HEART-BEAT RATE AS A MEASURE OF WORK COST OF REACHING SELECTED SHELF HEIGHTS

by

LUCY READER TORMEY

B. S., Kansas State University, 1940

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Family Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

Approved by:

Tessie Agan

Major Professor

ACKNOWLEDGMENTS

The writer wishes to express her gratitude to all who have assisted in making this study possible. Special gratitude is expressed to Miss Tessie Agan, Associate Professor of the Department of Family Economics, under whose guidance this investigation was planned and carried out, who was most generous with her time, efforts, encouragement, and valuable assistance.

Special appreciation is expressed to Dr. Stephan A. Konz, Associate Professor, Department of Industrial Engineering, for his guidance in carrying out this investigation, his assistance in obtaining and operating the electronic equipment, for giving constructive criticism of the manuscript, and for his encouragement.

Gratitude is also expressed to Dr. Richard L. D. Morse, Head and Professor of the Department of Family Economics, and to Dr. Dorothy Harrison, Professor, Department of Foods and Nutrition, for their aid in the study, for giving constructive criticism of the manuscript, and for their encouragement.

Appreciation is also expressed to Miss Katherine Regier, former graduate student, Department of Family Economics, who assisted with the testing of the subjects and the collection of data; to the twelve young women who served as subjects; to Bill Bailey and John Wenzl, General Research Laboratory, Department of Physics, who gave technical assistance in the installation and operation of the electronic equipment; and to my husband, Jim, whose encouragement and understanding made possible graduate study and the development of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Measurement of the physiological work cost of human performance has been developed for many different purposes. Few studies were reported on the comparative work cost of using housing facilities of various designs.

The study of work costs is one of the principal tools employed by industrial engineers to develop work station designs and to determine work loads. Work costs have been utilized by home economists to measure the physiological work costs of using devices of various designs and determining costs of various types of work carried on in the home.

Nutritionists in the United States Department of Agriculture were among the first to use calorimetry to study work costs. The devices required for measurement were appropriate for comparatively heavy work but were cumbersome. However, mechanization has changed the nature of work from strenuous to light both in industry and in the home, and now the need is for work cost studies of light work.

Home economists need information on work costs to aid the homemaker as she performs work, and to provide information on which manufacturers and builders can base equipment and design improvements.

Of the various methods of measurement used to determine work cost, measurement of heart-rate or pulse-rate with electronic measuring devices is the most recent development. However, as early as 1920, Amar (1) recognized heart-rate as a convenient measurement of effort, but techniques for measurement were difficult.

Measurements of heart-beat rate or cardiac frequency by electronic devices for sensing and recording provides an approach to the measurement of light work. It is believed (4) that an increase in heart beat constitutes a discriminative index for slight muscular activity, and also is applicable to heavy work. Measurement of heart-beat rate indicates the cost to the body of work being done, and the physical fitness of the subject as evidenced by the length of time to reach normal resting rate after a period of work (6).

The purpose of this research was to investigate the use of heart-beat rate as a physiological measure of the cost of light work using the elemental motion of lifting a one-pound weight to various shelf heights, and to compare the results thus obtained with a similar study where indirect calorimetry was the measurement used. Richardson and McCracken (23) investigated work costs of reaching to shelf heights beginning 4 inches above the floor and extending to 68 inches above the floor. Zones of "very comfortable", "comfortable", and "uncomfortable" reaches were established. The present study was designed to duplicate these reaches, using heart-beat rate as the measure.

In preliminary work, methods were developed for selecting and preparing the subjects, conducting the experiment, including collecting and analyzing the data.

REVIEW OF LITERATURE

Literature reviewed includes research using various physiological indices of measurement for the appraisal of human performance, particularly those involving heart-beat rate. When shifting from a resting state to one of activity, either light or heavy, it is known that many physiological functions change. Heart-rate, blood pressure, cardiac output, pulmonary ventilation, oxygen consumption, carbon dioxide production, chemical composition of the blood and urine, body temperature, functioning of the central nervous system, and rate of perspiration all are modified by activity (6). By measuring any one of those known variables while resting, during work, and during recovery from work, the cost of work to the body can be determined.

Calorimetry Methods of Measurement

For the past 75 years calorimetry has been the most widely used method of measuring work cost. This method is based on the law of the conservation of energy: that energy can neither be created nor destroyed, and therefore the energy content of any system can be increased or decreased only by the amount of energy that is added to or subtracted from the system. Calorimetry studies applied to man are of two types: direct, the measurement of energy expenditure in the form of heat; indirect, energy expenditure determined from the amount of oxygen consumed and the carbon dioxide produced (9).

In the beginning, nutritionists used direct calorimetry to measure energy. It involved the use of respiration chambers ranging in size from small ones accommodating a man in a standing or reclining position to those large enough to accommodate farm animals (27). A chamber is constructed of multiple layer walls that include cold water pipes for cooling, electrical elements for heating, and thermocouples for measuring the temperature of the water pipes within the chamber. Insulated walls prevent transfer of heat. The heat produced by the subject in the chamber is absorbed by the series of circulating pipes, and the increase of water temperature is measured. This apparatus is expensive to construct and difficult to operate.

A second development was the Douglas method of indirect calorimetry. Expired air was breathed into a rubber bag and analyzed for oxygen and carbon dioxide content (28). This method is also referred to as respiration calorimetry. In measuring energy indirectly, the known proportionality between oxygen consumption or carbon dioxide production and total energy production is used to compute the cost of a given task (9). The usefulness of this method is limited because the collection apparatus is cumbersome and prevents free movement. Since it is not possible to ascertain how much of the energy used is caused by the weight and discomfort of wearing the collection apparatus, the results may be affected. Complicated psychological problems may also arise when this type of testing equipment must be worn.

Another indirect method of measuring energy is a respiration gas-meter designed and constructed by researchers at the Max Planck Institute for Work Physiology in Germany (24). It consists of a lightweight box containing a meter for recording the volume of expired air. Although it is less cumbersome than the Douglas bag, it is necessary for the subject to wear it strapped to his back. Many investigators in the United States as well as in Germany use this type of respiration gas meter to measure work costs. Extensive experiments of the physiological costs of strenuous agricultural tasks were carried out at the German institute.

Calorimetry was the only method used by McCracken and Richardson in their 1959 study of the energy costs of reaching various shelf heights (23). Their findings were reported in calories per minute so that the data could be compared with other similar data. Measurements were made of the comparative energy requirements for storing utensils on open shelves and in base cabinets. Work was done while sitting, standing, and using one or both hands. Eleven subjects, ages 20 to 46, were used. Restrictions were a basal metabolism rate within 15 per cent of standard, height between 62 and 65 inches, and weight between 110 and 160 pounds. A Muller respirometer was used to collect expired air samples during each work-rest period. These were analyzed with a Pauling-type electronic oxygen analyzer.

For the statistical analysis of the data, the Duncan Multiple Range test was used. In some instances, results were definite. In others, overlapping of groups where no significant differences were found made secondary analysis or data interpretation necessary. These interpretations were made both graphically and numerically and in each case produced the same results. Regions of shelf height were found in which the Duncan test showed no significant differences in energy requirements. In the graphic analysis, where energy means were plotted against shelf height, two breaks in the curve were evident between the points representing 52 and 60 inches and between the points for 12 and

68 inches. Each break represented a point in the progressive array of means at which there was a marked increase in change in energy requirement at the various shelf heights. For standing and using both hands to reach a shelf, three areas of energy expenditure were defined:

1. Minimum, 28 to 52 inches.
2. Intermediate, 20 to 28 inches and 52 to 68 inches.
3. Maximum, below 20 inches and above 68 inches.

In a study reported in 1965, Richardson and McCracken (22) used a Müller respirometer (indirect calorimetry) to establish work cost for working heights and arrangement of home laundry areas. Ten women students, ages 35 to 47, performed a minimum of six light work sequences during each work day. Sampling periods were short, being from one to five minutes. Individuals varied, but the energy expenditure curves for different working heights were similar. These investigators pointed out that figures from early studies of laundry and kitchen work can no longer be considered applicable because of less fatiguing tasks and the lighter and more modern equipment in the home.

The Heart-Rate Method

Some new approaches to methods of measurement of work cost have been made. Almost all the chemical methods, such as analysis for the measurement of metabolism through calorimetry and the tests for changes in the blood and urine, are in the process of being replaced by more direct physical methods, stated Consolazio et al. (8). Automatic electronic systems for sensing and recording have made possible a large increase in the amount of data secured. Modern direct-writing instruments permit continuous electrocardiography over long periods of time (13).

Physiology of the Heart-Rate Method

"The remarkable relation between the quantity of work done and the number of respirations and pulsations" was first noted in the eighteenth century by Lavoisier (1).

The mechanics of the heart generally are understood. Its function is to pump blood, which carries oxygen to all parts of the body. The capacity of the blood to carry oxygen is determined almost entirely by the concentration of hemoglobin in the red cells. Oxygen diffuses from the blood into the muscles where it is used for energy production, and carbon dioxide diffuses from the muscles into the blood to return to the lungs for excretion. "Cardiac output" is defined as the total volume of blood expelled by the heart per minute. There are three ways of getting more oxygen to the muscles:

1. Pump more per minute.
2. Pump more strokes per minute.
3. Increase A-V differential.

The body does all three in the preferred sequence of (2), (1), (3). When heart-beat increases, cardiac output increases, and the latter equals the heart-rate in beats per minute times the stroke volume in liters per beat. It also equals the oxygen consumption in cubic centimeters per minute divided by the mean arterio-venous (A-V) oxygen difference in cubic centimeters per liter:

$$\text{Cardiac Output} = \text{Heart Rate} \times \text{Stroke Rate} = \frac{\text{Total oxygen consumption}}{\text{Mean A-V oxygen difference}}$$

Nerve impulses, constantly flowing between the heart and the central nervous system, control the rate of the heart-beat. Impulses are of two types, those that inhibit and those that accelerate the rate of heart-beat. By their mutually antagonistic effort, the heart-beat is kept steady. In common with all muscles, the heart develops an electric current when it contracts. This is especially important from medical and research standpoints, because it means that the electrical changes that occur as the heart beats can be studied with precision.

The electrocardiograph makes a record of the electrical changes that occur as the heart beats. Each heart-beat consists of four parts, each identified by a letter as follows:

1. P wave. Passage of a positive current over the atria.
2. Q wave. A period of electric neutrality. It may be absent in a normal electrocardiograph.
3. R wave. A period of contraction of the ventricles. The recording is tall, upright, and sharply pointed. It normally designates heart-beat rate.
4. T wave. A positive electrical condition, following a brief moment of neutrality after the R wave.

As soon as muscular activity begins, heart-rate rises quickly. With the increase in heart-rate, the fraction of each cardiac cycle, called "Systole" or contraction, increases slightly, while the "diastole", or relaxation part, decreases. Systolic and pulse pressures increase with the work load, while diastolic pressure changes are insignificant. Bouisset, Henon, and Moned (4) found that immediately after activity began heart-rate was increased about 35 to 40 per cent above the resting rate depending on the rate of work. Sometimes, when exhaustion develops rapidly, rates of 140 to 150 beats per minute are recorded. However, the heart usually slows down and returns to the resting level within three minutes. This can take place progressively or abruptly.

Methods of Counting Heart-Rate

A variety of methods have been used for recording heart-rate. In setting standards for Army field tests, Consolazio et al. (8) simply took the pulse manually of subjects before and after physical activity. A more sophisticated method, reported by Holter (13), used radio for the accurate transmission of electrocardiograms from freely exercising subjects. An "electrocardiocaster" worn in an upper coat pocket or fastened to the chest sent data to the receiving unit, enabling long range observations.

Photo-cell ear lobe clamps that send signals set in motion by each systole were used by Bouisset et al. (4) to measure cardiac frequency. Their ten subjects were seated at a work station and moved two weights of 200 grams each simultaneously and symmetrically. Each subject carried out two trials, separated by several days interval. Work periods were three minutes in length with three minute rest periods between, each sequence being preceded by a five-minute rest period. His recordings revealed the sensitive increase of heart-rate during the course of periods of work. From this study he reported that "the increase of cardiac frequency constitutes a discriminative variable even for slight muscular activity."

Factors to Consider in Heart-Rate Measurement

Individual differences must be considered when human subjects are used as an object of research. Age, fitness, and sex influence the body's adaptation to muscular work (6). In addition, training, anticipation, adverse conditions in the environment, and placement of the electrodes must also be controlled.

Age. Age as a factor to be considered in conducting research using heart-beat rate was studied by Karpovich (15).

Subjects should be within the same age group in any study of this type because heart-rate changes throughout life. Before birth, the heart-rate is high, ranging from 120 to 160 beats per minute. There is a steady decline after birth until a fairly constant average is reached at about age 15, when normal heart-rate is between 59 and 98 with an average of 72. In adolescents, however, Brouha (6) found a higher correlation between the ability to perform hard exercise and size of the individual than with those older. He concluded that after the age of 25 or 30 cardiovascular and respiratory capacity decrease and also oxygen consumption diminishes progressively.

Fitness. Fitness is probably the most important factor influencing capacity for doing physical work. The Harvard Step Test was developed by Consolazio et al. (9) for use by the Armed Forces in determining physical fitness. Index of measurement was pulse-rate taken manually before work and at thirty second intervals for two minutes, beginning at the end of the first minute of rest. Certain responses differentiate the fit from the unfit (6). The fit show less increase in pulse rate for submaximal exertion and quick recovery in pulse rate following activity than the unfit.

Sex. Men and women show marked differences in their physiological capacity to perform hard exercise. Brouha (6) pointed out that men were able to reach a greater ventilation and oxygen consumption, a higher respiratory quotient, and were therefore able to carry on work for a longer period of time than women. The means and extremes of maximum heart-rate were almost identical in both sexes, but the women reached the maximum in almost half the time (6). In addition, all the other body systems of women were taxed to the limit in a much shorter time than those of men.

Training. Training improves the precision and economy of any motion involving muscular activity. A decrease in energy expenditure after training of up to 25 per cent of the total energy required before training was reported by Brouha (6).

Anticipation. Anticipation is an important factor when measuring work with the heart-rate method (18). Using a telemetry system, he obtained heart-beat records from ten gymnasts in excellent physical condition, ages 17 to 21, in a rope climb, a severe short duration activity. Heart measurements were made for the pre-warm-up period, during the climb, at the end of the climb, and ten seconds later. The percentage of anticipatory heart-rate increase over the basal value of the post warm-up for the climb was approximately 25 per cent.

Location of Electrodes. The location of the electrodes on the body is important to the proper measurement of heart-rate. Kozar (18) used two surface electrodes placed in the areas of the base and apex of the heart. This was away from the large muscle mass, to minimize "muscle noise".

The type of work also influences the choice of position of the electrodes. When the activity required bending forward (15), electrodes were taped to the backs of male subjects stripped to the waist for ease of performing work. A stethoscope was used to locate the area where a strong heart-beat would be sensed by the electrodes.

From these and other studies it was indicated that a common method employed is to place the electrodes in the heart area, one above and one below the heart. A third electrode is often used as a grounding device.

Adverse Conditions in the Environment. Adverse conditions in the environment can transform an easy task into a hard one, according to the findings of Brouha and Maxfield (7). They cautioned that room temperature, humidity, noise, physical strain, and fatigue should be controlled when cardiac tests are conducted (7). Temperature and humidity controls were used by Karpovich (15) in a heart-rate study in which male subjects worked in sequences of two minutes warm-up, two minutes work, and two minutes rest.

Relationship Between Heart-Rate and Calorimetry

Several investigators attempted to determine if a relationship exists between heart-rate and calorimetry. Using both calorimetry and a heart-rate method, Brouha (6) tested a 29-year-old woman and a 35-year-old man. They rested ten minutes, then peddled ergometers for eight or ten successive work periods of ten minutes each, with intervening rest periods to return to the pre-exercise oxygen level. The data supported the contention that the work rate may be indicated either by the rate of oxygen consumption obtained by the calorimetry method, or the physiological strain in the individual measured by the heart-beat rate response. Cardiac cost was defined as a measurement of the area under the heart-rate curve obtained from plotting the rate for each minute of work and recovery. Total cardiac cost is the sum of the excess heart-beats that occur during work plus the sum of the excess heart-beats during recovery.

Using a Beckman oxygen analyzer simultaneously with electrocardiogram electrodes on the chest, linked to a cardiotachometer through a FM radio transmitter in a head-band, Andrews (2) obtained both calorimetry and heart-beat measure of work cost. From these data he concluded that the effect of different subjects can be reduced to statistical insignificance by using incremental (the change from resting level) rather than gross measures of heart-rate and rate of oxygen consumption. His subjects performed 15 tasks representative of four dimensions:

1. Dynamic and static work.
2. Arm and leg work.
3. Standing and bending work.
4. Symmetrical and assymetrical work.

Heart-Rate Pilot Studies

Two pilot studies conducted cooperatively by Tormey (26) and Regier (21) investigated further the heart-beat rate as a method to measure work cost. Ten women students chosen at random worked for two minutes in each of 18 conditions representing four shelf heights, two above counter and two below counter. Moving cans of food was the task and heart-rate was the index of measurement of work. Variables were performing this task sitting and standing, using one hand and using both hands simultaneously and symmetrically, and lifting one and two pound weights.

For the above counter shelves, the least costly condition, placing a one-pound weight on a shelf 52 inches from the floor while the subject stood, resulted in an average of 7.4 heart-beats above basal. The most costly condition, placing two one-pound weights on a shelf 64 inches above the floor while sitting, resulted in an average of 22.6 heart-beats above basal.

In the below counter reaches, the least costly, placing two one-pound cans on a shelf 24 inches above the floor while sitting, resulted in an average of 20 heart-beats above basal. The most costly, placing two one-pound weights on a shelf 5 inches above the floor while standing and using a knee-bend, resulted in an average of 89 heart-beats above basal.

Some difficulties were encountered in this pilot study because of the test environment and the choice of subjects. The test area was not controlled in temperature or humidity, and there was lack of privacy. There was some difficulty in scheduling subjects for a second trial, and some of the subjects were fatigued from other activities upon arrival. The range of height, weight, and physical condition was wide. All these factors were considered and improved upon in planning for the research reported here.

Other Laboratory Methods Used for Work Measurement

The Force Platform

A description of the force platform is reported by Brouha (6). It is a laboratory tool that measures all muscular activity and is so delicate that it detects the heart-beat of a subject standing still and performing no other motion. The basic principle of this device is that any force exerted on an equilateral triangle can be resolved in three planes. It was invented by Lucien Lauru in France in 1953, and later improved upon by Barany at Purdue University. Lauru's platform, consisting of a stage to support an operator, had a piezo-electric sensing device, through which mechanical energy was converted to electrical energy. Barany's platform used two superimposed triangles to measure upward and downward motions. The muscular effort to do a task plus the force required to keep the body in balance are measured by the force platform and recorded electronically. While working to improve the force platform, Greene (11) was able to include the measurement of heart-rate in addition to other muscular effort.

A force platform measuring torque as well as upward and downward motions was developed and reported by Konz at Kansas State University (17). Ten undergraduate subjects, including three women, performed a simple push-pull task while standing on the force platform. The output in terms of muscular effort was recorded electronically by a trace on the recording paper. Measurements of the area under the curve created by the trace were made with a planimeter. Konz pointed out that the total energy required for a task has two components: the energy to do the task itself, and the energy required to position and control the body while doing the task.

Knowles (16) used a device similar to the force platform, called a mechanical recording platform, that transmitted a signal to a kymograph for recording. She tested the effects of the ironing surface on the woman worker, using as subjects four women ages 22 to 40. Each repeated three tests for three days. Force exerted was measured in pounds per second. At the same time, she measured metabolism with a Sanborn waterless metabolism tester. Also, she measured blood pressure with a Mercury Manometer before and after each test period.

Chemical and Other Methods

Histologists, skilled in the microscopic study of the structure of cells, use various tests of the blood and urine that show changes during work and recovery. Eosinophil count is one of these. Methods of chemical analysis are described by Consolazio (9).

Other tests involve changes in the functioning of the central nervous system: finger tremor measured in both frequency and amplitude (19); flicker-fusion for light and flutter-fusion for sound, in which flicker and flutter are no longer observed when fatigue sets in (25).

Galvanic skin response, the electrical activity in the skin, has also been used as a measurement technique. Perspiration is a good conductor of electric current and this reaction is reflected in electrical resistance as effort increases (25).

METHOD OF PROCEDURE

Design of the Experiment

The first consideration in the design of the experiment was the choice among the methods of measurement known to be used to evaluate physiological work costs. After deciding upon heart-rate as the method to be used in this study, the various methods of obtaining a heart-rate record were surveyed. Those for which equipment was available were tested. One of them was a photo cell attached to a finger. Also, consideration was given to using an ear-lobe clamp photo cell. A force platform was tried, with surface electrodes as the sensing device. Chest electrodes for sensing with an electronic amplifier, scaler, and recorder were the final choice. These instruments were the most reliable sensing and recording equipment available that give a continuous written record.

A second consideration involved the control of many of the factors that might have an adverse effect on the data. Differences in human subjects included age, weight, height, attitude toward the project, fatigue, and response to anticipation. External factors were period of the day, temperature, relative humidity, and occurrence of interruptions.

Task

Lifting a one-pound weight to and from shelves of nine different heights was selected as the task to be performed. This task is commonly done in the home; it employs simple motions performing light work. Work height was tested.

In studying memomotion films of women at work in the Experimental Kitchen Laboratory (Depertment of Family Economics, Justin Hall, Room 325), the investigator observed that much of the work done with arms end hands involved lifting light weight objects. Primarily, hand, arm, and upper trunk muscles were involved, plus the effort of the muscles required to hold the body in balence while performing the task.

It was recognized that the worker lifts the weight of the arm end hand, about twelve pounds (10) in the average woman of the size chosen for this study, in eddition to the weight of the can of food.

Shelf heights corresponded to the Richardson and McCracken study (23). A shelf 36 inches from the floor simulated counter height. The shelves on which the one-pound can of food was pleced were 4, 12, 20, 28, 44, 52, 60, 68, and 76 inches from the floor (Plate I).

Order of conditions as designated by shelf height was randomized to equalize the effects of fetigue, enticipation, end other physiological reections (Appendix A).

Shelves were located in the Experimental Kitchen Laboratory, an air-conditioned room where the tempereture was set et 74°F. During testing, a daily record was kept of the room temperature and relative humidity (Table 1).

Subjects

The subjects were e homogeneous group. Their ages ranged from 17 to 25 with e mean of 22. Their weights ranged from 119.5 to 140 pounds with a mean of 127.6. Their heights were from 63 to 65.375 inches

EXPLANATION OF PLATE I

Open shelf floor cabinets. Heights of each shelf were:

Number 1--4 inches from floor

Number 2--12 inches from floor

Number 3--20 inches from floor

Number 4--28 inches from floor

Counter--36 inches from floor

Number 5--44 inches from floor

Number 6--52 inches from floor

Number 7--60 inches from floor

Number 8--68 inches from floor

Number 9--76 inches from floor

PLATE I

TABLE 1.--Temperature and humidity readings

Subject	Date	Temperature	Relative Humidity
A	6-27-67	76.2° F.	52%
C	6-29-67	75.25	54
D	6-30-67	75.5	55
E	7-3-67	75.25	46
F	7-4-67	75.3	46
G	7-5-67	76.3	51
H	7-6-67	75.1	52
I	7-7-67	77.8	48
J	7-10-67	76.25	56
K	7-11-67	75.5	58
L	7-12-67	76.25	51
Mean		75.9° F.	51.73%
Range		75.1 - 77.8	46% - 58%

with a mean of 64.01. Shoulder height while standing ranged from 51.375 to 53.75 with a mean of 52.63. Arm length ranged from 26.0 to 29.75 with a mean of 28.52. A summary of subject data is given in Table 2.

Subject B appeared to be an outlier when the data were studied. The Dixon criteria for the rejection of outlying observations was used to confirm this observation (Appendix B), and on this basis the data for subject B were not included in Table 2.

Discussion during the pre-test period with the subjects revealed that they were an active group of young women. One walked to and from the campus, two miles each day, for the past school year. Another walked three miles every other day to reach the campus from her home, and also swam almost every day. One, a young mother of two small children, said she water-skied, did yard work, and had painted her house, in addition to her normal household work.

The subjects were instructed to wear comfortable fitting blouses opening down the front to facilitate the placement of the electrodes in the heart area, and slacks or shorts to permit freedom of movement. This is typical of the clothing worn by the young homemaker as she performs her work in the home, and contributes to freedom of movement and a relaxed atmosphere.

All subjects worked at the same time of day, all were right-handed and used the right hand, and pace was determined by a metronome set at 32 beats per minute. All stood at the same place on the floor.

TABLE 2.--Summary of age, weight, and anthropometric measurements

Subject	Age	Weight in Pounds	Height in Inches	Shoulder Height, Standing (in.)
A	22	140	64.125	53.625
C	20	121	63.875	52.75
D	18	120	63.625	52.0
E	17	128	65.375	53.375
F	18	119.5	63.625	52.0
G	22	123	63.625	52.25
H	21	125	64.875	53.25
I	21	128	63.75	53.75
J	19	126	63.625	51.375
K	25	133	63.0	51.625
L	20	140	64.25	53.0
Mean	22	127.6	64.01	52.63
Range	17.25	119.5 - 140	63.0 - 64.875	51.375 - 53.75

Elbow Height, Standing (in.)	Arm Length, Shoulder to End of Thumb (in.)	Normal Upward Reach Above Floor (in.)	Maximum Upward Reach Above Floor (in.)	Normal Downward Reach Above Floor (in.)
39.5	29.75	75.25	81.0	26.875
41.0	26.875	77.0	79.5	26.625
40.0	28.5	76.5	80.25	25.5
39.5	28.625	77.125	81.5	26.75
38.75	28.75	76.25	80.0	27.5
38.75	27.75	75.75	79.875	26.0
40.0	29.25	75.5	80.5	26.75
39.5	26.0	79.0	81.0	27.0
38.25	30.5	76.25	81.5	26.0
40.0	28.0	73.75	78.5	28.75
39.5	29.5	75.25	81.0	27.75
39.5	28.52	76.15	80.15	26.8
38.25 - 41.0	26.0 - 29.75	73.75 - 79.0	78.5 - 81.5	26.0 - 27.75

Apparatus

The apparatus used in performing the experiment follows:

1. Three electrodes and a custom-built heart-beat junction-box by Konz.

2. Sanborn low-level amplifier, Model 150-1500 with power supply Model 150-400, and Model 151 Strip Recorder.

3. Baird-Atomic, Inc. Multiscaler II, Model 132.

4. Apollo 7-jewel stop-watch, calibrated in minutes and half minutes.

5. Seth Thomas metronome.

6. Set of custom-built shelves.

7. One one-pound can tomato sauce.

For the rest periods, the following were used:

1. Chair with arm rests.

2. Cot for ten-minute reclining rest periods.

3. Orange drink served to subject mid-way in test period.

Equipment used for taking weight, height, and anthropometric measurements included:

1. Custom-built anthropometer; specifications by Department of Family Economics and constructed by Department of Industrial Engineering, Kansas State University.

2. Custom-built sliding body calipers; specifications by Department of Family Economics and constructed by Department of Industrial Engineering, Kansas State University.

3. Yardstick.

4. Standard tape measure.

5. Steel tape measure.

6. Decto-medic scale, 300 pound capacity.

Procedure

The work area was set up before the subject arrived. Knowing that emotion could occur undetected, the investigator attempted to establish an easy rapport with each subject before the actual test began.

On arrival, the subject was shown the research area and informed about the experiment. Then, after the use of oral instructions concerning placement of the electrodes for sensing the heart-beat and a photograph, she attached them to her own body (Plate II).

Next the electrode leads were attached to the heart-beat junction-box, a small device attached to a belt worn around the waist (Plate III). The junction-box was attached to the Sanborn amplifier and the Sanborn strip-recorder through a long lead wire, giving freedom of movement within the work and rest areas. When adjustment of the recording apparatus was made, the subject was shown how she could "see" her own heart-beat as the electrodes sensed her heart-beat and the trace on the recorder made a printed record of the "R" waves (Plate IV).

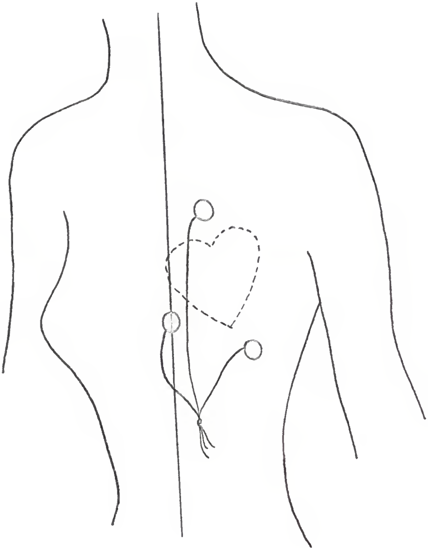
Oral instructions were given concerning the procedure to follow, and the subject practiced briefly to establish a working rhythm with the metronome and to become familiar with the work routine. The practice session was followed by a ten-minute reclining rest before the first recorded work-rest sequence began.

The investigator and her assistant operated the electronic equipment (Plate V), reading the scaler, marking the strip chart paper with a

EXPLANATION OF PLATE II

Location for placement of the three electrodes around the heart area.

PLATE II



EXPLANATION OF PLATE III

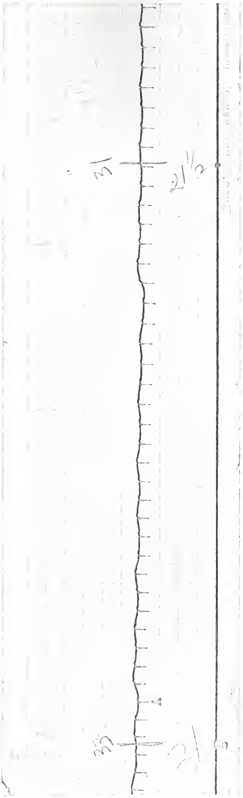
An over-all view of the work area. Subject stands in working position in front of the labeled shelves. The marking parallel to the front of the cabinet indicates position of feet when reaching above the counter. The diagonal marking indicates position of feet when reaching below the counter. The heart-beat junction-box is worn attached to subject's belt. Wiring extends from it through the front of the subject's blouse to electrodes. A long wire lead, enabling freedom of motion, extends from the junction-box to the Sanborn low level amplifier. A comfortable arm office chair was located near for rest periods. The metronome, used for pacing the reaches, was located near at hand.

PLATE III

EXPLANATION OF PLATE IV

Chart-paper from Sanborn strip recorder, showing (A) the R-waves of the heart-beat, and (B) the 30-second interval markings.

PLATE IV



EXPLANATION OF PLATE V

The assembly of instruments used in the measurement of the heart-beat:

A. Sanborn low-level amplifier, to which the heart-beat monitor was attached, at the lower left hand corner.

B. Sanborn strip-recorder, attached to the Sanborn low-level amplifier. The R-waves of the heart-beat were recorded on chart paper by this instrument.

C. Baird-Atomic scaler, attached to Sanborn low-level amplifier. It metered the number of heart-beats per minute, which were read and recorded, and served as a check on the recordings of the Sanborn strip-recorder.

D. Apollo stop-watch used for indicating the half-minute intervals on the chart-paper of the Sanborn strip-recorder and to record readings from the Baird-Atomic scaler.

PLATE V

device on the Sanborn recorder, and instructing the subject in the procedure to follow as the experiment progressed.

Oral instructions given the subject were "stand", "begin work", "shelf 5, shelf 3, etc.", "stop work", and "sit".

The experiment was replicated in two runs the same day. The sequence of lifts for one subject is shown in Chart 1. The can was placed on the 36-inch counter and was returned to it at the end of each lift.

	Shelf Sequence:				
RUN I Part 1:	5	3	6	4	9
BREAK					
Part 2:	8	1	7	2	

BREAK - ORANGE DRINK - REST

2	6	5	4	9
3	1	7	8	

Chart 1.--Random sequence for Subject A

The first 28 minute work-rest sequence was performed by the subject following her own random order of work (Appendix A), with 3 minutes rest and 2 minutes work. Five work-rest periods were included (Chart 1).

During each 3 minute rest period, the subject rested in a chair to the right of the work area (Plate VI). At the end of the first part of the first run, the leads from the electrodes were detached from the heart-beat junction-box, the belt holding the junction-box was then removed from the subject, and she rested reclining for ten minutes on a cot placed immediately in front of the test area (Plate VII).

The second part of the first run had four work-rest periods. It was 23 minutes in length and completed Run I.

Mid-way in the entire test period, the electrode leads were detached from the heart-beat monitor. The subject was given opportunity to relax, and had an eight-ounce glass of orange drink, followed by a second ten minute reclining rest.

The second replication, or Run II, with a second set of random reaches, proceeded in a similar manner.

When Run II was completed, the subject was weighed and anthropometric measurements were taken (Appendix C).

Data Reduction

The data were recorded electronically by the Sanborn strip recorder on single-channel chart paper at a speed of 5 mm/second. Each half minute period was marked by pushing a control switch on the instrument. Since the chart paper was calibrated to show a timing of 5 mm/second,

EXPLANATION OF PLATE VI

Subject sitting to rest, wearing heart-rate monitor attached by a lead wire to the Sanborn recorders.

PLATE VI

EXPLANATION OF PLATE VII

Subject reclining to rest. The heart-rate monitor is detached.

PLATE VII

the time periods were checked by measuring with a millimeter rule. Readings also were taken at half minute intervals from the Baird-Atomic scaler and recorded on a data sheet (Appendix D).

Heart-beats were counted manually from the trace on the chart paper and checked with the scaler readings. A curve was plotted on 46-0700 graph paper for each subject, each shelf height (Appendix E). To obtain a cost-of-work reading, the area under the curve for each work period plus the recovery period following it, measured with a planimeter, gave extra heart-beats per minute for each subject for each shelf height.

A basal heart-rate was calculated for each subject by averaging the fourth and fifth half-minutes of Run I rest periods with the fifth half-minute of Run II rest periods. In analyzing the data, it was noted that anticipation or nervousness affected the recovery periods of every subject during Run I. Therefore, to counterbalance this, the fourth and fifth half-minutes of recovery were used to establish all the basal figures for Run I.

RESULTS AND DISCUSSION

Heart-Rate Response During Work and Recovery

The eleven women retained for this test lifted the one-pound weight from a counter 36 inches from the floor to nine shelves spaced 8 inches apart beginning 4 inches from the floor and ending 76 inches from the floor.

Extra heart-bests above basal for each subject for each shelf height are shown in Appendix G.

Ranked in order of lowest work cost as determined by extra heart-beats per minute above basal in work and recovery, the 28 inch shelf, immediately below the 36 inch counter, was easiest, using 43 extra heart-beats. This was followed by the 20 inch shelf, using 46 extra heart-beats.

The next most costly was the 44 inch shelf immediately above the counter, using 49 extra heart-beats per minute, and the 52 inch shelf, using 50 extra heart-beats. In ascending order, work cost in extra heart-beats per minute above basal in work and recovery, were all the other shelves above the counter, 60 inches, 68 inches, and 76 inches. The most costly were the shelves 12 inches and 4 inches above the floor, requiring 57 and 66 extra heart-beats per minute, respectively (Fig. 1, Appendix G).

Statistical Analysis

The Wilcoxon Matched-Pairs Signed-Ranks statistical test was used to evaluate the difference between the means of the extra heart-beats above basal resulting from reaching to selected pairs of shelves. Procedure for calculation of the test is described in Appendix F.

When using the Wilcoxon Matched-Pairs Signed-Ranks test, a significant difference between the two pairs of data at the .05 level is considered statistically reliable. In some of the comparisons, results were near the .05 level of significance. In these cases, significant difference was determined also at the .06, .08, and .10 levels (Table 3). The following general hypothesis was investigated: height of shelf affects physiological cost to the body as measured by extra heart-beats per minute above basal.

The Wilcoxon Matched-Pairs Signed-Ranks test showed the following results:

1. No significant difference at the .05 level in work cost was found when reaching to the two lowest shelves, 4 inches and 12 inches above the floor; these two required the largest number of extra heart-beats per minute. A significant difference at the .10 level indicated that it was somewhat more difficult to reach the 4-inch shelf than the 12-inch shelf.

2. A significant difference at the .05 level was found between reaching to the 4-inch shelf and all the other shelves from 20 inches to 68 inches, with the 4-inch shelf requiring more extra heart-beats per minute.

3. Although the 4-inch shelf required a few more extra heart-beats per minute than the 76-inch shelf, no significant difference was found between them. It would be as difficult to reach to the 76-inch shelf requiring a slight shift of the shoulders as to stoop to the 4-inch shelf. There was a significant difference at the .08 level indicating that it was somewhat more difficult to reach the 4-inch shelf than the 76-inch shelf.

4. Although the 12-inch shelf required more extra heart-beats per minute than the 52-inch, 60-inch, 68-inch, and 76-inch shelves, there was no significant difference between them.

TABLE 3.--Pairs of shelf heights where significant differences occurred when tested by the Wilcoxon Matched-Pairs Signed-Ranks test[1]

Shelf Heights Compared	
4" vs 12"[b]	4" vs 68"[a, b]
4" vs 20"[a, b]	4" vs 76"[b]
4" vs 28"[a,b]	28" vs 68"[a, b]
4" vs 44"[a, b]	28" vs 60"[b]
4" vs 52"[a, b]	

[1]The tests were made at the 0.05 level of significance, but when found to be not significantly different at this level, but nearly so, tests also were made at the 0.06, 0.08, and 0.10 levels of significance.

[a]Significant difference at 0.05.

[b]Significant difference at 0.10.

5. Although the 28-inch shelf, 8 inches below the counter, required the least extra heart-beats per minute, there was no significant difference between it and any of the shelves above the counter until the shelf 68 inches above the floor was reached. However, the 60-inch shelf, not significant at the .05 level, was significant at the .06 level. Thus it was bordering on being more difficult to reach the 60-inch shelf than the 28-inch shelf. There seems to be an area between 28 inches and 60 inches which showed little difficulty in reaching.

6. No significant difference was found between the 44-inch shelf and any shelf above it, nor was there any significant difference between any other pair of shelf heights above the 44-inch shelf. Summary of these findings are shown in Chart 2.

After these preliminary statistical tests were made, the analysis of variance test also was applied with the null hypotheses being tested for several shelf heights. The results of the various tests are as shown in Table 4.

Relationship of the Extra Heart-Beat Method to the Calories per Minute Method of Work Cost

The initial purpose for measuring extra heart-beats above basal when performing a task was to determine if this method of measuring work cost is a suitable and reliable substitute for the method in which calorimetry is used. The likeness of the curve when the two sets of data are plotted is shown in Fig. 2.

The data for the extra heart-beats per minute when lifting a one-pound can of food to nine shelves were superimposed on a graph showing the calories per minute data from the Richardson and McCracken study in which five pounds were lifted to the same height of shelves. It is acknowledged that there is a disparity in the weight of the loads but it is pointed out that it is now desired to learn the work cost of light loads, and that lifting five pounds is about the lightest weight possible to measure accurately by the calorimetry method.

Chart 2.--Summary of findings from Wilcoxon Matched-Pairs Signed-Ranks test as applied to extra mean heart-beats when selected shelf heights were compared

Height of Shelf:	28	20	44	52	60	68	76	12	4
Mean Heart-beats:	40.8	46.4	48.8	49.9	52.5	54.6	56,3	56.9	65.8

(Lines indicate significant difference when α = .05).

Height of Shelf:	28	20	44	52	60	68	76	12	4
Mean Heart-beats:	40.8	46.4	48.8	49.9	52.5	54.6	56.3	56.9	65.8

(Lines indicate significant difference when α = .10).

TABLE 4.--Analysis of variance of mean extra heart-beats used when selected shelf heights were compared

Source of Variation	Degrees of Freedom	Mean Square	F
Heights	8	556.82	2.93**
Subjects	10	1,304.4	6.87**
Error	80	189.89	
Total	98		

Hts. LSD* = 11.8

Height	Mean Extra Heart Beats		Comparison and Significance
4"	65.8	(1)	4 vs 12 ns
12"	56.9	(2)	4 vs 20 *
76"	56.3	(3)	4 vs 76 ns
68"	54.6	(4)	12 vs 52 ns
60"	52.5	(5)	20 vs 52 ns
52"	49.9	(6)	28 vs 44 ns
44"	49.6	(7)	12 vs 28 *
20"	46.4	(8)	44 vs 68 ns
28"	40.8	(9)	44 vs 76 ns

*$P < 0.05$.

**$P < 0.01$.

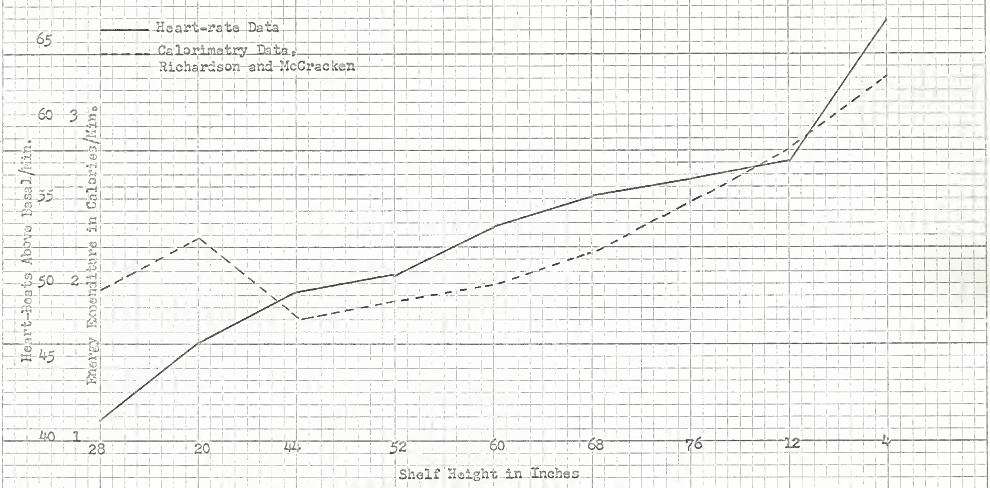


Fig. 2.--Graph showing a comparison of the values for the heart-rate method used in this study and the calorimetry method used in the Richardson-McCracken study. The coefficient of correlation was 0.819 for the two sets of data. Omitting the 20-inch and the 28-inch shelves, the coefficent of corralation was 0.966.

By observation it was shown that values in the two graphs were similar with the exception of the two shelves, 20 inches and 28 inches below the counter, and the first shelf, 44 inches above the counter. The values for the 44-inch shelf were similar but slightly different for both sets of data, but the relative positions of the other two shelves to the 44-inch shelf were different.

From the calorimetry data the 44-inch shelf was the least in work cost and the 28-inch shelf was slightly more costly. The 20-inch shelf was still more costly.

From the extra heart-beat data it was shown that the 28-inch shelf was by far the least work costly and the 20-inch shelf was also low in work cost. Both were far below the 44-inch shelf, which was more in work cost than when calorimetry was used. It would appear that, at least for the first two shelves below the counter, there is a difference between the two methods of determining work cost. Or it may be that there is a real difference in the way the body is managed at these levels when it is lifting one pound with one hand and when it is lifting five pounds with two hands.

When the test for the coefficient of correlation was applied to the two sets of data, the result was 0.819 with 6 df. The test was also applied to the data omitting the 20-inch and 28-inch shelves. The result of this test was 0.966 with 4 df (Fig. 2).

By the statistical tests it can be assumed that the extra heart-beats above basal method of computing work costs was a reliable substitute for the calorimetry method for this particular task.

The study reported by Richardson and McCracken established zones in which they recommended the location for storage of heavy items, or those used frequently, between 28 to 52 inches; for storage of lighter weight objects or those used infrequently, between 20 and 28 inches and between 52 and 60 inches; and those seldom used objects in areas above and below these heights. To arrive at these conclusions, their total study included measurements for some lighter loads, down to one pound, heavier loads up to 15 pounds, working while sitting and while standing, and reaching over several different distances to deposit a load on a shelf.

The results of the study reported here compare well with the recommendations proposed by Richardson and McCracken, considering that only a light weight was lifted and one simple motion was employed, standing and using one hand to lift; whereas, in the Richardson and McCracken study a five-pound weight was lifted and two hands were used. Both studies established the highest and lowest shelves as the greatest in work cost. Although not shown to be significantly different when lifting a light weight, the area between 20 inches and 52 inches from the floor was least costly for work. This was close to the area designated by Richardson and McCracken for the heavy or most frequently used items.

It is recommended further work be done using the extra heartbeats above basal as the measurement. The measurements should begin with simple elemental motions applied to simple tasks, thus establishing work costs that can be applied to more complex work.

Relationship of Extra Heart-Beats Above Basal to Anthropometric Measures

Many researchers have studied the relationship of the body measurements of women and the mechanics of their motions to the heights of various storage elements. The data in this study showed a relationship in the response of the heart in terms of work cost to the various storage levels.

It is noted that the 28-inch shelf is near (within 1.2 inches) the normal downward reach of these subjects. This suggests that gravity may absorb some of the work cost at this level of reaching. The fact that the next lower shelf, 20 inches from the floor, used only three more extra heart-beats per minute would seem to substantiate this observation.

The first two shelves above the counter, 44 and 52 inches, were the next most costly as measured by extra heart-beats. The 52-inch shelf was in line with the average height of the subject's shoulders. It could be said that beginning with a shelf at shoulder height the work cost of lifting a one-pound weight decreased until the normal downward reach, and increased slightly for the next eight inches.

The 12 and 4-inch shelves required lowering the torso to reach them, which weight was added to the weight of the one-pound can, and together were the most costly as measured by extra heart-beats.

Above the shoulder, the work cost in extra heart-beats per minute increased in ascending order as the height in shelves increased.

The 76-inch shelf was 14 inches above the average height of this group of subjects. Reach to it appeared to be attained easily, but not without some upward shift in the position of the shoulder. This shift was necessary in spite of the fact that the average arm length added to average shoulder height is 81.15 inches, or 5.15 inches higher than the highest shelf reached, 76 inches.

Even with the greatest stretch comfortable to use, the highest average upward reach was only 80.15 or one inch less than the average combined arm length and shoulder height. Thus, to reach this height with a one-pound weight, the subject was lifting the weight of her arm and part of the mass of the body at the shoulder in addition to the one-pound weight.

SUMMARY

The purpose of this research was to investigate the use of heart-rate as a physiological measure of the cost of light work. The results thus obtained were compared with a similar study where calorimetry was the measurement used by Richardson and McCracken at the Institute of Home Economics, United States Department of Agriculture.

Count of the extra heart-beats above basal of eleven women subjects was recorded electronically while they lifted a one-pound weight from a counter height of 36 inches to nine different shelf heights. Ranked in ascending order of work cost as determined by extra heart-beats in work and recovery, it was found that placing the weight on a shelf 28 inches from the floor required the least, or 40.8 mean heart-beats

above basal. The most difficult condition, a shelf 4" from the floor, required 65.8 extra heart-beats. Nearly as difficult, and not significantly different, was the reach to a shelf 76 inches from the floor, requiring 56.3 mean heart-beats above basal.

A comparison was made between the findings of this study and the data from the Richardson and McCracken study. Work costs and rank order were similar with the exception of two below counter shelves, 20 and 28 inches from the floor, and one above counter shelf, 44 inches from the floor. From the calorimetry data the 44-inch shelf was least in work cost, the 28-inch shelf was slightly more costly, and the 20-inch shelf was still more costly. From the extra heart-beat data the 28-inch shelf ranked lowest in work cost, the 20-inch shelf was next, and the 44-inch shelf ranked third. However, for this study, statistical tests showed no significant differences in heart-rate cost between any combination of the 28-inch shelf, the 20-inch shelf, or the 44-inch shelf.

From the results of studies using reaching under several different conditions, Richardson and McCracken were able to establish areas of minimum, intermediate, and maximum reach. Results of this heart-rate work cost study corresponded with their results in a general way at the extremes and more broadly in the areas of intermediate and minimum reach. The two sets of data were tested for the coefficient of correlation, resulting in .819 for all the different heights of reaches. Excluding the differing 28-inch and 20-inch shelves the correlation was .966.

Comparing the anthropometric measurements of the subjects to the work cost of lifting to the various shelf heights, it was found that beginning with a shelf at shoulder height, 52 inches from the floor, the work cost of lifting one pound decreased progressively until the point of downward reach. It increased slightly at the next lower shelf, 20 inches. The two lower shelves, 4 and 12 inches from the floor, were the most costly since the torso had to be lowered to reach them. Above the shoulders, the work cost in extra heart-beats per minute increased in ascending order as the height of the shelves increased. At this point there was some upward shift in shoulder position, resulting in the necessity to lift part of the mass of the body as well as the weight of the arm and the one-pound weight.

It is recommended that further investigation be carried on using extra heart-beats above basal as the measurement. Simple tasks employing elemental motions should be tested, such as the basic hand and arm movements with and without the lifting of various weights; forward and backward, rotary and torque motions; walking with and without a load; and bending or stretching the body to perform various tasks. Investigations of this kind would further establish heart-rate as a simple and reliable method of measuring work costs that could be applied to any work requiring such motions.

LITERATURE CITED

1. Amar, Jules. The Human Motor. Dutton & Co. 1920.

2. Andrews, Robert B. "Indices of Heart Rate as Substitutes for Respiratory Calorimetry." American Industrial Hygiene Association Journal. Vol. 27, 1966.

3. Barnes, R. Motion and Time Study. John Wiley & Sons, Inc., New York. 1958.

4. Bouisset, S., Henon, D., and Moned, H. "Influence of the Amplitude of Movement on the Cost of Muscular Work." Ergonomics. 1962. p. 256-270.

5. Bratton, Esther. "Some Factors of Cost to the Body in Standing to Work and Sitting to Work Under Different Postural Conditions." Memoir 365, Cornell University Agricultural Experiment Station. 1959.

6. Brouha, L. Physiology in Industry. Pergamon Press. 1960.

7. Brouha, L. and Maxfield, M. E. "Practical Evaluation of Strain in Muscular Work and Heat Exposure by Heart-Rate Recovery Curves." Ergonomics. Vol. 5. 1962. p. 87-92.

8. Consolazio, C. Frank, Johnson, Robert E., and Pecora, Louis J. "Environmental Temperature and Energy Expenditure." Journal of Applied Physiology. Vol. 18. 1965.

9. Consolazio, C. Frank, Johnson, Robert E., and Pecora, Louis J. Physiological Measurements of the Metabolic Functions in Man. McGraw-Hill Book Co., Inc., New York. 1963.

10. Contini, Renato, Drillis, Rudolfs J., and Bluestein, Maurice. "Determination of Body Segment Parameters." Human Factors. Vol. 5:5. 1963. p. 493-504.

11. Greene, James H. "The Design and Initial Evaluation of a Force Platform for Measuring Human Work." Ph,D. Dissertation, University of Iowa, Iowa City, Iowa. 1957.

12. Goldman, J. and Nadler, G. "Electronics for Measuring Human Motions." Science. Vol. 124:3226. October, 1956. p. 807-810.

13. Holter, Norman J. "A New Method for Heart Studies." Science. Vol. 134:3486. October, 1961. p. 1214-1220.

14. Jeans, C. "A Study of the Physiological Costs of Symmetrical and Simultaneous Motions." Master's Thesis, Kansas State University, Manhattan, Kansas. 1966.

15. Karpovich, P. V. Physiology of Muscular Activity. W. B. Saunders Co., Philadelphia. 1948.

16. Knowles, Elaine. "Some Effects of the Ironing Surface on the Worker." Bulletin No. 833, Cornell University Agricultural Experiment Station. 1946.

17. Konz, Stephan A. "Design of Work Stations." Journal of Industrial Engineering. Vol. 18:7. 1967.

18. Kozar, A. J. "Anticipatory Heart-Rate in Rope Climbing." Ergonomics. Vol. 7. 1964. p. 311-315.

19. Mize, Jessie J., Bland, Frankye E., Hood, Maude Pye, and Simons, Joseph W. Space Requirements and Design for Baking Centers. Bulletin N. S. 23, Georgia Agricultural Experiment Station, May, 1956.

20. Nichols, D. "Physiological Evaluation of Selected Principles of Motion Economy." Ph.D. Dissertation, Purdue University. 1958. University Microfilms, Inc., Ann Arbor, Michigan.

21. Regier, Katherine. "The Physiological Cost of Body Measurements as Measured by the Heart-Beat Rate." Unpublished report, 1967 (in the files of the Department of Industrial Engineering, Kansas State University, Manhattan, Kansas).

22. Richardson, Martha, and McCracken, Earl. "Work Surface Levels for Laundry Tasks in Relation to Human Energy Expenditure." Journal of Home Economics. Vol. 58:8. August, 1965. p. 662-668.

23. Richardson, Martha, and McCracken, Earl. "Human Energy Expenditures as Criteria for the Design of Household Storage Facilities." Journal of Home Economics. Vol. 51:3. March, 1959. p. 198-206.

24. Schmidtke, H. "The Influence of Motion Speed on Motion Accuracy." Arbeitphysiol. Vol. 17. p. 252-270. (Trans. by Nentwich, Fritz, Department of Industrial Engineering, Kansas State University, Manhattan, Kansas. 1967.)

25. Steidl, Rose, E. and Bratton, Esther Crew. Work in the Home. John Wiley & Sons, New York. 1968.

26. Tormey, Lucy Reader. "The Physiological Cost of the Basic Arm Movements Using Heart-Beat Rate as a Measuring Device." Unpublished report, 1967 (in the files of the Department of Industrial Engineering, Kansas State University, Manhattan, Kansas).

27. Whitney, R. J. "The Strength of the Lifting Action in Man." Ergonomics. Vol. 1:3. p. 101.

28. Wilson, Eva D., Fisher, Katherine H., Fuqua, Mary E. Principles of Nutrition. John Wiley & Sons. New York, 1966. p. 110-113.

APPENDICES

APPENDIX A

RANDOM ORDER OF SHELF REACH FOR EACH SUBJECT

Subject	Run I	Run II
A	5 3 6 4 9 8 1 7 2	2 6 5 4 9 3 1 7 8
C	3 7 6 1 2 5 4 9 8	9 2 7 3 8 6 5 4 1
D	2 3 5 8 7 4 9 6 1	2 5 7 9 8 6 1 4 3
E	6 3 7 4 9 5 8 1 2	4 9 5 1 8 3 2 7 6
F	1 7 2 8 9 4 5 6 3	3 4 1 8 9 2 5 7 6
G	6 1 4 5 7 2 9 3 8	8 6 9 4 1 7 5 3 2
H	3 7 9 5 4 8 2 6 1	9 5 4 1 3 2 7 8 6
I	7 4 6 9 2 1 8 5 3	8 3 5 6 1 4 7 9 2
J	3 7 6 2 5 4 8 9 1	4 6 3 2 8 9 1 5 7
K	7 9 6 8 5 2 1 3 4	1 6 8 4 2 7 3 5 9
L	4 1 8 3 7 6 9 2 5	3 8 7 5 4 9 1 2 6

APPENDIX B

CALCULATION OF DIXON CRITERIA FOR REJECTION OF OUTLYING OBSERVATIONS

Given: differences between Run I and Run II basals, using Shelf 4 as example:

Other Subjects:	Subject B:
0 1 1 1 1 2 3 5 5 6 6	11

Formula:

$$\frac{X_n - X_{n-2}}{X_n - X_2} = \frac{11 - 6}{11 - 1} = \frac{5}{10} \text{ or } .5$$

Critical Value at 10% risk: .490

Since .500 > .490, conclude that 11 is an outlier.

APPENDIX C

PROCEDURES FOR TAKING ANTHROPOMETRIC MEASUREMENTS

I. Weight

Instrument -- Balance Scale (Detecto-Medic Scale by Detecto Scales, Inc., Brooklyn, N. Y.)

Position of Subject -- Subject asked to stand quietly on the center of the platform and not to shift her weight during the weighing.

Procedure -- Measurer checked that the indicator was pre-set at zero before subject stood on scale, then measurer adjusted lower and then upper slides until indicator arrow balanced.

II. Stature -- Standing

Instrument -- Anthropometer mounted on a 2' x 4' 3/4" plywood base which served as a platform.

Position of Subject -- The subject stood with her back toward the anthropometer. Positioning her body with eyes directed forward, she moved backward slowly until some part of her body touched the upright scale of the anthropometer. Subject's arms were by her side, palms on thighs, weight evenly distributed with feet as close together as comfortable. Then the crossbar was lowered to the level of the vertex of the subject's head.

Position of Measurer -- The measurer stood to the left of the subject so she could easily lower the crossbar and read the scale.

Procedure --The left hand of the measurer located the vertex of the head of the subject, taking into consideration the texture of the hair, then the right hand of the measurer lowered the crossbar of the anthropometer until it rested on the vertex of the subject's head. The crossbar was set at that point. Standing height was taken without shoes.

III. Shoulder Height -- Standing

Instrument -- Anthropometer mounted on a 2' x 4' 3/4" plywood base which served as a platform.

Position of Subject -- The subject stood erect, feet as close together as comfortable facing the anthropometer. Her eyes were directed forward, arms at the side, palms placed on thighs.

Position of the Measurer -- The measurer stood to the right of the subject.

Procedure -- The subject bent her arm so that a right angle was formed by the outside of the arm (upper arm hanging straight and forearm parallel to the floor). The crossbar was moved to the elbor level, the subject standing close enough to the crossbar so that it touched the arm slightly. The recorder of the measurements sighted to see that the under edge of the elbor was parallel with the crossbar.

IV. Elbow

Instrument -- Anthropometer mounted on 2' x 4' 3/4" plywood base which served as a platform.

Position of Subject -- Subject stood to the left facing the anthropometer, and at a distance from it so that the crossbar could be lowered to show the elbow height.

Position of the Measurer -- The measurer stood to the right of the subject.

Procedure -- The subject bent her arm so that a right angle was formed by the outside of the arm (upper arm hanging straight and forearm parallel to the floor). The crossbar was moved to the elbor level, the subject standing close enough to the crossbar so that it touched the arm slightly. The recorder of the measurements sighted to see that the under edge of the elbow was parallel with the crossbar.

V. Waist

Instrument -- Anthropometer mounted on 2' x 4' 3/4" plywood base which served as a platform.

How Waist Landmark was Located -- Prior to taking the waist height, the waist level was located and landmarks placed on the body of the subject. The waist level used lies at the lower edge of the lowest rib and was found by palpating the sides of the body at midaxillary line. To locate it, the measurer sat in front of the subject and felt the right and left sides simultaneously, using the index fingers to press against the sides in line with the arm pits. The hands were held with the palms directed toward the floor and fingers extended and together. The thumb side of the middle joint of the index finger was placed against the subject. When the lower edge of the lowest rib was felt on the back surface of the index finger, the level of the mid-line of the index finger was taken as the waist level. Without displacing the skin, the level was marked with a dot in line with the arm pit on the right and left in turn. The waist levels of the right and left sides frequently differ. The average height from the floor of the two sides was therefore considered the waist level.

Position of the Subject -- The subject stood erect, at right angles to the anthropometer crossbar. She was cautioned against shifting her weight from one foot to the other and from heels to toes. Her arms hung loosely at the sides, palms on thighs and slightly to the back.

Position of the Measurer -- The measurer stood facing the landmark as she lowered the crossbar.

Procedure -- The crossbar was lowered until it rested on the landmark.

VI. Hip

Location of Hip Landmark -- The level was determined independently for the right and left sides and the average of the two taken as the hip level. The extended index and middle fingers of the measurer's right hand were used to palpate the region of the trochanter. The measurer squatted so that her eyes were approximately at the level of the trochanter. The direction of the palpation was from below upward. To locate the proper level it was often necessary to ask the subject to bend slightly forward or rotate the femur by turning the toes laterally and by pivoting on the heel. A rounded region was thus located, the midpoint of which was marked with a preliminary dot to indicate the hip level.

Position of the Subject -- The subject stood at right angles to the anthropometer, erect, with her hands on her hips and her weight evenly distributed.

Position of the Measurer -- Measurer knelt to the right of the subject keeping her eye on a level with the landmark.

Procedure -- The crossbar was lowered to rest on the landmark designating hip level.

VII. Knee Height (Tibiale)

Location -- This measure was best located on the inside of the knee. The tibiale was taken as the highest point on the margin of the glenoid (hollowed like a shallow pit, like a ball-and-socket joint) of the tibia when the subject stood erect. The medial "cleft" of articulation between the condyles (an enlarged and prominent end of a bone) of the femur and the upper end of the tibia was used as a guide in locating this. It was palpated by grasping the knee firmly while it was alternately flexed and extended and by moving the index finger or thumb in the region of the "cleft" until the ends of the bones were located. The tiabiale was marked by a dot at the level of the cleft; or -- The subject placed her left foot on the experimental kitchen platform. She was asked to keep her weight distributed as evenly as possible on her feet, and the main axis of her right leg perpendicular to the floor. The right foot was directed straight forward and a landmark placed at this location.

Position of the Subject -- Subject stood at right angles to anthropometer crossbar.

Position of the Measurer -- The measurer squatted at the subject's right side; with her eyes at the knee level of the subject.

Procedure -- The crossbar was brought to rest on the landmark.

VIII. Height of Finger Tip

The distance from the dactylion (the tip of the extended middle finger) to the floor.

Position of Subject -- Subject stood facing the anthropometer.

Position of the Measurer -- Measurer stood to the right and front of subject, squatting to bring her eye level to that of the finger tip.

Procedure -- Subject was asked to hold fingers straight but not rigid. The measurer lowered the crossbar until it was at the level of the finger tip.

WIDTH MEASUREMENTS

IX. Standing -- Greatest Width at Shoulders

Instrument -- Sliding caliper.

Position of Subject -- Subject stood erect, feet together as closely as comfortable. Arms at sides, palms on thighs.

Position of Measurer -- Measurer stood directly behind subject.

Procedure -- Measurer held the caliper with the shaft parallel to the floor and touching back of subject at shoulder height. The fixed bar of the caliper was placed against the left arm of the subject at the furthest extension (not more than one inch below the highest point of shoulder cap). The movable bar was slid against the right upper arm of the subject at the furthest extension.

X. Greatest Width Arms Bent

Instrument -- Sliding Caliper

Position of Subject -- Subject stood erect with feet together comfortably. She held a 16 1/2" x 12" x 1" tray as she would normally carry it (about waist height).

Position of Measurer -- Measurer held the caliper shaft parallel to the floor with the fixed bar against the outside of the left elbow and slid the movable bar against the outside of the right elbow.

XI. Greatest Width Below 36"

Instrument -- Sliding Caliper

Position of Subject -- Subject stood erect, weight evenly distributed, eyes directed ahead, hands clasped at the waist.

Position of Measurer -- Measurer stood directly behind the subject.

Procedure -- The measurer held the shaft of the caliper parallel with the floor and kept level, the fixed bar and the movable bar were fitted on either side of the subject at the waist. The caliper was lowered until the greatest extension below 36" was located.

DEPTH MEASUREMENTS

XII. Bust

Instrument -- Sliding caliper.

Position of Subject -- Subject stood erect on the floor, feet as close together as comfortable, weight evenly distributed over both feet, eyes directed ahead and hands by side.

Position of Measurer -- Measurer stood at the right side facing the subject.

Procedure -- The shaft of the caliper was half level and parallel to the floor while the fixed bar was placed at bust height on the back of the subject. The movable bar was slid up to the furthest extension of the bust.

XIII. Abdominal -- Standing

Instrument -- Sliding caliper.

Position of Subject -- Subject stood erect on the floor, feet as close together as comfortable, weight evenly distributed over both feet, eyes directed ahead and hands by side.

Position of Measurer -- Measurer stood at the right side facing the subject.

Procedure -- With the shaft of the caliper still parallel to the floor the caliper was lowered and the movable bar adjusted until greatest thickness of abdomen was found.

XIV. Bust Measurement

Instrument -- Tape measure.

Position of Subject -- Subject stood with arms at side.

Position of Measurer -- The measurer stood back of subject.

Procedure -- Tape measure placed over largest part of bust and brought to back of subject.

XV. Hip Measurement

Instrument -- Tape measure.

Position of Subject -- Subject stood with arms at sides.

Position of Measurer -- The measurer stood back of subject.

Procedure -- Tape measure placed over greatest width of hip and read at back of subject.

APPENDIX D

Sheet Number____

DATA SHEET

Subject Number________ Age________ Date____________

	WORK				REST					
	Number of Heart Beats Each 30 Seconds				Number of Heart Beats Each 30 Seconds					
	30	60	90	120	30	60	90	120	150	180
Pre-rest										
Condition										
Reading 1										
Reading 2										
Average										
Basal *										
Average - Basal										
Av - B. x 2=Heart Beats/Minute										
Condition										
Reading 1										
Reading 2										
Average										
Basal										
Average - Basal										
Av - B. x 2=Heart Beats/Minute										
Condition										
Reading 1										
Reading 2										
Average										
Basal										
Average - Basal										
Av - B. x 2=Heart Beats/Minute										
Condition										
Reading 1										
Reading 2										
Average										
Basal										
Average - Basal										
Av - B. x 2=Heart Beats/Minute										

* (Basal = Heart-Beat Rate of fifth Half-Minute of Rest Period II x2:___ x2=___)

[illegible]

Subject ____

Condition — Seconds - Work — Seconds - Rest

Set 1	30	60	90	120	30	60	90	120	150	180
Set 2										

APPENDIX E

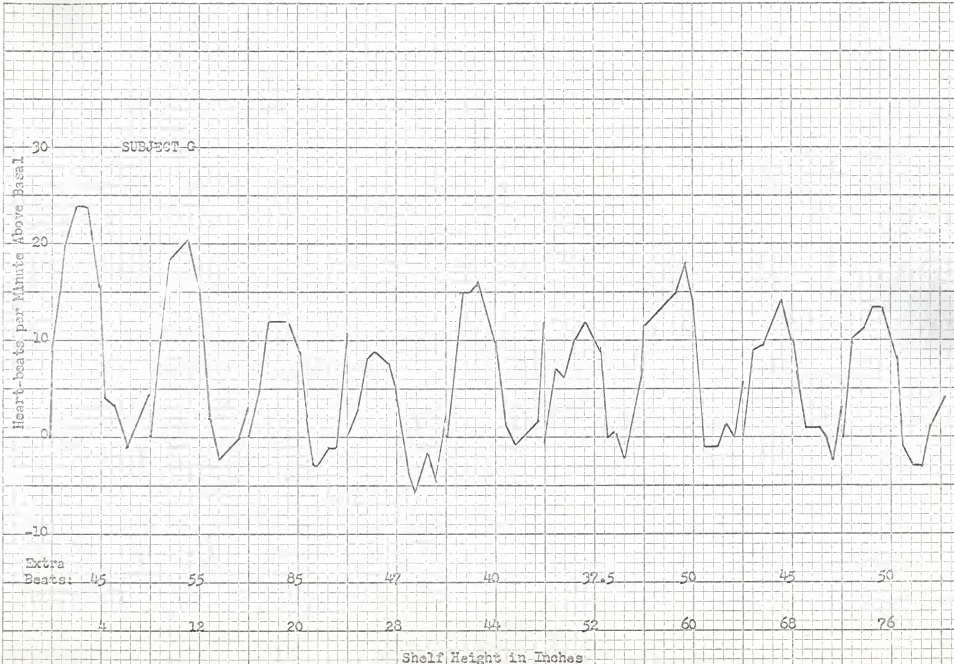


Fig. 3--Sample of Curve of Heart-beats Above Basal Plotted for Each Subject

APPENDIX F

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

The function of this appendix is to give the procedure for the calculation of the Wilcoxon Matched-Pairs Signed-Ranks test. The step by step procedure is the following:

1. Choose α, the level of significance. (α = .05 is the most commonly used.)

2. For each pair of conditions to be compared, record the sign of the difference. (Use extra-heart-beats for each subject from table entitled "Extra Heart-Beats in Work and Recovery." Every condition can be compared with every other condition, but if it is found, for example, that there is no significant difference between Conditions 3 and 7, you can then assume that there would be none between any of the pairs in between that range.)

   Disregard any difference that is 0. Let "n" be the number of differences.

   Disregarding signs, assign a rank of 1 to the numerically smallest difference, "d", 2 to the next, etc. For ties, assign an average rank.

3. To the assigned ranks, now prefix a sign, + or -. Count the number of the <u>less</u> frequently appearing signs and call it T_a.

4. Look up in table the critical T_{α}, n. If T_a is less than T_c, conclude that a significant difference exists.

APPENDIX G

Extra heart beats per minute above basal for each subject for each shelf height

	Height of shelf in inches								
Subjects	4"	12"	20"	28"	44"	52"	60"	68"	76"
A	67.5	39	46	45	24	60	49	68	50
C	45	55	85	47	40	37.5	50	45	50
D	60	75	45	49	35	41	85	80	61.5
E	60	47	45	55	48.5	50	65	65	50
F	60	57.5	56	30	50	60	20	37.5	35
G	50	40	20.75	12.5	40	32.5	33.5	25	25
H	72.5	45	0	15	56.65	28.3	45	28.3	42.5
I	70	70	35	40	85	57.5	40	80	70
J	65	57	57.5	65	41.5	42.5	42.5	45	60
K	86.5	70	65	45	50	75	72.5	60	75
L	87.5	70	55	45	75	65	75	72.5	100
Means	65.8	56.9	46.4	40.8	48.8	49.9	52.5	54.6	56.3

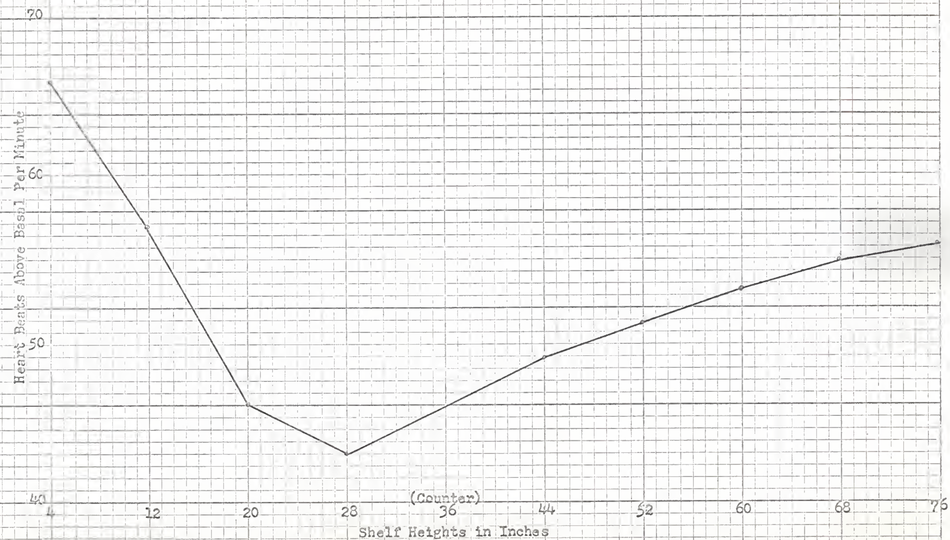


Fig. 1.--Graph of mean heart-beats above basal per minute for each of nine shelf heights.

HEART-BEAT RATE AS A MEASURE OF WORK COST
OF REACHING SELECTED SHELF HEIGHTS

by

LUCY READER TORMEY

B. S., Kansas State University, 1940

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Family Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

The purpose of this research was to investigate the use of heart-rate as a physiological measure of the cost of light work. The results were compared to a study where calorimetry was the measurement used (Richardson and McCracken).

Count of the extra heart-beats above basal of eleven women subjects was recorded electronically while they lifted a one-pound weight from a counter height of 36 inches to nine different shelf heights. Ranked in ascending order of work cost, as determined by extra heart-beats above basal in work and recovery, placing the weight on a shelf 28 inches from the floor used the least, a mean of 40.8. The most difficult, a shelf 4 inches from the floor, required 65.8 extra heart-beats. Nearly as difficult, but not significantly different, was the reach to a shelf 76 inches from the floor, requiring a mean of 56.3.

The comparison between the findings of this study and the calorimetry data from the Richardson and McCracken study showed work costs and rank order were similar with the exception of two below counter shelves, 20 and 28 inches from the floor, and one above counter shelf, 44 inches from the floor. From the extra heart-beat data the 28-inch shelf ranked lowest in work cost, the 20-inch shelf was next, and the 44-inch shelf ranked third. Statistical tests showed no significant differences in heart-rate cost between any two combinations of the 28-inch shelf, the 20-inch shelf, or the 44-inch shelf.

From the results of studies using reaching under several different conditions, Richardson and McCracken were able to establish areas of minimum, intermediate and maximum reach. Results of this heart-rate work cost study corresponded with their results in a general way at the extremes and more broadly in the areas of intermediate and minimum reach. When the test for the coefficient of correlation was applied to the two sets of data, the result was 0.819. The test also was applied to the data omitting the 20-inch and 28-inch shelves. The result of this test was 0.966.

On the basis of anthropometric measurements of the subjects, beginning with a shelf at shoulder height (52 inches from the floor), the work cost of lifting one pound decreased progressively until the point of normal downward reach. Work cost increased slightly at the next lower shelf, 20 inches. The two lower shelves, 4 and 12 inches from the floor, were the most costly since the torso had to be lowered to reach them. Above the shoulders, the work cost in extra heart-beats per minute increased in ascending order as the height of the shelves increased.

It is recommended that further investigation be carried on using extra heart-beats above basal as the measurement. The work cost of simple tasks employing elemental motions should be measured. Examples of such motions are the basic hand and arm movements with and without the lifting of various weights; forward, backward, rotary, and torque motions; walking with and without a load; and bending or stretching to perform various tasks. Such investigations could establish further heart-rate as a simple and reliable method of measuring work costs that could be applied to any work requiring similar motions.