PREDICTION OF CARDIAC RESPONSE TO PHYSICAL STRESS

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ABSTRACT

This paper presents a method for predicting an individual's cardiac response to a series of fixed intensity tasks. It was determined that cardiac responses to exercise at given work loads are similar for subjects of the same sex and level of physical fitness when they are expressed in terms of resting heart rate. Using this observation as a basis, a prediction model was developed by extrapolating from emperically derived heart rate patterns. The prediction error was no more than five to ten percent of the actual heart rate value in ninety percent of the predictions.

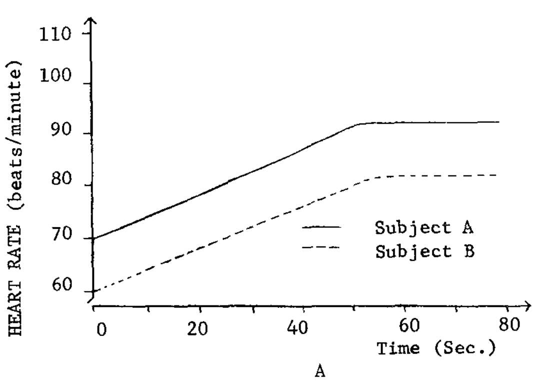
INTRODUCTION

Protection of the worker's health through proper job design, workplace design, and control of the environment is a basic responsibility of the human factor specialist. An important consideration in evaluating both the job and the worker's capacity to perform the job is the assessment of the worker's physiological response to physically demanding tasks; however, the measurement of a worker's response is often impractical in production floor situations. In such situations, prediction of the worker's response is the only alternative, but extreme interpersonal variations has made available prediction techniques unacceptably inaccurate. The elimination of this interpersonal variation was a necessary prerequisite to the development of an accurate prediction technique.

A prediction model, which minimizes interpersonal variation by using a simple transformation was developed to predict a worker's cardiac response to physical tasks in the aerobic range. The model permits several step changes in work load to occur but is restricted to a total period of activity of no more than four minutes in order to avoid complications due to fatigue. Because of the size of the required data base and the complexity of the computational procedures, the model is computer dependent.

MODEL DEVELOPMENT

The most apparent deterrent to predicting an individual's heart rate response (heart rate pattern) to work is the extreme variation in absolute heart rate between individuals working on the same job. This variation can be substantially reduced by viewing cardiac responses to exercise in terms of the percent of an individual's average resting heart rate (%RHR). This transformation provides a common origin for heart rate patterns produced by different individuals. The reduction in interpersonal variation caused by this transformation is illustrated in Figure 1.



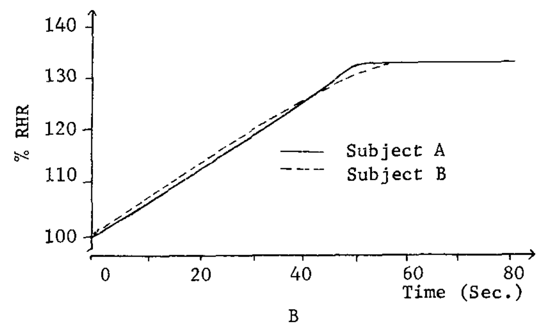


Figure 1. Heart rate patterns for two subjects performing a task of light intensity.

Of the numerous environmental and human variables which affect the magnitude and rate of change of heart rates, only the human variables of sex, physical fitness, and resting heart rate were included in this study. The subject categories which can be defined by two levels each of sex and physical fitness were: (1) male of good physical fitness (MG), (2) sedentary male (MS), (3) female of good physical fitness (FG), and (4) sedentary female (FS). The experiment was designed to minimize variation within other variables which might effect heart rate response to exercise. The ability to evaluate physical fitness by techniques not requiring extensive medical facilities is poor. This inability to easily measure physical fitness necessitated the use of an easily identifiable dichotomy in classifying physical fitness of the subject.

The only physiological measurement required by the prediction model is the individual's resting heart rate. For the purpose of this study resting heart rate was defined as the average seated heart rate over a five minute period following fifteen minutes of rest.

All exercise data for the development of the predictive model were gathered while the subject was exercising on a bicycle ergometer. Two types of data were required. First, it was necessary to develop a relationship between a work load and the steady state %RHR, the dependent variable. Regression equations are as follows:

For MG	$S = .47W + 106$	$r = .95$
MS	$S = .26W + 100$	$r = .99$
FG	$S = .48W + 108$	$r = .97$
FS	$S = .43W + 103$	$r = .98$

Where,

S = Steady state %RHR
W = Work load (watts)
r = Correlation coefficient

There is no statistically significant difference in the slopes of the MG, FG, and FS equations. However, the slope of the MS equation is significantly different than the slopes of the MG, FG, and FS equations. Consistent patterns in the data strongly suggest that when a larger data base has been developed, these slopes will be shown to be significantly different from each other. Based on this observation, the model was developed using separate relationships for each subject category. A later comparison of predictive results with a model which combined the regression equations into an average equation showed that there was no loss in accuracy in using separate equations.

Second, the predictive model required especially derived heart rate patterns from which a predicted cardiac response could be extrapolated. Twelve patterns,in terms of %RHR, having one of four possible initial values (IV = 100, 120, 140 or 160% RHR) and one of four possible steady state values (SS=100, 120, and 140, or 160% RHR), were derived by testing.

THE PREDICTIVE METHOD

The prediction is accomplished by extrapolating an expected cardiac response, in terms of %RHR, from an appropriate pair of emperically derived heart rate patterns. The derived patterns are selected from those of a particular subject category such that the pair of patterns bracket the prediction to be made. The only information needed for selecting the pair of patterns is the initial value of the prediction, which is known, and the expected steady state value which is obtained from the workload versus steady state %RHR relationships.

A graphic example of the derivation of a predicted heart rate pattern is shown in Figure 2. The pattern to be predicted (P) has an initial value of 129% RHR (given) and a steady state value of 146%RHR (100 watt work load for FS). A pattern not adjusted for time (Z) with the required steady state value of 146%RHR can be obtained by linear interpolation between the high (140 to 160%RHR) and low (120 to 140% RHR)

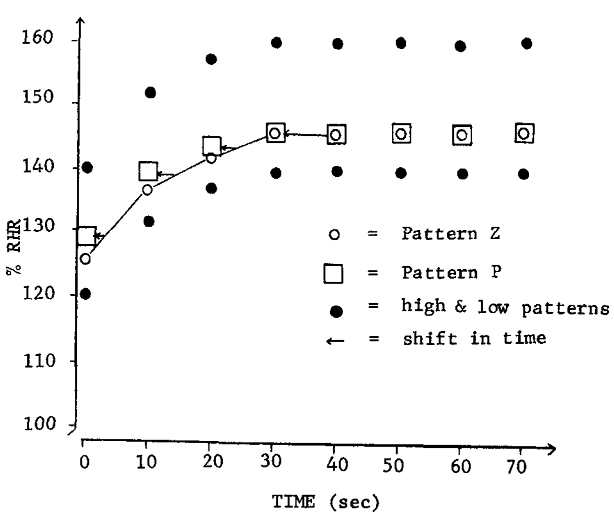


Figure 2: Graphic example of derivation of predicted heart rate pattern. Arrows represent shift of Z to intercept at an initial value of 129.

patterns. However, it can be observed that the resultant initial value of Z is 126% RHR and not the required 129%RHR. Therefore it is necessary to shift Z to the left such that the intercept at time zero for pattern Z is 129%RHR. The resultant pattern P is the pattern to be predicted. All patterns, for either positive or negative step changes in work load are determined in a similar manner and are expressed in terms of %RHR. Given the resting heart rate of a particular individual, P can be translated into actual heart rate values.

The predictive model will accommodate a series of fixed intensity tasks with a combined duration of no more than four minutes. The only purpose of the four minute time restriction is to avoid the effects of fatigue. As long as fatigue is not significant, the model will yield an accurate prediction. The predicted heart rate pattern for each task is derived according to the aforementioned procedures and then they are combined to obtain a prediction for the series. Suppose that it is desired to predict the cardiac response of a sedentary male with a resting heart rate of 76 beats per minute to a series composed of the tasks requiring work loads of 110 watts for 70 seconds, 175 watts for 80 seconds, and zero watts for 90 seconds. First, the heart rate pattern for the 110 watt task is predicted for 70 seconds. The heart rate value at time equal to 70 seconds becomes the initial value for the second task, and the heart rate pattern for the second task is determined. Task three is recovery to a resting state starting at time equals 150 seconds. Table 1 presents the predicted cardiac response as produced by the prediction model. Figure 3 is a plot of the predicted and observed heart rate values for the subject and tasks of the example.

Table 1 : Prediction model output for the subject and tasks of the example.

CARDIAC RESPONSE

MALE

SEDENTARY

RHR IS 76

WORK LOAD (WATTS)	ELAPSED TIME (SECONDS)	HEART RATE (BPM)	%RHR
110	0	76	100
110	10	88	115
110	20	94	123
110	30	97	127
110	40	98	129
110	50	99	130
110	60	99	130
175	70	99	130
175	80	104	136
175	90	107	141
175	100	110	145
175	110	111	146
175	120	112	147
175	130	112	147
175	140	112	147
0	150	112	147
0	160	105	138
0	170	99	131
0	180	95	125
0	190	89	118
0	200	86	113
0	210	82	108
0	220	81	106
0	230	79	104
0	240	77	102

EVALUATION OF THE PREDICTIVE ACCURACY

In order to verify the accuracy of the prediction model, a subject representative of each of the four subject categories performed six exercise series similar to the above example. Upon examining the distribution of the error, it was determined that

90% of the time errors of the prediction model were no more than 5% to 10% of the observed heart rate value.

SUMMARY

The purpose of this study was to investigate the feasibility of developing a predictive technique for heart rate which required a minimum of descriptive information. By expressing the heart rate data in terms of the percent of resting heart rate, a prediction model was developed and verified to be accurate. However, the prediction model, in its present form, accommodates only a segment of the adult working population and a limited range of physical activities. Much work remains to be done before the potential applicability of this technique can be fully realized.

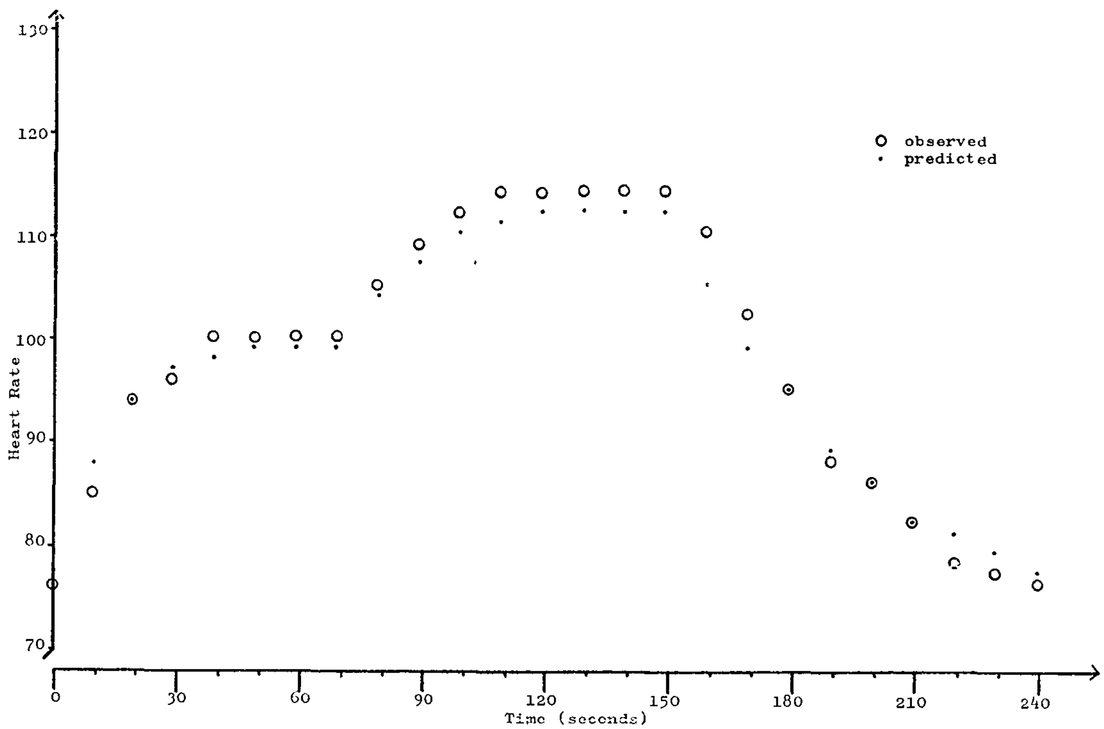


Figure 3: Plot of predicted and observed heart rate responses for the subject and tasks of the example.