z_{t+10} < Z_t$.

The net effect of the above transformation is to shift Z to the right (1-R2)10 seconds or to the left R2(10+a) seconds; therefore,

$$P_t = Z_{t-(1-R2)10} \text{ for shifts to right,}$$

or

$$P_t = Z_{t+R2(10+a)} \text{ for shifts to left.}$$

It can be noted that when Z is shifted to the right, that a time interval of "negative time" is involved. It is therefore necessary to project the high and the low patterns through the time interval of -10 to 0 seconds. This is accomplished by including a point on L and H at time -10. These extra points are not extrapolated from the hard data patterns. This would induce considerable error and is not necessary since the only reason for the negative time requirement is to determine the ratio R2 when Z is shifted to the left. In order that only one data point be included, it is assumed that if the low and high patterns were extrapolated to negative time, they would be approximately 20 %RHR apart at time -10 or be parallel projections. The data indicate that this assumption is well founded. Since they are parallel, the included data points can be fixed such that the range of %RHR for the interval (20 %RHR) is included in the 10 second interval from -10 to 0 seconds. For increasing L and H, the data points at time -10 are 20 %RHR lower than L_o and H_o. For decreasing L and H, the projected points become 20 %RHR higher than L_o and H_o. For steady state L and H, the projected points become the steady state value.

The predicted heart rate pattern P is in terms of %RHR. It is a simple procedure to translate P to a heart rate pattern which predicts the absolute heart rate (H). This is accomplished by the following equation:

$$H_t = (P_t \times RHR)/100$$

where:

RHR = resting heart rate.

Predicting Heart Rate Patterns for a Series of Fixed Intensity Tasks

The predictive model will accommodate a series of up to three tasks with a combined duration of no more than four minutes. The predicted heart rate pattern for each task is derived according to the procedures presented in the preceding sections. Each heart rate pattern predicted for each task is of 3 minutes duration; however, only that portion of pattern which is called for in the input specifications is utilized (e.g., 50 watts for 100 seconds). The model predicts the pattern for task number one first, task number two second and so on. The final %RHR predicted for task number one becomes the initial value for task number two, and so on. In the example above, P_{100} of task number one becomes P_o of task number two. It is in this manner that a series of heart rate patterns can be linked together.

A Numeric Example of the Predictive Model

The following discussion is a numeric example of the method by which the predictive model predicts the cardiac response to a series of tasks. The following information is given:

Sex		Female
Physical fitness		Sedentary
Resting heart rate		80 beats/minute
Initial value		100 %RHR
Number of tasks		3
Task number 1	work load	60 watts
	duration	70 seconds
task number 2	work load	100 watts
	duration	70 seconds
task number 3	work load	0 watts (rest)
	duration	100 seconds

It is not necessary to perform all calculations for all tasks in order to illustrate the basic procedures followed by the model in predicting heart rate patterns. The patterns for task two and three are presented in the following example. The prediction of pattern two illustrates the basic predictive technique for all step changes in task intensity and, also, most clearly illustrates the linking of the three patterns. The prediction of pattern three illustrates the specific predictive technique used for predicting patterns for recovery to a resting state. Assume that the heart rate pattern for task number one has already been predicted and is known. The steady state %RHR (SS) is 129 %RHR at an elapsed time of 50 seconds and, therefore, time equal to 70 seconds, the time at which the task intensity is changed to 100 watts. The initial value (IV) for the 100 watt task (task number two) then becomes 129 %RHR.

The steady state %RHR is determined from the appropriate empirically derived work load to steady state %RHR relationship. For sedentary females:

$$SS = .431W + 103$$

where:

SS = expected steady state %RHR

W = work load in watts.

At 100 watts, SS becomes 146 %RHR. The step change in %RHR is then expected to be 129 %RHR to 146 %RHR.

After having determined the step change in cardiac response, the high and low hard data patterns are selected from the sixteen hard data patterns of the sedentary female subject category. The details of the selection procedure were presented in the preceding section in Figure 12. In this example, the initial value is between 120 and 140 %RHR and the steady state value is between 140 and 160 %RHR.

These limits for IV and SS require the hard data patterns of B3 (120 to 140 %RHR) for the low pattern and C4 (140 to 160 %RHR) for the high pattern. The data for these patterns are presented in Appendix 3. Figure 13 is a plot of the high and low patterns.

The pattern not adjusted for time, **Z**, is then derived from the high and the low patterns. It is known that the SS is expected to be 146 %RHR. The high and low steady states are 160 and 140 respectively. The ratio R1 can be computed.

$$R_1 = \frac{146 - 140}{160 - 140} = .3$$

Z can then be computed.

$$Z_o = (140\text{-}120).3 + 120 = 126$$
$$Z_{10} = (152\text{-}132).3 + 132 = 138$$
$$Z_{20} = (157\text{-}137).3 + 137 = 143$$
$$Z_{30} = (160\text{-}140).3 + 140 = 146$$
$$Z_{40}, Z_{50}, \ldots, Z_{180} = \text{steady state } 146$$

Z is shown in Figure 13. It can be observed that the initial value of pattern **Z** is 126 %RHR. The desired initial value is 129 %RHR. The pattern **Z** must be shifted to the left and adjusted for time such that the intercept is 129 %RHR.

Since Z_o is less than IV, **Z** is shifted to the left to intercept at 129 %RHR. The interval of $Z(Z_a$ to $Z_{a+10})$ in which IV is contained is then determined in order to determine the magnitude of the shift. In the example,

$$Z_o \leq IV < Z_{10},$$

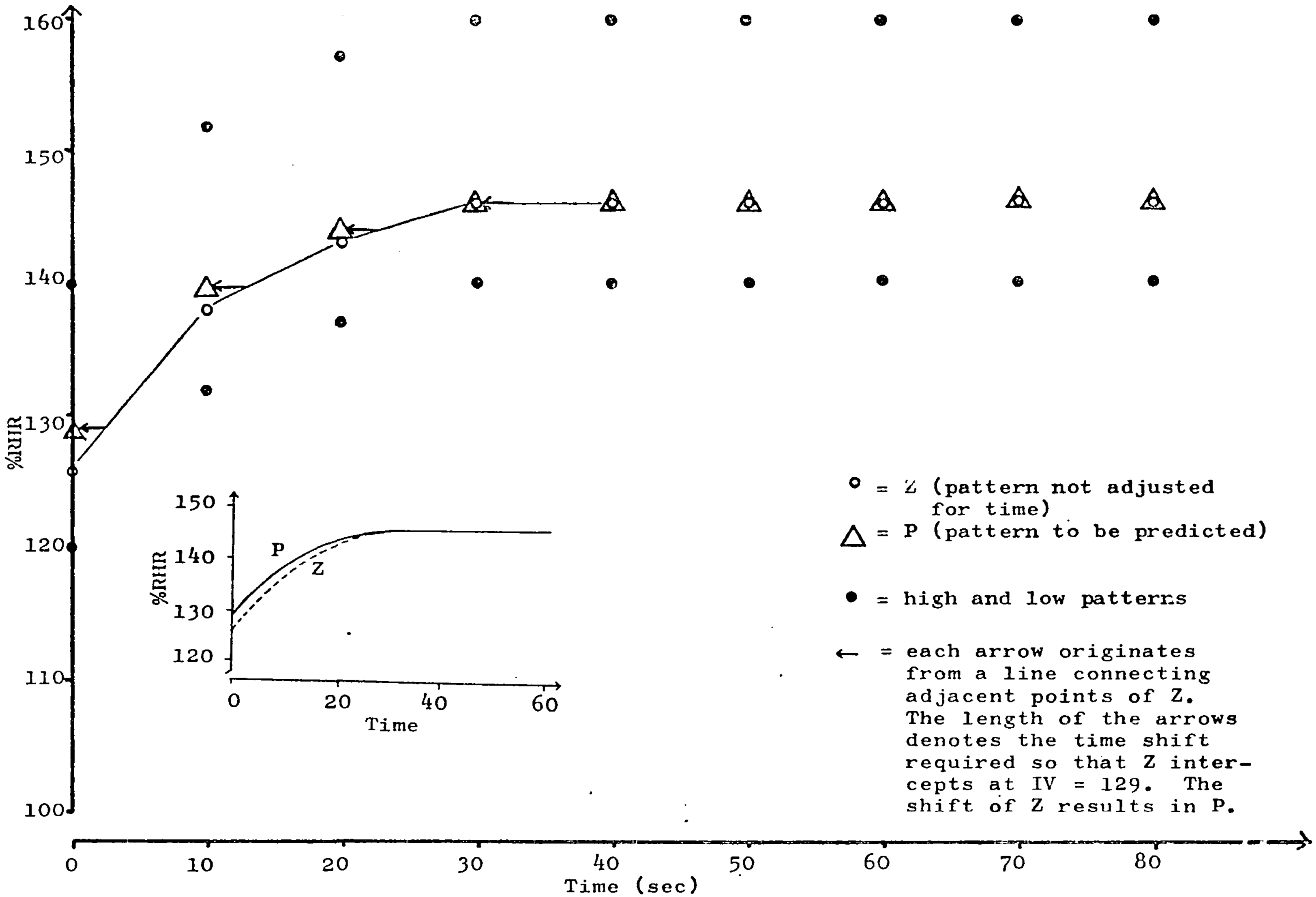

Figure 13. Graphic example of derivation of predicted heart rate pattern. Inset shows lateral shift of Z to intercept at IV = 129, thereby becoming P.

$$126 \leq 129 < 138.$$

Based on the above interval R2 is computed.

$$R2 = \frac{129 - 126}{138 - 126} = .25$$

P is then computed as follows:

$$P_o = 126 + (138\text{-}126).25 = 129$$

$$P_{10} = 137 + (143\text{-}138).25 = 138$$

$$P_{20} = 143 + (146\text{-}143).25 = 144$$

$$P_{30} = 146 + (146\text{-}146).25 = 146$$

$$P_{40}, P_{50}, \ldots, P_{180} = \text{steady state } 146$$

The arrows on Figure 13 indicate the direction and magnitude of the shift of Z. The magnitude for a shift to the left is .25(10+0) seconds (2.5 seconds).

Since the series of tasks is ongoing, the predicted heart rate pattern must be placed in the appropriate time period. Task number one is of 70 seconds duration with task number two beginning at time 70. Therefore, P_o is at time 70, P_{10} at 80 and so on, until the duration of task two has elapsed at time 150. After 150 seconds the work load becomes zero (task number three) and the cardiac response to recovery is then predicted. The initial value is 146 %RHR and the expected steady state is 100 %RHR.

Since the step change indicates combination (7) of Table 6 and, also, the step change is to a resting state, both the high and low patterns are patterns which decrease to 100 %RHR. It can be observed from Figure 14 that the low and high patterns are hard data patterns C1(140 to 100 %RHR)

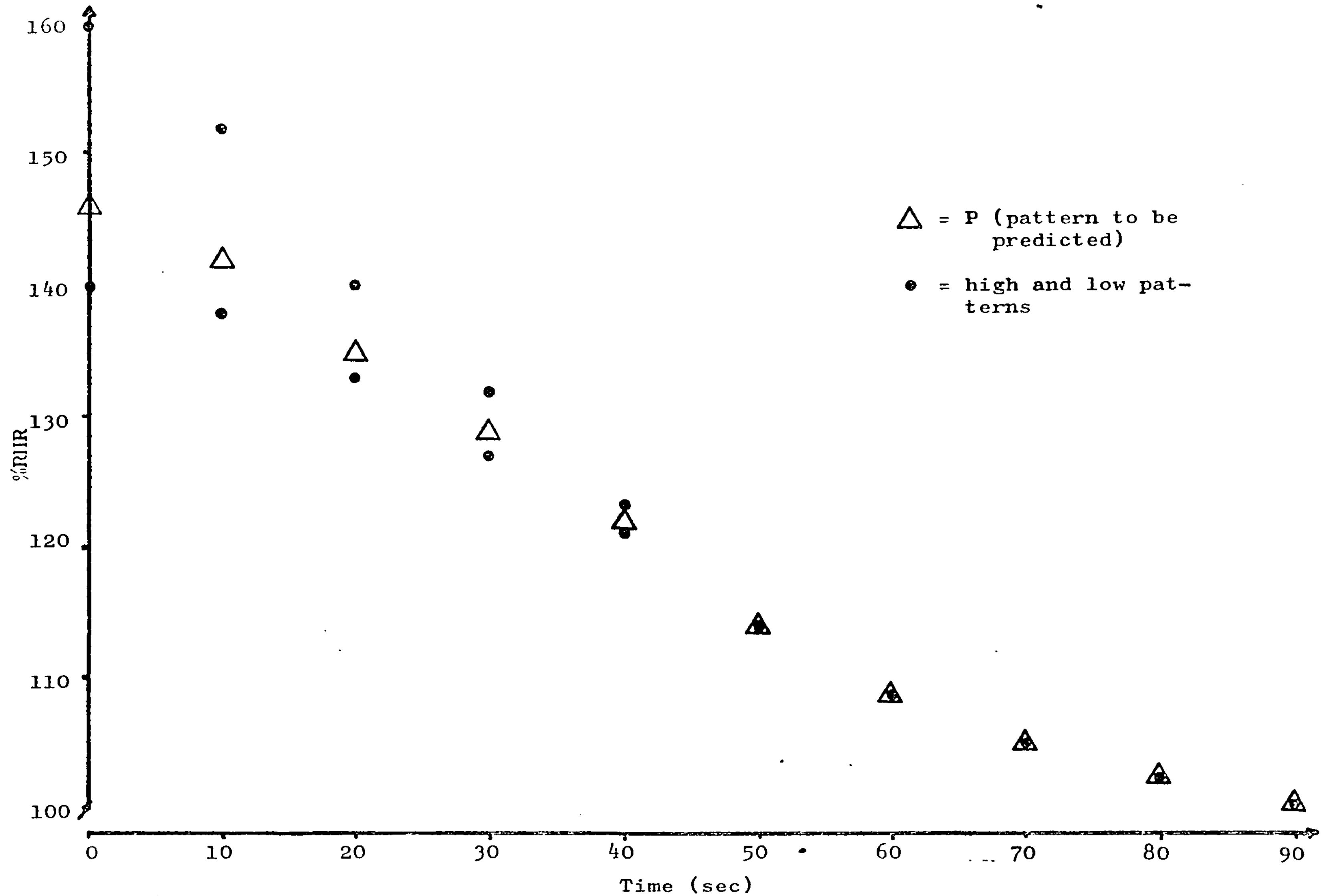

Figure 14. Graphic example of derivation of predicted heart rate pattern for recovery to a resting state.

and D1 (160 to 100 %RHR), respectively, for the sedentary female subject category. The data for these patterns are shown in Appendix 3. Figure 14 is a plot of the high and low patterns.

P can be derived directly from the hard data patterns. R3 is calculated as follows:

$$R3 = \frac{146 - 140}{160 - 140} = .3$$

then,

$$P_0 = (160-140).3 + 140 = 146$$

$$P_{10} = (152-138).3 + 138 = 142$$

$$P_{20} = (140-133).3 + 133 = 135$$

$$P_{30} = (132-127).3 + 127 = 128$$

$$P_{40} = (123-121).3 + 121 = 122$$

$$\vdots$$

$$P_{90}, P_{100}, \ldots, P_{180} = (100-100).3 + 100 = 100.$$

Since the series of tasks is ongoing, the predicted pattern must be placed in the appropriate time period. Therefore, P_o is at time 150, P_{10} at 160, and so on, for total elapsed time of 240 seconds. A plot of H, L and P is shown in Figure 14.

Table 7 presents the predicted cardiac response for the subject and the series of tasks of this example, as produced by the predictive model. The computer program and associated documentation for the predictive model are shown in Appendix 8.

TABLE 7

OUTPUT OF PREDICTIVE MODEL FOR THE SERIES OF FIXED INTENSITY TASKS OF THE NUMERIC EXAMPLE

************************CARDIAC RESPONSE FOR************************

FEMALE

SEDENTARY

RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE
60	0	80	100
60	10	91	114
60	20	96	121
60	30	100	125
60	40	102	127
60	50	103	128
60	60	103	129
100	70	103	129
100	80	111	139
100	90	115	144
100	100	117	146
100	110	117	146
100	120	117	146
100	130	117	146
100	140	117	146
0	150	117	146
0	160	114	142
0	170	108	135
0	180	103	128
0	190	97	122
0	200	91	114
0	210	87	109
0	220	84	105
0	230	82	103
0	240	80	100

CHAPTER V

ANALYSIS OF RESULTS

This chapter, containing the analysis of the results, is divided into four discussion areas. First, the results and analysis of the work load to steady state %RHR relationships are presented. Second, the hard data, collected for the purpose of supplying hard data patterns for the predictive model, are interpreted and analyzed. Third, the predictive model is compared with previous models. Finally, the validity of the predictive model is investigated by comparing predicted results with observed results of the validation testing.

Regression Analysis of Work Load to Steady State %RHR

In order to determine the level of %RHR at which an individual's heart rate could be expected to reach a steady state for a given work load, it was necessary to examine the relationship between work load and steady state %RHR. The independent variable was work load in watts and the dependent variable was steady state %RHR.

Simple linear regression was the technique used to examine the relationship, and a regression was run for each subject category. The data points of Table 8 were plotted and the regression lines are shown in Figure 15. The regression equations are as follows:

for MG:	$SS = .474W + 106.3$	$r = .95$	$r^2 = .90$
for MS:	$SS = .259W + 100.4$	$r = .99$	$r^2 = .98$
for FG:	$SS = .484W + 108.3$	$r = .97$	$r^2 = .94$
for FS:	$SS = .431W + 103.0$	$r = .98$	$r^2 = .96$

where:

SS = steady state %RHR

W = work load (watts)

r = correlation coefficient.

The high correlation coefficients indicate that there is a strong linear relationship between work load and steady state %RHR for work loads requiring steady states of 100 to 160 %RHR. Although all correlations are relatively high, it can be observed that those of the sedentary subject categories are slightly greater than those of the subjects of good physical fitness. From the square of the correlation coefficient, the percent of the variance of steady state %RHR (SS) accounted for by the regression of SS on work load (W) can be determined. From 90 to 98% of the variance of SS is explained by the regression equations.

The range of the regression coefficients, .225(.484-.259), is considerable. The slope of the FG equation is almost twice that of the MS equation. However, it can be observed from Figure 15 that the range of the regression coefficients,

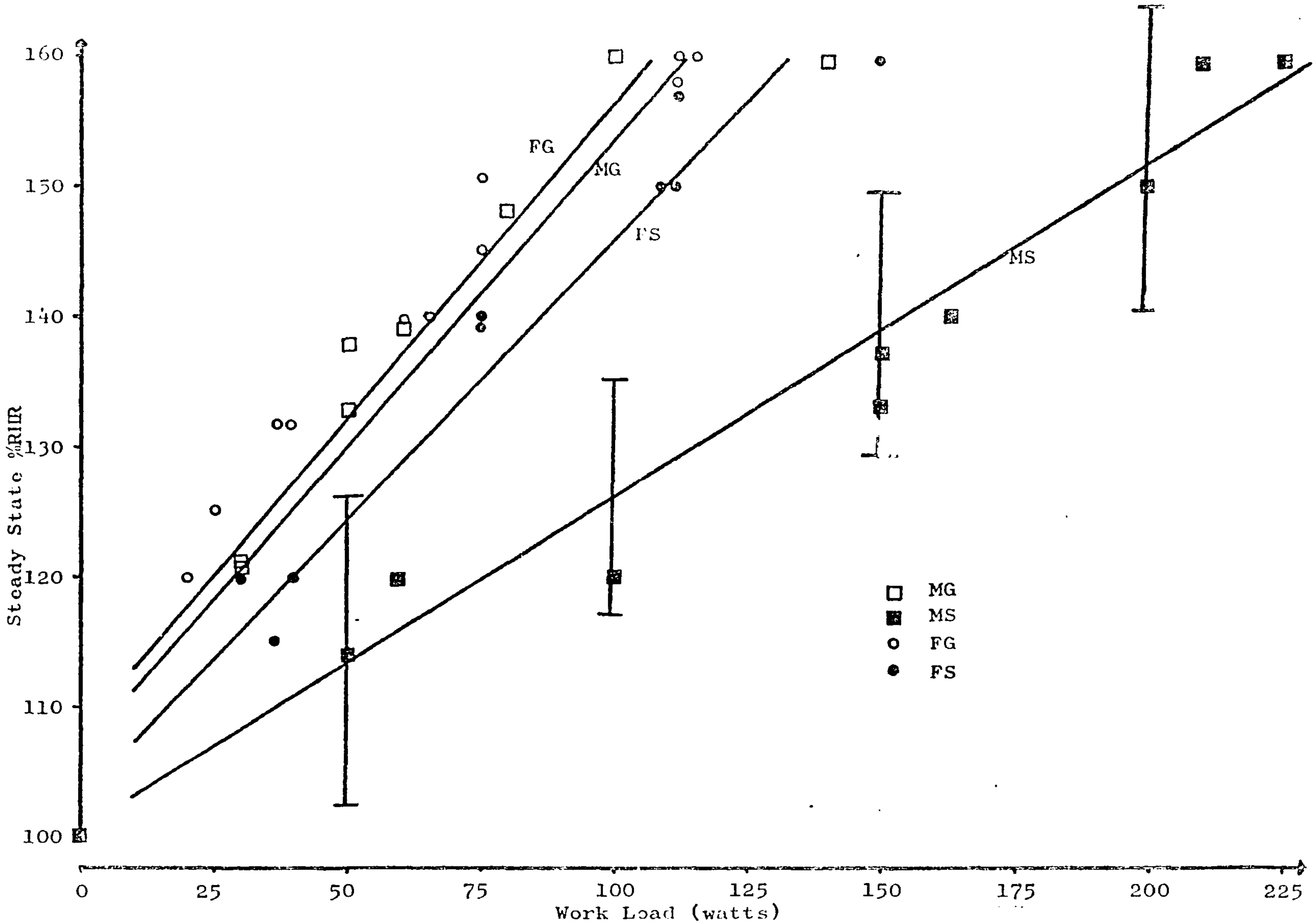

Figure 15. Steady state %RHR versus work load relationship for all subject categories. 95% confidence limits are shown for MS.

TABLE 8

DATA FOR WORK LOAD TO STEADY STATE %RHR RELATIONSHIPS BY SUBJECT CATEGORY

MG		MS		FG		FS	
Watts	SS %RHR	Watts	SS %RHR	Watts	SS %RHR	Watts	SS %RHR
0	100	0	100	0	100	0	100
0	100	0	100	0	100	0	100
30	120	50	114	20	120	30	120
30	120	50	118	25	125	37	115
50	133	60	120	37	132	40	120
50	138	100	120	37	132	75	140
60	140	150	133	60	140	75	140
80	148	150	137	65	140	110	150
100	160	155	140	75	145	112	150
140	160	200	150	75	151	112	157
		200	155	112	158	150	160
		210	160	112	160		
		225	160	115	160		

.053(.484-.431), for MG, FG and FS is small. Because of the range of the coefficients and the cluster of the three high coefficients, each pair was examined to determine if significant difference exists. Only the confidence interval about the regression for MS was shown in Figure 15 in order to emphasize the difference between MS and the other three regressions.

A "t" test (Crow, 1961, p. 161) was used to determine the significance of the regression coefficients of each pair (six in all) of equations. This procedure required the assumption that the standard errors of the estimate for the two regressions be equal. An "F" test was used to show the equivalence of the standard errors. Table 9 shows the critical and computed values of F. As indicated in Table 9, the assumption that the standard errors are equal was shown to be true for all pairs. The programs written to calculate the necessary sums of squares for determining the "t" statistics are shown in Appendix 12.

The hypothesis used for testing the regression coefficient is the following:

$$H_o: \quad b_1 = b_2$$
$$H_A: \quad b_1 \neq b_2$$

where b_1 and b_2 are pairs of regression coefficients. The results are shown in Table 10 and indicate that there is significant evidence to reject the null hypothesis that the regression coefficient of the MG equation is the same as any one of the other three (MS, FG, FS), in favor of the alternative hypothesis, that they are not equal. The null

TABLE 9

CRITICAL AND COMPUTED VALUES OF "F" FOR TESTING THE NULL HYPOTHESIS THAT THE STANDARD ERRORS OF PAIRS ARE EQUAL

Pairs	$F_{.025}$	D.F.	F	.05 Level of Significance
MG-MS	3.44	9,12	3.28	Accept H_o
MG-FG	3.44	9,12	1.68	Accept H_o
MG-FS	3.78	9,10	2.34	Accept H_o
MS-FG	3.25	12,12	1.95	Accept H_o
MS-FS	3.37	10,12	1.42	Accept H_o
FG-FS	3.62	10,12	1.38	Accept H_o

TABLE 10

CRITICAL AND COMPUTED VALUES OF "t" FOR TESTING THE NULL HYPOTHESIS THAT THE REGRESSION COEFFICIENTS OF PAIRS ARE EQUAL VERSUS THEY ARE NOT

Pairs	Regression Coefficients		$t_{.025}$	D.F.	t	.05 Level of Significance
MG-MS	.474	.259	2.09	19	4.76	Reject H_o
MG-FG	.474	.484	-2.09	19	-.16	Accept H_o
MG-FS	.474	.431	2.11	17	.12	Accept H_o
MS-FG	.259	.484	-2.07	22	-5.99	Reject H_o
MS-FS	.259	.431	-2.09	20	-5.68	Reject H_o
FG-FS	.484	.431	2.09	20	1.10	Accept H_o

hypothesis was accepted for all pairs of regression coefficients not involving the MG coefficient.

It can be concluded that the slope of the MS regression equation is one apart from the slope of the MG, FG and FS equations. This conclusion can best be explained by reference to the classical method of presenting cardiac responses to work load relationships. The classical method utilizes heart rate instead of %RHR. The regression lines for MG and MS for both the classical method and the method of this study are shown in Figure 16. The regression equations are as follows:

for MG:
$$SS = .49W + 106.3$$
$$HR = .28W + 57.5$$

for MS:
$$SS = .259W + 100.4$$
$$HR = .21W + 87.5$$

Where:

SS = steady state %RHR

HR = steady state heart rate.

The MG regression coefficients are greater than the MS coefficients for both methods. It can be observed from Figure 16 that although sedentary males can maintain greater work loads for heart rates within the range of this study (230 watts at 160 %RHR for MS versus 115 watts for MG at 160 %RHR), the males of good physical fitness can be expected to maintain a greater work load at any given heart rate above the range of this study. The difference in the intercepts (87.5-57.5) is the reason that it appears the MS category is working more efficiently than the MG category. When, in fact, those persons of good physical fitness have a

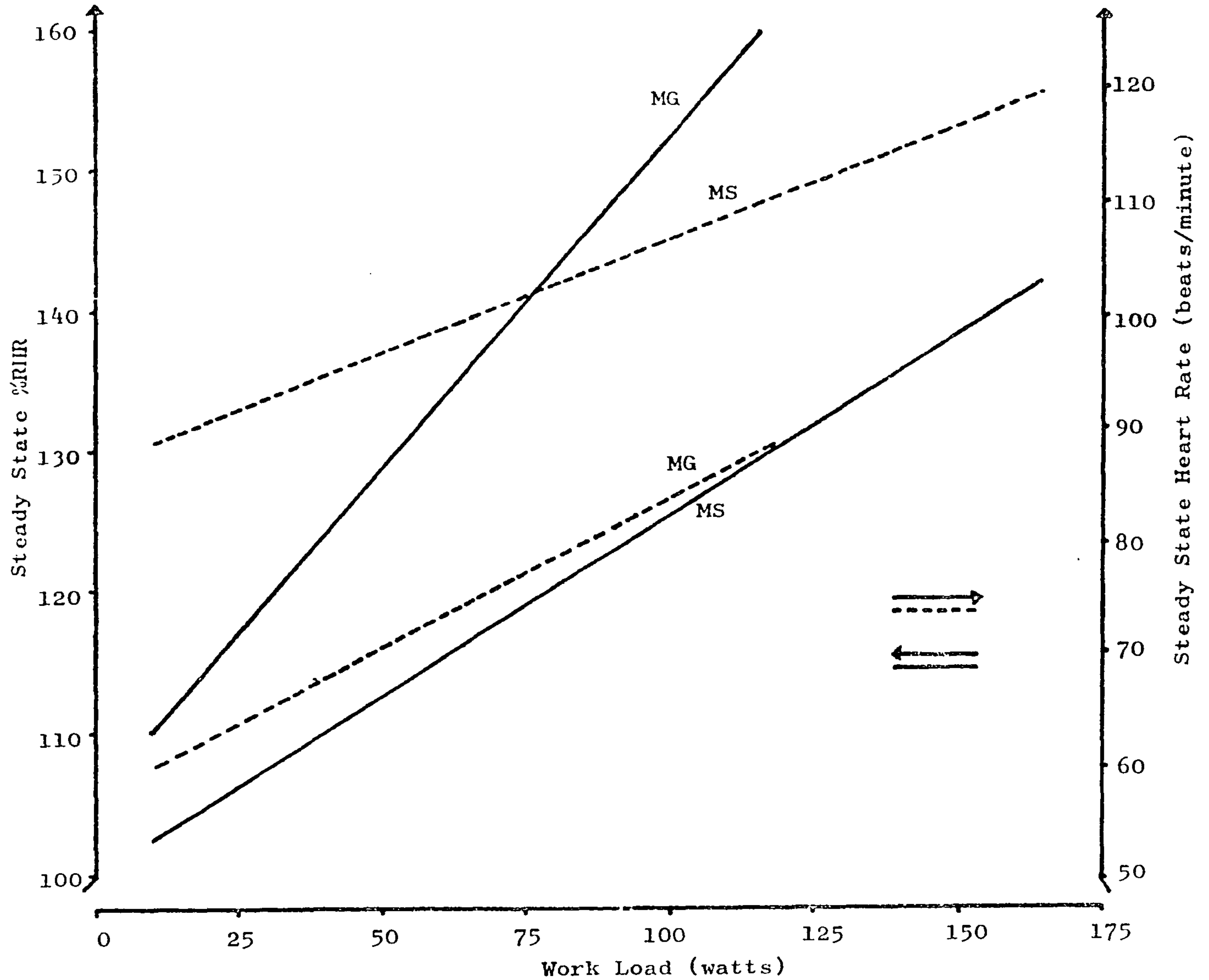

Figure 16. Work load to steady state %RHR and heart rate for male of good physical fitness (MG) and sedentary male (MS). Note that MS regression lines are not extended to include the terminal points at 230 watts.

greater power output per beat increase (.28 vs. .21). The transformation from beats/minute to percent of resting heart rate (%RHR), although graphically confusing, does not alter this fact. Also, the power output per beat increase is greater for FG than FS (.30 versus .21).

There is no statistical difference between regression coefficients for any pair of MG, FG, or FS. However, the correlations for each of these regressions were very high, and it is expected that if it were in the scope of this study to examine enough subjects, a statistical difference would evolve. It is expected that by using a regression equation for each of the subject categories in the predictive model, a greater precision would result in determining the expected steady state %RHR.

Analysis of Hard Data Patterns

Introduction

Analysis of variance was used to examine the transient responses of the twelve hard data patterns which were results of a step change in task intensity (four were steady state). The main effects and interactions are shown in the mathematical model of Chapter IV.

The data for the twelve hard data patterns is presented in Appendix 3. Each data point in Appendix 3 (except for the steady state patterns A1, B2, C3 and D4) is the cell mean for one subject category by time period. These patterns serve as the base patterns for the predictive model. All predicted heart rate patterns are extrapolated from these hard data patterns. The purpose for the analysis of variance was to examine each pattern with respect to the two levels each of sex and physical fitness and the interactions of these factors. Since each pattern was a step change in heart rate over time, the time period factor was expected to be significant. The time period factor was included specifically for the purpose of obtaining a computerized output of cell means by time period; therefore, an analysis of the time period factor and interactions with the time period factor is not required. A complete summary of each of the twelve ANOVAs (ANOVA and EMS tables shown in Appendix 4) is presented in Table 11. It can be observed that the time period factor is significant for all tasks.

The power of the F test in the ANOVAs was the same for both sex and physical fitness. In each ANOVA there were four subjects supplying two data points for each of nine time periods for a total of 72 data points for each treatment level. Special charts (Pearson and Hartley, 1951, pp. 112-130) were used for calculating the power function for the analysis of variance test. The assumption was made that the experimenter was interested in detecting differences among means such that the largest difference is equal to one standard deviation of the error. It was determined that the power was .99 with a Type 1 error of .01.

Analysis of ANOVA Results

It is apparent from the ANOVA summary in Table 11 that, for the most part, the sex and physical fitness effect, and

TABLE 11

ANOVA SUMMARY (LEVEL OF SIGNIFICANCE INDICATED)

	Main Effects and Interactions						
Task	S	P	T	SP	ST	PT	SPT
A2			.01				
A3	.05	.05	.01		.05	.01	
A4		.01	.01	.05	.10	.10	.01
B1			.01				
B3			.01				
B4			.01	.01			.01
C1		.01	.01			.01	.05
C2			.01				
C4	.10		.01				
D1			.01				
D2			.01			.10	
D3			.01				

S = Sex P = Physical Fitness T = Time Period the sex-physical fitness (SP) interactions were not significant. Most of the significant effects were for patterns which had initial values of 100 %RHR (A3 and A4). Only one SP interaction was significant for patterns which had initial values of 120 %RHR (B4). There were two significant main effects for patterns which had initial values of 140 %RHR (C1 and C4) and no significant effects for patterns which had initial values of 160 %RHR. There does not appear to be any special trend of significant effects or interactions.

Figure 17 displays a plot of pattern A3 by sex. The significance is due mainly to the response of the male of good physical fitness (MG). Figure 25 (p. 115) shows the heart rate response by subject category. It can be observed that MG steady states at 20 seconds where MS and FG steady state at 50 seconds and FS at 70 seconds. It can also be observed that the MS and FG patterns are very similar. Figure 18 displays a plot of physical fitness patterns for task A3. Again, the significance can be attributed to the fast response to steady state of subject category MG.

Figure 19 displays a plot of heart rate pattern A4 by physical fitness. Figure 26 (p.116) displays the heart rate response by subject category. It should be noted that, for both task A3 and A4, the responses to steady state are more rapid for the subjects of good physical fitness than for the sedentary subjects. The MS response of task A4 was the cause of the significance of the physical fitness effect. There

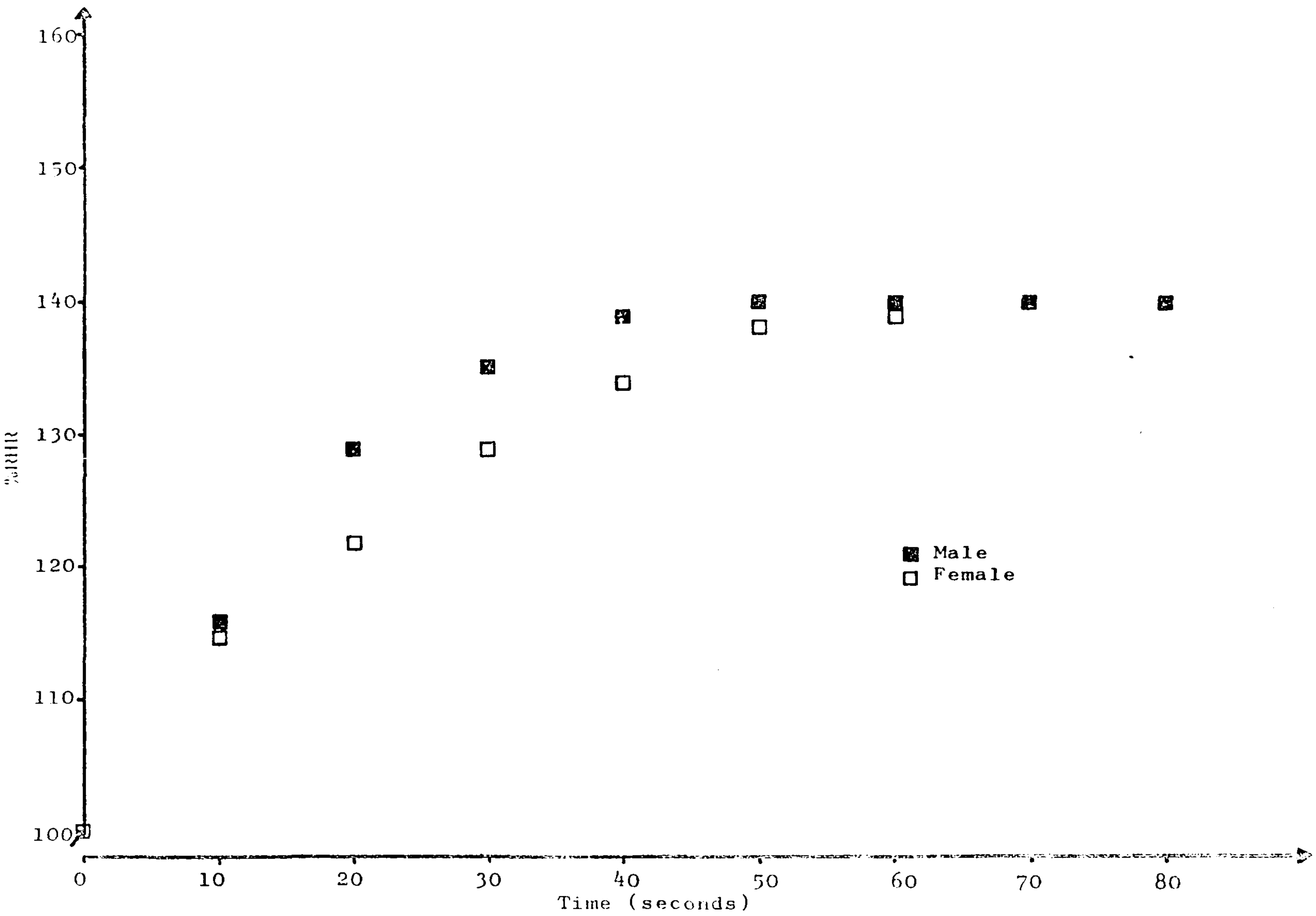

Figure 17. Plot of sex effect for task A3 (%RHR vs. time). Significance level is .05.

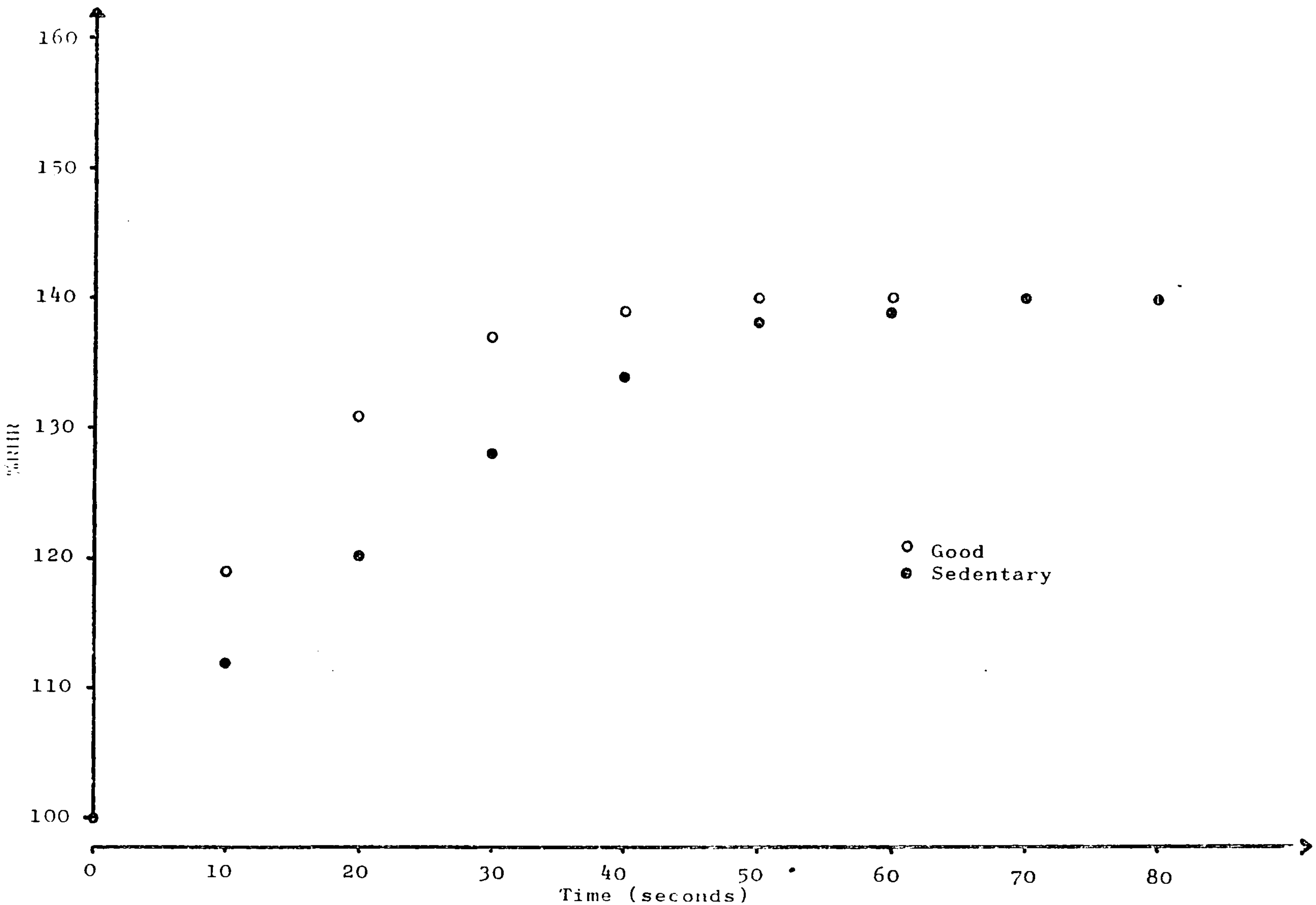

Figure 18. Plot of physical fitness effect for task A3 (%RHR vs. time). Significance level is .05.

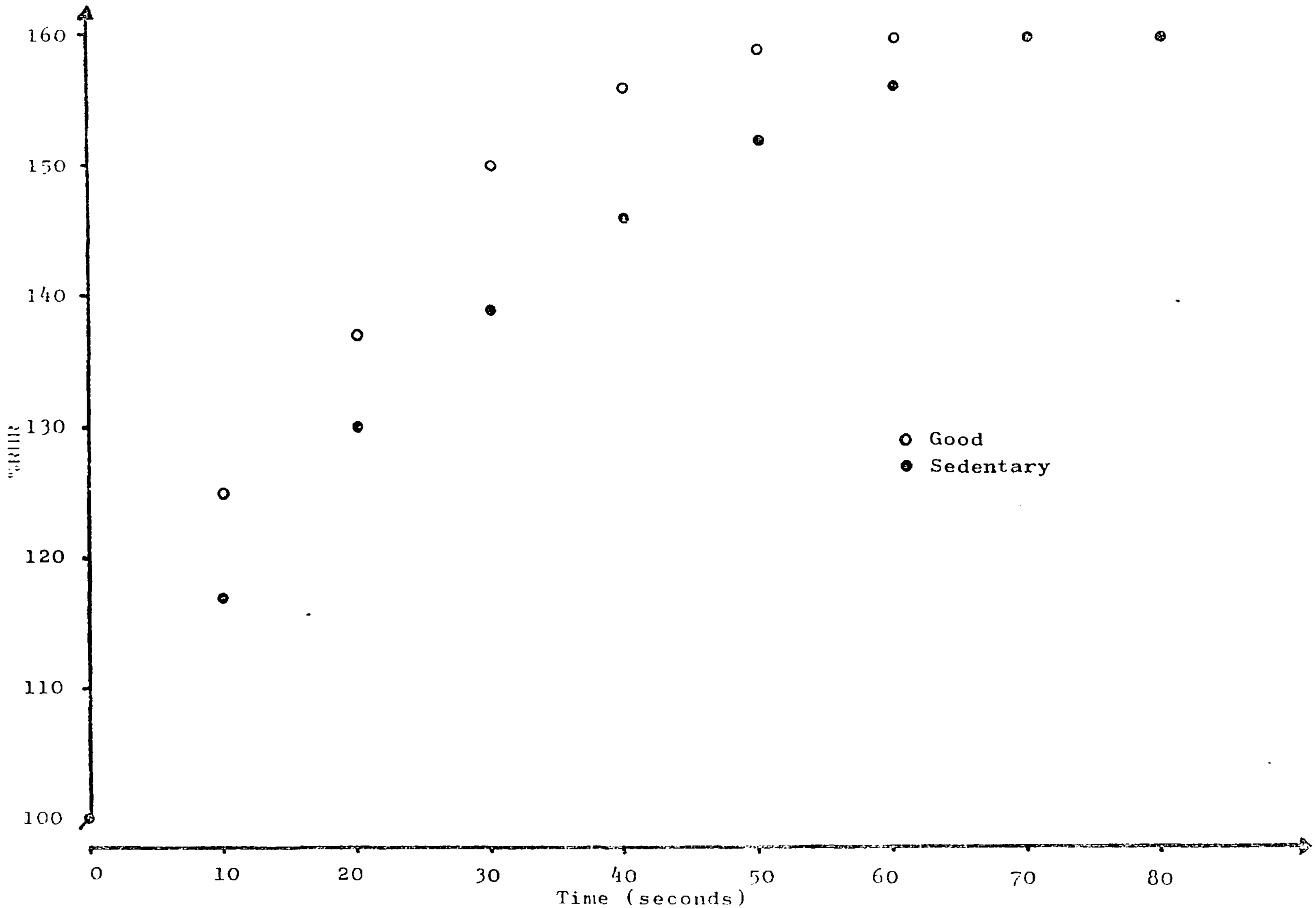

Figure 19. Plot of physical fitness effect for task A4 (%RHR vs. time). Significance level is .01.

is a linear trend for the MS response where the responses of the other three subject categories were very similar.

Figure 20 displays a plot of the sex-physical fitness interaction for task A4. It can be observed that a definite interaction exists for each time period up to steady state. The degree of interaction is greatest at 40 and 50 seconds. At 50 seconds the FS response is at steady state and the FG response is still approaching a steady state. It is expected, and is true for most of the hard data patterns, that the MG and FG patterns accelerate to steady state more rapidly than the MS and FS patterns. The overlap in FG and FS patterns can also be observed in Figure 26 (p. 116).

The sex-physical fitness interactions are much more pronounced for task B4 than for A4. Figure 21 is a plot of the interactions by time period. Again, as in pattern A4, the FS response to steady state is more rapid than the FG response. There is no apparent explanation as to why the FG response accelerates to steady state more slowly than the FS response for tasks A4 and B4, since in most step changes the opposite is true.

Figure 22 displays a plot of patterns C1 by physical fitness. Figure 30 (p. 118) displays the heart rate responses by subject category. Again, the heart rates of the MG and FG subject categories decelerate more rapidly to steady state than do the heart rates of the MS and FS categories. The plot for sedentary subjects exhibits a strong linear trend.

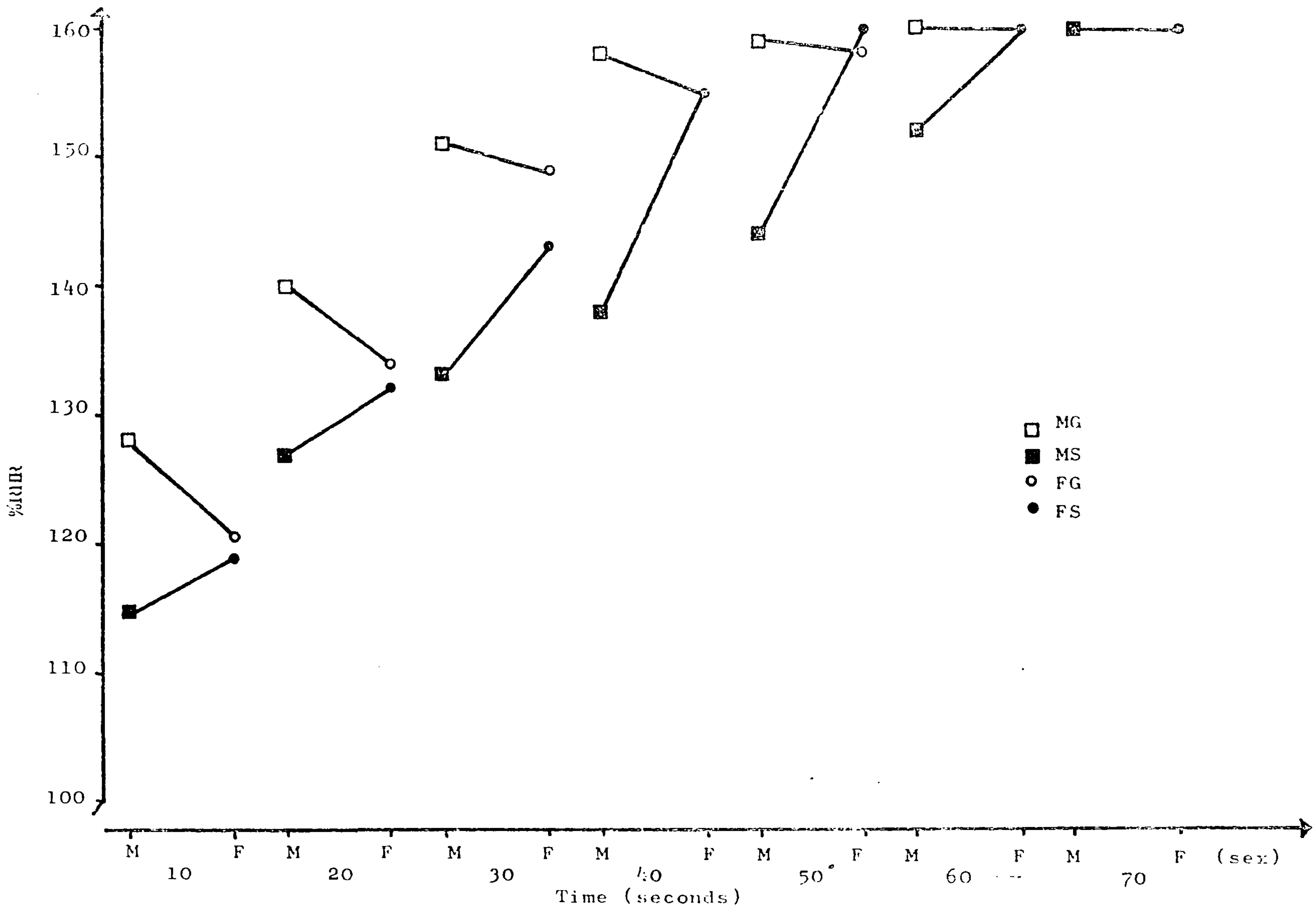

Figure 20. Physical fitness--sex interaction for Task A4 (significance level is .05). Interaction is shown for each time period. Lines connect subject categories of similar physical fitness.

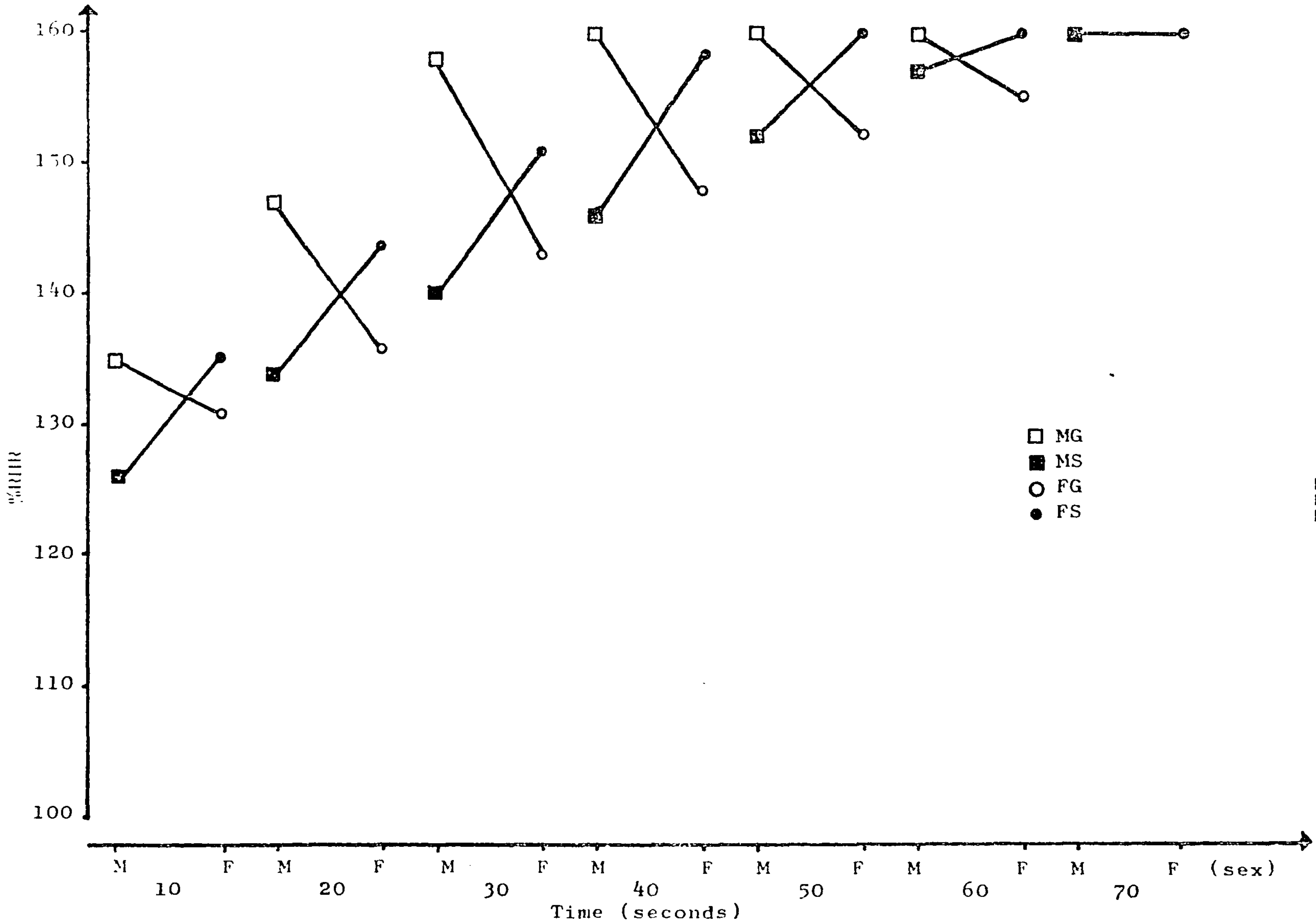

Figure 21. Physical fitness--sex interaction for Task B4 (significance level is .01). Interaction is shown for each time period. Lines connect subject categories of similar physical fitness.

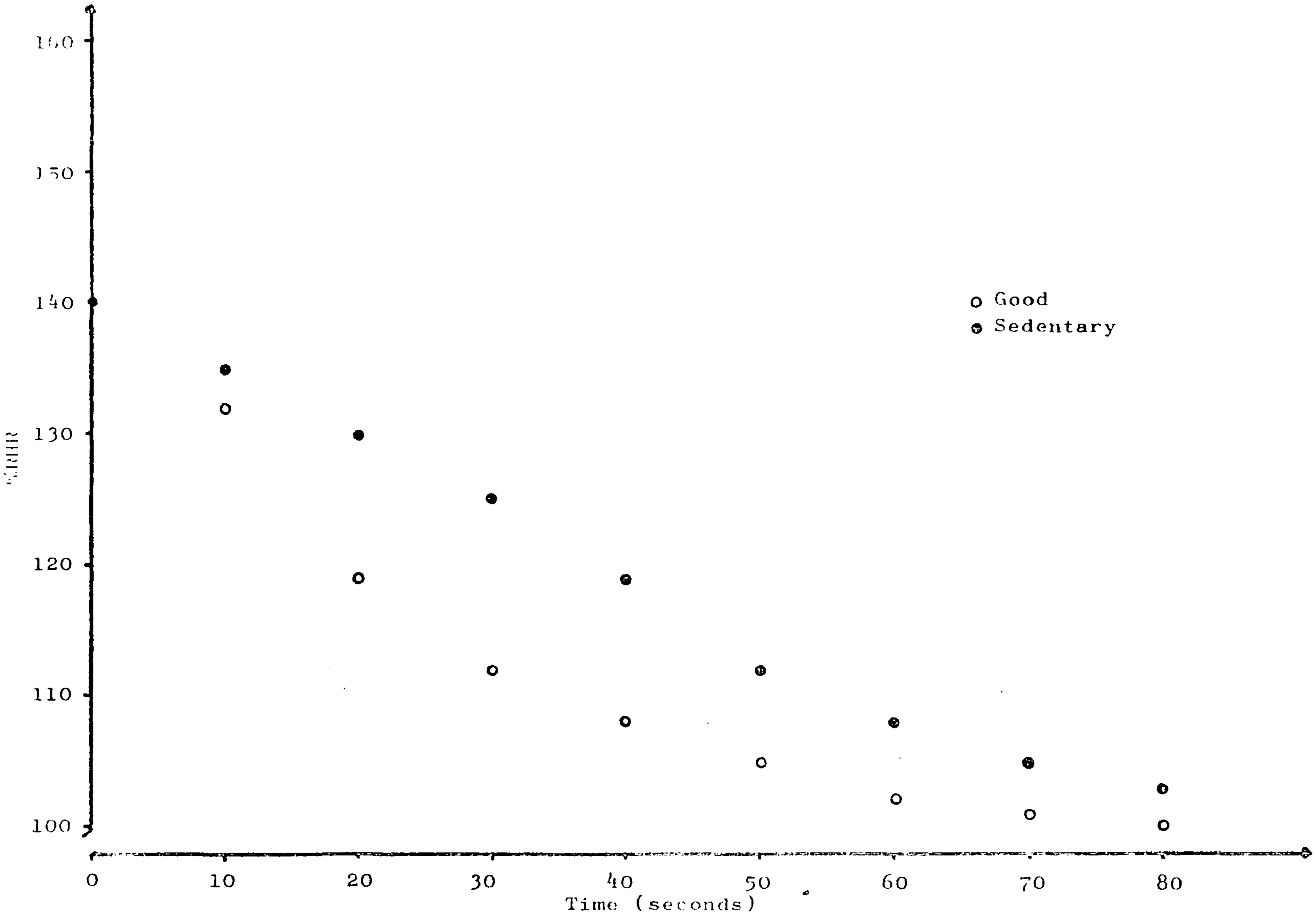

Figure 22. Plot of physical fitness effect for Task C1 (%RHR vs. time). Significance level is .10.

This trend is also apparent for MS and FS separately (see Figure 30). The significance of physical fitness for task C1 can be attributed to the differences in cardiac responses for the female subjects since the responses of the male subjects were very similar.

Figure 23 displays a plot of heart rate pattern C4 by sex. Figure 32 displays the heart rate responses by subject category. The significance was only at the .10 level; however, the patterns for both FG and FS are numerically greater then those of both MG and MS for all data points from the initial value to steady state.

The step changes in task intensity required a net change of either 20, 40, or 60 %RHR. It can be observed that those highly significant effects and interactions (.01 and .05 levels) are for tasks which have step changes of 40 or 60 %RHR. Certainly there is a greater potential for deviation in responses for step changes of 40 and 60 %RHR than for step changes of 20 %RHR. All tasks which required step changes of 40 or 60 %RHR, except D1 and D2, resulted in at least one significant effect or interaction.

Step Decreases in Task Intensity for Sedentary Subjects

The predictive model does not include the prediction of cardiac responses to step decreases in task intensity for sedentary subjects when the initial value is greater than 140 %RHR and the expected steady state value is other than

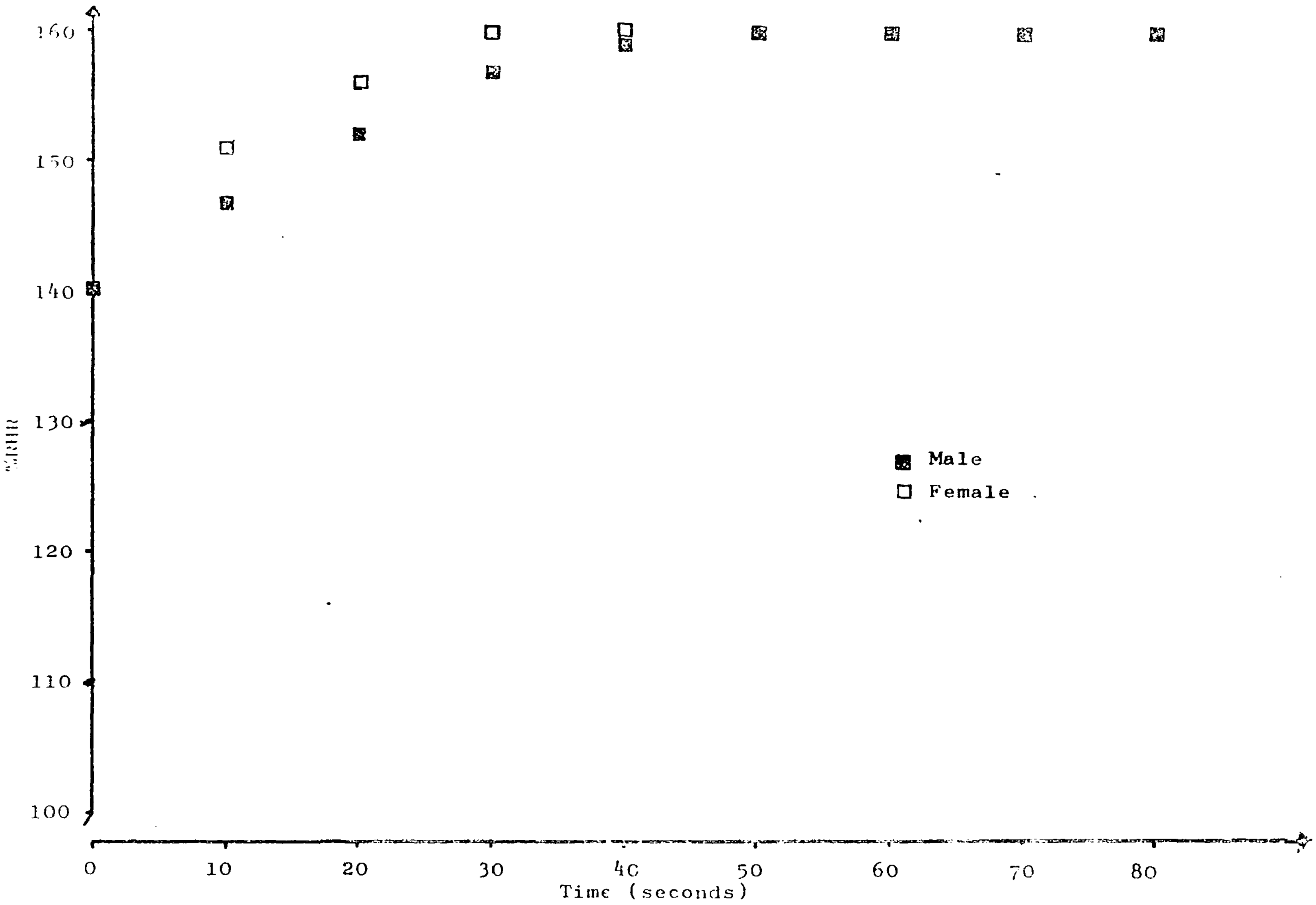

Figure 23. Plot of sex effect for Task C4 (%RHR vs. time). Significence level is .10.

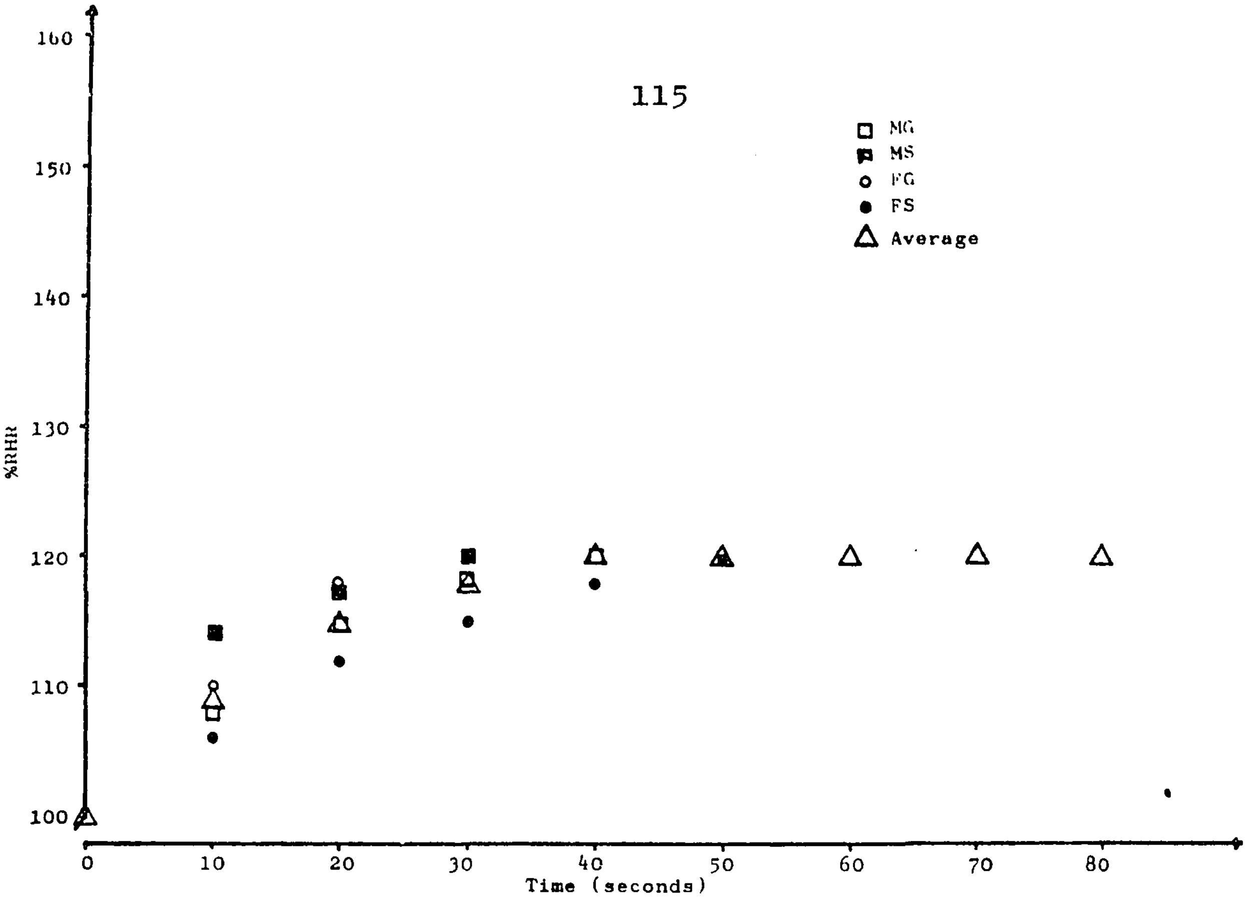

Figure 24. Hard data patterns--Task A2. Subject category symbols not continued after steady state.

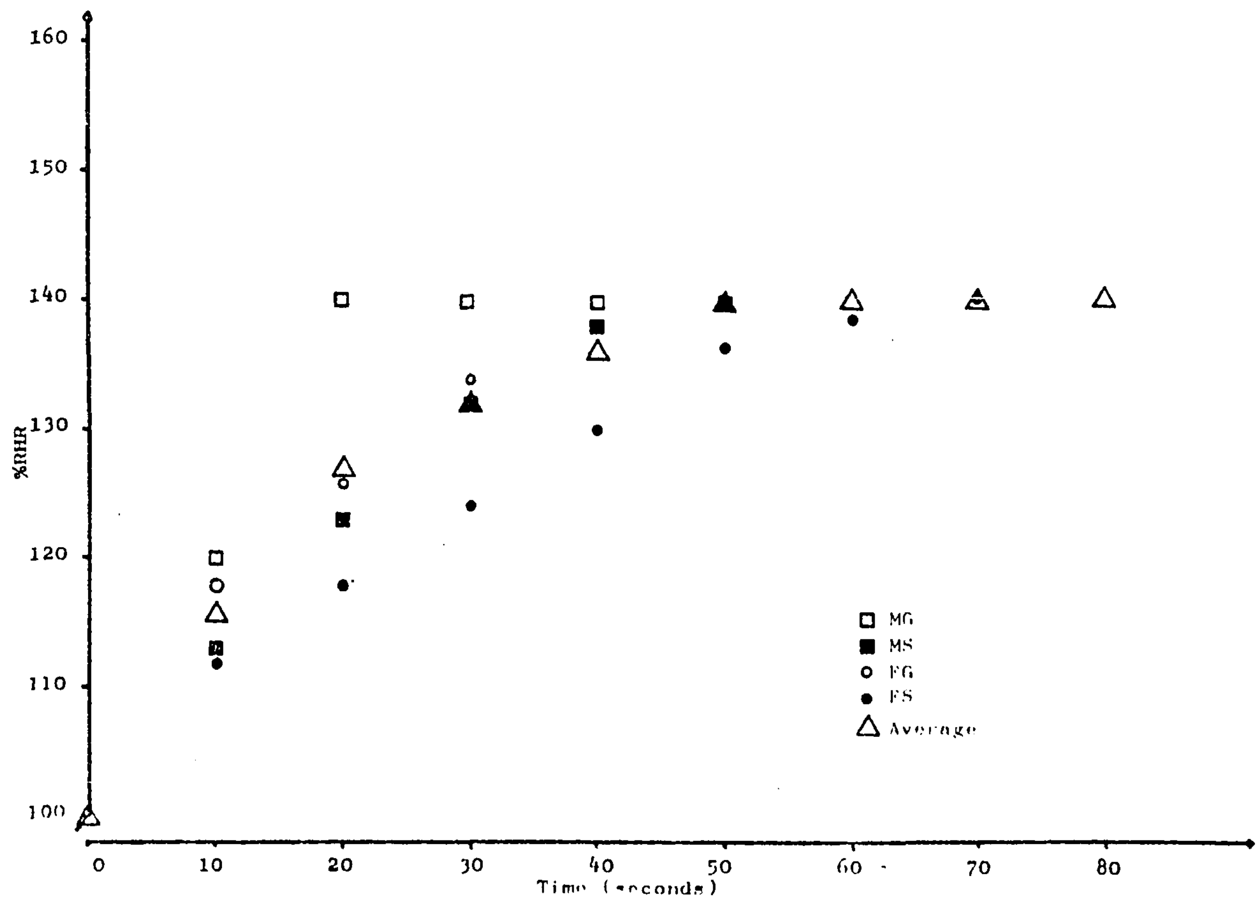

Figure 25. Hard data patterns--Task A3.

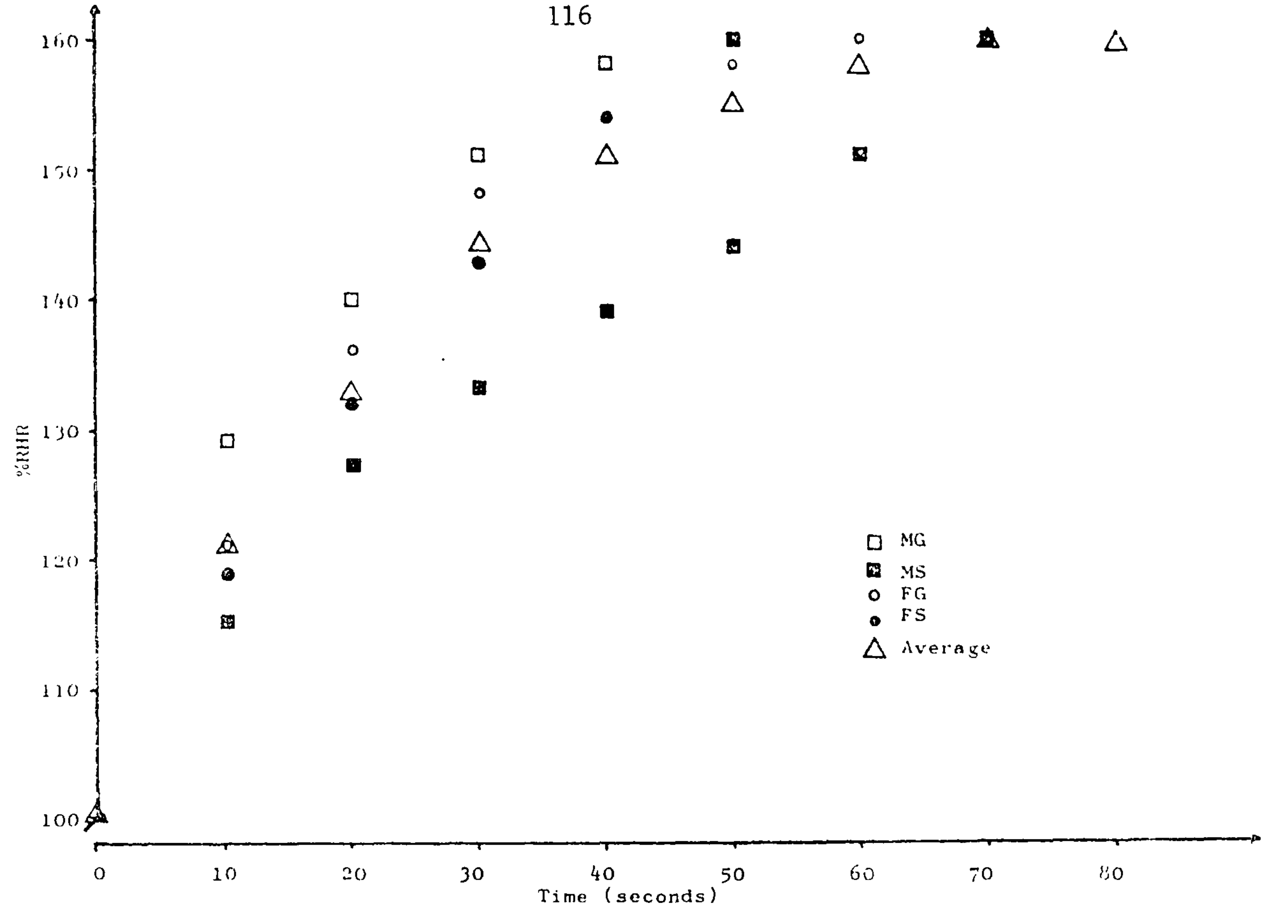

Figure 26. Hard data patterns--Task A4.

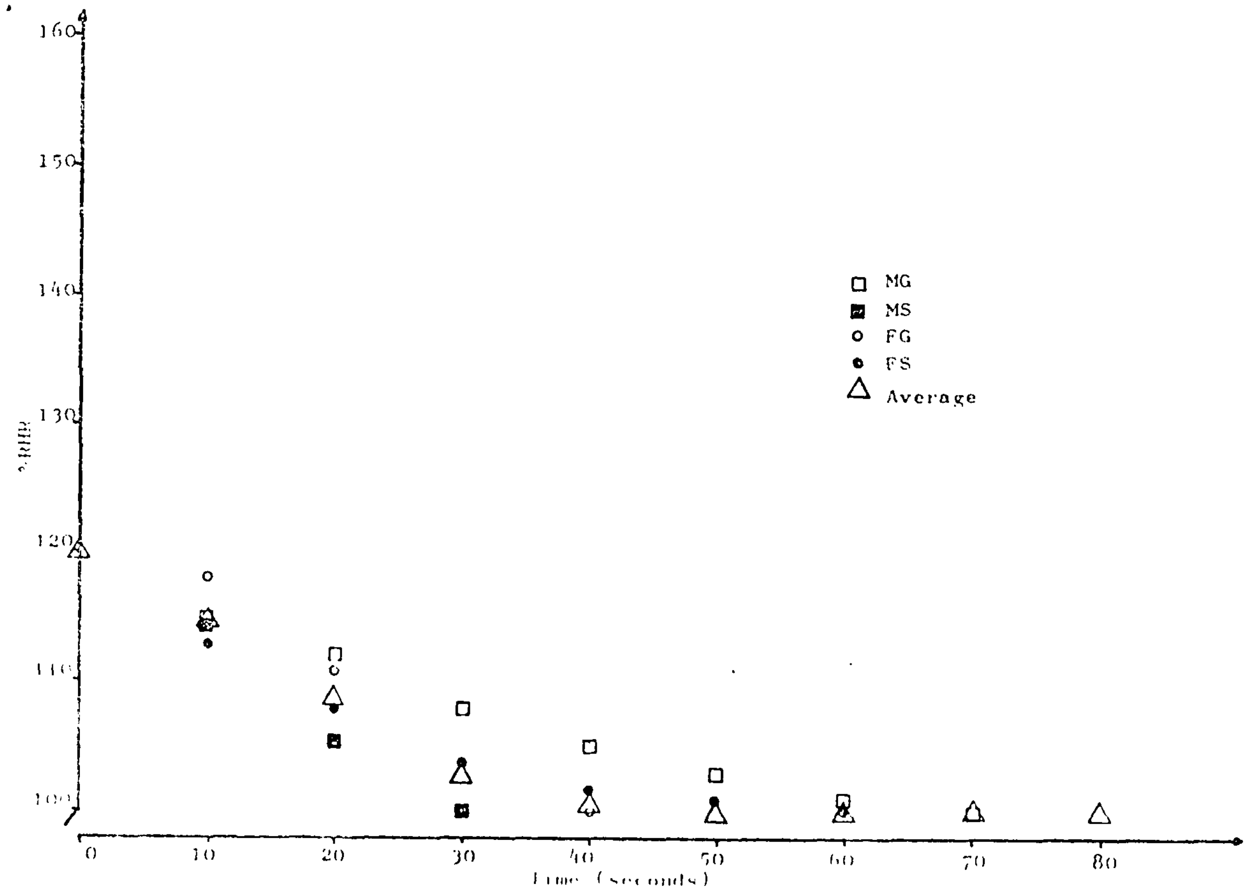

Figure 27. Hard data patterns--Task B1.

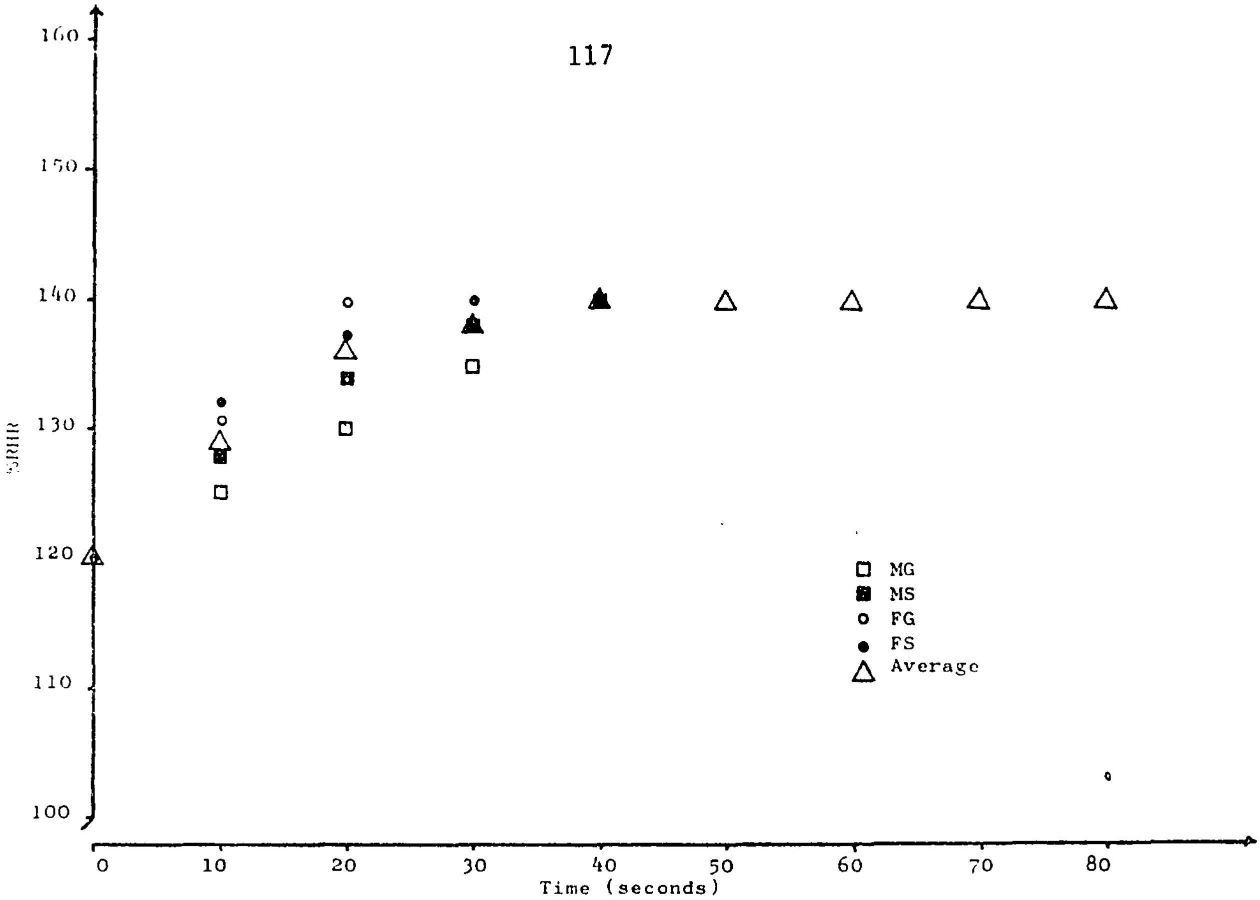

Figure 28. Hard data patterns--Task B3.

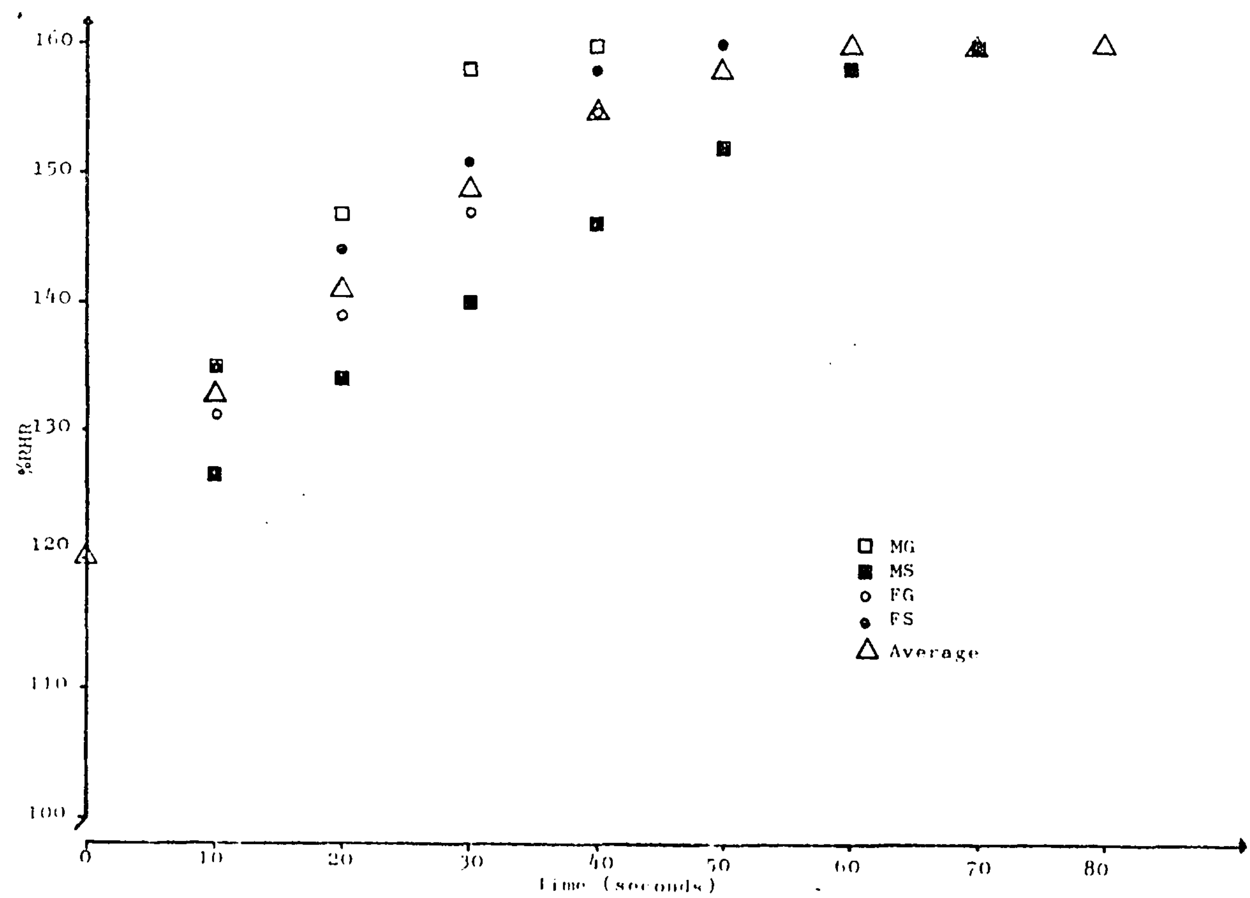

Figure 29. Hard data patterns--Task B4.

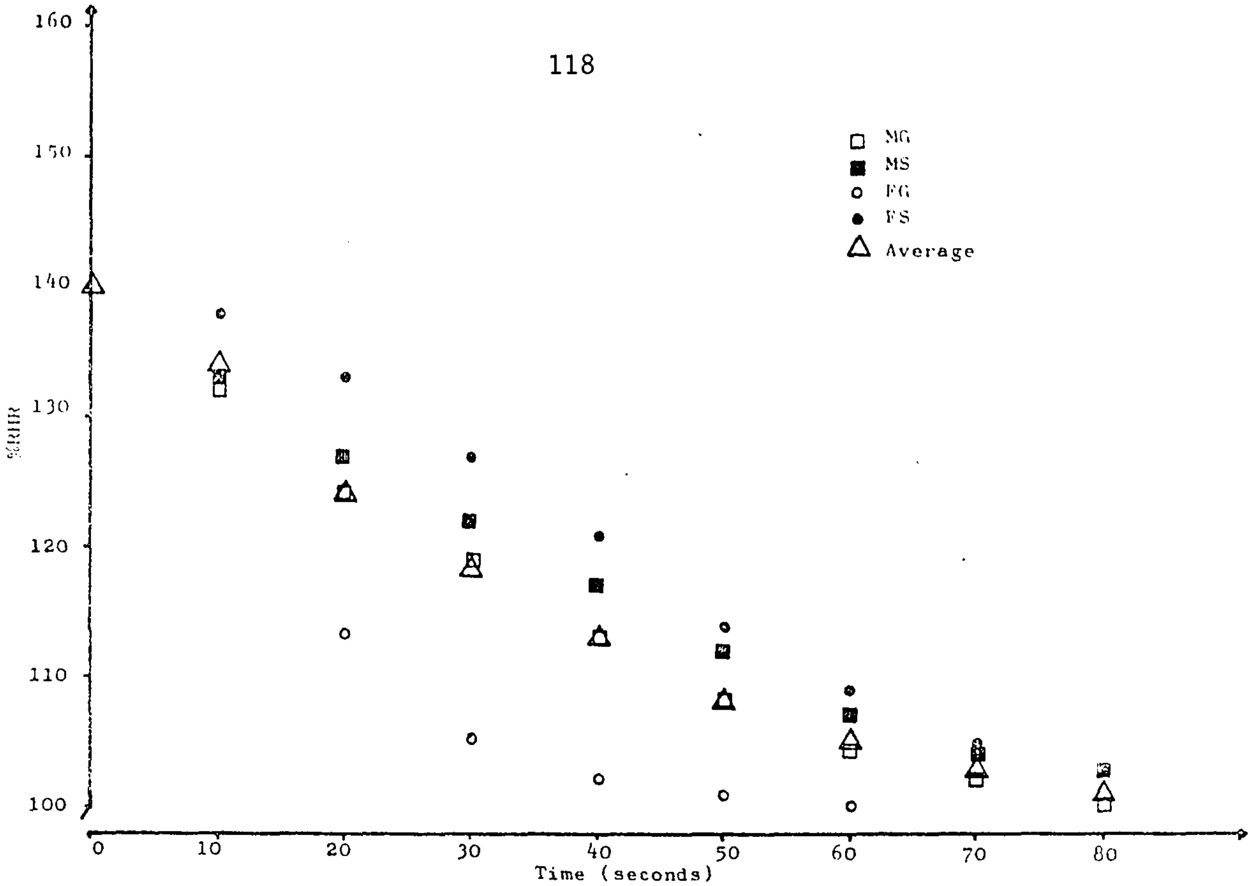

Figure 30. Hard data patterns--Task C1.

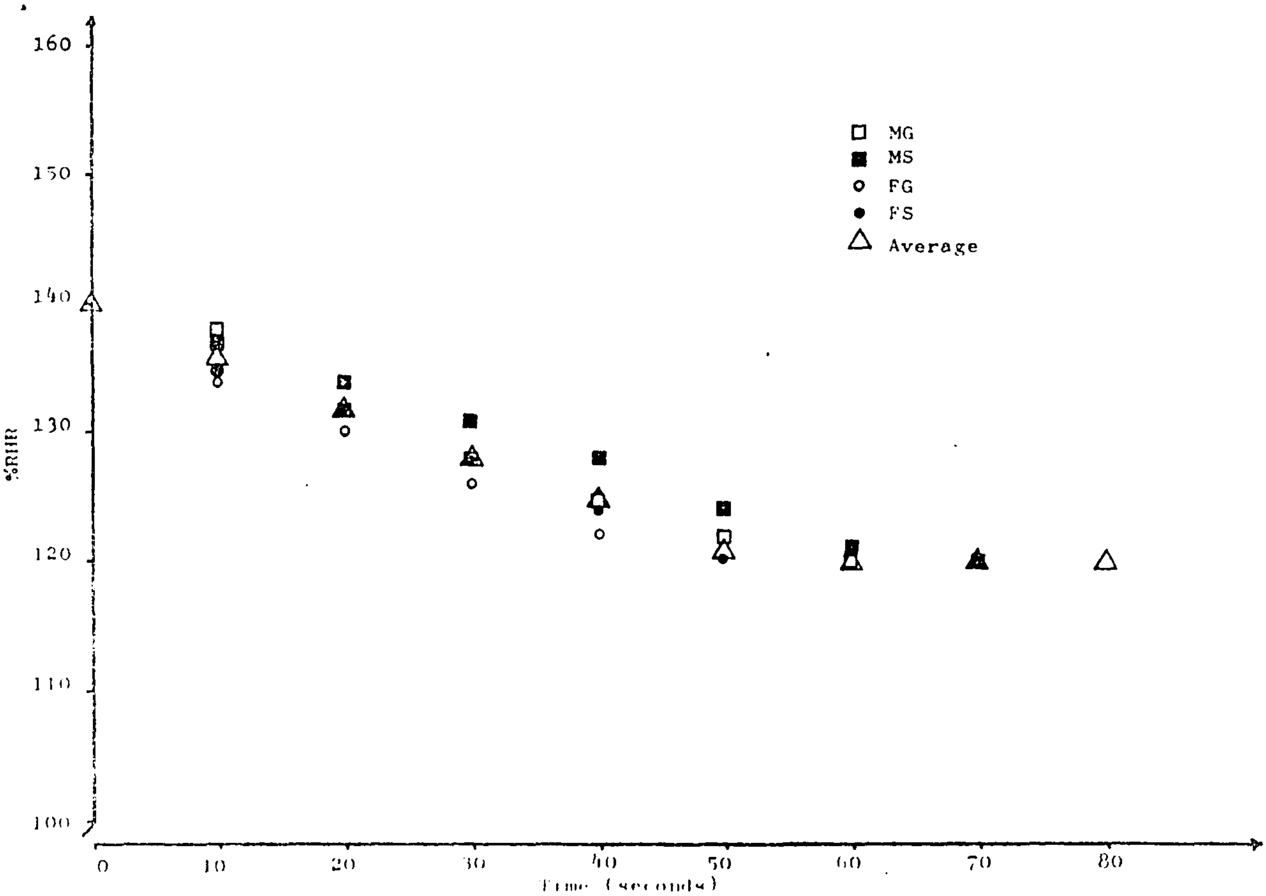

Figure 31. Hard data patterns--Task C2.

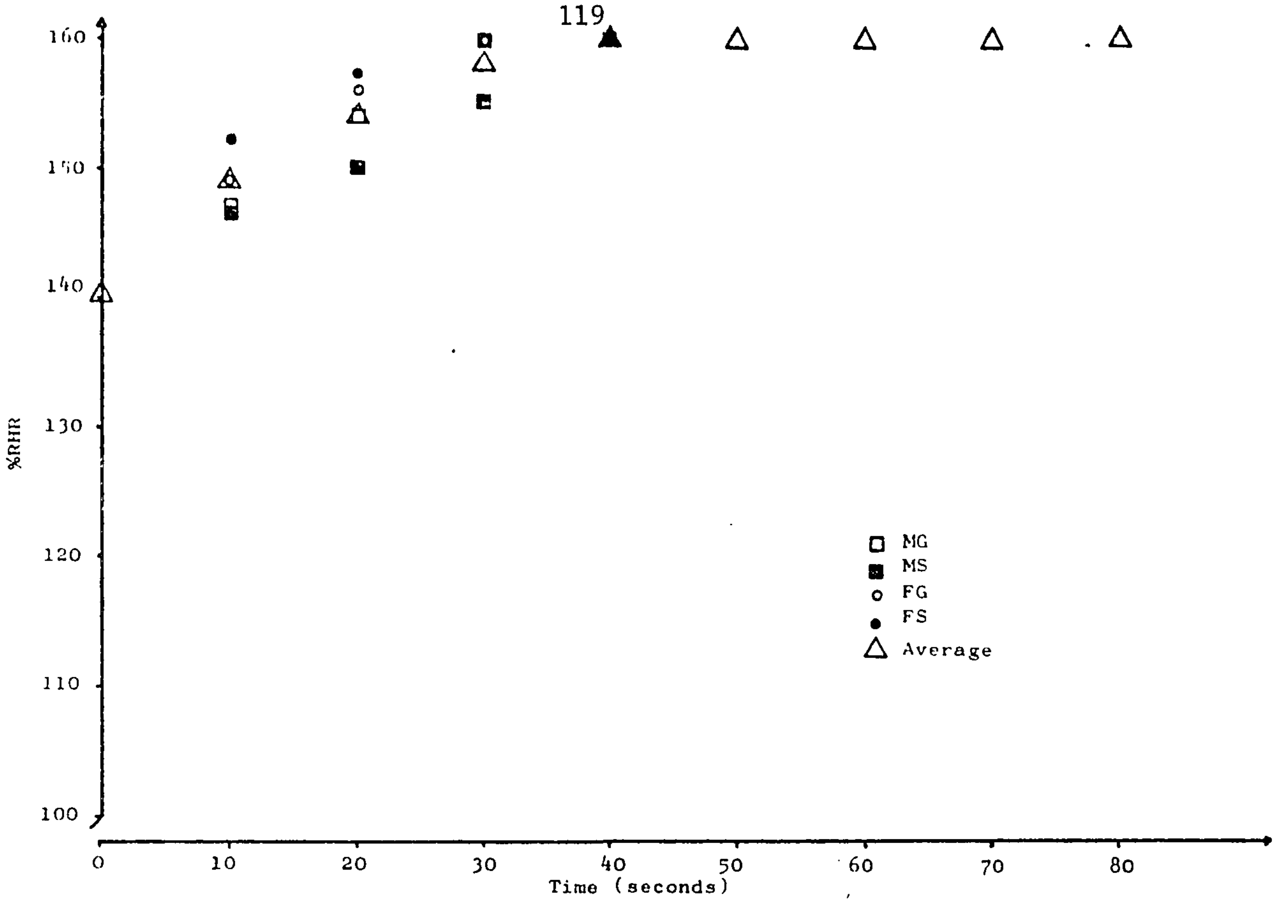

Figure 32. Hard data patterns--Task C4.

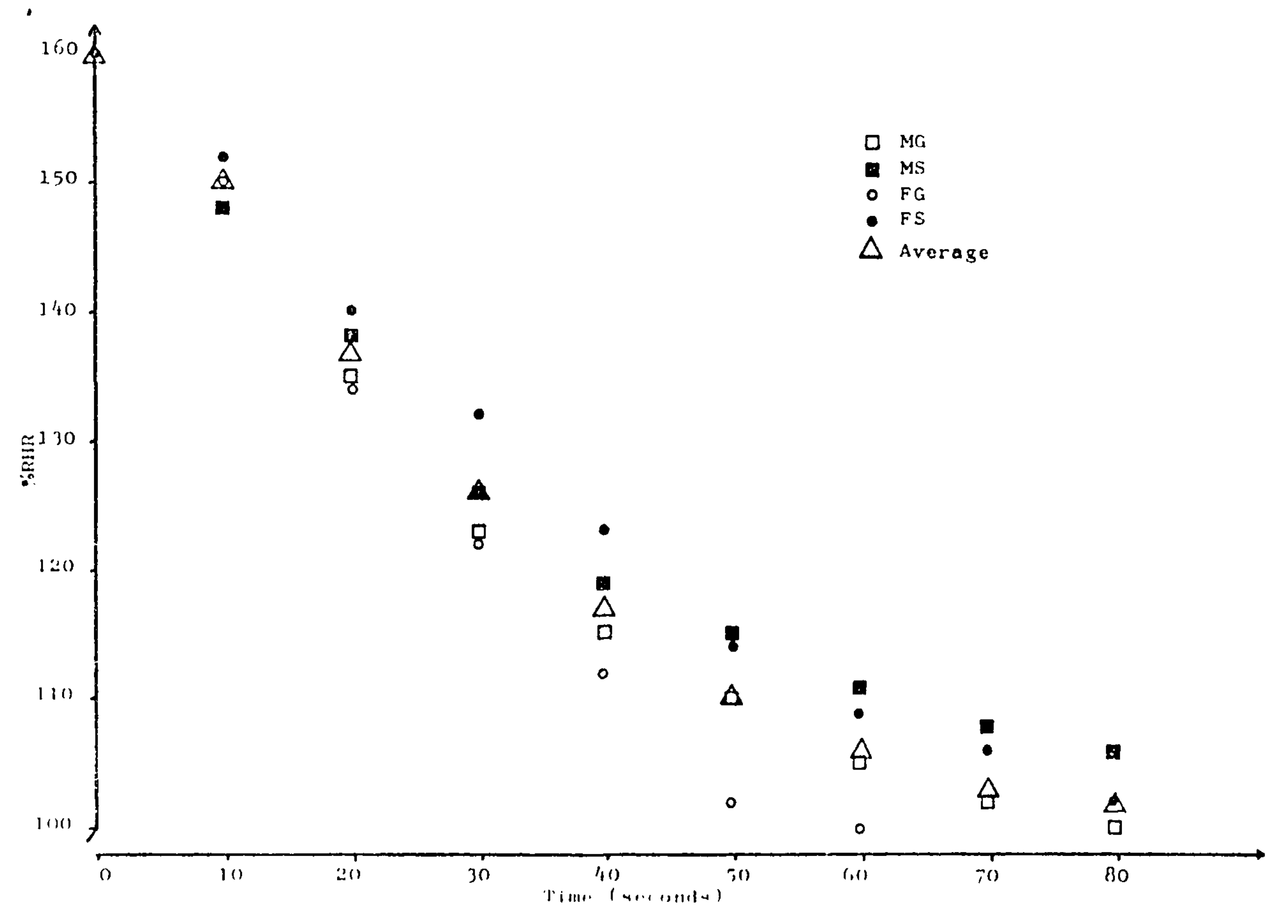

Figure 33. Hard data patterns--Task D1;

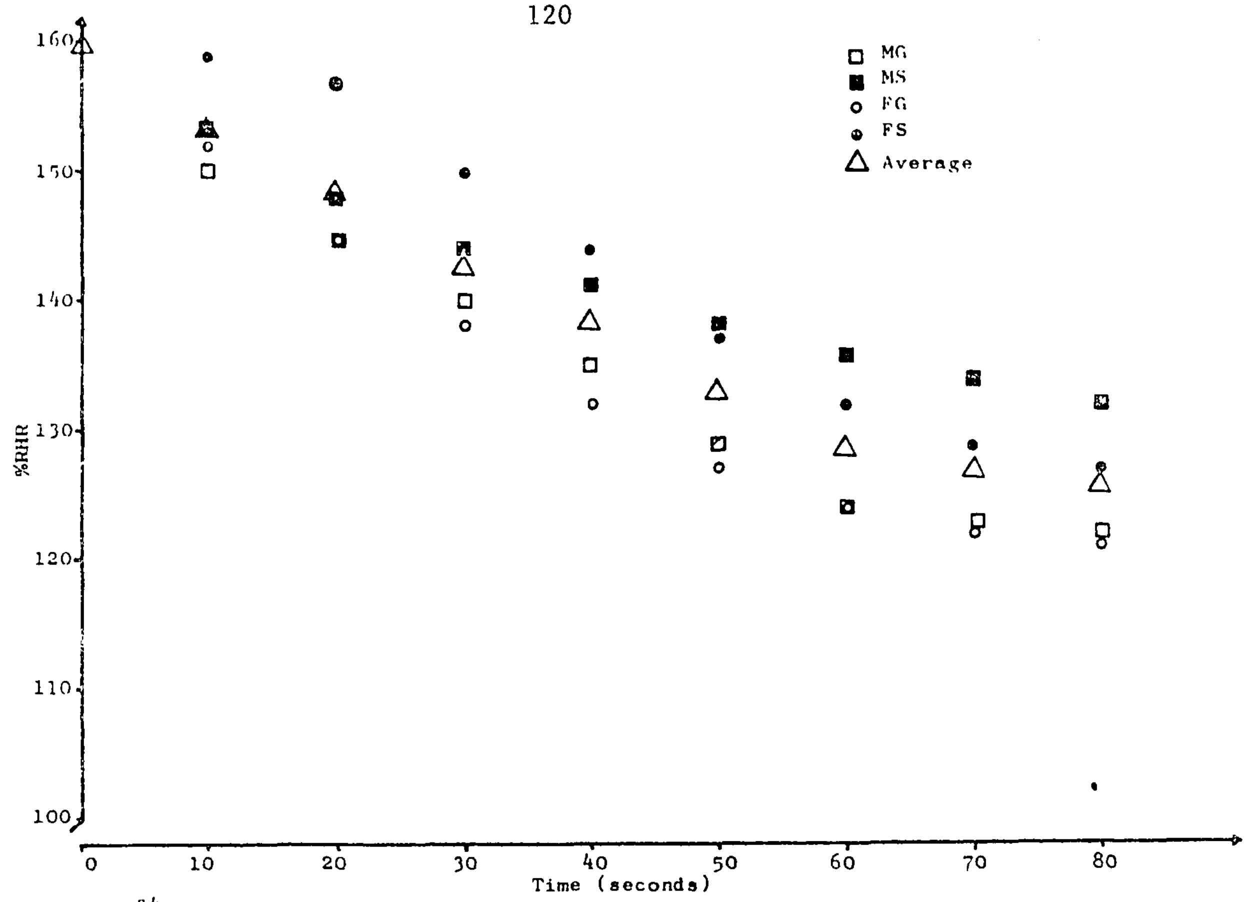

Figure 34. Hard data patterns--Task D2.

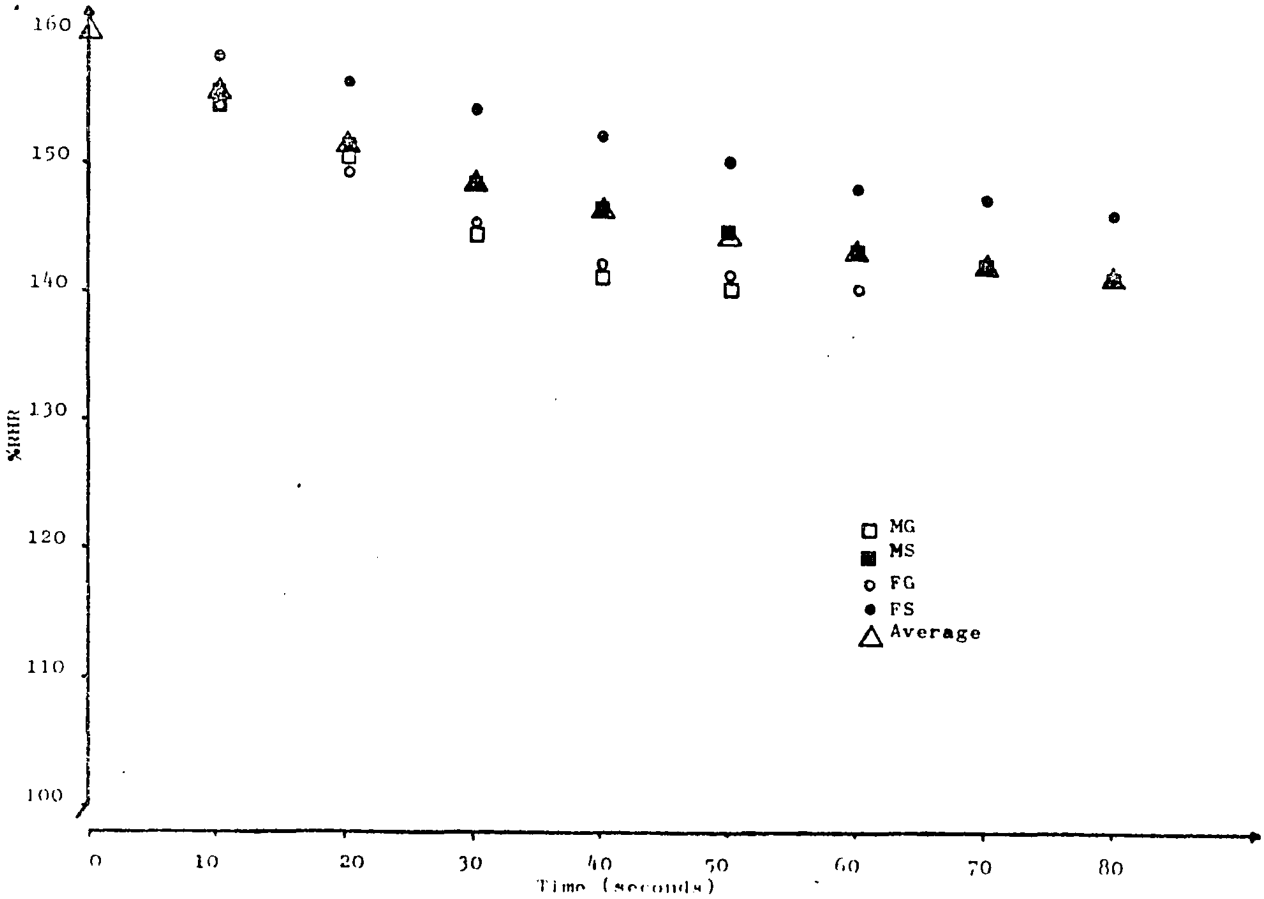

Figure 35. Hard data patterns--task D3.

100 %RHR. Although the predictive model includes the mechanism for handling this circumstance, the necessary hard data patterns could not be obtained through experimentation with consistency for sedentary subjects. Only one subject in each of the sedentary categories produced patterns D2 (160 to 120 %RHR) and D3 (160 to 140 %RHR). The cardiac response of the other subject in each category was such that steady state values of 120 and 140 %RHR were not realized within the time limit for each task (180 seconds). Since only one of the two subjects in each of the sedentary categories reached a steady state within the time limit, step changes for sedentary subjects which required hard data patterns for tasks D2 and D3 cannot be accommodated by the predictive model. The hard data patterns D2 and D3 for MS and FS of Appendix 3 represent only those responses of the subjects who did realize respective steady states of 120 and 140 %RHR. However, those patterns were not included in the predictive model.

The most probable cause of the lag in decrease to steady state for the two subjects was that they were exercising above their respective aerobic capabilities. The tasks were designed such that, according to the literature, no task required an anaerobic contribution at steady state. However, although the heart rates for these subjects were below the maximum aerobic heart rate (Åstrand, 1971, p. 132) of 134 beats/minute for males and 138 beats/minute for females, their heart rates at 160 %RHR were within five beats/minute of these heart rates. The maximum heart rates presented by Åstrand are averaged figures and intended to represent the whole population for the age group of this study. These two subjects were probably exceptions and were exercising at the limits of or above their aerobic capacities. In order to investigate this possibility, two sedentary male subjects were tested to determine if they were exercising above aerobic capacity at 160 %RHR. The necessary work load of 230 watts was derived from the steady state %RHR to work load relationship for sedentary males. Each subject performed the task and the oxygen uptake was measured for both exercise and recovery to a resting state. By making the ordinate oxygen consumption instead of %RHR in Figure 7 (p. 27), the reader can more easily understand the comparison. The ratio of oxygen debt (Area A) to oxygen payback (Area B) for one subject was approximately 1.0 and approximately 2.1 for the other. This observation indicates that one MS subject required an anaerobic contribution where another did not. Both the hard data patterns and the oxygen consumption test indicate that sedentary subjects are on the border line of aerobic capacity at 160 %RHR. Since the cardiac responses to tasks D2 and D3 are not produceable by all sedentary subjects within the time span of this study, the hard data patterns were not included in the predictive model.

Comparative Analysis of Hard Data Patterns

The statistical analysis of the hard data patterns indicated that the proper use of the hard data patterns would be to use only the averaged patterns for the predictive model, thereby eliminating the need for hard data patterns by sex and physical fitness. However, a statistical analysis in itself is not sufficient to describe the hard data patterns. Certain observations led this writer to believe that further testing and larger sample sizes would result in hard data patterns by subject category which are significantly different. These observations are presented in the following discussion.

Subject Category versus Averaged Hard Data Patterns

Table 12 shows a comparison of predicted results by averaged hard data patterns and by hard data patterns for subject categories. The observed and predicted results are shown for the first step change of series four. This particular step change was selected for comparison since only a portion of the transient response was predicted for all subject categories, and the work load was great enough to effect a considerable cardiac response (100 to 146 %RHR). It can be observed by examining the errors (e_S and e_A) of Table 12 that the predictions using hard data patterns by subject category (P_S) were more accurate than the predictions using averaged hard data patterns. In only two of the twelve time periods presented (MS-20, FG-20) was P_A more accurate than P_S when compared to the observed heart rate value. These results indicate that the exclusive use of averaged hard data patterns for the predictive model would reduce the accuracy potential of the predictive model.

TABLE 12

COMPARISON OF PREDICTED HEART RATES USING HARD DATA PATTERNS BY SUBJECT CATEGORY (P_S) AND BY USING AVERAGED HARD DATA PATTERNS (P_A). THE OBSERVED (O) AND PREDICTED HEART RATES ARE FOR THE FIRST STEP CHANGE OF SERIES FOUR.

Subject Category	Time (sec)	O (beats/min)	P_S	e_S (P_S-O)	P_A	e_A (P_A-O)
MG	0	58	58	0	58	0
	10	69	69	0	67	-2
	20	80	79	-1	74	-6
MS	0	76	76	0	76	0
	10	88	86	-2	88	0
	20	95	94	-1	98	3
FG	0	72	72	0	72	0
	10	85	85	0	83	-2
	20	93	92	-1	92	0
FS	0	80	80	0	80	0
	10	90	92	2	94	4
	20	95	99	4	103	8

Analysis by Inspection of Plotted Hard Data Patterns

An analysis by inspection of the plotted hard data patterns of Figures 24 through 35 on pages 115 through 120 is required to fully develop an argument for using hard data patterns by subject category. The following discussion addresses trends within and between hard data patterns by subject category.

It is interesting to note that for step changes of 20 %RHR in hard data patterns A2, B1, and B3, those of MS accelerate or decelerate to steady state more rapidly than those of MG. This is graphically displayed in Figures 24, 27, and 28. However, for step changes of 20 %RHR with greater initial values (140 %RHR), the acceleration to steady state is more rapid for the MG category (see Figures 31 and 32). This leads to the conclusion that for ongoing exercises of light (approximately 120 %RHR) work loads, the heart rate patterns, realized for a small step change of approximately 20 %RHR, accelerate to steady state more rapidly for sedentary males. For ongoing exercises of moderate (approximately 140 %RHR) work loads, the opposite is true. For all step changes of 40 to 60 %RHR, the response to steady state is more rapid for males of good physical fitness than for sedentary males.

In comparing responses for FG and FS categories, there appears to be only one consistent trend. For all hard data patterns for recovery to a resting state (B1, C1 and D1), the elapsed time to steady state is at least 20 seconds less for FG than for FS. These responses are displayed in Figure

27, 30, and 33. This is not true for the male subject categories. In this case, the elapsed time to steady state is 30 seconds less for MS than MG for recovery from light exercise (see Figure 27) and 30 seconds more for MS than MG for recovery from moderate exercise (Figure 33). The responses are similar for light to moderate exercise (Figure 30).

Most of the heart rate patterns for step changes in work load were nonlinear. However, the heart rate response for the sedentary males exhibited definite linear trends for almost all of the step changes. These trends are visually apparent in Figures 25, 26, 27, 29, 30, 31, and 32 of patterns A3, A4, B1, B4, C1, C2, and C4.

It is apparent from these observations that there exist certain consistent trends within and between the hard data patterns which are not portrayed in a statistical analysis. Since these trends do exist, and since the predictive model has a greater accuracy potential (see preceding section) by using hard data patterns by subject category, the hard data patterns utilized in the predictive model are by subject category.

Comparison of the Accuracy of Various Predictive Models

Differences between Previous Models and the Predictive Model

There were three predictive models presented in detail in Chapter II which were developed by Schilpp, Suggs and Vogt. There are several apparent differences between these previous models and the model of this study which need to be addressed before comparing the predicted heart rate patterns of each.

The first, and perhaps most significant difference, is that for any given work load and resting heart rate, the predicted heart rate pattern will be the same for all persons, regardless of sex or physical fitness. It becomes readily apparent that this approach is questionable when it is considered that many sedentary females or females of good physical fitness are incapable of steady state heart rates at a work load of 200 watts. Whereas, even sedentary males are capable of maintaining steady state heart rates at a work load of 200 watts.

None of these models has the capability of linking heart rate patterns for an exercise with a series of step changes in task intensity. Each model can predict only one step change at a time. The results in Table 13 were compiled by predicting the increasing step change, and then predicting the recovery to a resting state. The two patterns were then linked together manually.

Another difference is that only Vogt described a definitive mechanism for determining the expected steady state heart rate for a given task. Neither Suggs' nor Schilpp's model can make a priori prediction of heart rate patterns since the exercise must be completed and the steady state heart rate recorded before a "prediction" can be accomplished.

However, the author of this paper augmented and refined each of these studies such that a priori prediction would be possible.

Since each of these models is mathematical in form, each is dependent on time constants. The time constants depict the elapsed time for heart rate to reach a steady state. There is only one time constant for Schilpp's model; therefore, the time to steady state is the same for all work loads. There are only three levels of time constants for Suggs' model; therefore, only three times to steady state. Vogt's model is the only model where the time constant is dependent on the task intensity and resting heart rate, and therefore, varies accordingly.

It might also be noted that none of the authors submitted a formal definition of resting heart rate. Yet, each model required resting heart rate as an input variable.

The computational aspects of the predictive model of this study are more complex than those of the previous models and require the use of a computer to store and select the appropriate hard data patterns and to compute a predicted cardiac response to exercise. It is possible to compute a predicted cardiac response by hand (see Chapter IV), but the procedure is long and tedious and requires a computer for all practical purposes.

There is a detailed comparison of the approach and methodology of the previous models presented in Chapter III.

Comparison of Predicted Cardiac Response

Introduction

The predictive models of Schilpp, Suggs, and Vogt were incomplete as presented in their respective papers. In order to obtain actual predicted results, it was necessary for the author of this study to augment and, in some cases, make corrections to these previous predictive models. This was done so that a comparison could be made between the outputs of the previous models and the output of the predictive model of this study, referred to as the predictive model.

Interactive computer programs were written to accommodate each of the models such that the input variables for all models would be comparable. Since the cardiac response to only one step change in task intensity can be predicted for each of the previous models, the input variables are resting heart rate, duration of the task and work load. The interactive computer programs, output of predicted patterns, and associated documentation are presented in Appendices 9, 10 and 11 for models of Schilpp, Suggs and Vogt, respectively.

The observed results of series three of the validation testing were compared to the predicted results of all predictive models. Series three was selected for several reasons. First, series three consists of only two tasks, the second of which is recovery to a resting state. It is required that the second task be to resting since Schilpp's model does not accept decreasing step changes to other than a zero work load. Also, the three previous predictive models are very limited in their respective capabilities to predict cardiac response at low work loads because of the limitations of the time constants, therefore, series three was selected because of the relatively high work load. When the observed results of all series of validation testing were compared to the results of the predictive model of this study (detailed analysis in following section) it was determined that for every subject category the predicted results of series three compared less favorably to the observed results than any of the other five series (based on mean error and standard deviation of the error). Therefore, so as not to bias the comparison of the predictive models, the least favorable results of the predictive model of this study were used.

The predicted results and the observed results are presented by subject category in Tables 13, 14, 15, and 16. The error (predicted minus observed) is shown for the previous model which exhibited the best estimates of the observed heart rate values. Also, the error is shown for the predictive model of this study. Mean, standard deviation, and range are presented for each column of errors.

Analysis

The following discussion is an analysis of the results of the various predictive models. The results are discussed by subject category.

TABLE 13

PREDICTED AND OBSERVED CARDIAC RESPONSES FOR SERIES 3-MG. THE ERROR (PREDICTED MINUS OBSERVED) IS SHOWN FOR THE BEST PREDICTION (SCHILPP, SUGGS, VOGT) AND FOR THE PREDICTIVE MODEL.

Time	Work Load	Schilpp's Model	error (P-O)	Suggs' Model	Vogt's Model	Predictive Model	error (P-O)	Observed
0	105	58	0	58	60	58	0	58
10	105	74	-2	64	66	69	-7	76
20	105	80	-7	80	70	78	-9	87
30	105	84	-3	89	74	85	-2	87
40	105	87	0	98	78	90	3	87
50	105	90	3	105	81	91	4	87
60	105	92	5	112	83	91	4	87
70	105	93	6	117	84	91	4	87
80	105	95	8	123	86	91	4	87
90	105	96	9	128	89	91	4	87
100	105	97	10	132	91	91	4	87
110	0	97	21	132	92	78	8	76
120	0	88	23	128	91	77	12	65
130	0	81	21	123	85	71	11	60
140	0	76	18	118	80	66	8	58
150	0	72	14	113	76	64	6	58
160	0	69	11	108	72	61	3	58
170	0	66	8	104	69	59	1	58
180	0	64	6	101	66	58	0	58
190	0	63	5	97	64	58	0	58
200	0	62	4	94	62	58	0	58
210	0	61	3	91	60	58	0	58
220	0	60	2	88	59	58	0	58
230	0	60	2	86	58	58	0	58
240	0	59	1	84	57	58	0	58
Mean			7.0				2.3	
S.D.			7.9				4.8	
Range			30.0				21.0	

TABLE 14

PREDICTED AND OBSERVED CARDIAC RESPONSES FOR SERIES 3-MS. THE ERROR (PREDICTED MINUS OBSERVED) IS SHOWN FOR THE BEST PREDICTION (SCHILPP, SUGGS, VOGT) AND FOR THE PREDICTIVE MODEL.

Time	Work Load	Schilpp's Model	error (P-O)	Suggs' Model	Vogt's Model	Predictive Model	error (P-O)	Observed
0	220	76	0	76	80	76	0	76
10	220	111	23	96	110	90	2	88
20	220	123	28	114	129	95	0	95
30	220	131	28	131	142	102	-1	103
40	220	138	27	145	150	106	-5	111
50	220	143	25	158	155	111	-7	118
60	220	147	27	169	158	115	-5	120
70	220	151	29	180	160	119	-3	122
80	220	153	31	188	161	120	-2	122
90	220	155	33	197	162	120	-2	122
100	220	157	35	203	163	120	-2	122
110	0	154	37	210	163	120	-2	122
120	0	148	37	190	143	111	0	111
130	0	140	29	181	130	104	-5	109
140	0	125	17	172	120	96	-12	108
150	0	114	9	165	110	90	-15	105
160	0	106	4	158	104	87	-15	102
170	0	99	0	151	98	84	-15	99
180	0	94	-1	145	94	82	-13	95
190	0	90	0	140	90	81	-9	90
200	0	86	-2	135	88	79	-9	88
210	0	84	-1	130	85	78	-7	85
220	0	82	2	126	83	76	-4	80
230	0	80	1	122	81	76	-3	79
240	0	79	1	118	80	76	-2	78
Mean			16.6				-5.4	
S.D.			14.7				5.2	
Range			39.0				17.0	

TABLE 15

PREDICTED AND OBSERVED CARDIAC RESPONSES FOR SERIES 3-FS. THE ERROR (PREDICTED MINUS OBSERVED) IS SHOWN FOR THE BEST PREDICTION (SCHILPP, SUGGS, VOGT) AND FOR THE PREDICTIVE MODEL.

Time	Work Load	Schilpp's Model	error (P-O)	Suggs' Model	Vogt's Model	Predictive Model	error (P-O)	Observed
0	125	80	0	80	82	80	0	80
10	125	100	12	91	98	95	7	88
20	125	106	12	101	108	106	12	94
30	125	111	11	110	115	113	13	100
40	125	115	10	118	120	118	13	105
50	125	118	7	125	123	123	12	111
60	125	120	0	131	125	125	5	120
70	125	122	-3	137	126	125	0	125
80	125	124	-1	142	128	125	0	125
90	125	125	0	146	129	125	0	125
100	125	126	1	150	129	125	0	125
110	0	127	2	154	129	125	0	125
120	0	127	2	152	119	120	0	120
130	0	116	2	147	113	111	-3	114
140	0	108	0	140	108	105	-3	108
150	0	101	9	135	103	98	6	92
160	0	97	12	130	99	91	-6	85
170	0	93	13	125	97	87	-9	80
180	0	90	10	121	94	84	-4	80
190	0	88	8	117	92	82	2	80
200	0	86	6	113	90	80	0	80
210	0	85	5	110	88	80	0	80
220	0	84	4	107	87	80	0	80
230	0	83	3	104	86	80	0	80
240	0	82	2	103	84	80	0	80
Mean			5.1				2.9	
S.D.			4.9				5.1	
Range			16.0				17.0	

TABLE 16

PREDICTED AND OBSERVED CARDIAC RESPONSES FOR SERIES 3-FG. THE ERROR (PREDICTED MINUS OBSERVED) IS SHOWN FOR THE BEST PREDICTION (SCHILPP, SUGGS, VOGT) AND FOR THE PREDICTIVE MODEL.

Time	Work Load	Schilpp's Model	Suggs' Model	Vogt's Model	error (P-O)	Predictive Model	error (P-O)	Observed
0	100	72	72	73	1	72	0	72
10	100	88	81	86	-2	85	-3	88
20	100	93	96	94	-4	93	-5	98
30	100	97	98	99	-8	99	-8	107
40	100	100	105	103	-1	104	-6	110
50	100	103	111	106	-4	108	-2	110
60	100	105	117	107	-3	110	0	110
70	100	106	122	109	-1	110	0	110
80	100	107	126	110	-1	110	-1	111
90	100	108	130	111	0	110	-1	111
100	100	109	133	111	0	110	-1	111
110	0	110	137	111	0	110	-1	111
120	0	101	132	104	-2	104	-2	106
130	0	95	128	99	0	91	-8	99
140	0	89	123	95	7	88	0	88
150	0	85	119	88	9	83	4	79
160	0	82	116	86	13	78	5	73
170	0	79	112	84	12	73	1	72
180	0	78	109	82	10	72	0	72
190	0	77	106	80	8	72	0	72
200	0	75	103	79	7	72	0	72
210	0	74	100	78	6	72	0	72
220	0	73	97	77	5	72	0	72
230	0	72	94	76	4	72	0	72
240	0	72	91	75	3	72	0	72
Mean					2.3		-1.1	
S.D.					5.5		3.0	
Range					21.0		13.0	

The predicted and observed results for series three, male of good physical fitness, are presented in Table 13. It can be observed that of all the previous predictive models, none exhibited a steady state for either exercise or recovery within the time span of each task. Whereas, the observed elapsed times to steady state for exercise and recovery are 20 seconds and 40 seconds, respectively. Since there were no steady state values exhibited for any of the previous predictive models, the inaccuracies would be greater if the duration of the exercise task was longer. Both Schilpp's and Vogt's output appeared to be leveling at about 100 seconds.

The accuracies of Schilpp's and Vogt's models were approximately equivalent. However, the standard deviation of Schilpp's output, 11.1 (not shown in Table 13), was sufficiently greater than that of Vogt's, 7.9, to conclude that Schilpp's output is the best of the three previous models. The output of Suggs' model exhibited as much as 63 beats/minute error. The overprediction of Schilpp's model is substantially greater than that of the predictive model (7.0 versus 2.3 beats/minute). There is also a broader dispersion of error for Schilpp's model than for the predictive model (standard deviations of 7.9 versus 4.8). Based on the preceding comparisons, the predictive model was more accurate than the three previous models.

The predicted results of the previous models for series three, sedentary male, are the most inaccurate of the results of the four subject categories (see Table 14). It can be observed by inspection that none of the three were even close, as all were overpredictions. Schilpp's model was slightly more effective than Vogt's but still exhibited a mean error of 16.6 beats/minute and a standard deviation of 14.7 beats/minute. At one standard deviation the error could be from 20 to 50 percent of the observed value. For the predictive model, the error at one standard deviation could be from 7 to 12 percent of the observed value. It should be noted that the mean error and standard deviation of the error of the predictive model results for Series 3-MS were greater than all other series investigated (24 in all).

The most accurate predictions of the previous models were made for series three, female of good physical fitness. These results are shown in Table 15. Again, however, the output of Suggs' model was not comparable to that of Schilpp's and Vogt's in terms of accuracy. Vogt's model exhibited a steady state heart rate for exercise equal to that of the observed, and was therefore considered more accurate than Schilpp's output. Again, the error means indicate a slight overprediction for Vogt's model (2.3 beats/minute) and a slight underprediction for the predictive model (-1.1 beats/minute); therefore, the mean error does not provide the necessary information for a conclusion as to which is the best prediction. However, the standard deviation of the error (5.5 vs. 3.0), indicates that there is a greater dispersion of error for Vogt's model. At one standard deviation, the error for Vogt's prediction could be from 7 to 13 percent of the observed; whereas, the error for the predictive model would be only 3 to 7 percent. Also the range of errors is considerably greater for Vogt's model (21 vs. 13 beats/minute).

Table 16 presents the predictions for series three, sedentary female. Schilpp's and Vogt's model again prove to be the best of the three previous models. Both are over-predictions, with mean errors of 5.1 for Schilpp's model and 7.6 (not shown in table) for Vogt's model. Schilpp's model was used for comparison to the predictive model since the mean error was less than that of Vogt's model. The observed results indicate a steady state heart rate of 125 beats/minute at 70 seconds, and the predictive model results indicate a steady state heart rate of 125 beats/minute at 60 seconds. The results of Schilpp's model do not indicate a steady state heart rate. This would imply that the error would increase with an increased duration for the exercise. Since the standard deviations (4.9 vs. 5.1) and ranges (16.0 vs. 17.0) are approximately the same, the error means can be compared directly. The overprediction for the predictive model (2.9) is less than that of Schilpp's model (5.1). This fact, coupled with the fact that Schilpp's results do not reach a steady state value, indicates that the predictive model presents a more accurate prediction.

Conclusions

Certain conclusions can be drawn from the predicted results of the three previous models. It was apparent for all subject categories that the predicted results of Suggs' model were far less accurate than those of Schilpp's and Vogt's model. It can also be noted that of the three, Schilpp's model was most appropriate for predicting cardiac responses, since Schilpp's model was shown to be more accurate for three of the four subject categories.

The results of the predictive model were shown to be more accurate than the best effort of the three previous models for each subject category when compared to observed heart rate responses. Again, it should be noted that the predicted results of the previous models, shown in Tables 13, 14, 15, and 16 apply to any individual regardless of physical fitness or sex. For example, in an actual test a sedentary male performed the exercise of Table 15 for a work load of 125 watts and realized a steady state of 108 beats/minute. It is apparent that the results of the previous models (126, 154 and 124 beats/minute) are erroneous for a sedentary male.

The results of this comparison render sufficient evidence to conclude that the predictive model can more accurately predict cardiac response to exercise than can previous models. The predictive model also exhibits a greater flexibility in that there are allowances made for sex and physical fitness and it can predict the cardiac response to a series of step changes in task intensity.

Evaluation of Predictive Model

Introduction

This section is a discussion of the validity of the predictive model. The observed data of validation testing are compared with the predicted values from the model. The results are discussed by time periods, by subject category and series. The results of the predictive model were compared to the observed data by examining the error (predicted value minus observed value).

Exercise Series of Validation Testing

A subject from each of the four subject categories performed six exercise series. Each series consisted of two or three tasks. The tasks and their respective durations are shown in Table 17. It can be observed that although the durations are the same, the work loads vary between subjects for each series. The series were selected such that the expected cardiac responses would be similar in terms of %RHR. The steady state %RHR to work load relationship varies between subject category, consequently, the work loads vary within a series. The predicted and observed values by subject category and series are presented in Appendix 7. Figures 37 through 60 show plots of the predicted and observed values.

TABLE 17

EXERCISE SERIES FOR VALIDATION TESTING WITH DURATION AND INTENSITY OF RESPECTIVE TASKS

Series	Seconds	Subject Categories			
		MG Watts	MS Watts	FG Watts	FS Watts
1	70	50	110	45	60
	70	85	175	80	100
	100	0	0	0	0
2	30	30	75	25	40
	100	60	135	55	75
	110	40	90	35	50
3	110	105	220	100	125
	130	0	0	0	0
4	30	85	175	80	100
	110	0	0	0	0
	100	20	60	15	30
5	100	0	0	0	0
	130	40	90	35	50
	10	60	135	55	75
6	20	65	145	60	80
	140	40	90	35	50
	80	0	0	0	0

Distribution of the Error

The two sample problem of evaluating the predicted values against the observed values was condensed to a one sample problem by considering the error (predicted minus observed). The sign of the error relates whether the model is overpredicting (positive error) or underpredicting (negative error). The standard deviation and range of the error were used in conjunction with the mean error in order to determine accuracy in predicting and to estimate the maximum error.

The distribution of the error data for all validation testing is displayed graphically in the histogram in Figure 36. The error data is presented in Appendix 5 by series for each subject category. A Chi-square goodness-of-fit test was used to determine if the error distribution was distributed normally with mean equal zero. The calculated Chi-square value with 27 degrees of freedom was equal to 170. This value was much greater than the critical value of 44 at the .05 level. Consequently, it was concluded that the error distribution was not normal. However, there is a definite central tendency to zero, and there are certain characteristics exhibited which are associated with a standard normal distribution.

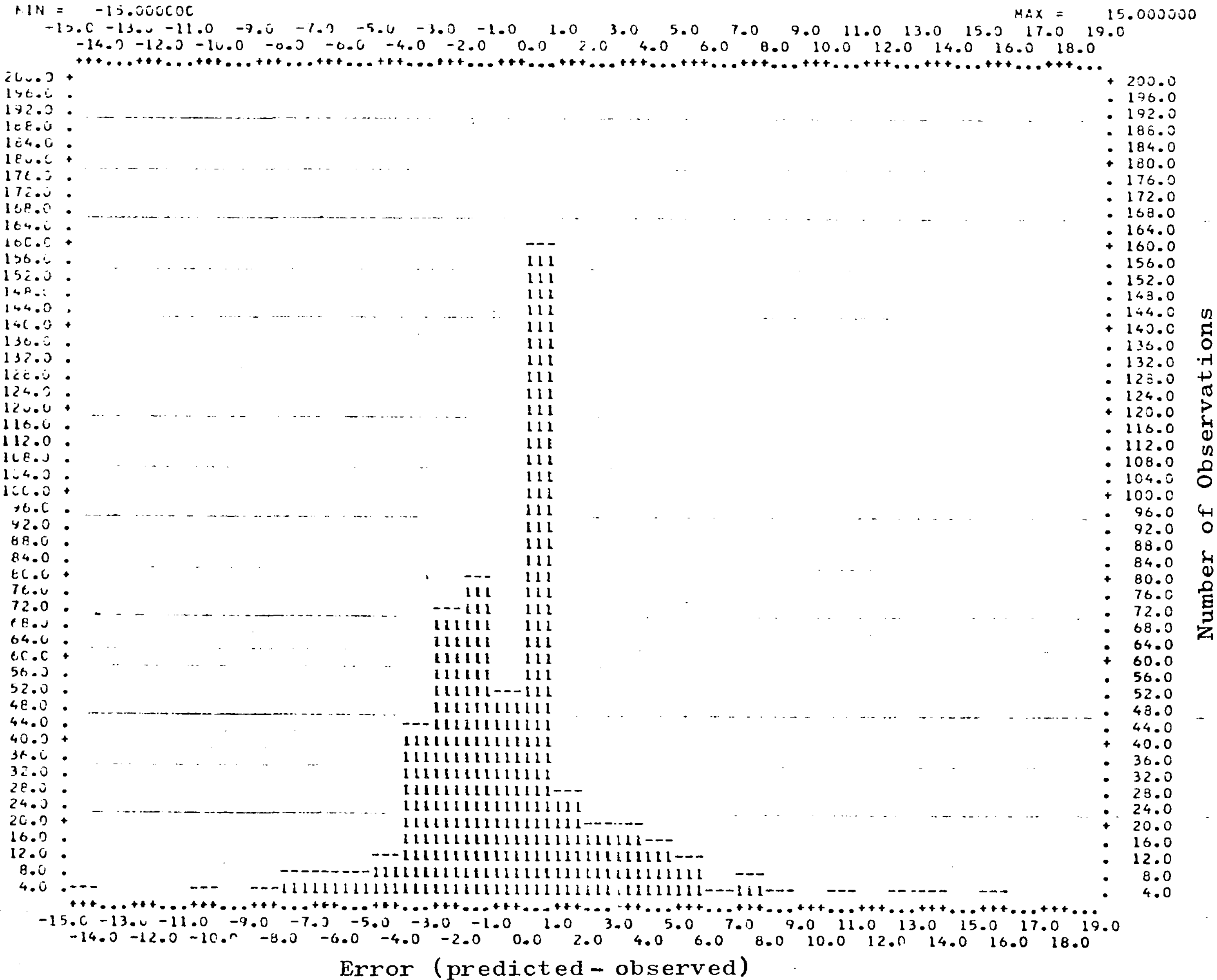

Figure 36. Histogram showing distribution of error (predicted minus observed) over all time periods and all series.

Although the mean is -.7795, the mode is zero (160 of 576 observations). The standard deviation of the error is 3.6681. Using a mean of zero, the error distribution compares favorably the normal distribution with 79%, 97%, and 99% of the observations within one, two and three standard deviations, respectively. This compares to 68%, 98% and 99.8% for the normal distribution. The "t" statistic used in the following analysis is appropriate if the sample comes from a normal population which is "within a reasonable degree of approximation" (Miller, Freund, 1965, p. 164). Since the error distribution exhibits certain properties of normally distributed data, the error distribution can be considered a "reasonable approximation" to the normal distribution.

It can be observed from Figure 36 that there were 28 underpredictions of more than 6 beats/minute and 28 overpredictions of more than 6 beats/minute. These 56 observations comprise approximately 10% of the total. Based on the total error data, it can then be surmised that the error at any point in time will be 6 beats/minute or less, 90% of the time. The heart rate responses investigated in this study ranged from approximately 60 to 130 beats/minute. Therefore, the error as a percentage of heart rate could be as much as 10% for 60 beats/minute to less than 5% for 130 beats/minute.

Consequently, 90% of the time a user of the predictive model could expect errors in predicted output to be no more than 5% to 10% of the observed heart rate value.

Time Period Analysis

The predictive model produces estimates of expected heart rate responses over time using only resting heart rate as a point of reference. This section discusses the possibility of increasing error over time. The approach selected for this analysis was to divide the series into four one minute time periods. By this approach, the relative accuracy for predictions in each time period can be determined.

All validation data was included in the analysis of time periods. The error data is presented in Appendix 5 and analyzed by time period in Table 18. Time period one is the first minute, time period two, the second minute, etc. It can be observed from Table 18 that the mean error for each time period is negative indicating an underprediction. Upon testing the hypothesis that the mean error is equal to zero, it was determined that only the mean error of time period one could be considered equal to zero. The null hypothesis was rejected in favor of the hypothesis that the mean was not equal to zero for all other time periods. It can be noted that the standard deviations of both time periods two and four were less than the standard deviation of time period one. This would indicate that the potential error at one standard deviation would be greater in time period one

No. of Observations

Time Periods

```
INTERVAL              1          2          3          4
 16.000 )
 12.000 )****                          ****
  8.000 )***             *             **          **
  4.000 )**********15**********12*********         *****
  0.0   )**********52**********62**********40**********72
 -4.000 )**********56**********60**********75**********56
 -8.000 )**********13*********         **********  *****
-12.000 )*               *             **          ***
-16.000 )                              ***         *

MEAN        -0.299      -1.014      -1.201      -0.604
S DEV        4.054       2.935       4.380       3.062
 N          144.        144.        144.        144.
```

underlined means significantly different than 0 at .05 level

ALL GROUPS COMBINED

MEAN	-0.7795
S DEV	3.6681
MAXIMUM	15.0000
MINIMUM	-15.0000

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
BETWEEN	70.[illegible]422	3	23.5807	1.7596
WITHIN	7665.6641	572	13.4015	
TOTAL	7736.4063	575		

TABLE 18. HISTOGRAMS AND DESCRIPTIVE STATISTICS FOR TIME PERIODS 1 (0 to 60 SECONDS), 2 (60 to 120 SECONDS), 3 (120 to 180 SECONDS), AND 4 (180 to 240 SECONDS). F RATIO TESTS HYPOTHESIS THAT THE MEANS ARE EQUAL. NOTE: HISTOGRAMS ARE PRESENTED HORIZONTALLY.

than in two and four (-4.34 compared to -3.94 and -3.66 beats/minute). It would appear that the greatest potential error would occur in time period three, since the differences from zero, as well as the standard deviations, are the greatest.

The F ratio of Table 18 tests the hypothesis that the time period means are equal. Since the value of the F ratio is less than F (.05, 3,592) (1.759 < 2.60), there is no statistical evidence to indicate that the means are different. There is very little difference in the standard deviations of the four time periods (2.94 to 4.38 for a range of error of -15 to +15). Considering only the means and standard deviations of the time periods, certainly there is no evidence to indicate that there is a significant difference in the error produced for each of the time periods. It might also be noted from the histograms of Table 18 that for every time period, the distribution of the error is such that 84 to 91 percent of the errors are within the interval of -6 to 2 beats/minute. This observation also indicates a uniformity in the distributions.

It can be concluded that there is no reason to suspect that the predictive model will compound in error over the four minute time period of this study, nor is there reason to suspect that the distribution of the error for any time period is different than that of another.

Statistical Analysis by Subject Category

A subject in each subject category performed six series of exercises consisting of step changes in work loads. Tables 19 and 20 present a histogram showing the distribution of the error for each series, and the mean and standard deviation for each series. Descriptive statistics for the combined series for each subject category are also presented. For analysis of data of this kind, straight forward approaches do not exist which result in statistically conclusive evidence that the predicted output for one series or subject category was superior to that of another series or subject category. However, certain conclusions become apparent by inspection of the means and standard deviations, and by inspection of the plots of observed and predicted heart rate responses of Figures 37 through 60 (pages 153-166).

Observe from the F ratios displayed in Tables 19 and 20 that for each subject category the hypothesis that the means are equal is rejected in favor of the hypothesis that they are not ($F(.05,5,138) = 2.21$). This finding was expected because of the diversity in configurations (task intensities and durations) of the six series. The magnitude of the F ratio renders insight as to the range of mean errors. The range of series means is greatest for the sedentary subject categories. The ranges are 3.7 and 1.8 for MG and FG, and, 5.1 and 4.4 for MS and FS, respectively. The range of means is a direct indication of the stability

```
INTERVAL                        Series
           1           2           3           4           5           6
 21.000 )
 18.000 )
 15.000 )*
 12.000 )*                      *
  9.000 )                       *           **
  6.000 )*                      ****        *
  3.000 )*           *********11********    ***                     **
  0.0   )**********             *******     *******     **********  *********17
 -3.000 )*********   ********** *           **********  *********12***
 -6.000 )***         ***                    *           **          **
 -9.000 )                       **
-12.000 )
-15.000 )
```

No. of Observations

MEAN	0.542	0.0	2.708	1.083	-1.042	-0.042	underlined means significantly
S DEV	4.890	3.270	4.894	3.977	1.459	2.116	different than 0 at .05 level
N	24.	24.	24.	24.	24.	24.	

ALL GROUPS COMBINED

			SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
MEAN	0.5417	BETWEEN	195.0732	5	39.0146	2.8905
S DEV	3.7934	WITHIN	1862.6609	138	13.4975	
MAXIMUM	16.0000	TOTAL	2057.7341	143		
MINIMUM	-9.0000					

```
INTERVAL                        Series
           1           2           3           4           5           6
  3.000 )**
  1.500 )**                     *                                   ***
  0.0   )******      ******     **          *****       *********14****
 -1.500 )****        **         *           **
 -3.000 )**********  *********15*******     *********12*********
 -4.500 )            *          *           *                       *********13
 -6.000 )*                      ***         **          *
 -7.500 )                       **          *
 -9.000 )                       *           *                       **
-10.500 )
-12.000 )                       **                                  *
-13.500 )                       *
-15.000 )                       ***                                 *
```

No. of Observations

MEAN	-0.667	-1.917	-5.750	-2.792	-0.875	-3.625	underlined means significantly
S DEV	2.014	1.316	5.227	2.284	1.393	4.251	different than 0 at .05 level
N	24.	24.	24.	24.	24.	24.	

ALL GROUPS COMBINED

			SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
MEAN	-2.6042	BETWEEN	436.5513	5	87.3102	8.9791
S DEV	3.5265	WITHIN	1341.8743	138	9.7237	
MAXIMUM	3.0000	TOTAL	1778.4255	143		
MINIMUM	-15.0000					

TABLE 19. HISTOGRAMS AND DESCRIPTIVE STATISTICS BY SERIES FOR MALE OF GOOD PHYSICAL FITNESS (TOP) AND SEDENTARY MALE (BOTTOM). F RATIO TESTS HYPOTHESIS THAT MEANS ARE EQUAL. NOTE: HISTOGRAMS ARE PRESENTED HORIZONTALLY.

Series

```
INTERVAL    1         2         3         4         5         6
   9.000 )
   7.500 )                              *
   6.000 )
   4.500 )                    *
   3.000 )*                   *
   1.500 )
   0.0   )*****     ***       *********15********   **********  *********
  -1.500 )**                            ***       *
  -3.000 )**********  *********17***    *********11*********12**
  -4.500 )*******   **                  *         *         *********13
  -6.000 )          **        **
  -7.500 )
  -9.000 )                    **
```

No. of Observations

	1	2	3	4	5	6
MEAN	<u>-2.042</u>	<u>-2.792</u>	-1.000	-0.958	<u>-1.708</u>	<u>-2.292</u>
S DEV	1.987	1.362	3.121	2.293	1.546	1.939
N	24.	24.	24.	24.	24.	24.

underlined means significantly different than 0 at .05 level

ALL GROUPS COMBINED

			SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
MEAN	<u>-1.7986</u>	BETWEEN	63.3567	5	12.6713	2.7943
S DEV	2.1953	WITHIN	625.7903	138	4.5347	
MAXIMUM	8.0000	TOTAL	689.1470	143		
MINIMUM	-8.0000					

Series

```
INTERVAL    1         2         3         4         5         6
  14.000 )
  12.000 )                    ****
  10.000 )
   8.000 )
   6.000 )          ****      ****                          **
   4.000 )******    *         **        *                   *
   2.000 )***                           **                  ****
   0.0   )*********11*********12*********12**      ********** **
  -2.000 )**        ****                ********  **        *********14
  -4.000 )          **        **        ***       *********11
  -6.000 )          *                   **                  *
  -8.000 )**                            ******    *
 -10.000 )
```

No. of Observations

	1	2	3	4	5	6
MEAN	0.958	0.750	<u>3.375</u>	<u>-2.833</u>	<u>-1.917</u>	-0.042
S DEV	3.223	3.326	5.037	3.632	1.886	3.127
N	24.	24.	24.	24.	24.	24.

underlined means significantly different than 0 at .05 level

ALL GROUPS COMBINED

			SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
MEAN	0.0486	BETWEEN	589.4377	5	117.8875	9.6423
S DEV	3.9901	WITHIN	1687.2063	138	12.2261	
MAXIMUM	13.0000	TOTAL	2276.6440	143		
MINIMUM	-8.0000					

TABLE 20. HISTOGRAMS AND DESCRIPTIVE STATISTICS BY SERIES FOR FEMALE OF GOOD PHYSICAL FITNESS (TOP) AND SEDENTARY FEMALE (BOTTOM). F RATIO TESTS HYPOTHESIS THAT MEANS ARE EQUAL. NOTE: HISTOGRAMS ARE PRESENTED HORIZONTALLY.

of the underprediction or overprediction for each series. The range of means is considerable for MG, MS and FS. However, since the range of means for FG is only 1.8, there appears to be a constant underprediction error of approximately 1 to 3 beats/minute.

By testing the hypothesis that the means are equal to zero versus they are not, it can be determined whether the underprediction or overprediction is significant for each series. The underlined means of Tables 19 and 20 indicate a rejection of the above hypothesis. Fourteen of the 24 means must be considered not equal to zero with 12 indicating an underprediction and 2 indicating an overprediction. Only the mean error for series 5 was significantly different than zero, for all subject categories. Otherwise, there was no apparent underprediction or overprediction for any given series. Since the first task of Series 5 was at zero work load and the third task was of only 20 seconds duration, most of the error for Series 5 can be attributed to the difference in the predicted and observed steady state values for the second task. As can be observed from Figures 41, 47, 53, and 59 the error at steady state for Task 2 (-1 for MG, -2 for MS -3 for FG and FS) is on the order of 1 to 3 percent. Since the validation sample is small and the prediction error minimal, this consistent and significant underprediction for series 5 is not sufficient evidence to recommend that the work load to steady state %RHR relationships be examined for work loads in the range of task two (35 to 90 watts). There is no consistent trend of means for the other series which indicate an underprediction or overprediction. Also, it can be noticed that overall error means for MG and FS are positive and overpredictions and the overall error means for MS and FG are negative and underpredictions.

There is no apparent trend to indicate a mean error of other than zero for predictions for MG and FS, since the hypothesis that the mean equal zero is accepted. However, the underprediction is consistent for MS and FG. The overall subject category means and the means of 9 of the 12 series are significantly different than zero. The validation results produced by the MS and FG subjects are definite indications that the work load to steady state %RHR relationship of MS and FG used exhibit a slight underprediction, for the two subjects tested.

Conclusions as to the relative validity of predictions for each subject category can be drawn by examining the overall means and standard deviations of each subject category (see Tables 19 and 20). At one standard deviation the potential error of MG, FG, and FS is approximately 4 beats/minute (4.3, 4.0, and 4.0, respectively). However, the potential error at one standard deviation for MS is 6.1 beats/minute. The error for MS is 50% greater than that of MG, FG and FS. It can then be concluded that the predicted results for MS are less accurate than those of the other three categories.

This is due to the underprediction and not necessarily the dispersion of the error since the range and standard deviation for MS is less than both MG and FS.

Analysis by Inspection of Plotted Results

Male of Good Physical Fitness

The predicted and observed results are plotted in Figures 37 through 42 for the MG subject category. The most apparent source of error is that the observed time to steady state is less than the predicted for all step changes of all series. Therefore, there is an underprediction for step increases and an overprediction for step decreases. Since only two levels of physical fitness were used for this study, varying degrees of physical fitness exist within each level (good or sedentary). The subject for validation testing had a highly developed cardiovascular system (see Appendix 2 for exercise history). Of the total population of persons within the classification of good physical fitness, subject MG-3 would surely be in the top 5% in physical fitness. Therefore his cardiac response to a step change in exercise was in all cases much faster. For step changes from an increasing or decreasing heart rate the error becomes more pronounced as shown in Figure 42 at time 20. In this case, the subject's heart rate approached the steady state level of task one more quickly than the model output. Therefore, the observed response was a decrease and the predicted response was an increase. These results certainly indicate the need for more

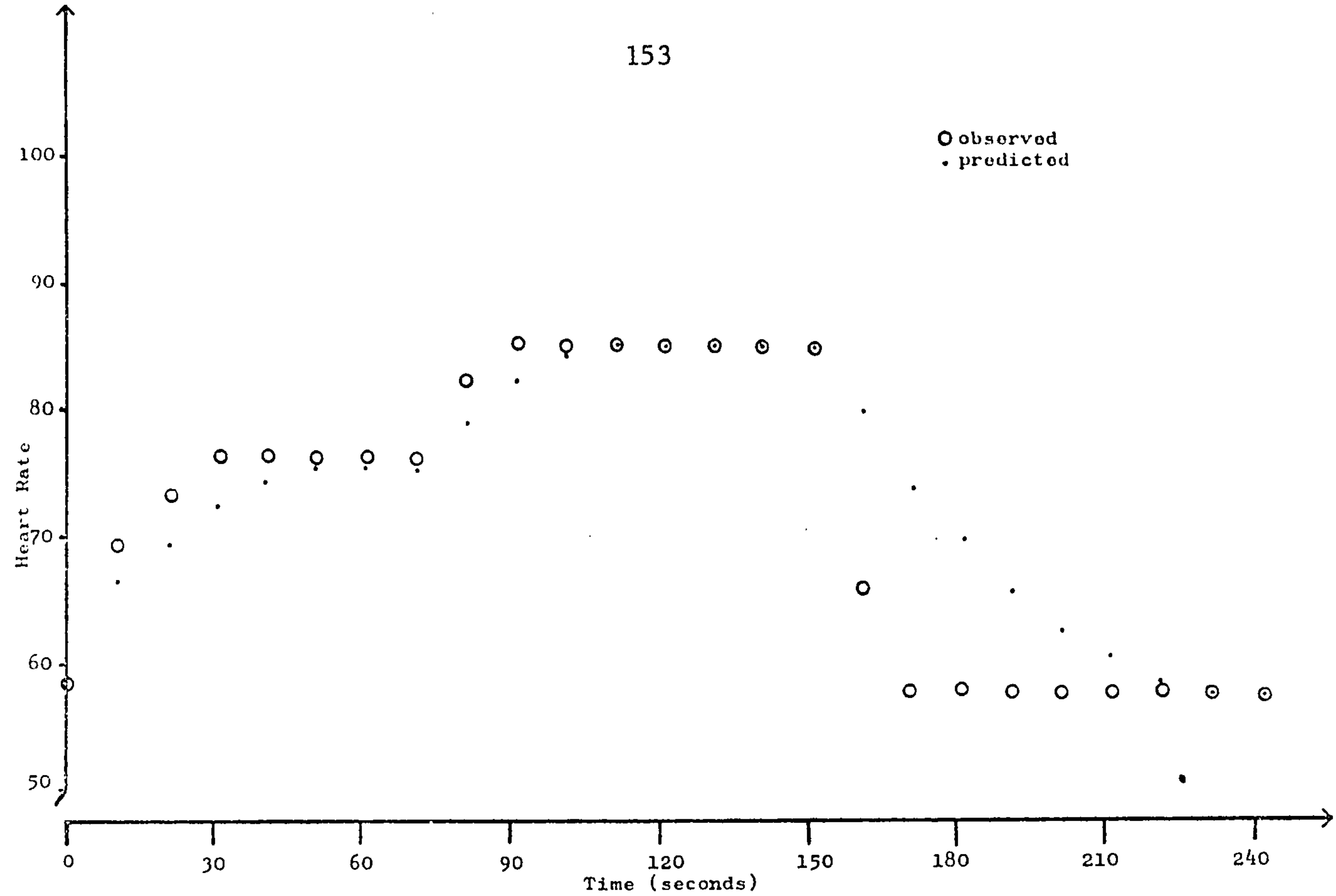

Figure 37. Plot of predicted and observed heart rate responses for Series 1--MG.

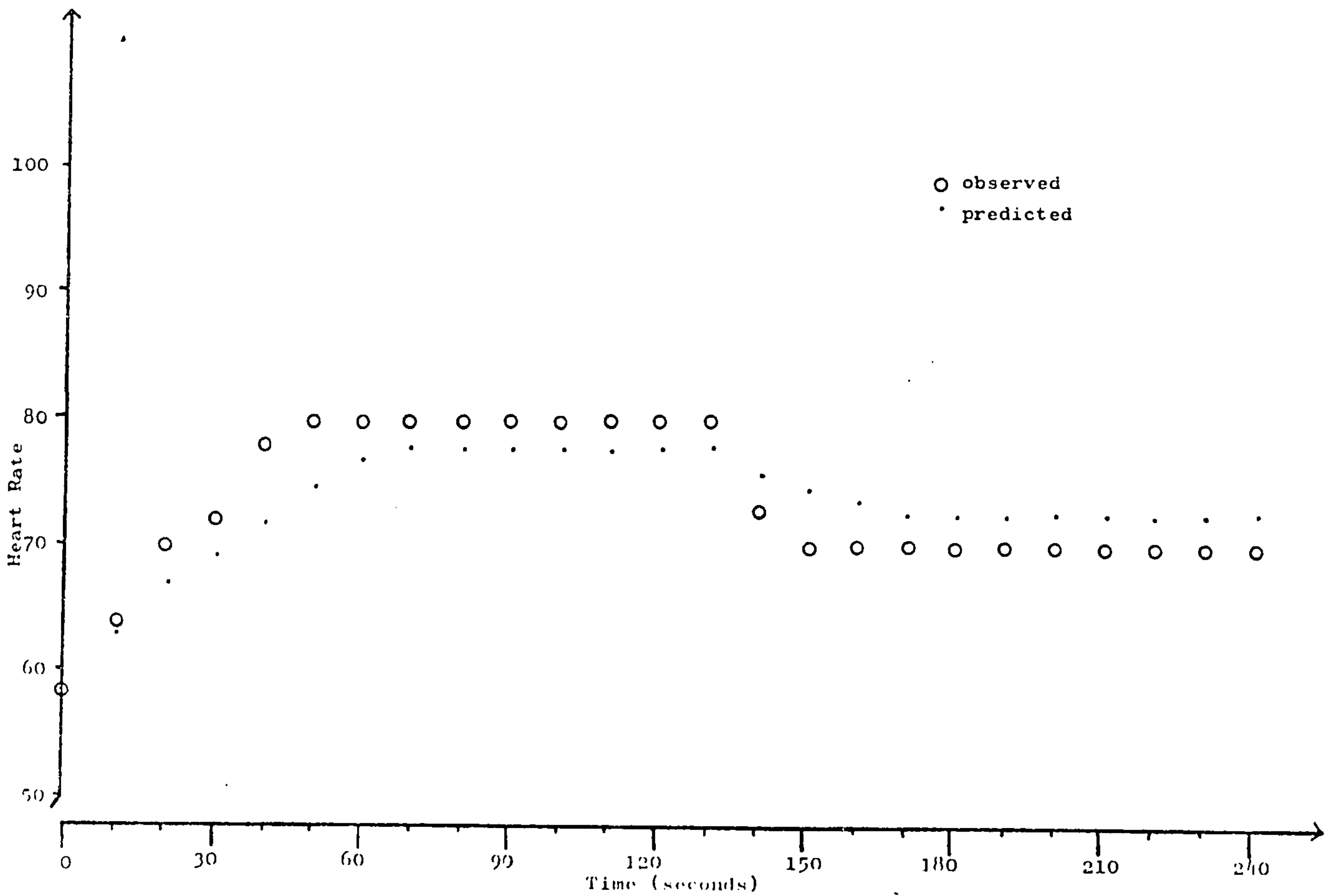

Figure 38. Plot of predicted and observed heart rate responses for Series 2-MG.

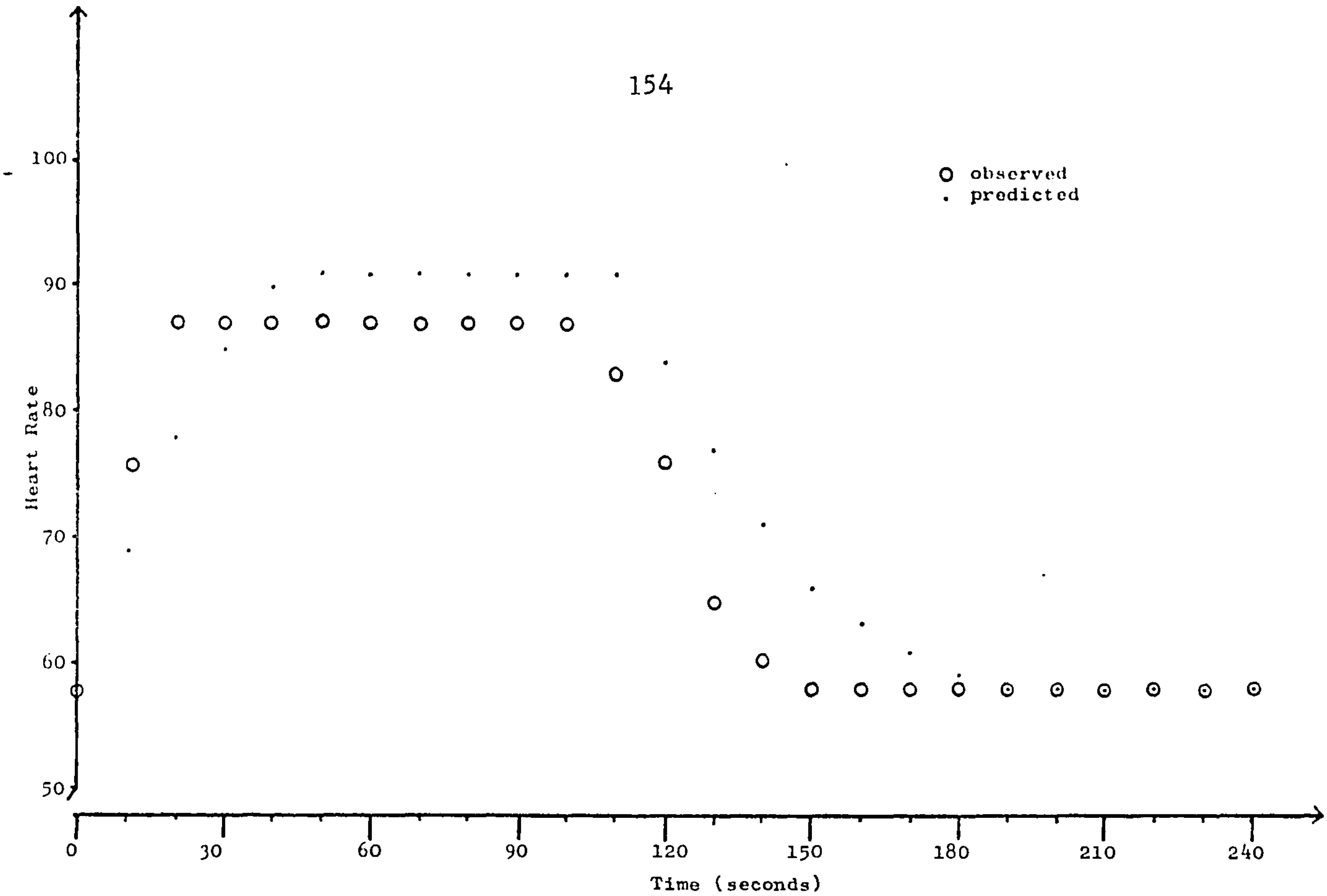

Figure 39. Plot of predicted and observed heart rate responses for Series 3-MG.

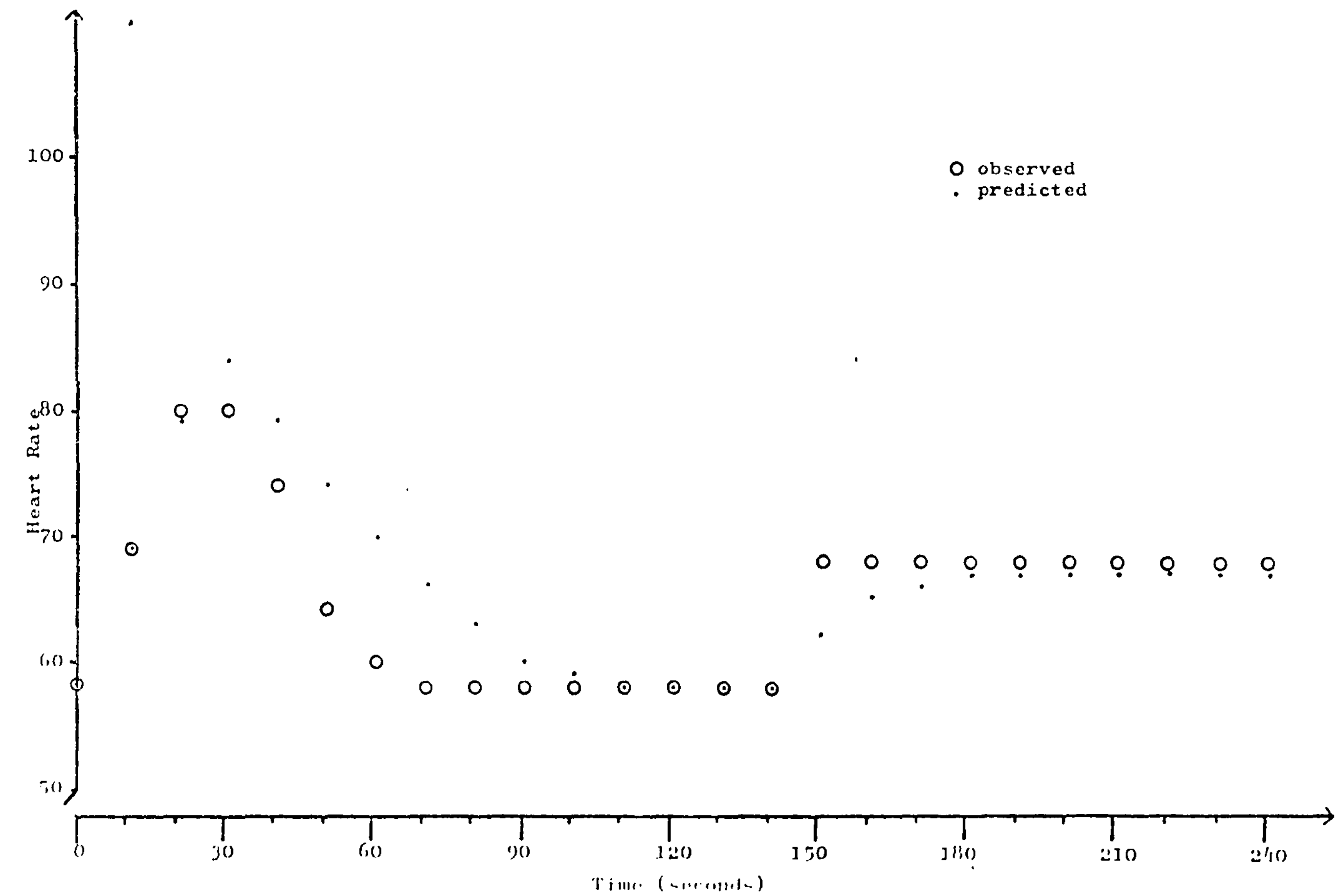

Figure 40. Plot of predicted and observed heart rate responses for Series 4-MG.

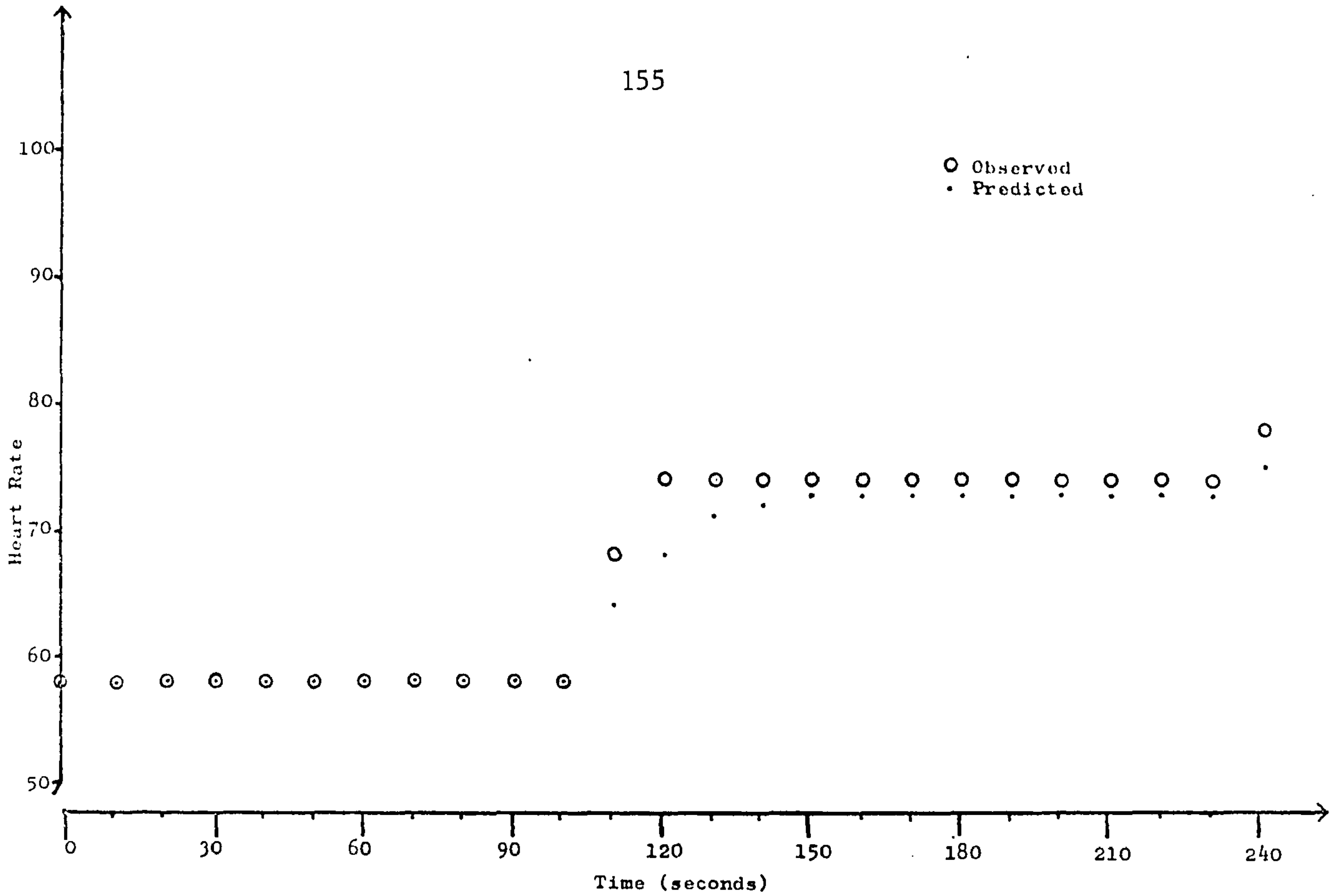

Figure 41. Plot of predicted and observed heart rate responses for Series 5-MG.

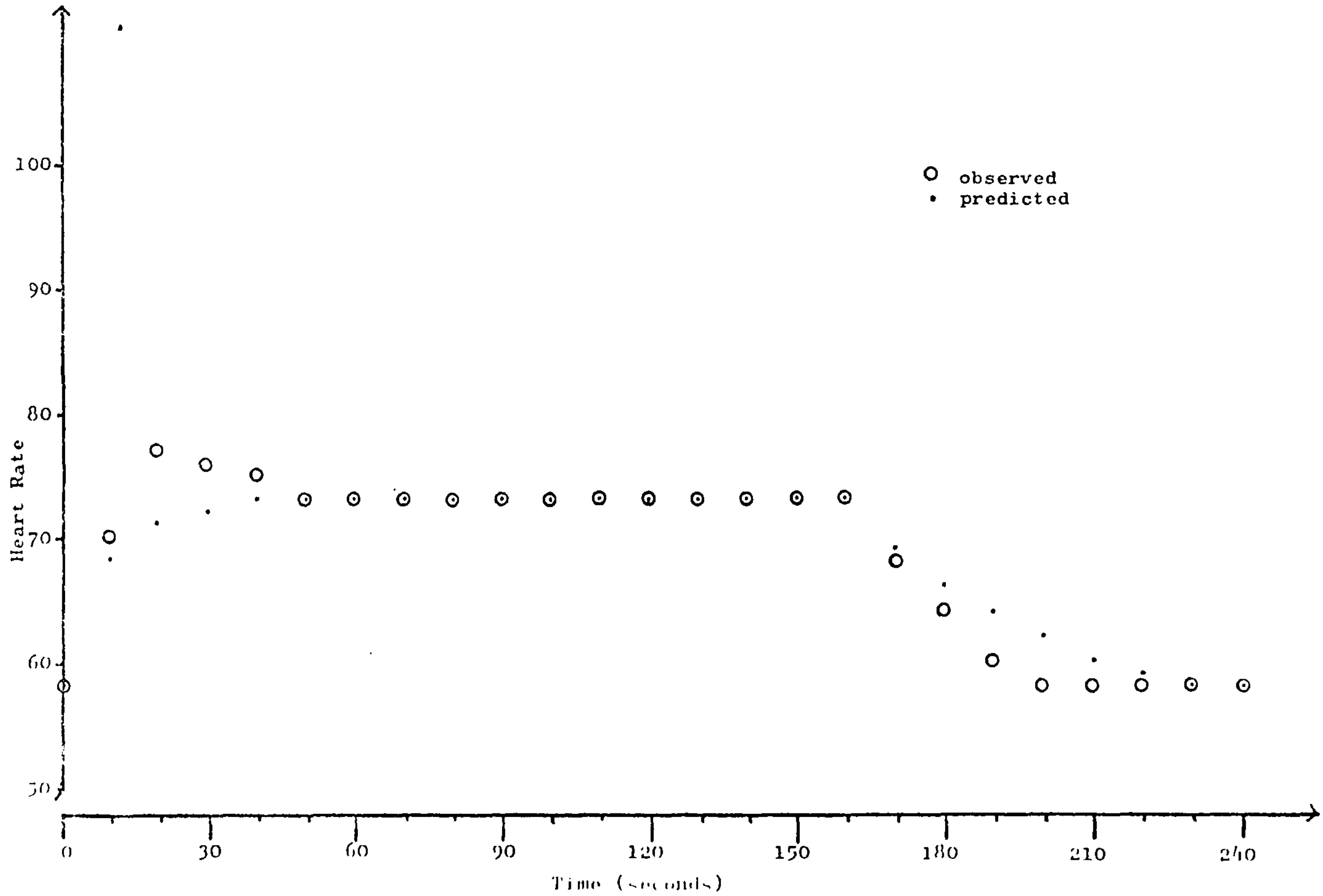

Figure 42. Plot of predicted and observed heart rate responses for Series 6-MG.

levels of physical fitness. (See recommendations of Chapter VI.)

Sedentary Male

The predicted and observed results are plotted in Figures 43 through 48 for the MS category. The observed results for decreasing step changes to a resting state in Figures 45, 46, and 48 are not consistent with the predicted results. Since the predicted and observed heart rate responses coincide for the decreasing step change of Figure 43, the observed deviation from the predicted must be attributed to individual variations in cardiac responses. The predicted and observed results were exceedingly close for all other step changes.

Female of Good Physical Fitness

The predicted and observed results are plotted in Figures 49 through 54 for the FG subject category. By inspection of all series for FG, it is readily apparent that an overall addition of 2 beats/minute to the predicted results would greatly improve the accuracy of the prediction. Only 7% of the results were overpredictions. The standard deviation for the FG category is considerably less than that of the other subject categories. Although there was a slight underprediction, it was consistent for all series, and since the dispersion of error was slight, the predictions could be considered good.

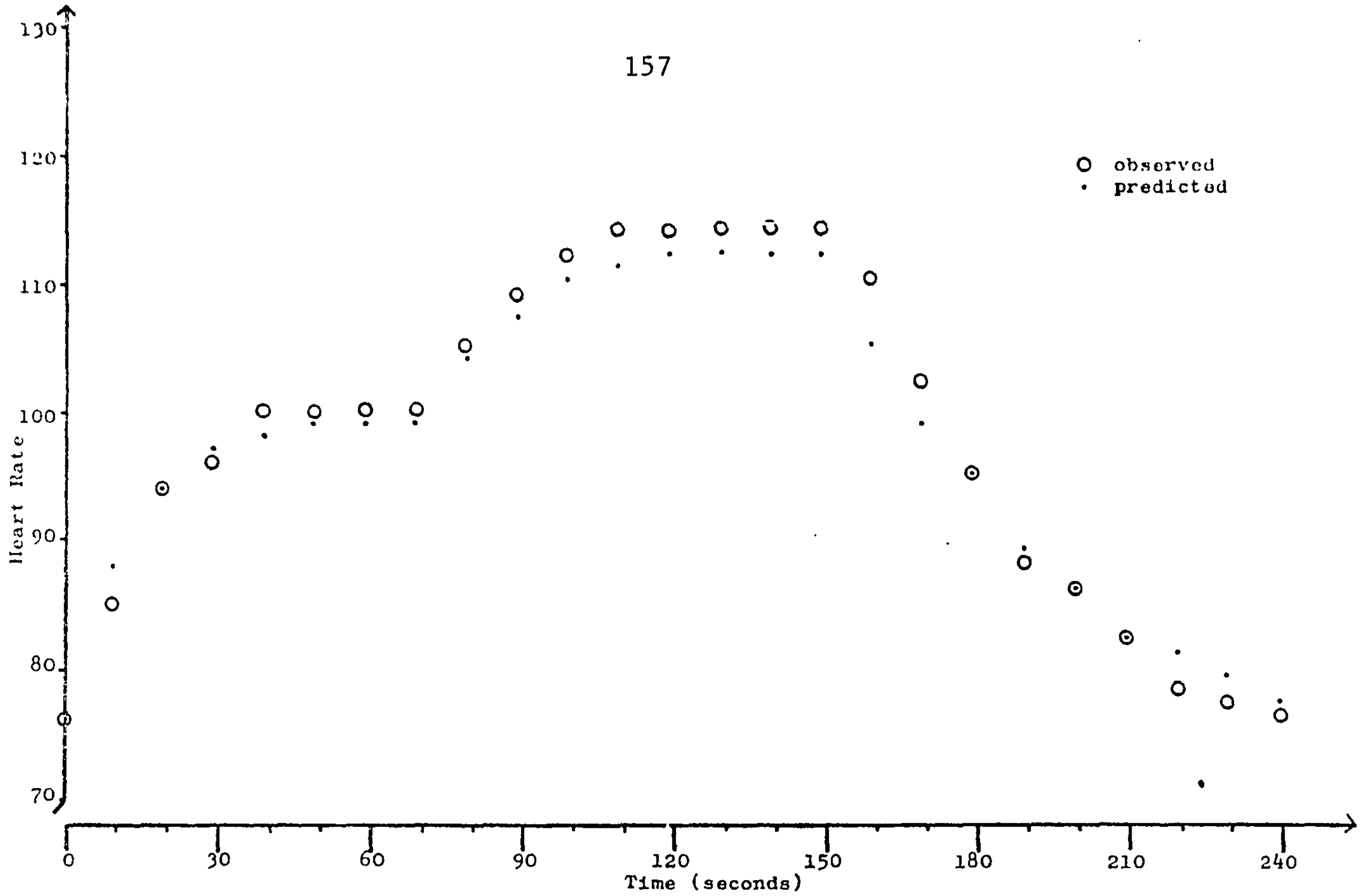

Figure 43. Plot of predicted and observed heart rate responses for Series 1-MS.

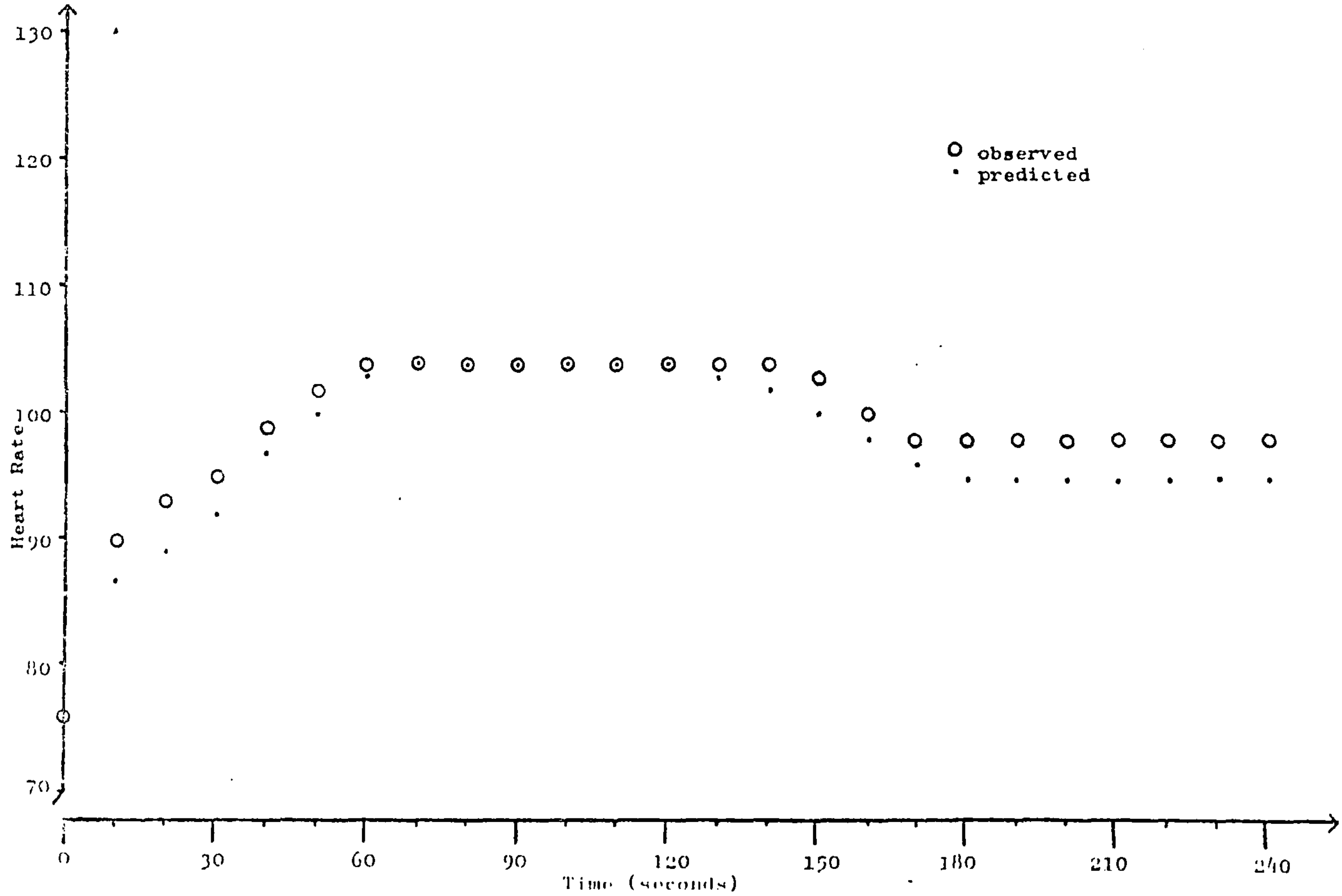

Figure 44. Plot of predicted and observed heart rate responses for Series 2-MS.

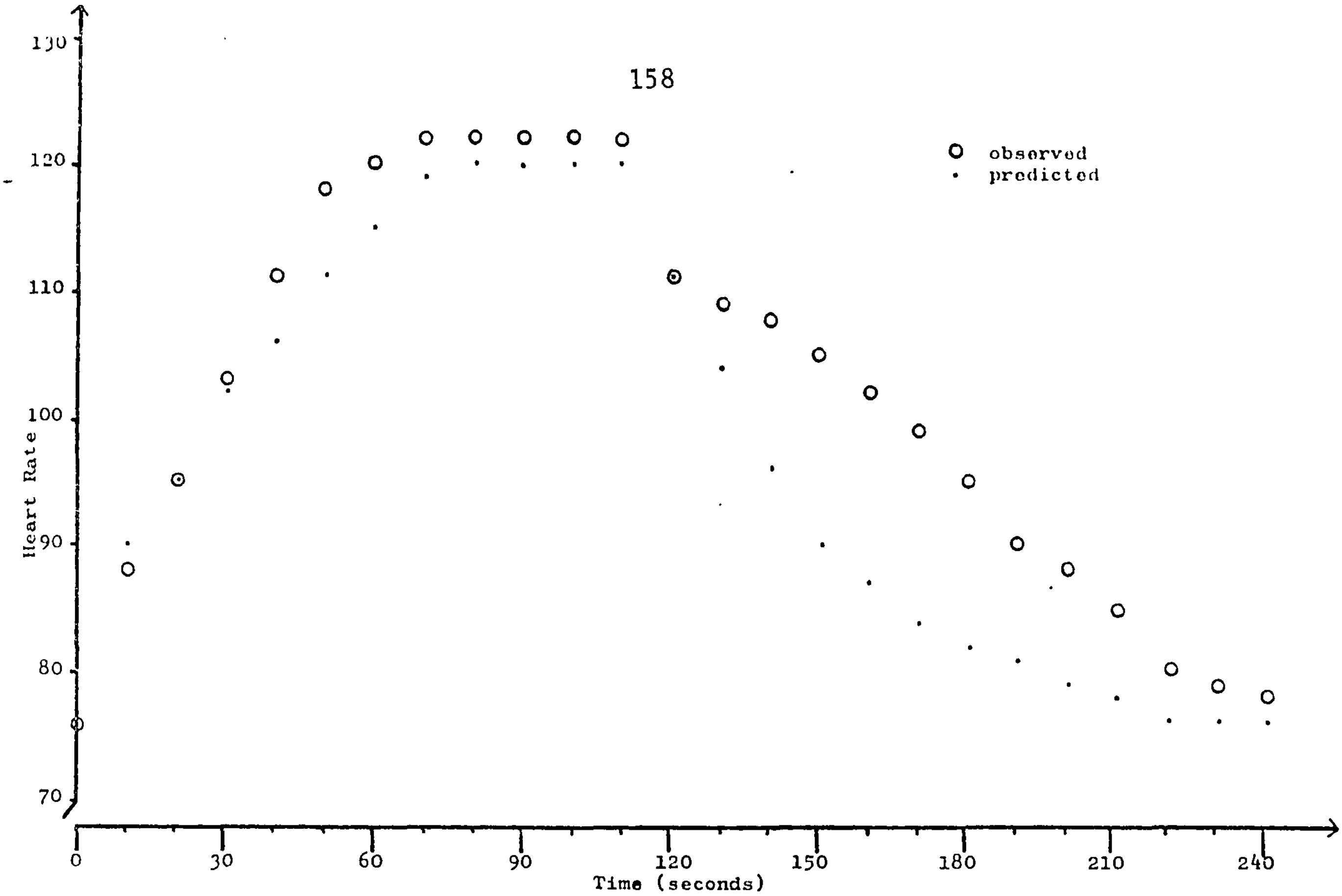

Figure 45. Plot of predicted and observed heart rate responses for Series 3-MS.

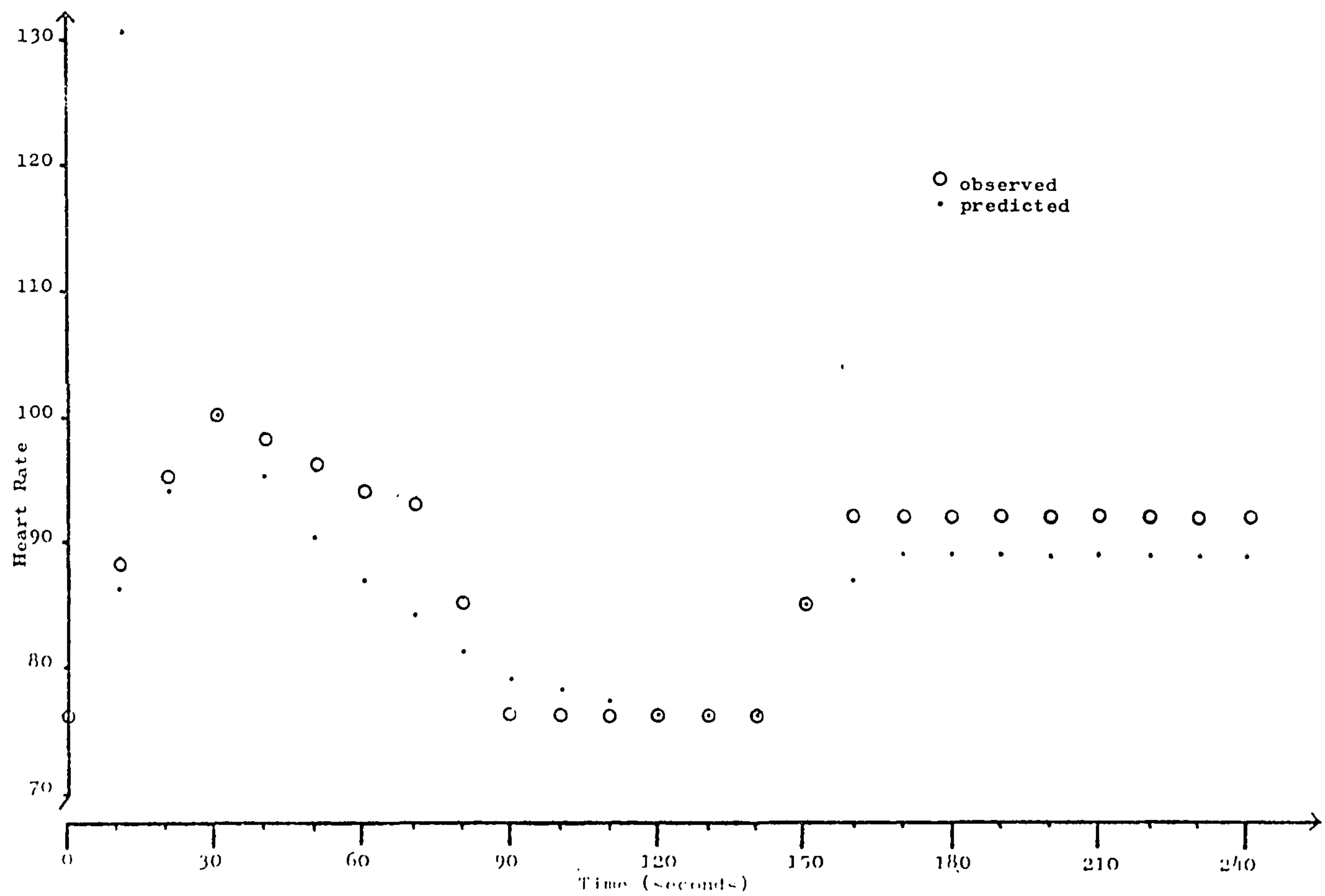

Figure 46. Plot of predicted and observed heart rate responses for Series 4-MS.

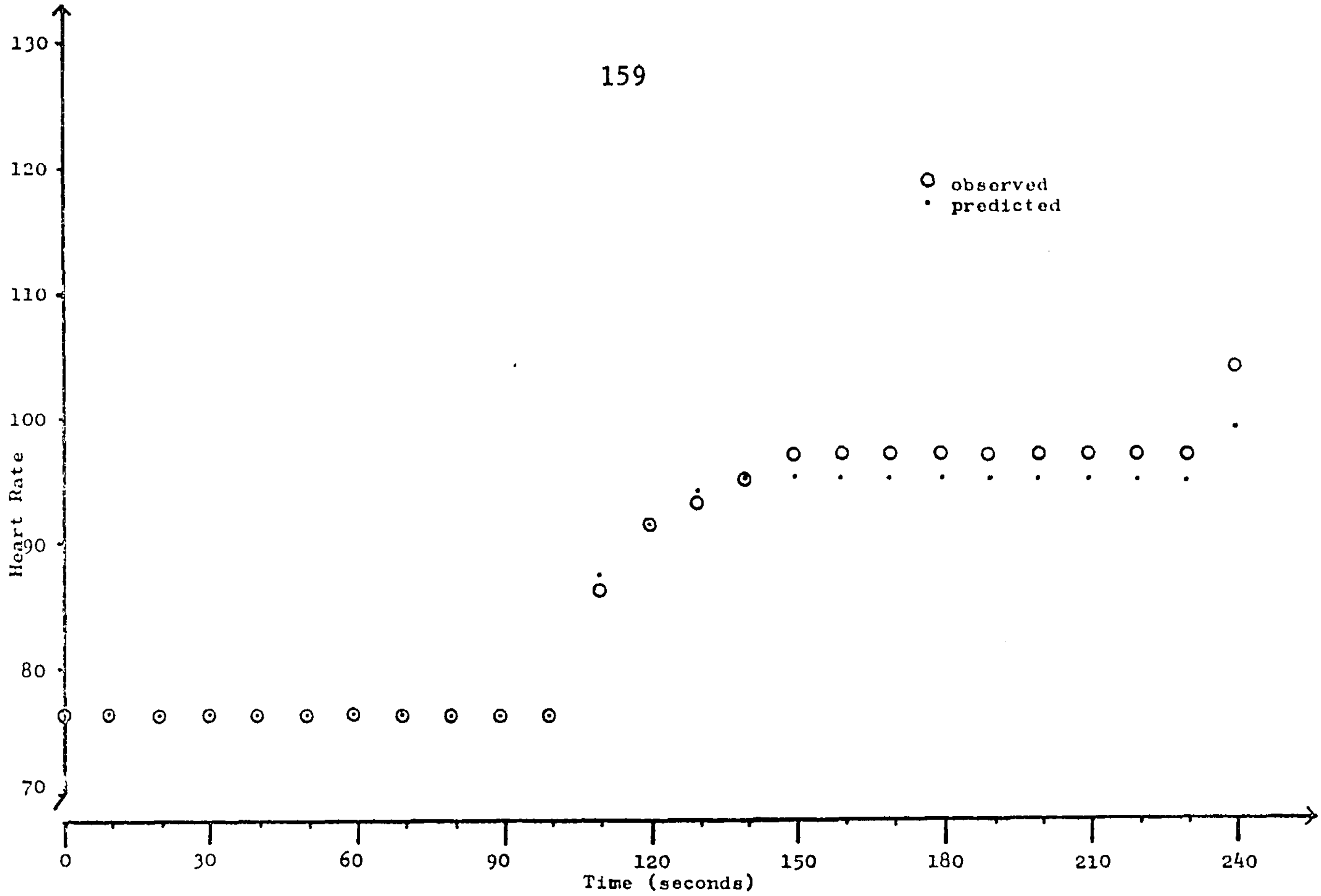

Figure 47. Plot of predicted and observed heart rate responses for Series 5-MS.

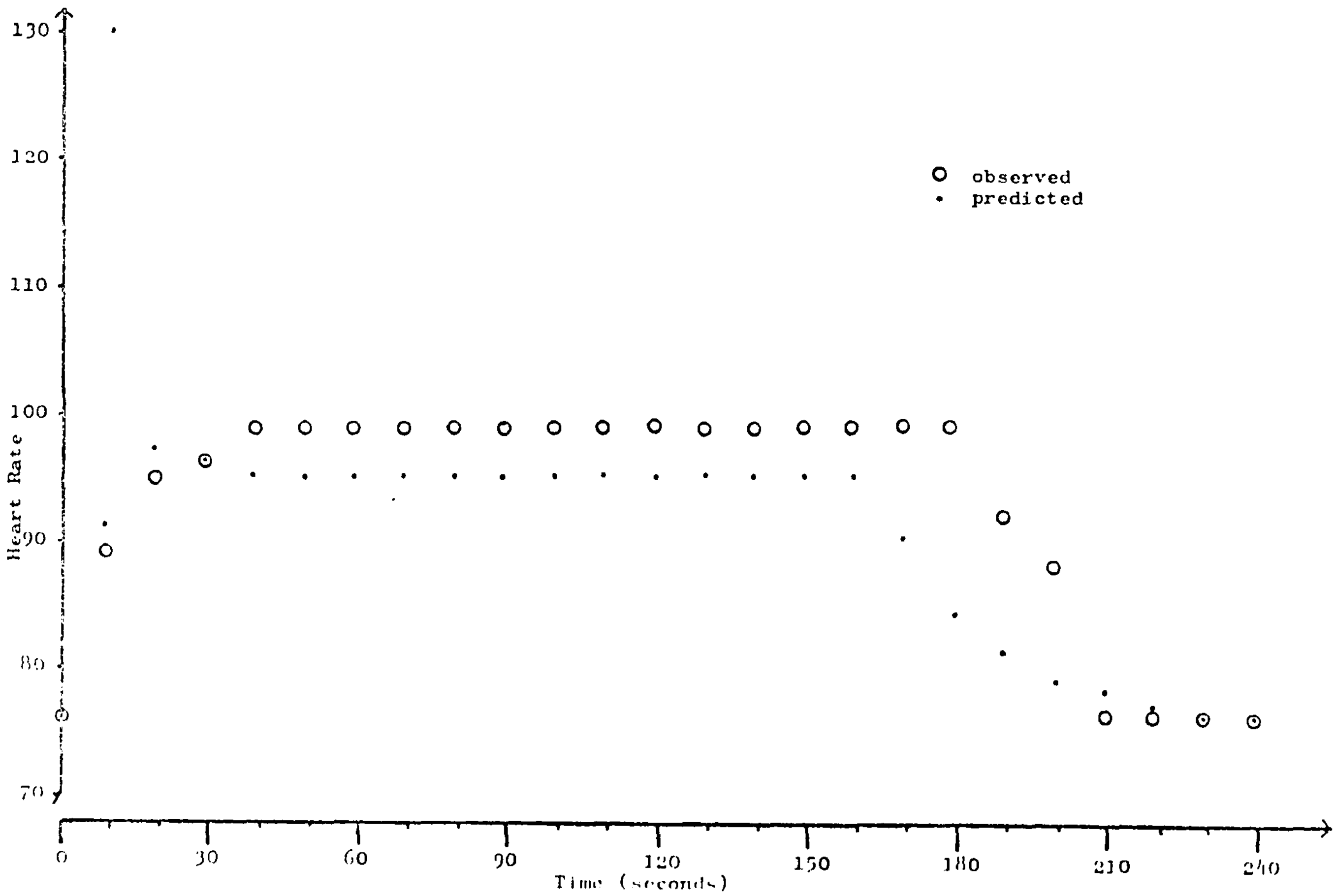

Figure 48. Plot of predicted and observed heart rate responses for Series 6-MS.

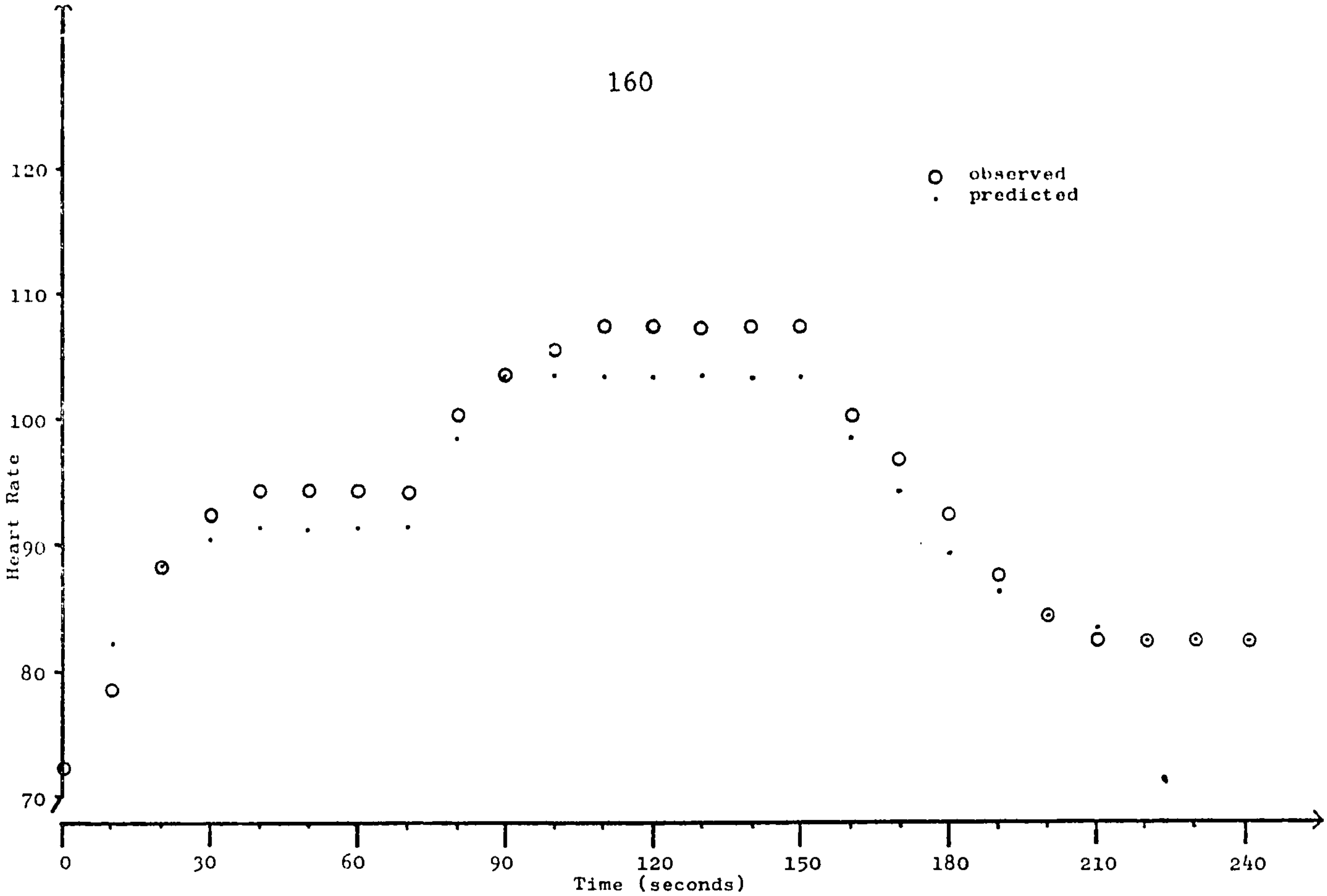

Figure 49. Plot of predicted and observed heart rate responses for Series 1-FG.

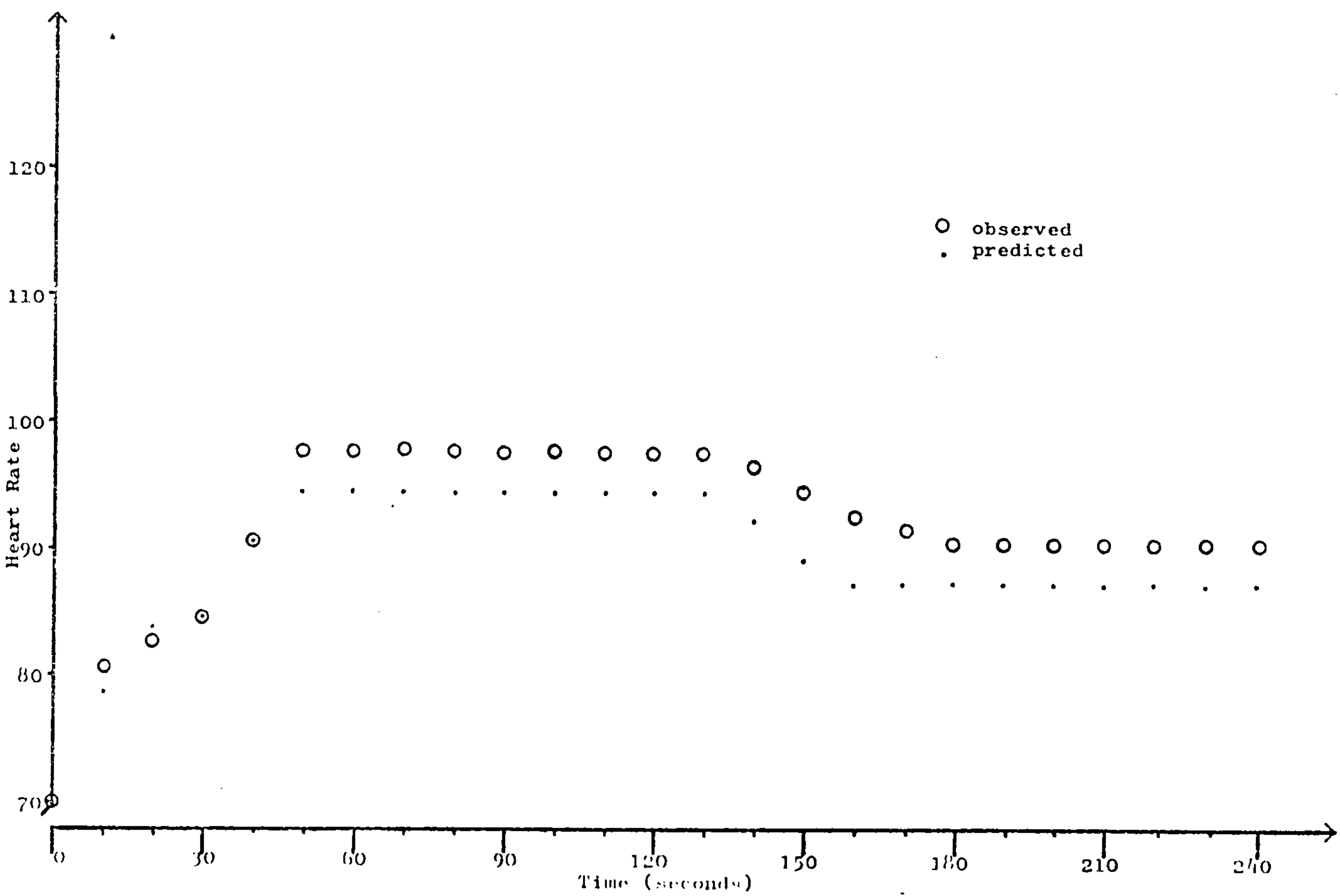

Figure 50. Plot of predicted and observed heart rate responses for Series 2-FG.

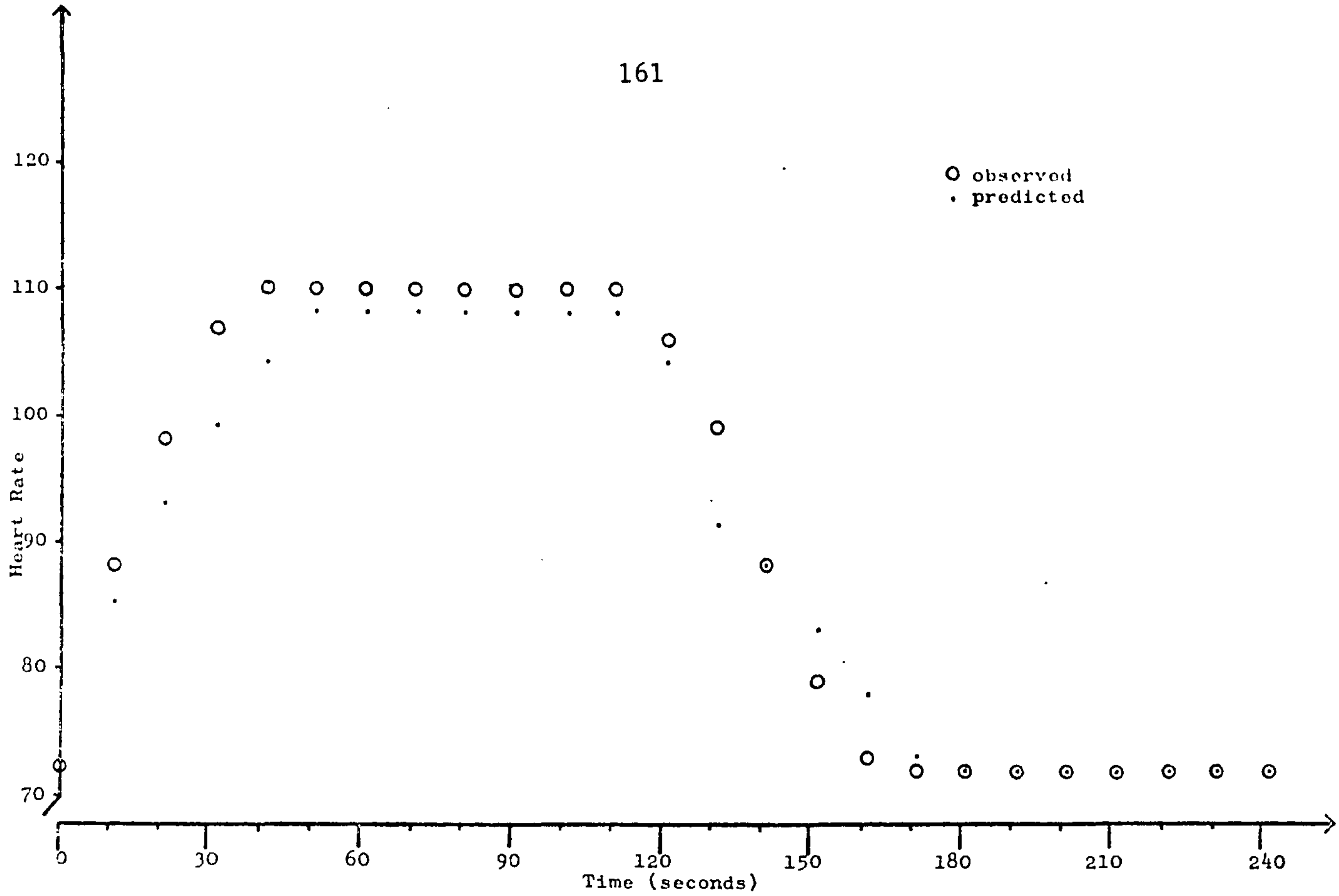

Figure 51. Plot of predicted and observed heart rate responses for Series 3-FG.

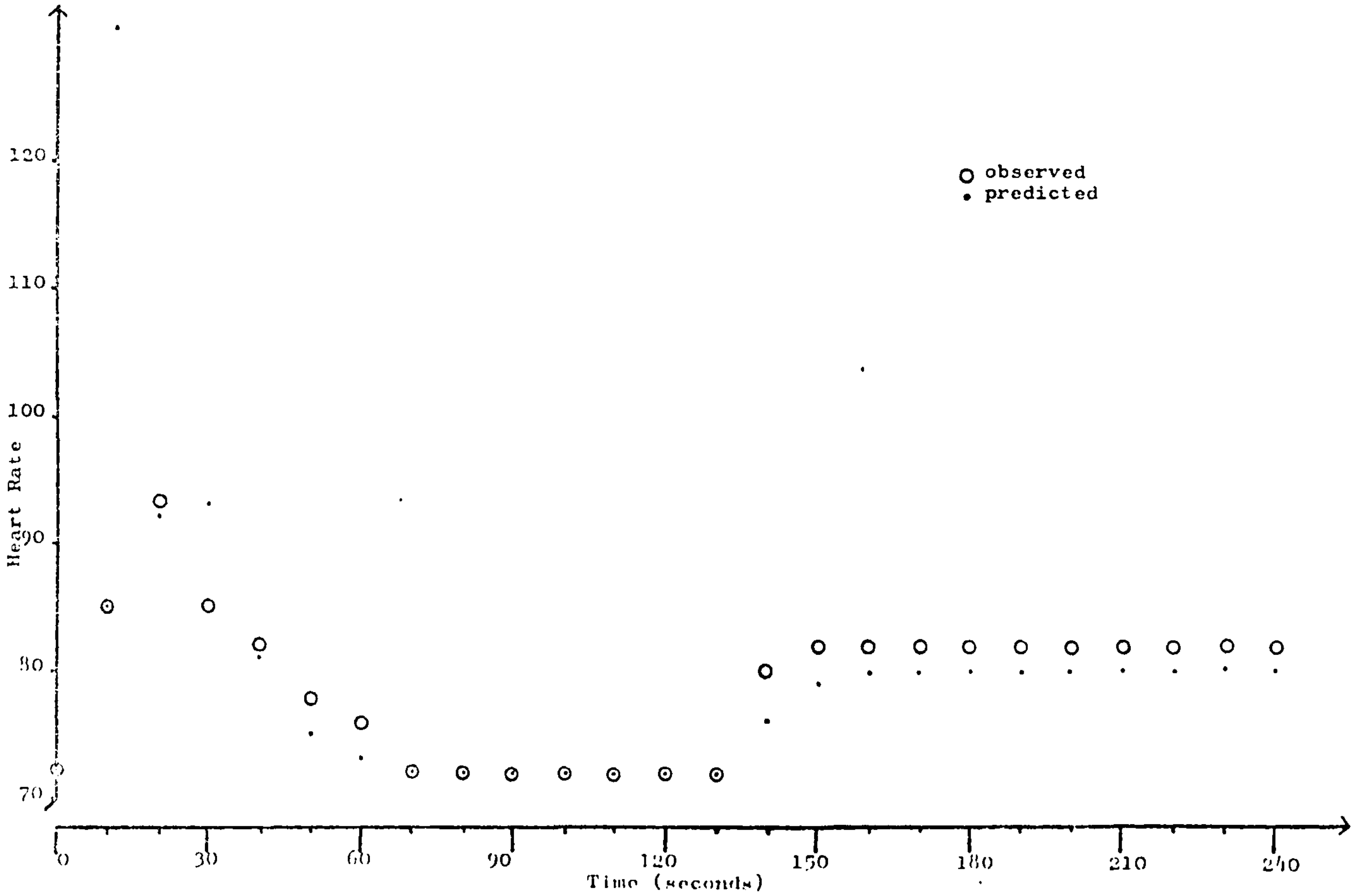

Figure 52. Plot of predicted and observed heart rate responses for Series 4-FG.

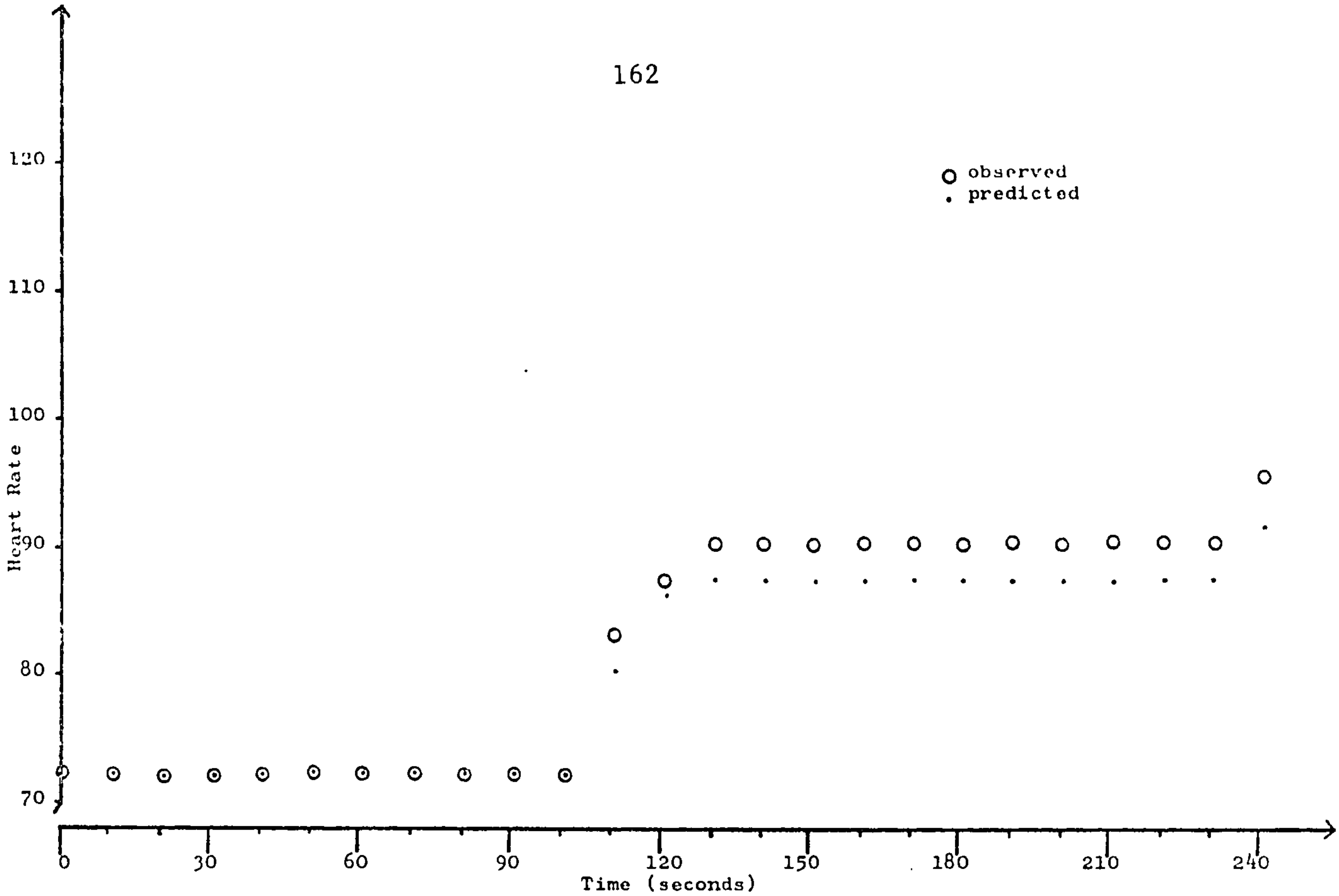

Figure 53. Plot of predicted and observed heart rate responses for Series 5-FG.

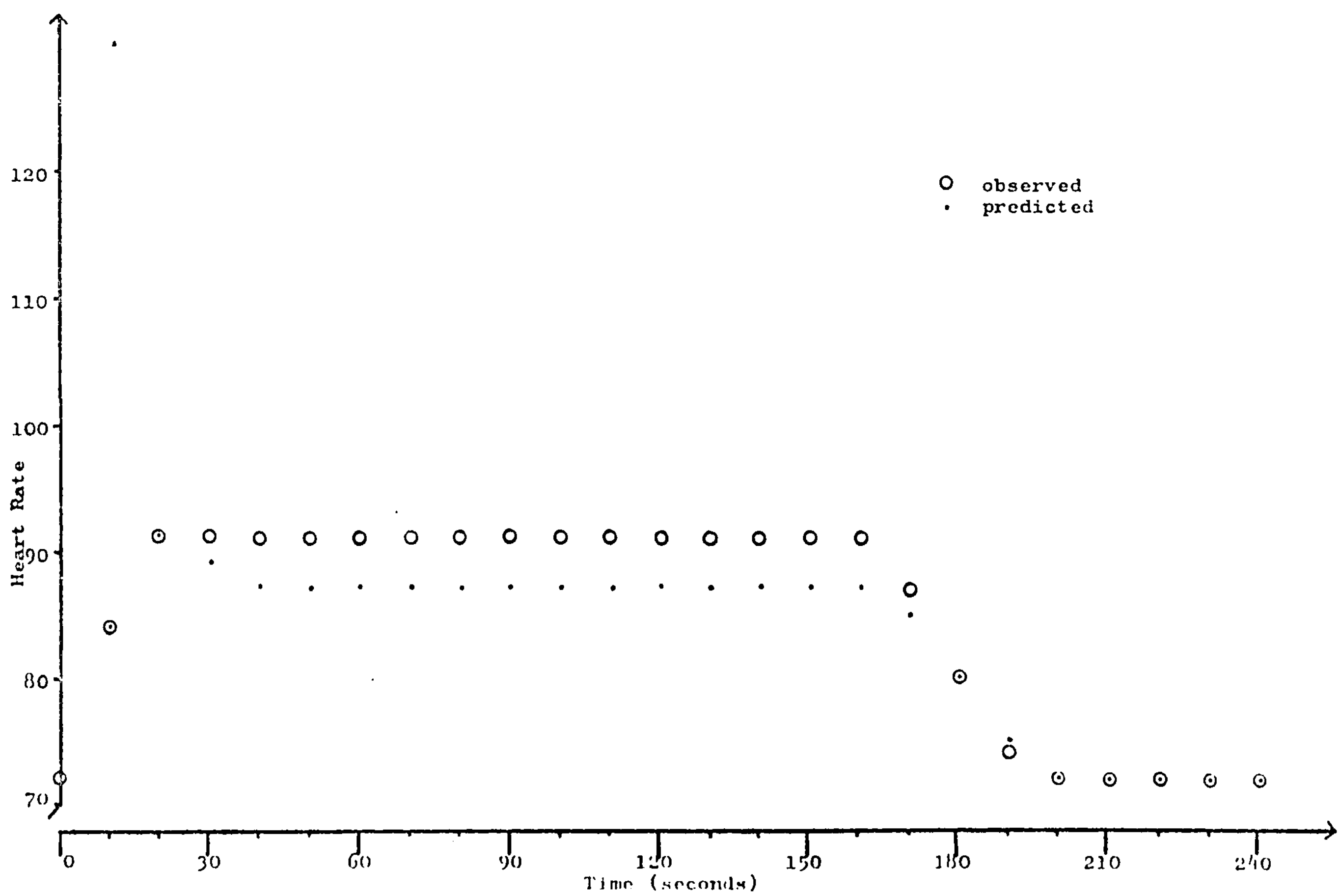

Figure 54. Plot of predicted and observed heart rate responses for Series 6-FG.

Sedentary Female

The predicted and observed results are plotted in Figures 55 through 60 for the FS subject category. The most apparent source of error for the FS series is that the heart rate responses to step changes in task intensity exhibit linear trends. There is an example of at least one linear response in each of the six series. For an observed linear response the predictive model will overpredict for increasing step changes and underpredict for decreasing step changes. The predictive model was more accurate for FS than MG, MS or FG in predicting steady state values. The observed and predicted steady state values differed by no more than 3 beats/minute.

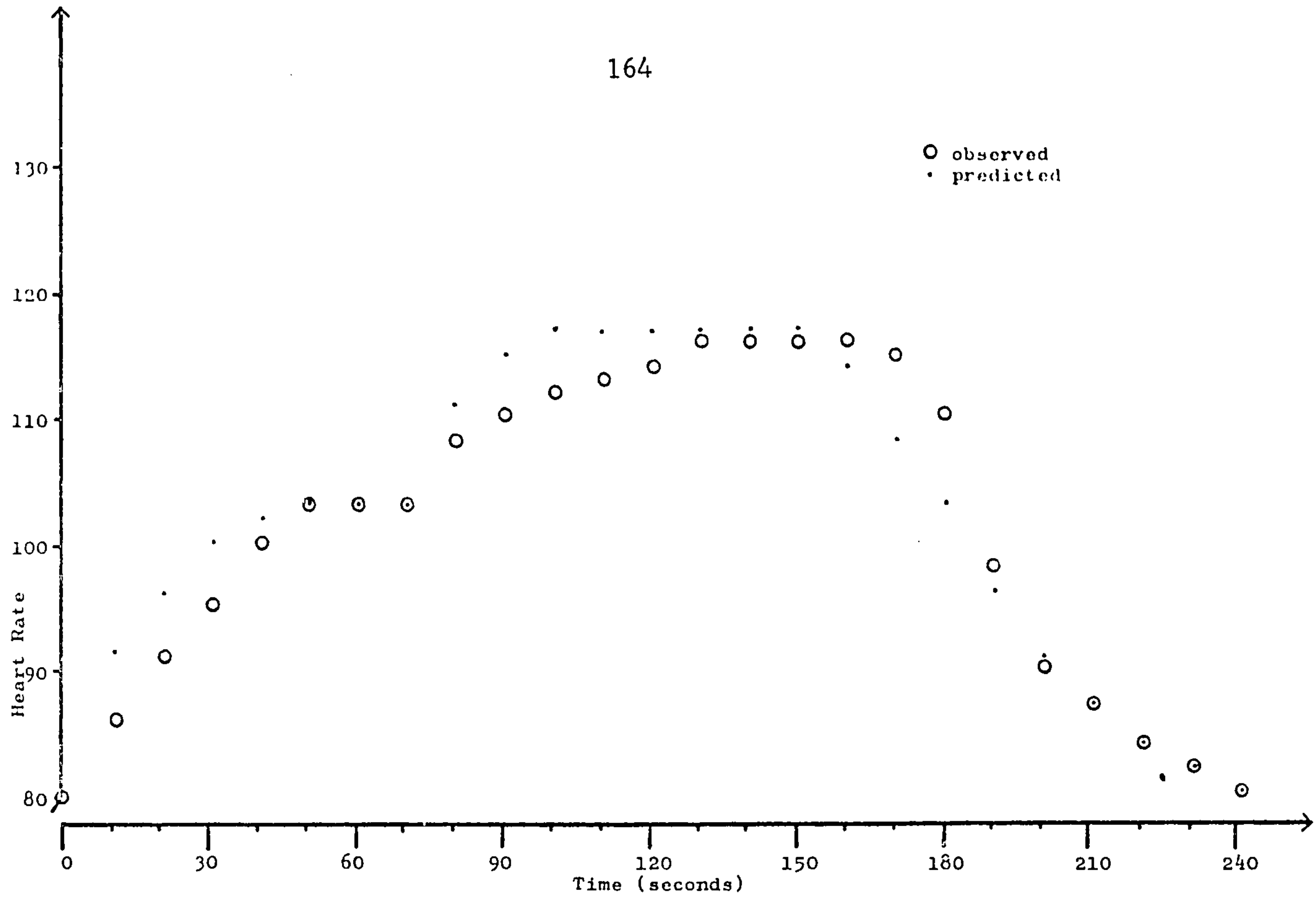

Figure 55. Plot of predicted and observed heart rate responses for Series 1-FS.

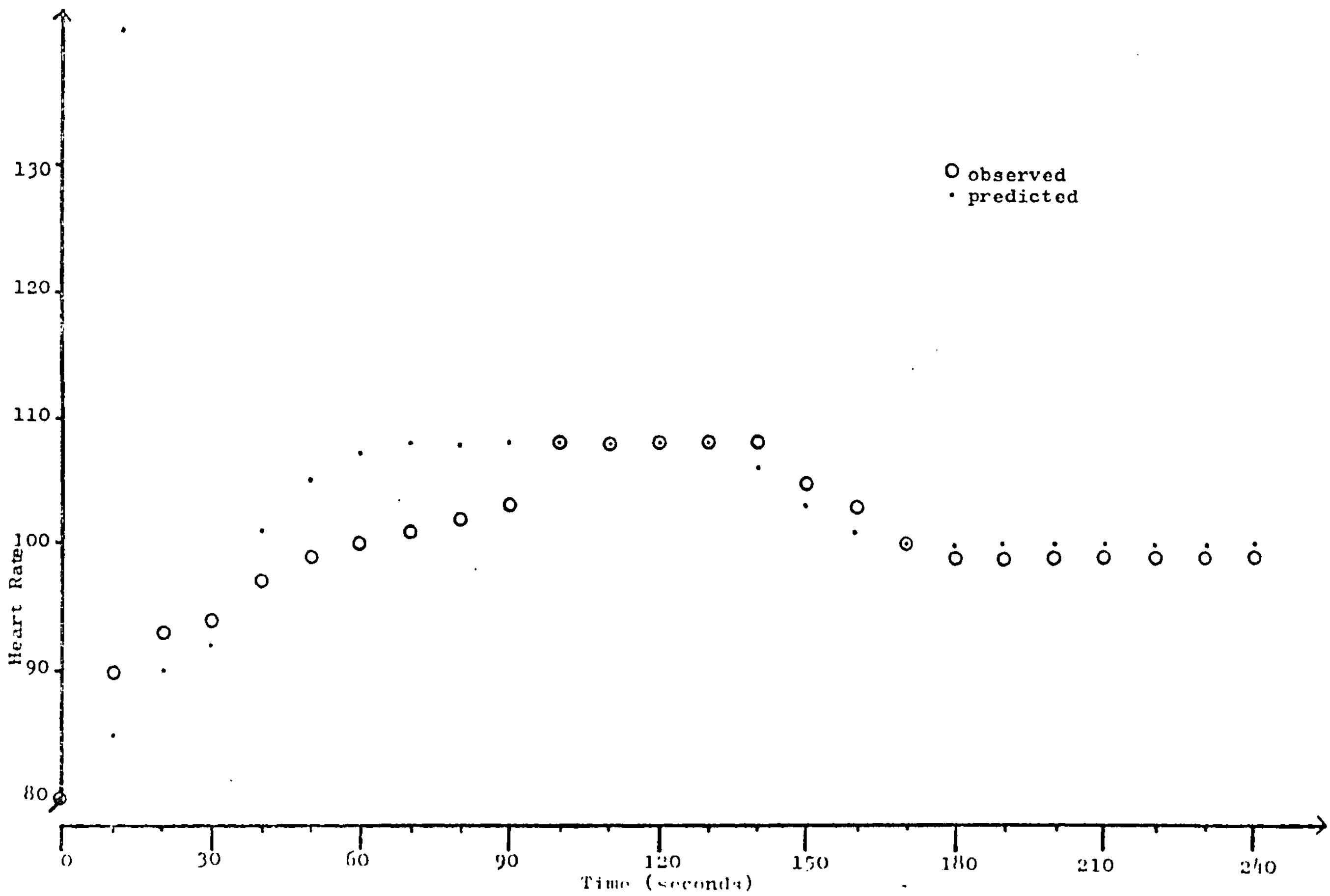

Figure 56. Plot of predicted and observed heart rate responses for Series 2-FS.

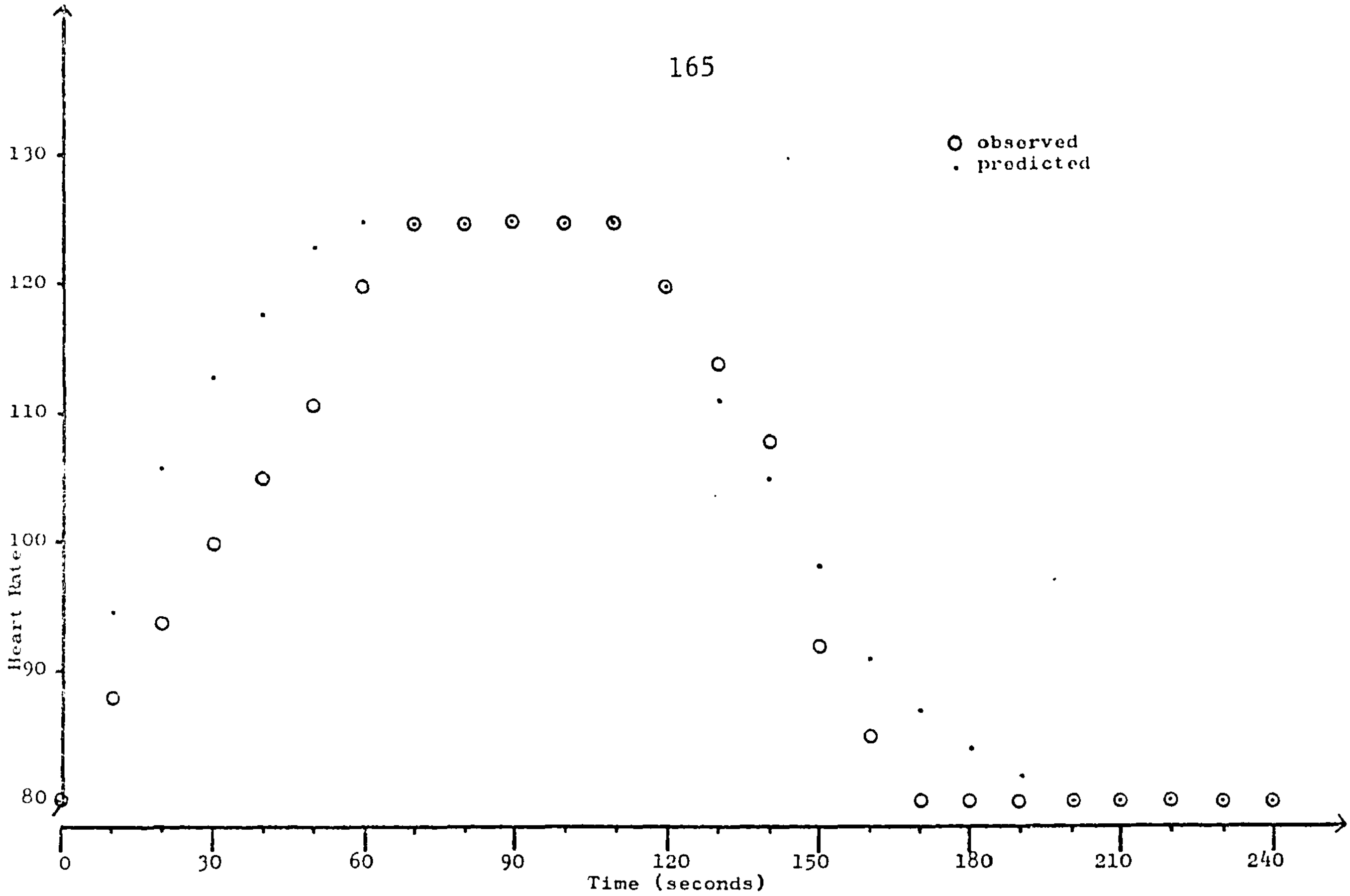

Figure 57. Plot of predicted and observed heart rate responses for Series 3-FS.

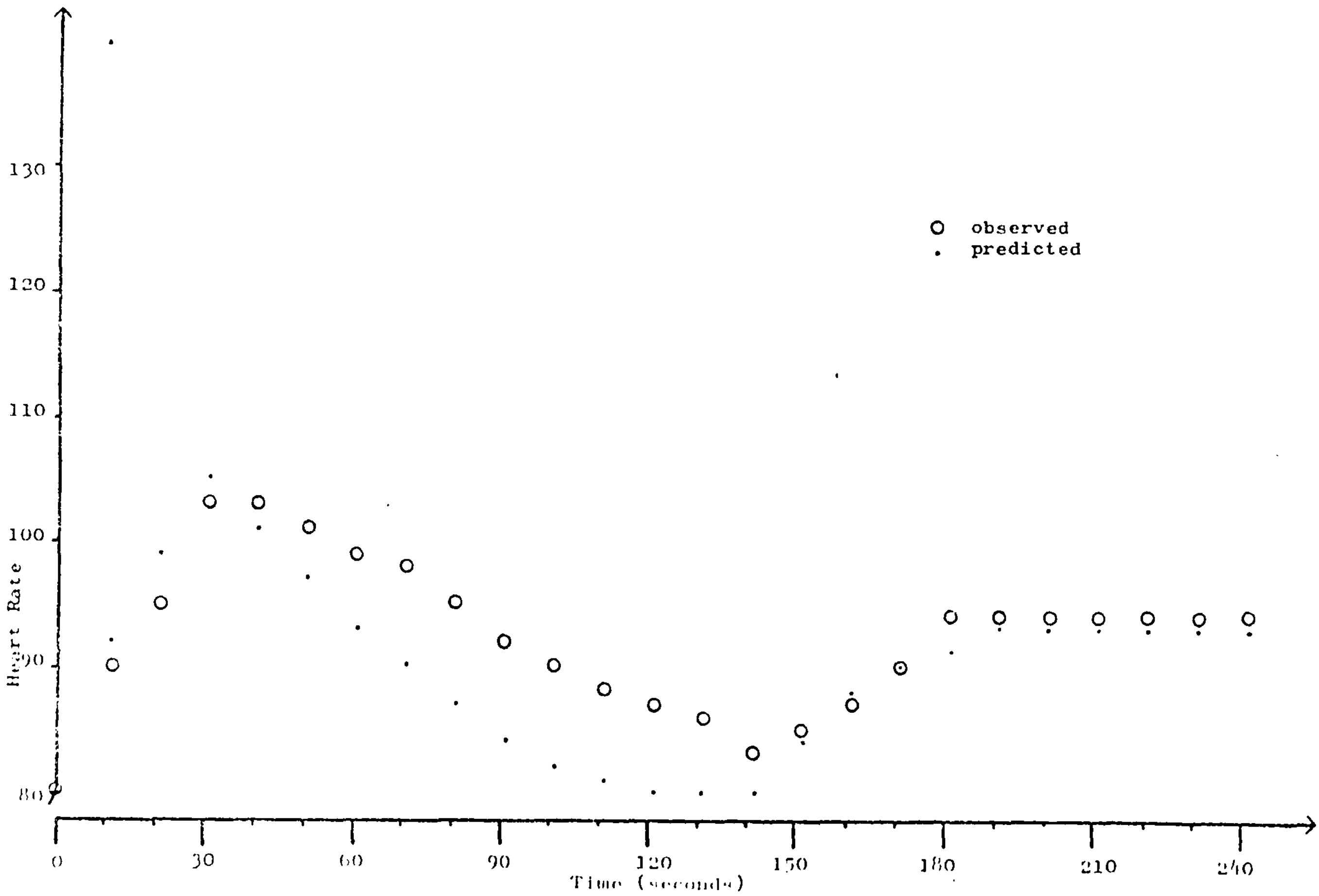

Figure 58. Plot of predicted and observed heart rate responses for Series 4-FS.

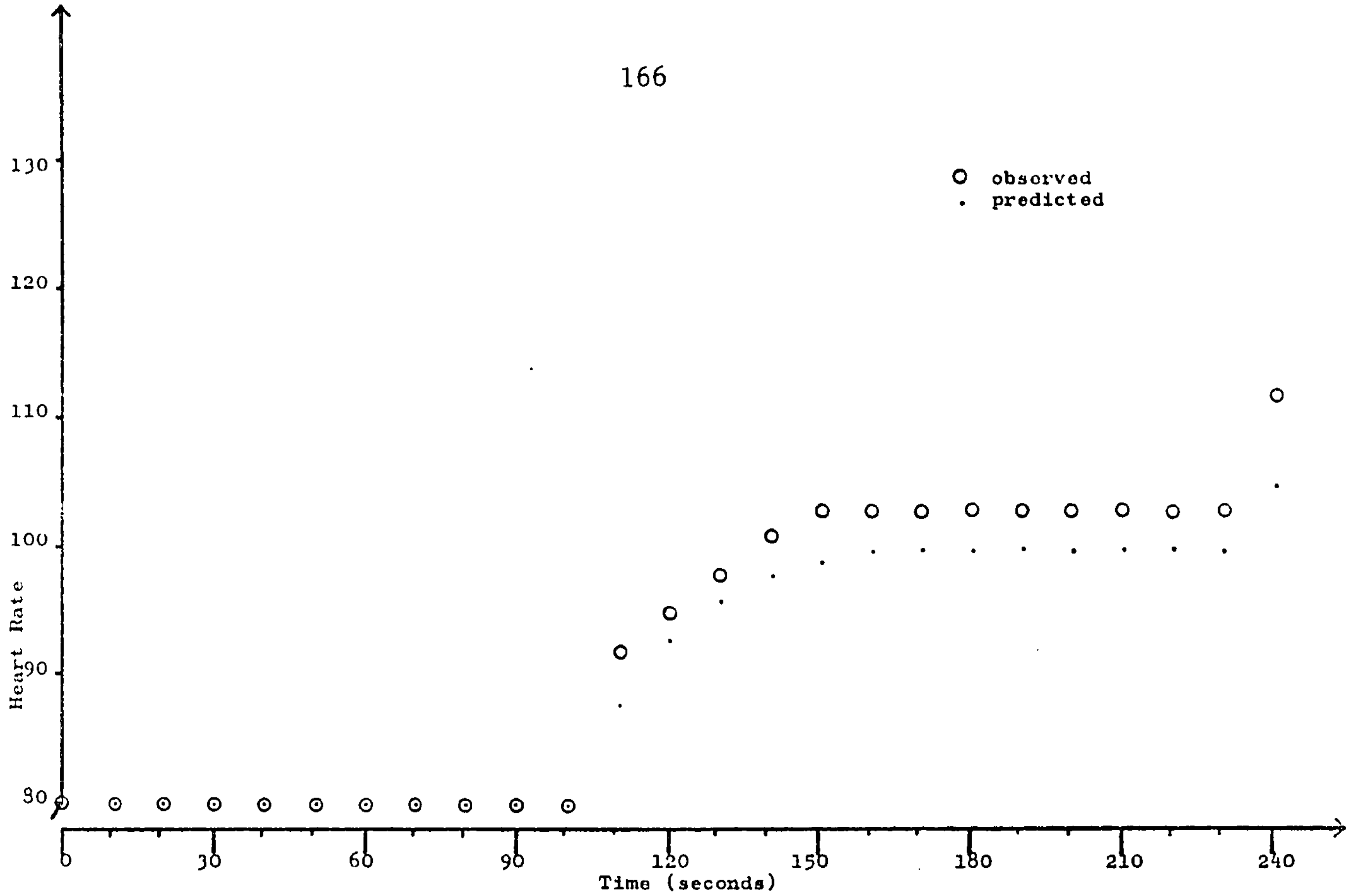

Figure 59. Plot of predicted and observed heart rate responses for Series 5-FS.

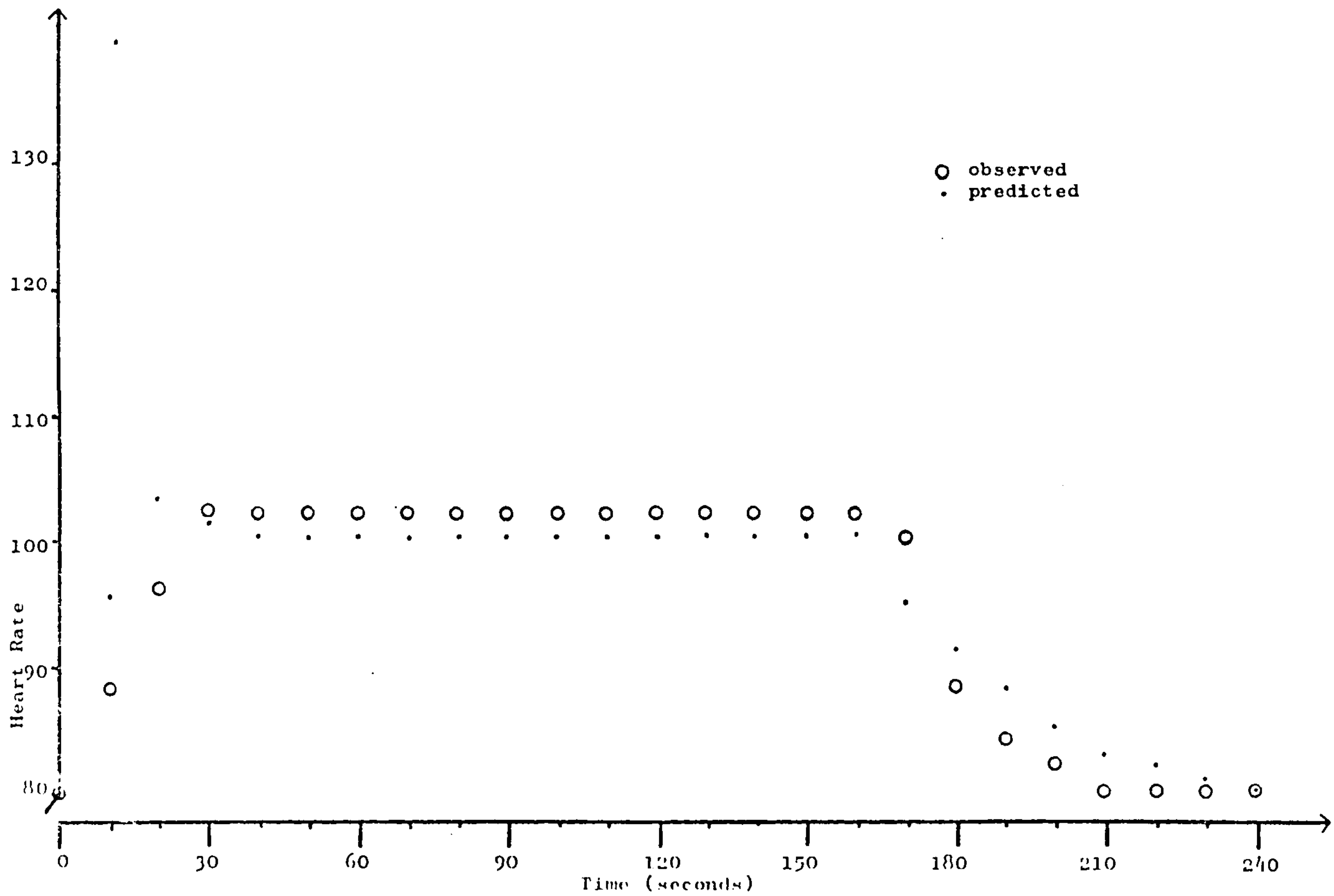

Figure 60. Plot of predicted and observed heart rate responses for Series 6-FS.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains conclusions which can be drawn from this study, recommendations for continued research, and a brief summary of this investigation.

Conclusions

The most apparent conclusion that can be drawn from this study is that by translating heart rate to percent of resting heart rate (%RHR), the heart rate patterns which represent the cardiac responses to a given work load will be approximately equivalent for all individuals of a given subject category. Based on this finding, it was then possible to develop work load versus steady state %RHR relationships for each of the four subject categories. A data bank of hard data patterns in terms of %RHR were accumulated through experimentation. By using the work load to steady state %RHR relationships and by drawing on the data bank of hard data patterns, a predictive model was developed which can depict an individual's cardiac response in %RHR to a series of varying work loads. The predicted responses in terms of %RHR are the same for any given subject category. However, the output in terms of heart rate is unique for each level of resting heart rate. In order for the predictive model to be useful, the only individual input variables required are sex, physical fitness and resting heart rate. It should be noted that the predictive model is computer dependent and requires a minimum of 8K memory; however, most industrial organizations have access to a computer of this size.

There are definite advantages in using %RHR as a physiological index. The only individual testing required is to determine an individual's resting heart rate. This is easily accomplished and requires no exercise. The use of %RHR provides a mechanism by which standards can be set for personnel selection and job evaluation by using actual and/or predicted heart rate response to exercise as criteria. Prior to the use of %RHR, the variation in heart rate between individuals made the use of heart rate as a comparative physiological variable difficult. By using %RHR as an index, the cardiac responses of persons of the same subject category can be compared directly and compared to preset standards (to be determined in subsequent studies).

In the analysis of variance of the empirically derived hard data patterns, the variability in heart rate responses caused by sex and/or by physical fitness had little statistical significance. However, plots of the hard data patterns by subject category indicated that certain trends were evident and that there may very well be a difference in the responses by sex and physical fitness. Statistical verification (reject null hypothesis that means are equal) of these trends would be expected by further data.

The previous predictive models of Schilpp, Suggs and Vogt were compared to the predictive model of this study. However, this writer had to refine the previous models before a comparison could be made. The range, magnitude, and direction of step change in work load which could be accommodated by the previous models were vastly limited. Also, none of the previous models made provisions for predicting the cardiac response to any series of step changes in work load. In a direct comparison of predicted results for series which could be predicted by the previous models, the results of the predictive model of this study were more accurate, for every series, than the predicted results of any of the previous models.

The responses obtained from the predictive model were compared to observed results for all subject categories. The findings indicated that the predictive model is accurate in predicting an individual's cardiac response to a series of fixed intensity tasks. The analysis also indicated that there was no accumulative error over time. When using the predictive model to predict heart rate response, 90 percent of the time the error (predicted minus observed) was no greater than 5 percent (for high heart rates) to 10 percent (for low heart rates) of the observed heart rate value.

Recommendations for Continued Studies

The concepts of using the steady state %RHR to work load relationships, predicting heart rate patterns directly from empirical data, and using %RHR as a transformation are in the infant stages of research at the conclusion of this study. There are a myriad of possibilities for extended research. The following discussion is what this author feels would be the logical approach to continued studies.

It is recommended that immediate research expand the scope of this study to include the whole of the adult working population. This could be accomplished in stages, with each stage addressing a different human variable. It is suggested that these variables be examined in the following order:

1. physical fitness
2. age
3. somatotype
4. weight
5. sex

There are, of course, other human variables which may affect heart rate response to exercise, but it is hypothesized by this writer that the above listed variables will be the dominant variables and override the effects of others.

There were two levels of physical fitness examined for this study. The author of this study interviewed more than 50 potential subjects in order to determine the level of physical fitness. During the interviews, it appeared that it would be possible to categorize subjects into five levels of physical fitness by simply relating their responses to standard questions to previously defined standards. It is suggested that research be conducted to determine the steady state %RHR to work load relationship for each of five categories of physical fitness. The results could then be used to expand the scope of the predictive model to include five levels of physical fitness. The inclusion of three more levels of physical fitness would serve to encompass the whole of the working population with regard to physical fitness and to refine the predicted results of the model. The results could also be used as a submaximal test for physical fitness.

It is believed by this author that the age variable has little effect on the cardiac response in %RHR to light exercise. If there is an effect, it is probably a gradual effect, and therefore could be examined for age groups within 10 year spans (e.g., 20-30, 30-40, etc., years of age). It may be possible to reduce the number of groups to two with each having a 20 year span, or, perhaps the age factor could be completely eliminated as being insignificant.

Only subjects which were predominantly mesophoric were examined for this study, and, consequently the results reflect cardiac responses for this somatotype. Technically, there could be as many as 343 (7x7x7) different somatotypes using the system presented in this study, but realistically there would probably be no more than 30. However, an examination including only the categories of endomorphic, mesomorphic and ectomorphic physiques would probably be sufficient. However, if it is found in subsequent studies that the somatotype variable is highly significant, then it is recommended that two more categories be included which represent a mixture of (1) endormorphic and mesomorphic, and (2) mesomorphic and ectomorphic.

The subjects of this study were restricted such that there was only a 15 pound deviation in weight for each category of sex. Further studies should include a greater range of weight classes. Fifteen pound intervals from 90 to 225 pounds would probably suffice. It is recommended that the weight factor be examined independent of sex in order to determine if sex can be eliminated as a variable. It is possible that the variation in heart rate caused by sex could be incorporated in the weight factor.

It is the contention of this author that prediction of cardiac response to exercise can be done with reasonable accuracy and that the results can be used in the industrial environment for personnel selection, job evaluation and classification and for many other uses. However, the practicability of such efforts would be severely limited if the classification schemes for each of the variables required extensive individual testing and observation. Therefore, it is recommended that future researchers who wish to conduct followup research be keenly aware of the necessity of simplification of the classification schemes.

Future testing which is intended to include a representative cross-section of the adult working population should be set up as a computer based operation. The real time feedback capabilities afforded by the use of computers would be immensely helpful in experiments of this kind. Also, and perhaps more importantly, data could be smoothed and collected in a machine readable format during the testing sessions. Although the initial set-up time may be considerable, the marginal cost per subject tested would decrease appreciably as the number of subjects tested increased; however, the cost of manual collection and reduction of data would remain the same per subject tested.

After studies have been completed to investigate human variables which encompass the entire population, it is then necessary to expand the research to include exercises for the upper limbs only and whole body. It is hypothesized by this author that there will be a well-defined relationship between the responses to the exercises of this study and the aforementioned exercises. By developing the relationship between these different types of exercises, the predictive model could be expanded to include jobs frequently found in an industrial environment.

The work loads examined during this study were light to moderate and within aerobic capacity. Further research could include work loads which require an anaerobic contribution. A study of this emphasis could incorporate an investigation of whole body fatigue as a variable in an attempt to quantify whole body fatigue using heart rate patterns.

Since heart rate is perhaps the physiological variable most easily measured dynamically, it is suggested that an empirical relationship be developed between heart rate and physiological cost of work. This relationship would be established for each subject category. Since the human variables which most affect the physiological cost of work will be incorporated directly or indirectly in a future predictive model, the cost of work patterns as well as heart rate patterns could be produced as output of the predictive model.

Summary

The purpose of this study was to investigate the feasibility of using hard data patterns, in terms of percent of resting heart rate, to predict an individual's cardiac response to series of fixed intensity tasks. A predictive model was developed and, allowing for a reasonable tolerance in the prediction of heart rate values, verified to be accurate. However, the predictive model accommodates only a segment of the adult working population. Since the logic and methodology of this investigation have been shown to be not only feasible, but effective, it is recommended that research be continued such that eventually the whole of the working population can be accommodated by the predictive model.

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APPENDIX 1

INSTRUCTIONS TO SUBJECTS

Phase I of Testing

You have been selected as a subject to participate in an experiment which is designed to supply data which will serve as the basis for a predictive model. Specifically, the data will be heart rate. Your heart rate will be recorded continuously on this strip chart recorder as you perform physical tasks of varying intensity on this bicycle ergometer.

Once the experimenter has placed the electrodes on you, please be seated in an upright position with both feet on the floor. There is reading material available if you wish to read. You will be seated for approximately twenty minutes.

Please mount the bicycle ergometer and place your hands on the grips. Assume this position each time the experimenter asks you to mount the bicycle ergometer. For practice and familiarization, pedal as if you would a regular bicycle until the speedometer needle is on the second green mark, which indicates a rate of fifty rpm. Maintain this rate for all exercises. Pedal until asked to stop. On the stop signal, be seated. There will be a five minute rest period between each exercise. You can cease exercising now.

Do you feel comfortable with the bicycle ergometer? (If the response is negative, the subject is allowed to exercise until he or she feels comfortable.) Please be seated (if the response is affirmative). Are there any questions?

Phase II of Testing

Welcome back to Phase II of testing. This experimental session will complete your involvement in this experiment. The procedures will be the same as Phase I of testing. There will be a twenty minute rest period prior to exercise, a familiarization with the bicycle ergometer, and then exercises, separated by a five minute rest period. Are there any questions?

Evaluation Phase

You have been selected as a subject to participate in an experiment which is designed to supply data which will serve to evaluate the validity of a predictive model. Specifically the data will be heart rate. Your heart rate will be recorded continuously on this strip chart recorder as you perform a series of physical tasks of varying intensity on this bicycle ergometer.

Once the experimenter has placed the electrodes on you, please be seated in an upright position with both feet on the floor. There is reading material available if you wish to read. You will be seated for approximately twenty minutes.

Please mount the bicycle ergometer and place your hands on the grips. Assume this position each time the experimenter asks you to mount the bicycle ergometer. For practice and familiarization, pedal as you would a regular bicycle until the speedometer needle is on the second green mark, which indicates a rate of fifty cycles/minute. Maintain this rate for all exercises. Pedal until asked to stop, at which time, simply stop pedaling and remain in position on the bicycle ergometer. Begin pedaling when the experimenter signals begin. Be seated when the experimenter signals to stop and be seated. You can cease exercising now. Do you feel comfortable with the bicycle ergometer? (If the response is negative, the subject is allowed to exercise until he or she feels comfortable.) Please be seated (if the response is affirmative). There will be a fifteen minute rest period between each of six series of exercises. Are there any questions?

APPENDIX 2

SUBJECT SUMMARY

Number	Coded Classification	Physical Fitness	Sex	Age (Years)	Height	Weight (lbs)	Somatotype	Average Daily Exercise (Minutes)
1	MG1	G	M	23	5'11"	155	2-5-2	180
2	MG2	G	M	20	5'9"	150	3-5-2	180
3	MS1	S	M	24	5'11"	145	2-4-3	0
4	MS2	S	M	20	5'11"	145	2-4-3	0
5	FG1	G	F	23	5'2"	108	2-5-2	80
6	FG2	G	F	25	5'2"	120	3-5-2	120
7	FS1	S	F	26	5'4"	110	2-5-3	5
8	FS2	S	F	23	5'5"	112	2-5-3	5
9	MG3	G	M	25	5'11"	155	2-5-2	90
10	MS3	S	M	30	5'9"	155	3-4-2	0
11	FG3	G	F	26	5'4"	110	3-5-2	60
12	FS3	S	F	23	5'5"	110	2-5-2	0

Phase I, and II, Subjects 1-8
Validation Testing--Subjects 9-12

Table of Subject Data.

Subject Exercise History Two Months Prior to Testing

MG1--was an all-around gymnast who actively participated in international competition. He trained seven days/week.

MG2--was an all-around gymnast who actively participated in intercollegiate competition. He trained seven days/week.

MS1--rode a bicycle short distances a few times each month.

MS2--engaged in no muscular activity other than walking short distances.

FG1--ran at least one mile/day and exercised while teaching tennis classes.

FG2--ran at least two miles/day and exercised while teaching body mechanics classes.

FS1--engaged in very light sporadic muscular exercise several times/month.

FS2--rode a bicycle short distances a few times each month.

MG3--was a sub-four minute miler who actively participated in international competition. He trained seven days/week.

MS3--engaged in no muscular activity other than walking short distances.

FG3--exercised intensively four days/week and engaged in light exercise three days/week.

FS3--engaged in no muscular exercise other than walking short distances.

APPENDIX 3

HARD DATA

This section contains the data points for all hard data patterns used in the predictive model. The patterns are presented by task and then by subject category.

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	100	100	100	100
10	100	100	100	100
20	100	100	100	100
30	100	100	100	100
40	100	100	100	100
50	100	100	100	100
60	100	100	100	100
70	100	100	100	100
80	100	100	100	100
90	100	100	100	100
100	100	100	100	100
110	100	100	100	100
120	100	100	100	100
130	100	100	100	100
140	100	100	100	100
150	100	100	100	100
160	100	100	100	100
170	100	100	100	100

Hard Data--Task A1

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	100	100	100	100
10	[illegible]	114	110	[illegible]
20	115	117	[illegible]	112
30	118	120	120	115
40	120	120	120	118
50	120	120	120	120
60	120	120	120	120
70	120	120	120	120
80	120	120	120	120
90	120	120	120	120
100	120	120	120	120
110	120	120	120	120
120	120	120	120	120
130	120	120	120	120
140	120	120	120	120
150	120	120	120	120
160	120	120	120	120
170	120	120	120	120

Hard Data--Task A2

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	100	100	100	100
10	120	113	118	112
20	140	123	127	118
30	140	132	134	125
40	140	138	138	130
50	140	140	140	136
60	140	140	140	138
70	140	140	140	140
80	140	140	140	140
90	140	140	140	140
100	140	140	140	140
110	140	140	140	140
120	140	140	140	140
130	140	140	140	140
140	140	140	140	140
150	140	140	140	140
160	140	140	140	140
170	140	140	140	140

Hard Data--Task A3

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	100	100	100	100
10	120	115	121	119
20	140	127	136	132
30	151	133	148	143
40	158	138	154	154
50	160	143	158	160
60	160	151	160	160
70	160	155	160	160
80	160	160	160	160
90	160	160	160	150
100	160	160	160	160
110	160	160	160	160
120	160	160	160	160
130	160	160	160	160
140	160	160	160	160
150	160	160	160	160
160	160	160	160	160
170	160	160	160	160

Hard Data--Task A4

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	120	120	120	120
10	115	114	119	113
20	111	105	111	[illegible]
30	108	100	104	104
40	105	100	100	102
50	103	100	100	101
60	101	100	100	100
70	100	100	100	100
80	100	100	100	100
90	100	100	100	100
100	100	100	100	100
110	100	100	100	100
120	100	100	100	100
130	100	100	100	100
140	100	100	100	100
150	100	100	100	100
160	100	100	100	100
170	100	100	100	100

Hard Data--Task B1

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	120	[illegible]	[illegible]	[illegible]
10	120	120	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]
30	120	120	120	120
40	120	120	120	120
50	120	120	120	120
60	120	120	120	120
70	120	120	[illegible]	[illegible]
80	120	[illegible]	[illegible]	[illegible]
90	120	120	120	120
100	120	120	120	120
110	120	120	120	120
120	120	[illegible]	120	[illegible]
130	120	120	[illegible]	[illegible]
140	120	120	120	120
150	120	120	120	120
160	120	120	120	120
170	120	120	120	120

Hard Data--Task B2

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	120	120	120	120
10	125	128	131	132
20	130	134	140	137
30	135	138	140	140
40	140	140	140	140
50	140	140	140	140
60	140	140	140	140
70	140	140	140	140
80	140	140	140	140
90	140	140	140	140
100	140	140	140	140
110	140	140	140	140
120	140	140	140	140
130	140	140	140	140
140	140	140	140	140
150	140	140	140	140
160	140	140	140	140
170	140	140	140	140

Hard Data--Task B3

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	120	[illegible]	[illegible]	[illegible]
10	135	120	131	[illegible]
20	147	134	139	144
30	155	140	147	151
40	160	144	155	[illegible]
50	160	152	160	[illegible]
60	160	[illegible]	160	[illegible]
70	[illegible]	[illegible]	160	[illegible]
80	160	160	[illegible]	[illegible]
90	150	[illegible]	[illegible]	[illegible]
100	160	160	160	[illegible]
110	160	160	160	160
120	160	[illegible]	[illegible]	[illegible]
130	160	160	[illegible]	[illegible]
140	160	160	[illegible]	[illegible]
150	160	160	160	[illegible]
160	160	160	160	160
170	160	160	160	160

Hard Data--Task B4

TIME	MALE		FEMALE	
	GOOD	SEDENTARY	GOOD	SEDENTARY
0	140	140	140	140
10	137	133	133	137
20	124	127	113	133
30	117	124	105	127
40	113	117	102	121
50	108	112	101	114
60	104	107	100	109
70	102	105	10[illegible]	105
80	100	103	100	103
90	100	100	100	100
100	100	100	100	100
110	100	100	100	100
120	100	100	100	100
130	100	100	100	100
140	100	100	100	100
150	100	100	100	100
160	100	100	100	100
170	100	100	100	100

Hard Data--Task C1

TIME	MALE		FEMALE	
	GOOD	SEDENTARY	GOOD	SEDENTARY
0	140	14[illegible]	14[illegible]	14[illegible]
10	1[illegible]	137	[illegible]	1[illegible]
20	132	134	1[illegible]	1[illegible]
30	128	131	126	12[illegible]
40	125	12[illegible]	122	124
50	122	124	120	120
60	120	121	120	120
70	120	120	120	120
80	120	120	120	120
90	120	120	120	120
100	120	120	120	120
110	120	120	120	120
120	120	120	120	120
130	120	120	120	120
140	120	120	120	120
150	120	120	120	120
160	120	120	120	120
170	120	120	120	120

Hard Data--Task C2

TIME	MALE		FEMALE	
	GOOD	SEDENTARY	GOOD	SEDENTARY
0	140	140	140	140
10	140	140	140	140
20	140	140	140	140
30	140	140	140	140
40	140	140	140	140
50	140	140	140	140
60	140	140	140	140
70	140	140	140	140
80	140	140	140	140
90	140	140	140	140
100	140	140	140	140
110	140	140	140	140
120	140	140	140	140
130	140	140	140	140
140	140	140	140	140
150	140	140	140	140
160	140	140	140	140
170	140	140	140	140

Hard Data--Task C3

TIME	MALE		FEMALE	
	GOOD	SEDENTARY	GOOD	SEDENTARY
0	140	140	140	140
10	147	146	149	152
20	154	15[illegible]	156	157
30	160	155	160	160
40	160	158	160	160
50	160	160	160	160
60	160	160	160	160
70	160	160	160	160
80	160	160	160	160
90	160	160	160	160
100	160	160	160	160
110	160	160	160	160
120	160	160	160	160
130	160	160	160	160
140	160	160	160	160
150	160	160	160	160
160	160	160	160	160
170	160	160	160	160

Hard Data--Task C4

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	160	160	160	160
10	145	148	150	152
20	135	130	134	140
30	123	126	132	132
40	115	119	122	123
50	110	115	112	114
60	105	111	102	107
70	102	108	100	105
80	100	107	100	102
90	100	105	100	100
100	100	103	100	100
110	100	100	100	100
120	100	100	100	100
130	100	100	100	100
140	100	100	100	100
150	100	100	100	100
160	100	100	100	100
170	100	100	100	100

Hard Data--Task D1

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	160	[illegible]	[illegible]	[illegible]
10	150	[illegible]	150	[illegible]
20	145	[illegible]	145	[illegible]
30	140	144	138	15[illegible]
40	135	141	132	144
50	129	139	127	137
60	124	136	124	13[illegible]
70	123	134	122	12[illegible]
80	122	132	121	127
90	121	130	120	125
100	120	128	120	123
110	120	126	120	121
120	120	124	120	12[illegible]
130	120	122	120	120
140	120	120	120	120
150	120	120	120	120
160	120	120	120	120
170	120	120	120	120

Hard Data--Task D2

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	160	160	160	160
10	155	154	154	158
20	150	151	149	156
30	144	148	145	154
40	141	146	142	152
50	140	144	141	150
60	140	143	140	148
70	140	142	140	147
80	140	140	140	146
90	140	140	140	144
100	140	140	140	142
110	140	140	140	140
120	140	140	140	140
130	140	140	140	140
140	140	140	140	140
150	140	140	140	140
160	140	140	140	140
170	140	140	140	140

Hard Data--Task D3

TIME	MALE GOOD	MALE SEDENTARY	FEMALE GOOD	FEMALE SEDENTARY
0	160	160	160	160
10	160	160	160	160
20	170	160	160	160
30	160	160	160	160
40	160	160	160	160
50	160	160	160	160
60	160	160	160	160
70	160	160	160	160
80	160	160	160	160
90	160	160	160	160
100	160	160	160	160
110	160	160	160	160
120	160	160	160	160
130	160	160	160	160
140	160	160	160	160
150	160	160	160	160
160	160	160	160	160
170	160	160	160	160

Hard Data--Task D4

APPENDIX 4

ANALYSIS OF VARIANCE TABLES FOR ANALYSIS OF HARD DATA PATTERNS

The following twelve analysis of variance tables are for analysis of the data collected for the twelve hard data patterns. They are presented by the two character codes where the first character is alpha and refers to the initial value, and the second character is numeric and refers to the steady state value. A, B, C, and D are initial values of 100, 120, 140, and 160 %RHR, respectively. Digits 1, 2, 3, and 4 are steady state values of 100, 120, 140, and 160 %RHR, respectively. The sources of variation are numbered and refer to the following main effects or interactions:

1 mean
2 sex (S)
3 physical fitness (P)
4 time (T)
5 SP
6 ST
7 PT
8 subjects (V)
9 SPT
10 VT
11 error.

The indices i, j, k, l, and m are the same as those presented in the mathematical model in Chapter IV. A symbol to the left of the numbered source of variation indicates the level of significance, if any. The symbols are as follows:

○ = .10 level

□ = .05 level

△ = .01 level

TASK A2

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	1931173.	1	1931173.	144.000(1)	18.000(8)
2 J	I(JK)	0.2508	16.00000	1	16.00000	72.000(2)	18.000(8)
3 K	I(JK)	0.1114	7.111111	1	7.111111	72.000(3)	18.000(8)
△4 L	IL(JK)	55.3184	5929.285	8	741.1606	16.000(4)	2.000(10)
5 JK	I(JK)	1.7832	113.7778	1	113.7778	36.000(5)	18.000(8)
6 JL	IL(JK)	0.2754	29.51563	8	3.689453	8.000(6)	2.000(10)
7 KL	IL(JK)	0.2836	30.40234	8	3.800293	8.000(7)	2.000(10)
8 I(JK)			255.2220	4	63.80550	18.000(8)	
9 JKL	IL(JK)	1.3475	144.4332	8	18.05414	4.000(9)	2.000(10)
10 IL(JK)			428.7365	32	13.39808	2.000(10)	
11 M(IJKL)			233.3125	72	3.247396	1.000(11)	

TASK A3

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2426325.	1	2426325.	144.000(1)	18.000(8)
□2 J	I(JK)	19.0637	220.0278	1	220.0278	72.000(2)	18.000(8)
△3 K	I(JK)	44.5149	513.7776	1	513.7776	72.000(3)	18.000(8)
△4 L	IL(JK)	323.9789	24651.28	8	3081.410	16.000(4)	2.000(10)
5 JK	I(JK)	0.5415	6.250000	1	6.250000	36.000(5)	18.000(8)
□6 JL	IL(JK)	2.9422	223.9375	8	27.99219	8.000(6)	2.000(10)
△7 KL	IL(JK)	7.1630	545.1953	8	68.14941	8.000(7)	2.000(10)
8 I(JK)			46.16675	4	11.54169	18.000(8)	
9 JKL	IL(JK)	0.9383	71.41406	8	8.926758	4.000(9)	2.000(10)
10 IL(JK)			304.4504	32	9.514076	2.000(10)	
11 M(IJKL)			971.5703	72	13.49403	1.000(11)	

TASK A4

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2926949.	1	2926949.	144.000(1)	18.000(8)
2 J	I(JK)	3.9178	173.3611	1	173.3611	72.000(2)	18.000(8)
△3 K	I(JK)	23.3829	1034.694	1	1034.694	72.000(3)	18.000(8)
△4 L	IL(JK)	716.3533	55142.41	8	6892.801	16.000(4)	2.000(10)
□5 JK	I(JK)	15.4733	684.6943	1	684.6943	36.000(5)	18.000(8)
○6 JL	IL(JK)	4.8708	374.9375	8	46.86719	8.000(6)	2.000(10)
○7 KL	IL(JK)	8.5202	655.8555	8	81.98193	8.000(7)	2.000(10)
8 I(JK)			177.0000	4	44.25000	18.000(8)	
△9 JKL	IL(JK)	5.7247	440.6689	8	55.08362	4.000(9)	2.000(10)
10 IL(JK)			307.9063	32	9.622070	2.000(10)	
11 M(IJKL)			1099.238	72	15.26720	1.000(11)	

TASK B1

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	1607612.	1	1607612.	144.000(1)	18.000(8)
2 J	I(JK)	0.0009	.6250000E-01	1	.6250000E-01	72.000(2)	18.000(8)
3 K	I(JK)	1.4321	95.06250	1	95.06250	72.000(3)	18.000(8)
△ 4 L	IL(JK)	77.1014	7049.125	8	881.1406	16.000(4)	2.000(10)
5 JK	I(JK)	0.6203	41.17360	1	41.17360	36.000(5)	18.000(8)
6 JL	IL(JK)	0.2981	27.25781	8	3.407227	8.000(6)	2.000(10)
7 KL	IL(JK)	1.2005	109.7578	8	13.71973	8.000(7)	2.000(10)
8 I(JK)			265.5273	4	66.38184	18.000(8)	
9 JKL	IL(JK)	1.0623	97.11937	8	12.13992	4.000(9)	2.000(10)
10 IL(JK)			365.7068	32	11.42834	2.000(10)	
11 M(IJKL)			359.2188	72	4.989149	1.000(11)	

TASK B3

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2659344.	1	2659344.	144.000(1)	18.000(8)
2 J	I(JK)	2.2872	95.06250	1	95.06250	72.000(2)	18.000(8)
3 K	I(JK)	0.1044	4.340278	1	4.340278	72.000(3)	18.000(8)
△ 4 L	IL(JK)	50.2343	6172.494	8	771.5605	16.000(4)	2.000(10)
5 JK	I(JK)	0.2047	8.506936	1	8.506936	36.000(5)	18.000(8)
6 JL	IL(JK)	1.5443	189.7578	8	23.71973	8.000(6)	2.000(10)
7 KL	IL(JK)	0.3070	37.72656	8	4.715820	8.000(7)	2.000(10)
8 I(JK)			166.2499	4	41.56248	18.000(8)	
9 JKL	IL(JK)	0.2302	28.28604	8	3.535755	4.000(9)	2.000(10)
10 IL(JK)			491.4958	32	15.35925	2.000(10)	
11 M(IJKL)			115.2344	72	1.600477	1.000(11)	

TASK B4

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	3163358.	1	3163358.	144.000(1)	18.000(8)
2 J	I(JK)	0.4475	31.17360	1	31.17360	72.000(2)	18.000(8)
3 K	I(JK)	3.4119	237.6736	1	237.6736	72.000(3)	18.000(8)
△ 4 L	IL(JK)	252.2026	25926.25	8	3240.782	16.000(4)	2.000(10)
□ 5 JK	I(JK)	8.6756	604.3398	1	604.3398	36.000(5)	18.000(8)
6 JL	IL(JK)	0.6877	70.69531	8	8.836914	8.000(6)	2.000(10)
7 KL	IL(JK)	2.3853	245.2031	8	30.65039	8.000(7)	2.000(10)
8 I(JK)			278.6387	4	69.65967	18.000(8)	
△ 9 JKL	IL(JK)	5.7741	593.5781	8	74.19727	4.000(9)	2.000(10)
10 IL(JK)			411.1973	32	12.84991	2.000(10)	
11 M(IJKL)			1029.078	72	14.29275	1.000(11)	

TASK C1

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	1953704.	1	1953704.	144.000(1)	18.000(8)
2 J	I(JK)	0.3545	73.67360	1	73.67360	72.000(2)	18.000(8)
3 K	I(JK)	7.5392	1566.840	1	1566.840	72.000(3)	18.000(8)
4 L	IL(JK)	220.5566	24537.73	8	3067.216	16.000(4)	2.000(10)
5 JK	I(JK)	2.3821	495.0623	1	495.0623	36.000(5)	18.000(8)
6 JL	IL(JK)	1.8145	201.8672	8	25.23340	8.000(6)	2.000(10)
7 KL	IL(JK)	5.7701	641.9414	8	80.24268	8.000(7)	2.000(10)
8 I(JK)			831.3057	4	207.8264	18.000(8)	
9 JKL	IL(JK)	3.6578	406.9417	8	50.86771	4.000(9)	2.000(10)
10 IL(JK)			445.0146	32	13.90671	2.000(10)	
11 M(IJKL)			2979.039	72	41.37553	1.000(11)	

TASK C2

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2321050.	1	2321050.	144.000(1)	18.000(8)
2 J	I(JK)	0.9769	93.44444	1	93.4444	72.000(2)	18.000(8)
3 K	I(JK)	0.2614	25.00000	1	25.00000	72.000(3)	18.000(8)
4 L	IL(JK)	70.8869	6891.234	8	861.4043	16.000(4)	2.000(10)
5 JK	I(JK)	0.0003	.2777100E-01	1	.2777100E-01	36.000(5)	18.000(8)
6 JL	IL(JK)	0.8827	85.81250	8	10.72656	8.000(6)	2.000(10)
7 KL	IL(JK)	0.3807	37.00781	8	4.625977	8.000(7)	2.000(10)
8 I(JK)			382.6108	4	95.65271	18.000(8)	
9 JKL	IL(JK)	0.2953	28.70270	8	3.587837	4.000(9)	2.000(10)
10 IL(JK)			388.8577	32	12.15180	2.000(10)	
11 M(IJKL)			516.7656	72	7.177299	1.000(11)	

TASK C4

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	3488488.	1	3488488.	144.000(1)	18.000(3)
2 J	I(JK)	6.6719	68.06250	1	68.06250	72.000(2)	18.000(8)
3 K	I(JK)	0.9319	9.506944	1	9.506944	72.000(3)	18.000(8)
4 L	IL(JK)	154.1738	6337.352	8	792.1689	16.000(4)	2.000(10)
5 JK	I(JK)	3.2410	33.06248	1	33.06248	36.000(5)	18.000(8)
6 JL	IL(JK)	2.6857	110.3945	8	13.79932	8.000(6)	2.000(10)
7 KL	IL(JK)	0.8137	33.04922	8	4.131152	8.000(7)	2.000(10)
8 I(JK)			40.80556	4	10.20139	18.000(8)	
9 JKL	IL(JK)	1.1272	46.33205	8	5.791506	4.000(9)	2.000(10)
10 IL(JK)			164.4210	32	5.138156	2.000(10)	
11 M(IJKL)			533.2690	72	7.406514	1.000(11)	

TASK D1

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2198053.	1	2198053.	144.000(1)	18.000(8)
2 J	I(JK)	0.0345	18.06250	1	18.06250	72.000(2)	18.000(8)
3 K	I(JK)	1.8856	987.0068	1	987.0068	72.000(3)	18.000(8)
4 L	IL(JK)	195.7422	56941.45	8	7117.680	16.000(4)	2.000(10)
5 JK	I(JK)	0.1300	68.06250	1	68.06250	36.000(5)	18.000(8)
6 JL	IL(JK)	0.8291	241.1836	8	30.14795	8.000(6)	2.000(10)
7 KL	IL(JK)	1.0450	303.9961	8	37.99951	8.000(7)	2.000(10)
8 I(JK)			2093.806	4	523.4514	18.000(8)	
9 JKL	IL(JK)	0.5206	151.4570	8	18.93213	4.000(9)	2.000(10)
10 IL(JK)			1163.601	32	36.36252	2.000(10)	
11 M(IJKL)			2382.492	72	33.09016	1.000(11)	

TASK D2

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	2806462.	1	2806462.	144.000(1)	18.000(8)
2 J	I(JK)	0.0069	5.840278	1	5.840278	72.000(2)	18.000(8)
3 K	I(JK)	2.1988	1856.174	1	1856.174	72.000(3)	18.000(8)
4 L	IL(JK)	62.2140	19163.48	8	2395.435	16.000(4)	2.000(10)
5 JK	I(JK)	0.0513	43.34009	1	43.34009	36.000(5)	18.000(8)
6 JL	IL(JK)	0.7181	221.2070	8	27.65088	8.000(6)	2.000(10)
7 KL	IL(JK)	1.0279	316.6172	8	39.57715	8.000(7)	2.000(10)
8 I(JK)			3376.686	4	844.1714	18.000(8)	
9 JKL	IL(JK)	0.8032	247.4138	8	30.92673	4.000(9)	2.000(10)
10 IL(JK)			1232.100	32	38.50311	2.000(10)	
11 M(IJKL)			1681.125	72	23.34895	1.000(11)	

TASK D3

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	I(JK)	********	3152103.	1	3152103.	144.000(1)	18.000(8)
2 J	I(JK)	0.9665	264.0625	1	264.0625	72.000(2)	18.000(8)
3 K	I(JK)	2.8525	779.3401	1	779.3401	72.000(3)	18.000(8)
4 L	IL(JK)	57.1145	5145.465	8	643.1831	16.000(4)	2.000(10)
5 JK	I(JK)	0.9468	258.6736	1	258.6736	36.000(5)	18.000(8)
6 JL	IL(JK)	0.6522	58.75391	8	7.344238	8.000(6)	2.000(10)
7 KL	IL(JK)	2.6081	234.9688	8	29.37109	8.000(7)	2.000(10)
8 I(JK)			1092.861	4	273.2153	18.000(8)	
9 JKL	IL(JK)	0.3954	35.61938	8	4.452423	4.000(9)	2.000(10)
10 IL(JK)			360.3613	32	11.26129	2.000(10)	
11 M(IJKL)			220.2422	72	3.058919	1.000(11)	

APPENDIX 5

ERROR DATA

This section presents the validation data in terms of beats/minute error (predicted minus observed) at 10, 20, 30, . . . 240 seconds for each of the six series of exercises performed by a subject in each of the four subject categories. The data are presented by subject category. The large script numbers (1-6) are series. The small script numbers are time in seconds.

Time (seconds)

Time (seconds)	1	2	3	4	5	6
10	-3.00000	-1.00000	-7.00000	0.0	0.0	-2.00000
	-4.00000	-3.00000	-9.00000	-1.00000	0.0	-6.00000
	-4.00000	-4.00000	-2.00000	4.00000	0.0	-4.00000
	-4.00000	-6.00000	3.00000	5.00000	0.0	-2.00000
	-2.00000	-5.00000	4.00000	10.00000	0.0	-1.00000
60	-1.00000	-3.00000	4.00000	10.00000	0.0	0.0
	-1.00000	-2.00000	4.00000	8.00000	0.0	0.0
	-1.00000	-2.00000	4.00000	5.00000	0.0	0.0
	-3.00000	-2.00000	4.00000	2.00000	0.0	0.0
	-3.00000	-2.00000	4.00000	1.00000	0.0	0.0
	-1.00000	-2.00000	7.00000	0.0	-4.00000	0.0
120	0.0	-2.00000	6.00000	0.0	-6.00000	0.0
	0.0	-2.00000	12.00000	0.0	-3.00000	0.0
	0.0	3.00000	11.00000	0.0	-2.00000	0.0
	0.0	5.00000	5.00000	-6.00000	-1.00000	0.0
	0.0	4.00000	6.00000	-3.00000	-1.00000	0.0
	0.0	3.00000	3.00000	-2.00000	-1.00000	1.00000
180	16.00000	3.00000	1.00000	-1.00000	-1.00000	2.00000
	12.00000	3.00000	0.0	-1.00000	-1.00000	4.00000
	8.00000	3.00000	0.0	-1.00000	-1.00000	4.00000
	3.00000	3.00000	0.0	-1.00000	-1.00000	2.00000
	1.00000	3.00000	0.0	-1.00000	-1.00000	1.00000
	0.0	3.00000	0.0	-1.00000	-1.00000	0.0
240	0.0	3.00000	0.0	-1.00000	-1.00000	0.0

Male of Good Physical Fitness.

Time (seconds)	1	2	3	4	5	6
10	3.00000	-3.00000	2.00000	-2.00000	-0.0	2.00000
	0.0	-4.00000	0.0	-1.00000	-0.0	2.00000
	1.00000	-3.00000	-1.00000	-0.0	-0.0	-0.0
	-2.00000	-1.00000	-5.00000	-3.00000	-0.0	-4.00000
	-1.00000	-2.00000	-7.00000	-6.00000	-0.0	-4.00000
60	-1.00000	-1.00000	-5.00000	-7.00000	-0.0	-4.00000
	-1.00000	0.0	-3.00000	-9.00000	-0.0	-4.00000
	-1.00000	-0.0	-2.00000	-4.00000	-0.0	-4.00000
	-2.00000	-0.0	-2.00000	-3.00000	-0.0	-4.00000
	-2.00000	-0.0	-2.00000	-2.00000	-0.0	-4.00000
	-3.00000	-0.0	-2.00000	-1.00000	1.00000	-4.00000
120	-2.00000	-0.0	-0.0	-0.0	-0.0	-4.00000
	-2.00000	-2.00000	-5.00000	-0.0	1.00000	-4.00000
	-2.00000	-2.00000	-12.00000	-0.0	-0.0	-4.00000
	-2.00000	-3.00000	-15.00000	-0.0	-2.00000	-4.00000
	-5.00000	-2.00000	-15.00000	-5.00000	-2.00000	-4.00000
	-3.00000	-2.00000	-15.00000	-3.00000	-2.00000	-9.00000
180	0.0	-3.00000	-13.00000	-3.00000	-2.00000	-15.00000
	1.00000	-3.00000	-11.00000	-3.00000	-2.00000	-11.00000
	0.0	-3.00000	-9.00000	-3.00000	-2.00000	-9.00000
	2.00000	-3.00000	-7.00000	-3.00000	-2.00000	2.00000
	3.00000	-3.00000	-4.00000	-3.00000	-2.00000	1.00000
	2.00000	-3.00000	-3.00000	-3.00000	-2.00000	1.00000
240	1.00000	-3.00000	-2.00000	-3.00000	-5.00000	1.00000

Sedentary Male.

Time (seconds)

Time	1	3	5
10	4.00000	-3.00000	-0.0
	-0.0	-5.00000	-0.0
	-2.00000	-8.00000	-0.0
	-3.00000	-6.00000	-0.0
	-3.00000	-2.00000	-0.0
60	-3.00000	-0.0	-0.0
	-3.00000	-0.0	-0.0
	-2.00000	-0.0	-0.0
	-0.0	-0.0	-0.0
	-2.00000	-0.0	-0.0
	-1.00000	-0.0	-3.00000
120	-4.00000	-2.00000	-1.00000
	-4.00000	-8.00000	-3.00000
	-4.00000	-0.0	-3.00000
	-4.00000	4.00000	-3.00000
	-4.00000	5.00000	-3.00000
	-2.00000	1.00000	-3.00000
180	-4.00000	-0.0	-3.00000
	-3.00000	-0.0	-3.00000
	-1.00000	-0.0	-3.00000
	-0.0	-0.0	-3.00000
	-4.00000	-0.0	-3.00000
	-0.0	-0.0	-3.00000
240	-0.0	-0.0	-4.00000

Time	2	4	6
10	-2.00000	-0.0	-0.0
	1.00000	-1.00000	-0.0
	-0.0	-1.00000	-2.00000
	-0.0	8.00000	-4.00000
	-3.00000	-1.00000	-4.00000
60	-3.00000	-3.00000	-4.00000
	-3.00000	-3.00000	-4.00000
	-3.00000	1.00000	-4.00000
	-3.00000	-0.0	-4.00000
	-3.00000	-0.0	-4.00000
	-3.00000	-0.0	-4.00000
120	-3.00000	-0.0	-4.00000
	-3.00000	-0.0	-4.00000
	-4.00000	-0.0	-4.00000
	-5.00000	-4.00000	-4.00000
	-5.00000	-3.00000	-4.00000
	-4.00000	-2.00000	-2.00000
180	-3.00000	-2.00000	-0.0
	-3.00000	-2.00000	1.00000
	-3.00000	-2.00000	-0.0
	-3.00000	-2.00000	-0.0
	-3.00000	-2.00000	-0.0
	-3.00000	-2.00000	-0.0
240	-3.00000	-2.00000	-0.0

Female of Good Physical Fitness.

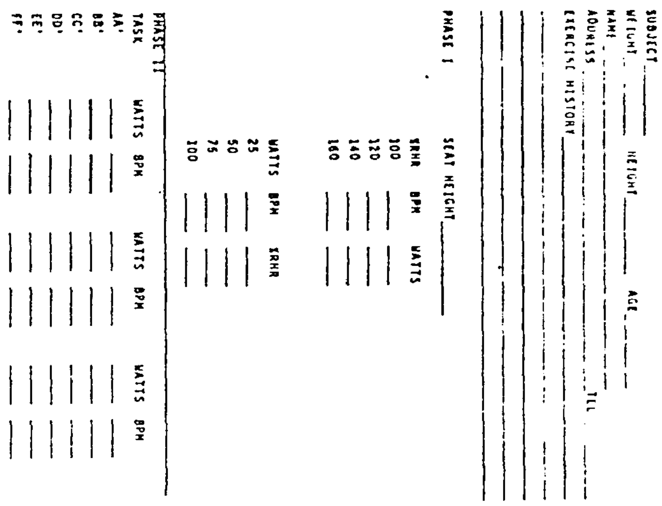
Time	1	3	5
10	5.00000	7.00000	-0.0
	4.00000	12.00000	-0.0
	5.00000	13.00000	-0.0
	2.00000	13.00000	-0.0
	0.0	12.00000	-0.0
60	0.0	5.00000	-0.0
	0.0	-0.0	-0.0
	3.00000	-0.0	-0.0
	5.00000	-0.0	-0.0
	5.00000	-0.0	-0.0
	4.00000	1.00000	-4.00000
120	3.00000	-0.0	-2.00000
	1.00000	-3.00000	-2.00000
	1.00000	-3.00000	-3.00000
	1.00000	6.00000	-4.00000
	-2.00000	6.00000	-3.00000
	-7.00000	7.00000	-3.00000
180	-7.00000	4.00000	-3.00000
	-1.00000	1.00000	-3.00000
	1.00000	-0.0	-3.00000
	-0.0	-0.0	-3.00000
	-0.0	-0.0	-3.00000
	-0.0	-0.0	-3.00000
240	-0.0	-0.0	-7.00000

Time	2	4	6
10	-5.00000	2.00000	7.00000
	-3.00000	4.00000	7.00000
	-2.00000	2.00000	-1.00000
	-4.00000	-2.00000	-2.00000
	6.00000	-4.00000	-2.00000
60	7.00000	-6.00000	-2.00000
	7.00000	-3.00000	-2.00000
	6.00000	-8.00000	-2.00000
	5.00000	-5.00000	-2.00000
	-0.0	-9.00000	-2.00000
	-0.0	-7.00000	-2.00000
120	-0.0	-7.00000	-2.00000
	-0.0	-6.00000	-2.00000
	-2.00000	-3.00000	-2.00000
	-2.00000	-1.00000	-2.00000
	-2.00000	1.00000	-2.00000
	-0.0	0.0	-5.00000
180	1.00000	-3.00000	3.00000
	1.00000	-1.00000	4.00000
	1.00000	-1.00000	3.00000
	1.00000	-1.00000	3.00000
	1.00000	-1.00000	2.00000
	1.00000	-1.00000	1.00000
240	1.00000	-1.00000	1.00000

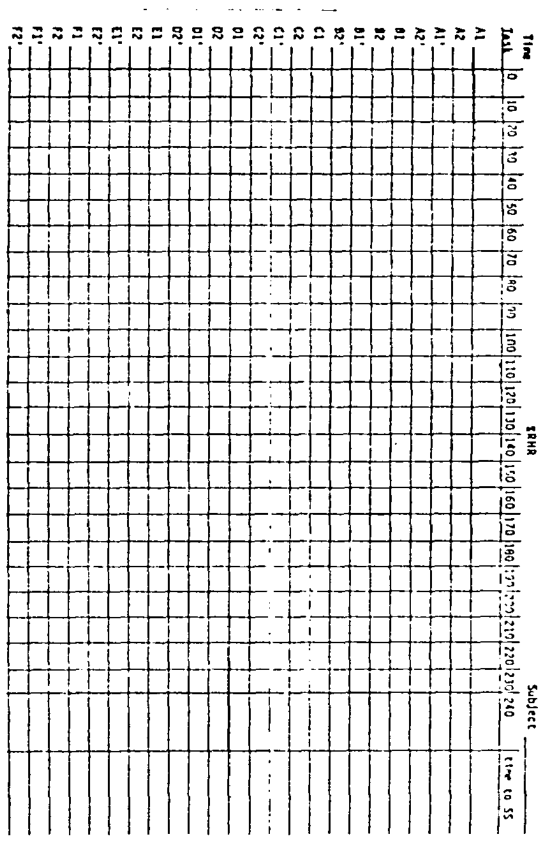
Sedentary Female.

APPENDIX 6

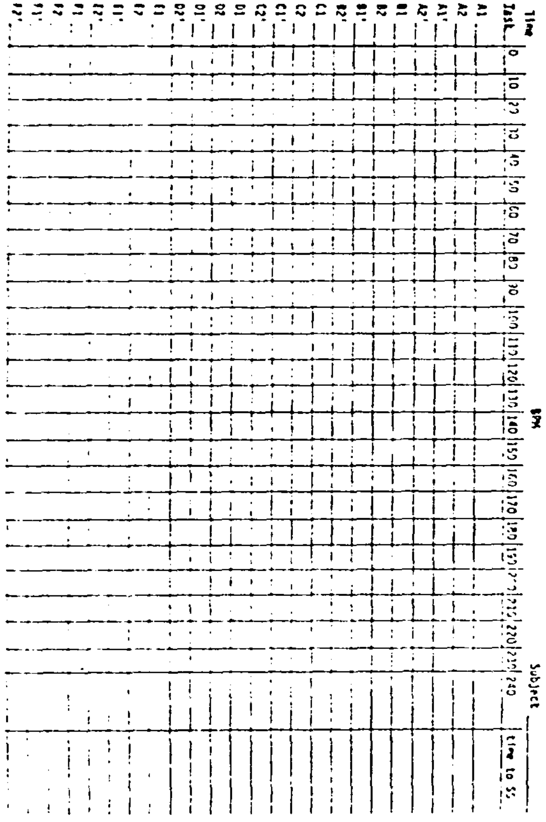
DATA COLLECTION FORMS



Form 1



Form 2



Form 3

APPENDIX 7

OUTPUT OF PREDICTIVE MODEL FOR VALIDATION

This section presents the actual predicted output of the predictive model for the series used in the validation testing. The results are presented for each series of tasks. The computer output shows the subject category, resting heart rate, power output, elapsed time, mean heart rate, and percent of resting heart rate. The observed heart rate values (in beats/minute) were typed in separately. The series number (1-6) and subject category are presented at the bottom of each series presentation. Male of good physical fitness is MG. Sedentary male is MS. Female of good physical fitness is FG. Sedentary female is FS.

*************************CARDIAC RESPONSE FOR*************************
MALE
GOOD PHYSICAL FITNESS
RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
50	0	58	100	58
50	10	66	113	69
50	20	69	120	73
50	30	72	125	76
50	40	74	128	76
50	50	75	130	76
50	60	75	130	76
85	70	75	130	76
85	80	79	136	82
85	90	82	141	85
85	100	84	145	85
85	110	85	147	85
85	120	85	147	85
85	130	85	147	85
85	140	85	147	85
0	150	85	147	85
0	160	80	138	64
0	170	74	128	58
0	180	70	120	58
0	190	66	114	58
0	200	63	109	58
0	210	61	104	58
0	220	59	102	58
0	230	58	100	58
0	240	58	100	58

Series 1-MG

*************************CARDIAC RESPONSE FOR*************************
MALE
GOOD PHYSICAL FITNESS
RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
30	0	58	100	58
30	10	63	108	64
30	20	67	115	70
60	30	68	118	72
60	40	72	124	78
60	50	75	129	80
60	60	77	133	80
60	70	78	135	80
60	80	78	135	80
60	90	78	135	80
60	100	78	135	80
60	110	78	135	80
60	120	78	135	80
40	130	78	135	80
40	140	76	132	73
40	150	75	129	70
40	160	74	127	70
40	170	73	126	70
40	180	73	125	70
40	190	73	125	70
40	200	73	125	70
40	210	73	125	70
40	220	73	125	70
40	230	73	125	70
40	240	73	125	70

Series 2-MG

*************************CARDIAC RESPONSE FOR*************************
MALE
GOOD PHYSICAL FITNESS
RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
105	0	58	100	58
105	10	69	119	76
105	20	78	135	87
105	30	85	147	87
105	40	90	155	87
105	50	91	156	87
105	60	91	156	87
105	70	91	156	87
105	80	91	156	87
105	90	91	156	87
105	100	91	156	87
0	110	90	156	83
0	120	84	145	76
0	130	77	133	65
0	140	71	122	60
0	150	66	115	58
0	160	64	110	58
0	170	61	105	58
0	180	59	102	58
0	190	58	100	58
0	200	58	100	58
0	210	58	100	58
0	220	58	100	58
0	230	58	100	58
0	240	58	100	58
0	250	58	100	58

~~Series 3-MG~~

*************************CARDIAC RESPONSE FOR*************************
MALE
GOOD PHYSICAL FITNESS
RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
85	0	58	100	58
85	10	69	119	69
85	20	79	137	80
0	30	84	145	80
0	40	79	136	74
0	50	74	127	64
0	60	70	120	60
0	70	66	114	58
0	80	63	109	58
0	90	60	104	58
0	100	59	102	58
0	110	58	100	58
0	120	58	100	58
0	130	58	100	58
20	140	58	100	58
20	150	62	106	58
20	160	65	112	68
20	170	66	114	68
20	180	67	116	68
20	190	67	116	68
20	200	67	116	68
20	210	67	116	68
20	220	67	116	68
20	230	67	116	68
20	240	67	116	68
				68

Series 4-MG

**************************CARDIAC RESPONSE FOR**************************

MALE

GOOD PHYSICAL FITNESS

RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
0	0	58	100	58
0	10	58	100	58
0	20	58	100	58
0	30	58	100	58
0	40	58	100	58
0	50	58	100	58
0	60	58	100	58
0	70	58	100	58
0	80	58	100	58
0	90	58	100	58
40	100	58	100	58
40	110	64	111	68
40	120	68	117	74
40	130	71	122	74
40	140	72	125	74
40	150	73	125	74
40	160	73	125	74
40	170	73	125	74
40	180	73	125	74
40	190	73	125	74
40	200	73	125	74
40	210	73	125	74
40	220	73	125	74
60	230	73	125	74
60	240	75	129	78

Series 5-MG

*************************CARDIAC RESPONSE FOR*************************

MALE

GOOD PHYSICAL FITNESS

RHR IS 58

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
65	0	58	100	58
65	10	68	118	70
40	20	71	123	77
40	30	72	124	76
40	40	73	125	75
40	50	73	125	74
40	60	73	125	73
40	70	73	125	73
40	80	73	125	73
40	90	73	125	73
40	100	73	125	73
40	110	73	125	73
40	120	73	125	73
40	130	73	125	73
40	140	73	125	73
40	150	73	125	73
0	160	73	125	73
0	170	69	119	68
0	180	66	114	64
0	190	64	111	66
0	200	62	107	58
0	210	60	104	58
0	220	59	102	58
0	230	58	101	58
0	240	58	100	58

Series 6-MG

**************************CARDIAC RESPONSE FOR**************************

MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
110	0	76	100	76
110	10	88	115	85
110	20	94	123	94
110	30	97	127	96
110	40	98	129	100
110	50	99	130	100
110	60	99	130	100
175	70	99	130	100
175	80	104	136	105
175	90	107	141	109
175	100	110	145	112
175	110	111	146	114
175	120	112	147	114
175	130	112	147	114
175	140	112	147	114
0	150	112	147	114
0	160	105	138	110
0	170	99	131	102
0	180	95	125	95
0	190	89	118	88
0	200	86	113	86
0	210	82	108	82
0	220	81	106	81
0	230	79	104	79
0	240	77	102	77

Series 1-MS

**************************CARDIAC RESPONSE FOR**************************

MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
75	0	76	100	76
75	10	87	114	90
75	20	89	118	93
135	30	92	121	95
135	40	97	127	98
135	50	100	132	102
135	60	103	135	104
135	70	104	136	104
135	80	104	136	104
135	90	104	136	104
135	100	104	136	104
135	110	104	136	104
135	120	104	136	104
90	130	103	136	104
90	140	102	134	104
90	150	100	131	103
90	160	98	129	100
90	170	96	126	98
90	180	95	125	98
90	190	95	125	98
90	200	95	125	98
90	210	95	125	98
90	220	95	125	98
90	230	95	125	98
90	240	95	125	98

Series 2-MS

*************************CARDIAC RESPONSE FOR*************************
MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
220	0	76	100	76
220	10	90	119	88
220	20	95	126	95
220	30	102	134	103
220	40	106	140	111
220	50	111	146	118
220	60	115	151	120
220	70	119	157	122
220	80	120	158	122
220	90	120	158	122
220	100	120	158	122
0	110	120	158	122
0	120	111	146	111
0	130	104	137	109
0	140	96	126	108
0	150	90	119	105
0	160	87	115	102
0	170	84	111	99
0	180	82	108	95
0	190	81	107	90
0	200	79	104	88
0	210	78	103	85
0	220	76	100	80
0	230	76	100	79
0	240	76	100	78
0	250	76	100	77

Series 3-MS

*************************CARDIAC RESPONSE FOR*************************
MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
175	0	76	100	76
175	10	86	114	88
175	20	94	124	95
0	30	100	132	100
0	40	95	125	98
0	50	90	118	96
0	60	87	114	94
0	70	84	110	93
0	80	81	107	85
0	90	79	104	76
0	100	78	103	76
0	110	77	102	76
0	120	76	100	76
0	130	76	100	76
60	140	76	100	76
60	150	85	112	85
60	160	87	114	92
60	170	89	117	92
60	180	89	117	92
60	190	89	117	92
60	200	89	117	92
60	210	89	117	92
60	220	89	117	92
60	230	89	117	92
60	240	89	117	92

Series 4-MS

**************************CARDIAC RESPONSE FOR**************************

MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
0	0	76	100	76
0	10	76	100	76
0	20	76	100	76
0	30	76	100	76
0	40	76	100	76
0	50	76	100	76
0	60	76	100	76
0	70	76	100	76
0	80	76	100	76
0	90	76	100	76
90	100	76	100	76
90	110	87	114	86
90	120	91	120	91
90	130	94	124	93
90	140	95	125	95
90	150	95	125	97
90	160	95	125	97
90	170	95	125	97
90	180	95	125	97
90	190	95	125	97
90	200	95	125	97
90	210	95	125	97
90	220	95	125	97
135	230	95	125	97
135	240	99	130	104

Series 5-MS

**************************CARDIAC RESPONSE FOR**************************

MALE
SEDENTARY
RHR IS 76

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
145	0	76	100	76
145	10	91	119	89
90	20	97	128	95
90	30	96	126	96
90	40	95	125	99
90	50	95	125	99
90	60	95	125	99
90	70	95	125	99
90	80	95	125	99
90	90	95	125	99
90	100	95	125	99
90	110	95	125	99
90	120	95	125	99
90	130	95	125	99
90	140	95	125	99
90	150	95	125	99
0	160	95	125	99
0	170	90	119	99
0	180	84	111	99
0	190	81	106	92
0	200	79	104	88
0	210	78	103	76
0	220	77	102	76
0	230	77	101	76
0	240	77	101	76

Series 6-MS

*************************CARDIAC RESPONSE FOR**************************

FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
45	0	72	100	72
45	10	82	113	78
45	20	88	122	88
45	30	90	126	92
45	40	91	126	94
45	50	91	126	94
45	60	91	126	94
80	70	91	126	94
80	80	98	136	100
80	90	103	143	103
80	100	103	143	105
80	110	103	143	107
80	120	103	143	107
80	130	103	143	107
80	140	103	143	107
0	150	103	143	107
0	160	98	136	100
0	170	84	116	88
0	180	79	109	82
0	190	76	105	77
0	200	74	103	74
0	210	72	100	73
0	220	72	100	72
0	230	72	100	72
0	240	72	100	72

Series 1-FG

*************************CARDIAC RESPONSE FOR*************************

FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
25	0	72	100	72
25	10	78	108	80
25	20	83	115	82
55	30	84	116	84
55	40	90	126	90
55	50	94	130	97
55	60	94	131	97
55	70	94	131	97
55	80	94	131	97
55	90	94	131	97
55	100	94	131	97
55	110	94	131	97
55	120	94	131	97
35	130	94	131	97
35	140	92	127	96
35	150	89	123	94
35	160	87	121	92
35	170	87	121	91
35	180	87	121	90
35	190	87	121	90
35	200	87	121	90
35	210	87	121	90
35	220	87	121	90
35	230	87	121	90
35	240	87	121	90

Series 2-FG

**************************CARDIAC RESPONSE FOR**************************
FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
100	0	72	100	72
100	10	85	118	88
100	20	93	129	98
100	30	99	137	107
100	40	104	145	110
100	50	108	150	110
100	60	110	153	110
100	70	110	153	110
100	80	110	153	110
100	90	110	153	110
100	100	110	153	110
0	110	110	153	110
0	120	104	144	106
0	130	91	127	99
0	140	88	123	88
0	150	83	115	79
0	160	78	108	73
0	170	73	101	72
0	180	72	100	72
0	190	72	100	72
0	200	72	100	72
0	210	72	100	72
0	220	72	100	72
0	230	72	100	72
0	240	72	100	72
0	250	72	100	72

Series 3-FG

**************************CARDIAC RESPONSE FOR**************************
FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
80	0	72	100	72
80	10	85	117	85
80	20	92	127	93
0	30	97	135	98
0	40	93	129	85
0	50	81	113	82
0	60	75	105	78
0	70	73	102	76
0	80	73	101	72
0	90	72	100	72
0	100	72	100	72
0	110	72	100	72
0	120	72	100	72
0	130	72	100	72
15	140	72	100	72
15	150	76	106	80
15	160	79	110	82
15	170	80	112	82
15	180	80	112	82
15	190	80	112	82
15	200	80	112	82
15	210	80	112	82
15	220	80	112	82
15	230	80	112	82
15	240	80	112	82

Series 4-FG

*************************CARDIAC RESPONSE FOR**************************

FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
0	0	72	100	72
0	10	72	100	72
0	20	72	100	72
0	30	72	100	72
0	40	72	100	72
0	50	72	100	72
0	60	72	100	72
0	70	72	100	72
0	80	72	100	72
0	90	72	100	72
35	100	72	100	72
35	110	80	111	83
35	120	86	119	87
35	130	87	121	90
35	140	87	121	90
35	150	87	121	90
35	160	87	121	90
35	170	87	121	90
35	180	87	121	90
35	190	87	121	90
35	200	87	121	90
35	210	87	121	90
35	220	87	121	90
55	230	87	121	90
55	240	91	127	95

Series 5-FG

*************************CARDIAC RESPONSE FOR**************************

FEMALE
GOOD PHYSICAL FITNESS
RHR IS 72

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
60	0	72	100	72
60	10	84	117	84
35	20	91	127	91
35	30	89	123	91
35	40	87	121	91
35	50	87	121	91
35	60	87	121	91
35	70	87	121	91
35	80	87	121	91
35	90	87	121	91
35	100	87	121	91
35	110	87	121	91
35	120	87	121	91
35	130	87	121	91
35	140	87	121	91
35	150	87	121	91
0	160	87	121	91
0	170	85	119	87
0	180	80	111	80
0	190	75	104	74
0	200	72	100	72
0	210	72	100	72
0	220	72	100	72
0	230	72	100	72
0	240	72	100	72

Series 6-FG

*************************CARDIAC RESPONSE FOR*************************
FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
60	0	80	100	80
60	10	91	114	86
60	20	96	121	91
60	30	100	125	95
60	40	102	127	100
60	50	103	128	103
60	60	103	129	103
100	70	103	129	103
100	80	111	139	108
100	90	115	144	110
100	100	117	146	112
100	110	117	146	113
100	120	117	146	114
100	130	117	146	115
100	140	117	146	116
0	150	117	146	116
0	160	114	142	116
0	170	108	135	115
0	180	103	128	110
0	190	97	122	98
0	200	91	114	90
0	210	87	109	87
0	220	84	105	84
0	230	82	103	82
0	240	80	100	80

Series 1-FS

*************************CARDIAC RESPONSE FOR*************************
FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
40	0	80	100	80
40	10	85	106	90
40	20	90	112	93
75	30	92	115	94
75	40	101	126	97
75	50	105	131	99
75	60	107	134	100
75	70	108	135	101
75	80	108	135	102
75	90	108	135	103
75	100	108	135	108
75	110	108	135	108
75	120	108	135	108
50	130	108	135	108
50	140	106	132	108
50	150	103	129	105
50	160	101	126	103
50	170	100	125	101
50	180	100	125	100
50	190	100	125	99
50	200	100	125	99
50	210	100	125	99
50	220	100	125	99
50	230	100	125	99
50	240	100	125	99

Series 2-FS

**************************CARDIAC RESPONSE FOR**************************

FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
125	0	80	100	80
125	10	95	119	88
125	20	106	133	94
125	30	113	141	100
125	40	118	148	105
125	50	123	154	111
125	60	125	156	120
125	70	125	157	125
125	80	125	157	125
125	90	125	157	125
125	100	125	157	125
0	110	126	157	125
0	120	120	150	120
0	130	111	139	114
0	140	105	131	108
0	150	98	123	92
0	160	91	114	85
0	170	87	109	80
0	180	84	105	80
0	190	82	102	80
0	200	80	100	80
0	210	80	100	80
0	220	80	100	80
0	230	80	100	80
0	240	80	100	80

Series 3-FS

**************************CARDIAC RESPONSE FOR**************************

FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
100	0	80	100	80
100	10	92	115	90
100	20	99	124	95
0	30	105	131	103
0	40	101	127	103
0	50	97	122	101
0	60	93	117	99
0	70	90	112	98
0	80	87	108	95
0	90	84	105	92
0	100	82	103	90
0	110	81	102	88
0	120	80	100	87
0	130	80	100	86
30	140	80	100	83
30	150	84	105	85
30	160	88	110	87
30	170	90	112	90
30	180	91	114	94
30	190	93	116	94
30	200	93	116	94
30	210	93	116	94
30	220	93	116	94
30	230	93	116	94
30	240	93	116	94

Series 4-FS

**************************CARDIAC RESPONSE FOR**************************
FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
0	0	80	100	80
0	10	80	100	80
0	20	80	100	80
0	30	80	100	80
0	40	80	100	80
0	50	80	100	80
0	60	80	100	80
0	70	80	100	80
0	80	80	100	80
0	90	80	100	80
50	100	80	100	80
50	110	88	110	92
50	120	93	116	95
50	130	96	120	98
50	140	98	122	101
50	150	99	124	103
50	160	100	125	103
50	170	100	125	103
50	180	100	125	103
50	190	100	125	103
50	200	100	125	103
50	210	100	125	103
50	220	100	125	103
75	230	100	125	103
75	240	105	131	112

Series 5-FS

**************************CARDIAC RESPONSE FOR**************************
FEMALE
SEDENTARY
RHR IS 80

POWER OUTPUT (WATTS)	ELAPSED TIME (SECONDS)	MEAN HEART RATE (BEATS/MINUTE)	PERCENT OF RESTING HEART RATE	observed
80	0	80	100	80
80	10	95	119	88
50	20	103	129	96
50	30	101	126	102
50	40	100	125	102
50	50	100	125	102
50	60	100	125	102
50	70	100	125	102
50	80	100	125	102
50	90	100	125	102
50	100	100	125	102
50	110	100	125	102
50	120	100	125	102
50	130	100	125	102
50	140	100	125	102
50	150	100	125	102
0	160	100	125	102
0	170	95	119	100
0	180	91	114	88
0	190	88	110	84
0	200	85	107	82
0	210	83	104	80
0	220	82	102	80
0	230	81	101	80
0	240	81	101	80

Series 6-FS

APPENDIX 8

DOCUMENTATION OF PROGRAM FOR THE PREDICTIVE MODEL

Input Card Specifications

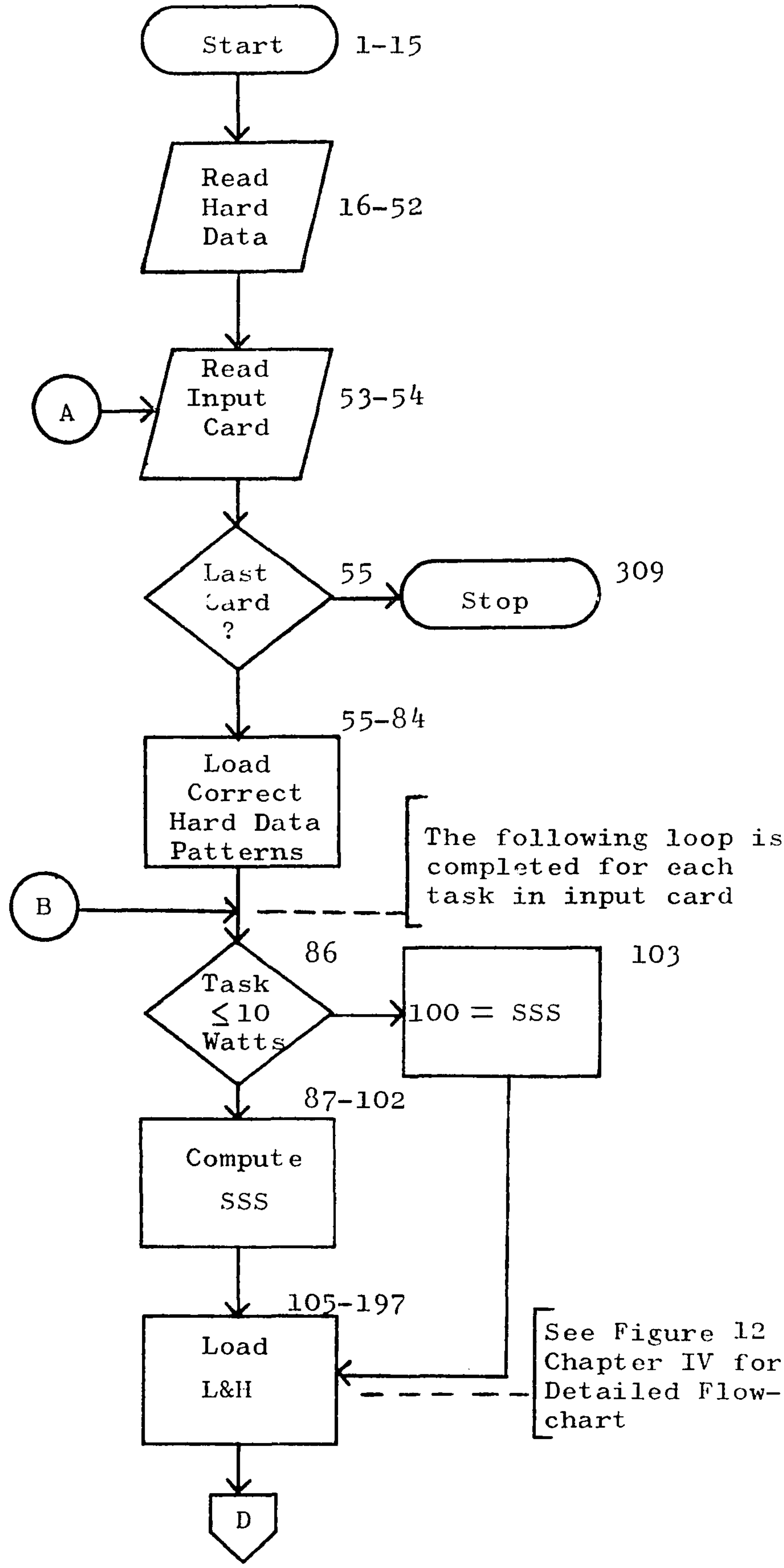
cc. 1- 2--subject category, MG, MS, FG, FS or XX (for last card)
cc. 4- 5--resting heart rate (beats/min)
cc. 7 --number of tasks (2 or 3)
cc. 9-11--initial value (%RHR)
cc. 13-15--1st task work load (watts)
cc. 17-19--1st task duration (seconds)
cc. 21-23--2nd task work load
cc. 25-27--2nd task duration
cc. 29-31--3rd task work load
cc. 33-35--3rd task duration

Any number of input cards can be included with XX as end-of-file.

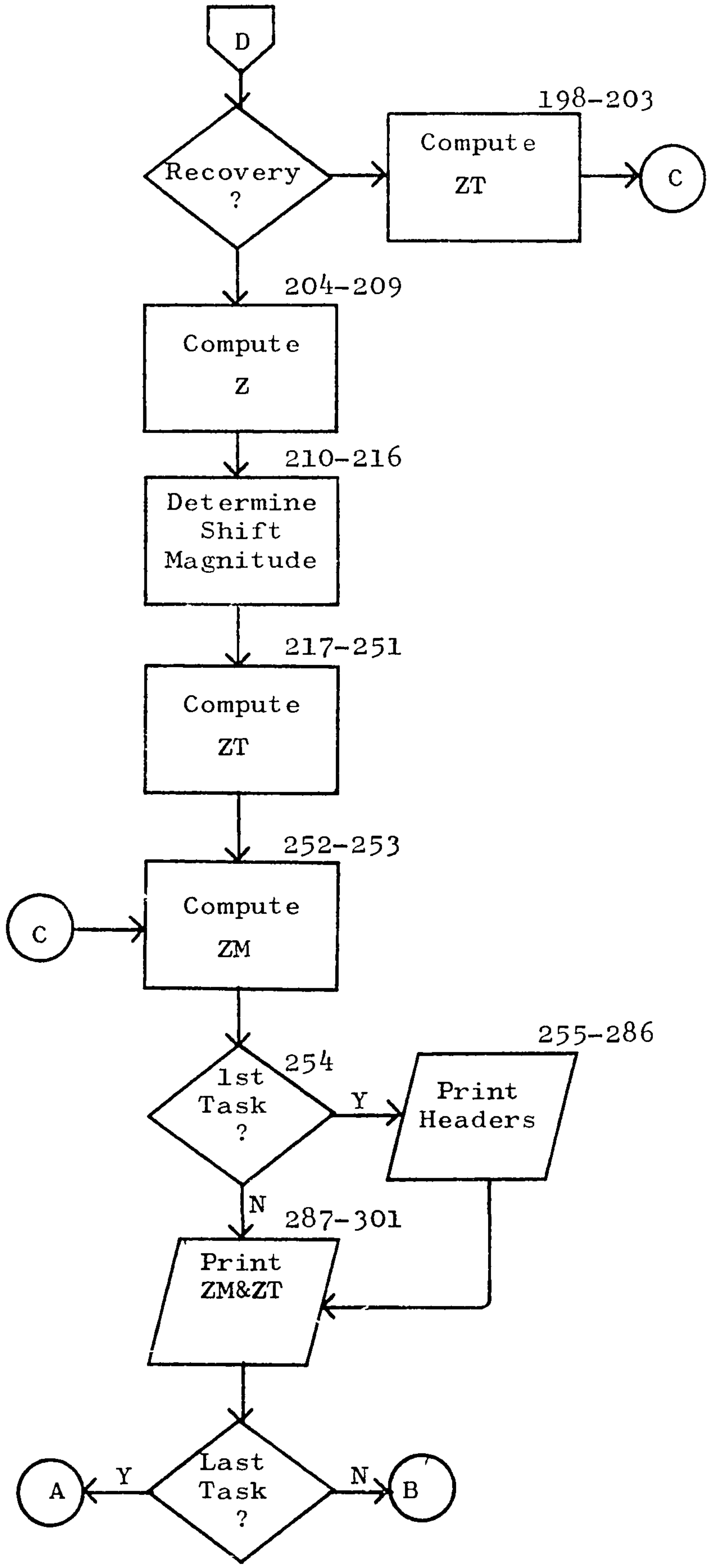
List of Variables (in order of appearance within program)

E1, E2, E3, E4 F1, F2, F3, F4 G1, G2, G3, G4 H1, H2, H3, H4	4x19 arrays which contain all hard data heart rate patterns-- row 1, is MG, 2 is MS, 3 is FG, and 4 is FS.
A1, A2, A3, A4 B1, B2, B3, B4 C1, C2, C3, C4 D1, D2, D3, D4	Appropriate hard data arrays are selected and transferred to these 19 element list for computation. (See Chapter IV for definitions)
WA, DU	3 element lists for work load and duration
Z	19 element HR pattern not adjusted for time (%RHR)
ZT	18 element HR pattern adjusted for time (%RHR)
ZM	18 element HR pattern (heart rate)

L, H	19 element low and high patterns
SC, SUB, PF	Character for subject category, sex, and physical fitness
IV	Initial value
IRHR	Resting heart rate
I	Number of tasks
SSS	Expected SS %RHR
IC	Test constant for L & H selection
R3	Ratio (see Chapter IV)
R1	Ratio (see Chapter IV)
R2	Ratio (see Chapter IV)
IC4	Test constant for SC
IT	Time
IWA, IZM, IZT	Integer for WA, ZM, ZT
XO, YO	Dummy lists of 19 elements



Flowchart of Program for Predictive Model.


D
Recovery ?
198-203
Compute ZT
C
204-209
Compute Z
210-216
Determine Shift Magnitude
217-251
Compute ZT
252-253
C
Compute ZM
254
1st Task ?
Y
255-286
Print Headers
N
287-301
Print ZM&ZT
Last Task ?
Y
A
N
B

PROGRAM FOR PREDICTIVE MODEL (WATFIV)

```
C       THIS PROGRAM CAN BE USED TO PREDICT AN INDIVIDUAL'S CARDIAC
C       RESPONSE TO A SERIES OF FIXED INTENSTY TASKS
C        ARRAYS E,F,G, AND H ARE THE ARRAYS WHICH HOLD HARD DATA IN RHR
C       ROW 1 IS MALE-GOOD
C       ROW 2 IS MALE-SEDENTARY
C       ROW 3 IS FEMALE-GOOD
C       ROW 4 IS FEMALE-SEDENTARY
        DIMENSION E1(4,19),E2(4,19),E3(4,19),E4(4,19)
        DIMENSION F1(4,19),F2(4,19),F3(4,19),F4(4,19)
        DIMENSION G1(4,19),G2(4,19),G3(4,19),G4(4,19)
        DIMENSION H1(4,19),H2(4,19),H3(4,19),H4(4,19)
C       ARRAYS A,B,C AND D ARE ARRAYS WHICH HOLD THE APPROPRIATE
C       HARD DATA FOR COMPUTATION
C       A1, A2, A3 AND A4 ARE 100 TO 100, 120, 140, AND 160 RESPECTIVELY
        DIMENSION A1(19),A2(19),A3(19),A4(19)
C       B1, B2, B3, AND B4 ARE 120 TO 100, 120, 140, AND 160 RESPECTIVELY
        DIMENSION B1(19),B2(19),B3(19),B4(19)
C       C1, C2, C3, AND C4 ARE 140 TO 100, 120, 140, AND 160 RESPECTIVELY
        DIMENSION C1(19),C2(19),C3(19),C4(19)
C       D1, D2, D3, AND D4 ARE 160 TO 100, 120, 140, AND 160 RESPECTIVELY
        DIMENSION D1(19),D2(19),D3(19),D4(19)
C       ARRAYS WA AND DU ACCEPT WATTS AND DURATION OF TASKS
        DIMENSION WA(3),DU(3)
C       ARRAYS Z -HR PATTRN IN  RHR ZT -ADJUSTED FOR TIME  ZM -ZT MEAN HR
        DIMENSION Z(19),ZM(18),ZT(18)
C       ARRAYS L  AND H ARE WORK AREAS THAT HOLD THE LOW AND HIGH HARD
C       DATA FOR EACH PREDICTED HR PATTERN
        REAL L
        DIMENSION L(19),H(19)
        CHARACTER SC*2,SUB*6,PF*21
C       READ IN HARD DATA
        J=1
      5 IF (J.EQ.5) GO TO 95
     10 FORMAT (19F4.0)
        READ(5,10)(A1(K),K=1,19)
        READ(5,10)(A2(K),K=1,19)
        READ(5,10)(A3(K),K=1,19)
        READ(5,10)(A4(K),K=1,19)
        READ(5,10)(B1(K),K=1,19)
        READ(5,10)(B2(K),K=1,19)
        READ(5,10)(B3(K),K=1,19)
        READ(5,10)(B4(K),K=1,19)
        READ(5,10)(C1(K),K=1,19)
        READ(5,10)(C2(K),K=1,19)
        READ(5,10)(C3(K),K=1,19)
        READ(5,10)(C4(K),K=1,19)
        READ(5,10)(D1(K),K=1,19)
        READ(5,10)(D2(K),K=1,19)
        READ(5,10)(D3(K),K=1,19)
        READ(5,10)(D4(K),K=1,19)
C       LOAD DATA TO APPROPRIATE HARD DATA ARRAYS
        DO 50 K=1,19
        E1(J,K)=A1(K)
        E2(J,K)=A2(K)
        E3(J,K)=A3(K)
        E4(J,K)=A4(K)
        F1(J,K)=B1(K)
        F2(J,K)=B2(K)
        F3(J,K)=B3(K)
```

```
      F4(J,K)=B4(K)
      G1(J,K)=C1(K)
      G2(J,K)=C2(K)
      G3(J,K)=C3(K)
      G4(J,K)=C4(K)
      H1(J,K)=D1(K)
      H2(J,K)=D2(K)
      H3(J,K)=D3(K)
      H4(J,K)=D4(K)
   50 CONTINUE
      J=J+1
      GO TO 5
C     INPUT DATA  SC=SUBJECT CATEGORY, IRHR=RESTING HEART RATE, I=NUM
C     TASKS, IV=INITIAL VALUE, WA=WATTS, DU=DURATION.
C     READ A DATA CARD FOR ONE INDIVIDUAL
   95 READ(5,100) SC,IRHR,I,IV,WA(1),DU(1),WA(2),DU(2),WA(3),DU(3)
  100 FORMAT (A2,I3,I2,I4,6F4.0)
C     XX IN THE SC FIELD INDICATES LAST CARD - TERMINATE PROGRAM
      IF (SC.EQ.'XX') STOP
C     DETERMINE APPROPRIATE HARD DATA ARRAY
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
      IF (SC.EQ.'MG') GO TO 101
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
      IF (SC.EQ.'MS') GO TO 102
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
      IF (SC.EQ.'FG') GO TO 103
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
      IF (SC.EQ.'FS') GO TO 104
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
  101 J=1
      GO TO 106
  102 J=2
      GO TO 106
  103 J=3
      GO TO 106
  104 J=4
C     LOAD APPROPRIATE HARD DATA INTO COMPUTATIONAL ARRAYS
  106 DO 107 K=1,19
      A1(K)=E1(J,K)
      A2(K)=E2(J,K)
      A3(K)=E3(J,K)
      A4(K)=E4(J,K)
      B1(K)=F1(J,K)
      B2(K)=F2(J,K)
      B3(K)=F3(J,K)
      B4(K)=F4(J,K)
      C1(K)=G1(J,K)
      C2(K)=G2(J,K)
      C3(K)=G3(J,K)
      C4(K)=G4(J,K)
      D1(K)=H1(J,K)
      D2(K)=H2(J,K)
      D3(K)=H3(J,K)
      D4(K)=H4(J,K)
  107 CONTINUE
C     THE FOLLOWING LOOP IS COMPLETED ONCE FOR EACH TASK- 2 OR 3
      DO 900 M=1,I
C     IF TASK REQUIRES LESS THAN 10 WATTS SET SSS = 0
      IF (WA(M)-10) 150,109,109
C     CHECK SUBJECT CATEGORY M=MALE,F=FEMALE,G=GOOD PF,S=SEDENTARY
```

```
      109 IF (SC.EQ.'MG') GO TO 110
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF (SC.EQ.'MS') GO TO 120
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF (SC.EQ.'FG') GO TO 130
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF (SC.EQ.'FS') GO TO 140
C         COMPUTE EXPECTED STEADY STATE  RHR (SSS)
C         FOR MG
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
      110 SSS=.474*WA(M)+106.33
          IC4=1
          GO TO 160
C         FOR MS
      120 SSS=.259*WA(M)+101.443
          IC4=2
          GO TO 160
C         FOR FG
      130 SSS=.484*WA(M)+104.306
          IC4=3
          GO TO 160
C         FOR FS
      140 SSS=.431*WA(M)+102.769
          IC4=4
          GO TO 160
      150 SSS=100
      160 CONTINUE
          IC=0
C         THIS SEGMENT DETERMINES WHICH HARD DATA ARRAYS TO USE-HIGH AND LOW
          IF (IV-120) 170,170,175
      170 IC=IC+1
          GO TO 200
      175 IF (IV-140) 180,180,185
      180 IC=IC+2
          GO TO 200
      185 IF (IV-160) 190,190,195
      190 IC=IC+3
          GO TO 200
      195 PRINT,'IV IS GREATER THAN 160 RHR'
          GO TO 95
      200 IF (SSS-120) 210,210,215
      210 IC=IC+10
          GO TO 250
      215 IF (SSS-140) 220,220,225
      220 IC=IC+20
          GO TO 250
      225 IF (SSS-160) 230,230,235
      230 IC=IC+30
          GO TO 250
      235 PRINT,'SSS IS GREATER THAN 160  RHR'
          GO TO 95
      250 IF (IC-11) 270,265,270
      265 IF (IV-SSS) 267,267,266
      266 CALL COPY(L,B1,19)
          CALL COPY(H,B2,19)
          GO TO 400
      267 CALL COPY(L,A1,19)
          CALL COPY(H,A2,19)
          GO TO 400
      270 IF(IC-12)280,272,280
```

```
      272 IF(WA(M)-0.0) 275,273,275
      273 CALL COPY(L,B1,19)
          CALL COPY(H,C1,19)
          GO TO 350
      275 CALL COPY(L,E1,19)
          CALL COPY(H,F2,19)
          GO TO 400
      280 IF (IC-13) 290,281,290
      281 IF(SC.EQ.'MS') GO TO 282
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF(SC.EQ.'FS') GO TO 282
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          GO TO 285
      282 IF (WA(M)-0.0) 283,284,283
      283 WRITE(6,319)
          GO TO 95
      284 CALL COPY(L,C1,19)
          CALL COPY(H,D1,19)
          GO TO 350
      285 IF(WA(M)-0.0) 287,284,287
      287 CALL COPY(L,C1,19)
          CALL COPY(H,D2,19)
          GO TO 400
      290 IF (IC-21) 300,295,300
      295 CALL COPY(L,A2,19)
          CALL COPY(H,B3,19)
          GO TO 400
      300 IF (IC-22) 310,305,310
      305 IF (IV-SSS) 307,307,306
      306 CALL COPY(L,C2,19)
          CALL COPY(H,C3,19)
          GO TO 400
      307 CALL COPY(L,E2,19)
          CALL COPY(H,B3,19)
          GO TO 400
      310 IF (IC-23) 320,312,320
      312 IF(SC.EQ.'MS') GO TO 318
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF(SC.EQ.'FS') GO TO 318
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          CALL COPY(L,C2,19)
          CALL COPY(H,D3,19)
          GO TO 400
      318 WRITE(6,319)
      319 FORMAT(1X,'STEP DECREASES IN TASK INTENSITY -EXCEPT TO RECOVERY -
         1 ARE NOT ACCEPTED FOR IV OF MORE THAN 140 RHR -SEDENTARY ONLY')
          GO TO 95
      320 IF(IC-31) 330,325,330
      325 CALL COPY(L,A3,19)
          CALL COPY(H,B4,19)
          GO TO 400
      330 IF(IC-32) 340,335,340
      335 CALL COPY(L,E3,19)
          CALL COPY(H,C4,19)
          GO TO 400
      340 IF(IV-SSS)347,347,342
      342 IF(SC.EQ.'MS') GO TO 346
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
          IF(SC.EQ.'FS') GO TO 346
*EXTENSION*  A CHARACTER VARIABLE IS USED WITH A RELATIONAL OPERATOR
```

```
      CALL COPY(L,D3,19)
      CALL COPY(H,D4,19)
      GO TO 400
  346 WRITE(6,319)
      GO TO 95
  347 CALL COPY(L,C3,19)
      CALL COPY(H,C4,19)
      GO TO 400
C     ROUTINE TO DETERMINE ZT FOR RECOVERY PATTERNS
C     OF IV GREATER THAN 120
  350 R3=(IV-H(2))/(H(2)-L(2))
      ZT(1)=IV
      DO 360 K8=2,18
      ZT(K8)=(H(K8+1)-L(K8+1))*R3+L(K8+1)
  360 CONTINUE
      GO TO 515
  400 IF(SSS-L(18)) 410,405,410
  405 CALL COPY(Z,L,19)
      GO TO 421
C     R1 IS THE RATIO BETWEEN SSS AND THE LOW SS AND THE HARD DATA H-L
  410 R1=(SSS-L(18))/20.0
C     COMPUTE THE EXPECTED HR PATTERN AND STORE IT IN Z
      DO 420 K=1,19
  420 Z(K)=((H(K)-L(K))*R1+L(K))
C     ADJUST INDEX FOR TIME IN 10 SECOND INCREMENTS
  421 IF(IV-SSS) 439,439,423
  423 DO 428 K=2,18
      IF(IV.GT.Z(K)) GO TO 427
      GO TO 428
  427 J=K-1
      GO TO 429
  428 CONTINUE
  429 IF(IV-Z(J+1)) 432,430,432
  430 R2=0.0
      GO TO 436
  432 IF(Z(J)-Z(J+1)) 435,433,435
  433 R2=1.0
      GO TO 436
  435 R2=(IV-Z(J+1))/(Z(J)-Z(J+1))
  436 ZT(1)=IV
      DO 437 K=2,18
      ZT(K)=(Z(J+1)-Z(J+2))*R2+Z(J+2)
      IF(Z(J+1).EQ.Z(J+2)) GO TO 500
      J=J+1
  437 CONTINUE
      GO TO 500
  439 DO 450 K=2,18
      IF(IV.LT.Z(K)) GO TO 440
      GO TO 450
  440 J=K-1
      GO TO 460
  450 CONTINUE
C     DETERMINE R2 THE RATIO OF THE DIFFERENCE BETWEEN IV AND ZA
C     AND BETWEEN ZA AND ZA PLUS 10
  460 IF(IV-Z(J))467,465,467
  465 R2=0.0
      GO TO 480
  467 IF(Z(J+1)-Z(J)) 470,468,470
  468 R2=1.0
      GO TO 480
```

```
  470 R2=(IV-Z(J))/(Z(J+1)-Z(J))
  480 ZT(1)=IV
C     COMPUTE THE EXPECTED HR PATTERN ADJUSTED FOR TIME AND STORE IN ZT
      DO 490 K=2,18
      ZT(K)=((Z(J+2)-Z(J+1))*R2)+Z(J+1)
      IF(Z(J+1).EQ.Z(J+2))GO TO 500
      J=J+1
  490 CONTINUE
  500 DO 510 K8=K,18
  510 ZT(K8)=SSS
C     COMPUTE HR PATTERN IN MEAN HR FOR A GIVEN RESTING HR
  515 DO 520 K=1,18
  520 ZM(K)=((ZT(K)*IRHR)/100)
      IF (M.NE.1) GO TO 695
C     DETERMINE HEADING VARIABLES
      GO TO (540,542,544,546),IC4
  540 SUB=' MALE '
      PF='GOOD PHYSICAL FITNESS'
      GO TO 560
  542 SUB=' MALE '
      PF='      SEDENTARY      '
      GO TO 560
  544 SUB='FEMALE'
      PF='GOOD PHYSICAL FITNESS'
      GO TO 560
  546 SUB='FEMALE'
      PF='      SEDENTARY      '
C     PRINT HEADING INFORMATION
  560 WRITE(6,570)
  570 FORMAT(1H1,25('*'),'CARDIAC RESPONSE FOR',25('*'))
      WRITE(6,580) SUB
  580 FORMAT(1X,31(' '),A7)
      WRITE(6,590) PF
  590 FORMAT(1X,24(' '),A21)
      WRITE(6,600) IRHR
  600 FORMAT(1X,29(' '),'RHR IS ',I3)
      WRITE(6,610)
  610 FORMAT(1X,' ')
C     PRINT COLUMN HEADINGS
      WRITE(6,620)
  620 FORMAT(1X,'  POWER OUTPUT     ','ELAPSED TIME      ','MEAN HEART R
     1RATE   ','PERCENT OF RESTING HEART RATE')
      WRITE(6,630)
  630 FORMAT(3X,'(WATTS)          ','(SECONDS)          ','(BEATS/MINUTE
     1)')
      IT=0
  695 K=1
C     ROUND ALL HR AND RHR OFF TO NEAREST INTEGER
      DO 698 IX=1,18
      ZM(IX)=ZM(IX)+.5
      ZT(IX)=ZT(IX)+.5
  698 CONTINUE
C     PRINT POWER OUTPUT, TIME, RHR, AND MEAN HR
  700 IWA=WA(M)
      IZM=ZM(K)
      IZT=ZT(K)
      WRITE(6,705)IWA,IT,IZM,IZT
  705 FORMAT(1X,I6,14X,I3,14X,I5,15X,I5)
      IT=IT+10
      K=K+1
```

```
      GO TO (710,720,730),M
C     CHECK DURATION OF TASK
  710 IF (IT.LT.DU(1)) GO TO 700
      GO TO 800
  720 IF (IT.LT.(DU(1)+DU(2))) GO TO 700
      GO TO 800
  730 IF (IT.LT.(DU(1)+DU(2)+DU(3))) GO TO 700
C     SET INITIAL VALUE FOR NEXT TASK
  800 IV=ZT(K)
  900 CONTINUE
      GO TO 95
      END

      SUBROUTINE COPY(XO,YO,NO)
C     SUBROUTINE COPY LOADS ARRAY XO INTO YO BOTH OF DIMENSION NO
      DIMENSION XO(NO),YO(NO)
      DO 1000 KO=1,NO
 1000 XO(KO)=YO(KO)
      RETURN
      END
```

APPENDIX 9

PROGRAM TO PREDICT HEART RATE PATTERNS USING SCHLIPP'S MODEL (BASIC).

```
00010 PRINT ' INPUT WORK LOAD IN WATTS, DURATION IN SECONDS, AND RHR'
00020 INPUT W,D,R
00030 B=.4*W
00040 A1=B*.25
00050 A2=B-A1
00060 PRINT 'TIME  HEART RATE'
00070 FOR T=0TODSTEP 10
00080 Y=A1*(1-(1/&E**(.385*T)))+A2*(1-(1/&E**(.0233*T)))
00090 H=Y+R
00110 PRINT T;H
00120 NEXT T
00130 PRINT 'INPUT DURATION OF RECOVERY'
00140 INPUT D
00150 PRINT 'TIME  HEART RATE'
00160 A3=.35*B
00170 FOR T=0TODSTEP 10
00180 Y1=A3*&E**(-.026*T)
00190 H=Y1+R
00210 PRINT T+10;H
00220 NEXT T
00230 END
EDIT
```

```
INPUT WORK LOAD IN WATTS, DURATION IN SECONDS, AND RHR
 ?   220,120,76
TIME  HEART RATE
 0     76
 10    111.2497
 20    122.5745
 30    131.1923
 40    138.0114
 50    143.4131
 60    147.6920
 70    151.0815
 80    153.7666
 90    155.8936
 100   157.5785
 110   158.9131
 120   159.9704
INPUT DURATION OF RECOVERY
 ?   120
TIME  HEART RATE
 10    159.6000
 20    140.4599
 30    1[illegible].7019
 40    11[illegible].3227
 50    105.5488
 60    98.78366
 70    93.56737
 80    89.54535
 90    86.44417
 100   84.05299
 110   82.20927
 120   80.78766
 130   79.69153
EDIT  run
```

W = watts
D = duration in seconds
R = RHR
B = expected bpm above RHR at SS
A1,A2 = fast and slow components
Y = bpm above RHR for increasing HR
H = HR at time T
A3 = fraction of B used for recovery
Y1 = bpm above resting for recovery

APPENDIX 10

PROGRAM TO PREDICT HEART RATE PATTERNS USING SUGGS' MODEL (BASIC).

```
00050 PRINT ' INPUT 1 FOR EXERCISE, 2 FOR RECOVERY, AND 3 FOR STOP'
00055 T1=0
00060 INPUT X
00068 IF X=1 THEN 100
00070 IF X=2 THEN 400
00072 IF X=3 THEN 500
00100 PRINT 'ENTER WATTS, DURATION IN MINUTES, AND RHR'
00110 INPUT W,D,R
00112 O=.014*W
00114 S=60*O+78
00120 A=S-R
00130 PRINT 'TIME  HEART RATE'
00140 FOR T=0TODSTEP.1666
00150 H=S-A*(&E**(-.693*T))
00160 PRINT T1;H
00164 T1=T1+10
00170 NEXT T
00172 GO TO 480
00400 PRINT
00410 PRINT 'INPUT SS FOR EXERCISE, DURATION, IV'
00420 INPUT S,D,I
00430 A=I-S
00440 FOR T=0TODSTEP.1666
00450 H=S+A*(&E**(-.499*T))
00460 PRINT T1;H
00464 T1=T1+10
00470 NEXT T
00480 PRINT ' DO YOU WISH ANOTHER'
00490 INPUT A$
00495 IF A$='YES' THEN 50
00500 END
EDIT
```

T1 = time periods in seconds
X = indicator
W = watts
D = duration in minutes
R = RHR
O = oxygen consumption
S = SS HR
T = time periods in minutes
H = HR at time T1
S = expect SS for exercise
D = duration in minutes
I = IV

```
INPUT 1 FOR EXERCISE, 2 FOR RECOVERY, AND 3 FOR STOP
 ?   1
ENTER WATTS, DURATION IN MINUTES, AND RHR
 ?   100,2,72
TIME  HEART RATE
 0     72
 10    81.81345
 20    90.55685
 30    98.34688
 40    105.2875
 50    111.4713
 60    116.9809
 70    121.8897
 80    126.2632
 90    130.1599
 100   133.6316
 110   136.7249
 120   139.4808
DO YOU WISH ANOTHER
 ?   'yes'
INPUT 1 FOR EXERCISE, 2 FOR RECOVERY, AND 3 FOR STOP
 ?   2

INPUT SS FOR EXERCISE, DURATION, IV
 ?   72,2,150
 0     150
 10    143.7778
 20    138.0520
 30    132.7829
 40    127.9342
 50    123.4722
 60    119.3662
 70    115.5877
 80    112.1107
 90    108.9110
 100   105.9665
 110   103.2570
 120   100.7636
DO YOU WISH ANOTHER
 ?   'yes'
```

APPENDIX 11

PROGRAM TO PREDICT HEART RATE PATTERNS USING VOGT'S MODEL (BASIC).

```
00010 PRINT 'ENTER 1 IF INCREASE AND 2 IF DECREASE'
00020 INPUT C1
00030 PRINT 'ENTER WATTS, DURATION IN MINUTES, IV AND RHR'
00040 INPUT W,D,I,R
00050 C=.4*W
00065 T1=0
00070 IF C1=1 THEN 200
00080 K=-.712-.0069*C
00090 GO TO 220
00200 K=-1.35-.0078*(I+C)
00220 PRINT 'TIME  HEART RATE'
00230 FOR T=0TOD STEP .166666
00235 P1=-K*T+.05
00236 P2=1/&E**P1
00237 H=C*(1-P2)
00240 IF C1=1 THEN 248
00242 H1=I-H
00244 GO TO 250
00248 H1=H+R
00250 PRINT T1;H1
00252 T1=T1+10
00260 NEXT T
00270 END
EDIT
```

C1 = indicator
W = watts
D = duration in minutes
I = IV
R = RHR
C = expected bpm above RHR at SS
T1 = time periods in seconds
K = time constant
T = time periods in minutes
P1,P2 = dummy variables
H = bpm above RHR
H1 = predicted HR

```
ENTER 1 IF INCREASE AND 2 IF DECREASE
 ?   1
ENTER WATTS, DURATION IN MINUTES, IV AND RHR
 ?   220,2,76,76
TIME  HEART RATE
 0     80.29182
 10    109.9916
 20    129.1539
 30    141.5173
 40    149.4942
 50    154.6409
 60    157.9615
 70    160.1040
 80    161.4863
 90    162.3781
 100   162.9536
 110   163.3248
 120   163.5644
EDIT  run
```

```
ENTER 1 IF INCREASE AND 2 IF DECREASE
 ?   2
ENTER WATTS, DURATION IN MINUTES, IV AND RHR
 ?   220,2,164,76
TIME  HEART RATE
 0     159.7082
 10    143.1864
 20    129.9256
 30    119.2821
 40    110.7394
 50    103.8828
 60    98.37947
 70    93.96239
 80    90.41711
 90    87.57158
 100   85.28766
 110   83.45454
 120   81.93323
EDIT  run
```

APPENDIX 12

PROGRAMS TO DETERMINE SIGNIFICANCE OF THE DIFFERENCE BETWEEN REGRESSION COEFFICIENTS OF TWO SEPARATE EQUATIONS (BASIC).

```
00010 A1=0
00020 A2=0
00030 PRINT' INPUT N'
00040 INPUT N
00050 FOR I=1TON
00055 INPUT X,Y
00060 A1=A1+Y
00070 A2=A2+Y**2
00080 B1=B1+X
00090 B2=B2+X**2
00100 NEXT I
00110 PRINT 'INPUT SLOPE'
00120 INPUT S
00130 S1=(N*B2-B1**2)/(N*(N-1))
00140 S2=(N*A2-A1**2)/(N*(N-1))
00150 S3=((N-1)/(N-2))*(S2-(S**2)*S1)
00160 PRINT 'SX','SY','SYX'
00170 PRINT S1,S2,S3
00180 END
EDIT
```

Program to compute sums of squares

N = number of observation

X,Y = values of independent and dependent variables

A1,A2,B1,B2 = accumulators

S = regression coefficient

S1,S2,S3 = $S_x, S_y, S_{x/y}$

(Crow, 1961, p. 160)

```
00010 PRINT' INPUT SY1X SX1 N1 SY2X SX2 N2'
00020 INPUT S1,X1,N1,S2,X2,N2
00030 S3=((N1-2)*S1+(N2-2)*S2)/(N1+N2-4)
00040 S4=S3*(1/((N1-1)*X1)+1/((N2-1)*X2))
00050 S5=S4**.5
00060 PRINT 'INPUT B1 AND B2'
00070 INPUT B1,B2
00080 T=(B1-B2)/S5
00090 PRINT 'T FOR B1 AND B2 OF',B1;B2
00100 PRINT 'T=';T
00110 END
EDIT
```

Program to calculate t statistic

S1,S2 = $S_{y/x1}$, $S_{y/x2}$

X1,X2 = S_{x1}, S_{x2}

N1,N2 = number of observation (1 and 2)

B1,B2 = regression coefficients (1 and 2)

T = computed t

APPENDIX 13

PROGRAM TO LIST ALL HARD DATA BY TASK (WATFIV).

```
C       THIS PROGRAM LISTS ALL HARD DATA BY TASK
        DIMENSION M(4,16,18)
        DO 100 I=1,4
        DO 110 J=1,16
        READ(5,105)(M(I,J,K),K=1,18)
  105   FORMAT(4X,18I4)
  110   CONTINUE
  100   CONTINUE
        DO 210 J=1,16
  135   IT=0
        WRITE(6,140)
  140   FORMAT(1H1,' TIME ','        MALE        ','        FEMALE')
        WRITE(6,150)
  150   FORMAT(1X,'          GOOD     ','SEDENTARY',' GOOD     ','SEDENTARY
        WRITE(6,155)
  155   FORMAT(1X,' ')
        DO 200 K=1,18
        WRITE(6,160) IT,M(1,J,K),M(2,J,K),M(3,J,K),M(4,J,K)
  160   FORMAT(2X,I3,4X,I3,6X,I3,6X,I3,6X,I3)
        IT=IT+10
  200   CONTINUE
  210   CONTINUE
        STOP
        END
```

M = 4x16x18 matrix
I = subject categories
J = tasks
K = time periods

APPENDIX 14

PROGRAM TO COMPUTE HEART RATE—%RHR CONVERSION TABLE FOR RESTING HEARTS OF 50 TO 90 BEATS/MINUTE (BASIC). TABLE SHOWN IN PART.

```
00010 FOR I=50TO90 STEP 10
00020 PRINT USING 50,I,I+2,I+4,I+6,I+8
00050 : RHR ###          RHR ###          RHR ###          RHR ###          RHR ###
00060 PRINT USING 70
00070 :BPM  %RHR     BPM  %RHR     BPM  %RHR     BPM  %RHR     BPM  %RHR
00080 PRINT
00090 FOR J=50 TO 140 STEP 2
00095 PRINT USING 100,J,(J/I)*100,J,(J/(I+2))*100,J,(J/(I+4))*100,J,(J/(I+6))*100,J,(J/(I+8))*100
00100 :###    ###    ###    ###    ###    ###    ###    ###    ###    ###
00110 NEXT J
00120 PRINT
00130 PRINT
00140 PRINT
00150 PRINT
00160 PRINT
00161 PRINT
00162 PRINT
00163 PRINT
00164 PRINT
00165 PRINT
00166 PRINT
00167 PRINT
00168 PRINT
00169 PRINT
00170 PRINT
00171 PRINT
00172 PRINT
00178 NEXT I
00180 END
EDIT  end
```

RHR 70		RHR 72		RHR 74		RHR 76		RHR 78	
BPM	%RHR	BPM	%RHR	BPM	%RHR	BPM	%RHR	BPM	%RHR
50	71	50	69	50	68	50	66	50	64
52	74	52	72	52	70	52	68	52	67
54	77	54	75	54	73	54	71	54	69
56	80	56	78	56	76	56	74	56	72
58	83	58	81	58	78	58	76	58	74
60	86	60	83	60	81	60	79	60	77
62	89	62	86	62	84	62	82	62	79
64	91	64	89	64	86	64	84	64	82
66	94	66	92	66	89	66	87	66	85
68	97	68	94	68	92	68	89	68	87
70	100	70	97	70	95	70	92	70	90
72	103	72	100	72	97	72	95	72	92
74	106	74	103	74	100	74	97	74	95
76	109	76	106	76	103	76	100	76	97
78	111	78	108	78	105	78	103	78	100
80	114	80	111	80	108	80	105	80	103
82	117	82	114	82	111	82	108	82	105
84	120	84	117	84	114	84	111	84	108
86	123	86	119	86	116	86	113	86	110
88	126	88	122	88	119	88	116	88	113
90	129	90	125	90	122	90	118	90	115
92	131	92	128	92	124	92	121	92	118
94	134	94	131	94	127	94	124	94	121
96	137	96	133	96	130	96	126	96	123
98	140	98	136	98	132	98	129	98	126
100	143	100	139	100	135	100	132	100	128
102	146	102	142	102	138	102	134	102	131
104	149	104	144	104	141	104	137	104	133
106	151	106	147	106	143	106	139	106	136
108	154	108	150	108	146	108	142	108	138
110	157	110	153	110	149	110	145	110	141
112	160	112	156	112	151	112	147	112	144
114	163	114	158	114	154	114	150	114	146
116	166	116	161	116	157	116	153	116	149
118	169	118	164	118	159	118	155	118	151
120	171	120	167	120	162	120	158	120	154
122	174	122	169	122	165	122	161	122	156
124	177	124	172	124	168	124	163	124	159
126	180	126	175	126	170	126	166	126	162
128	183	128	178	128	173	128	168	128	164
130	186	130	181	130	176	130	171	130	167
132	189	132	183	132	178	132	174	132	169
134	191	134	186	134	181	134	176	134	172
136	194	136	189	136	184	136	179	136	174
138	197	138	192	138	186	138	182	138	177
140	200	140	194	140	189	140	184	140	179

I = RHR
J = beats/minute