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To the Graduate Council:

I am submitting herewith a dissertation written by Joe Foust Smith entitled "Energy Costs of Specific Custodial Work Tasks." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Education, with a major in Physical Education.

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ENERGY COSTS OF SPECIFIC CUSTODIAL WORK TASKS

A Dissertation

Presented for the

Doctor of Education

Degree

The University of Tennessee

Joe Foust Smith

June 1975

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ABSTRACT

The purpose of this investigation was to establish average energy costs for various work tasks performed by custodial work crews. The data should provide information which would be of value to physicians in determining the degree of danger this particular occupation may hold for coronary patients returning to work.

The subjects were seven male employees of The University of Tennessee Physical Plant who performed custodial work tasks. Nine work tasks that were representative of the normal work activities of the crew were selected for measurement. Oxygen consumption and heart rate were the two parameters measured. Energy costs were determined from the oxygen consumption values and were expressed in several different units for comparison.

The average energy requirements of the various work tasks ranged from 3.4-6.4 kcal per minute with the largest value resulting from dust mopping the arena floor. This range would classify custodial work as moderate work. The average heart rates for the various work tasks ranged from 91-131 beats per minute which would classify the job according to heart rate as heavy work. The heart rate response to work should provide a more valid indication of the total physiological stress of the job.

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CHAPTER I

INTRODUCTION

It is a well established fact that cardiovascular diseases claim more American lives than all other causes of death combined. Over 27 million Americans have some form of cardiovascular disease which annually costs the nation over 27 billion dollars. This represents expenditures for medical care and lost wages in addition to the loss of 52 million man-days of production each year. Other costs in terms of loss of experienced management personnel, increased personnel training and development, and labor turnover are hard to determine (1).

Many people suffering from cardiovascular disease recover, are rehabilitated and eventually return to their jobs. Our ability to effectively rehabilitate these patients and return them to their work as soon as possible will help reduce the losses mentioned above.

A critical decision on the part of the physician is made when he decides that the patient can resume occupational activities. This decision is based on his knowledge of the patient's present and future functional capacity and a knowledge of the energy requirements and other characteristics of the occupation to which he is returning. The physician can determine the patient's functional capacity and usually does so by utilizing the following information: knowledge of physical function as a result of exercise testing, assessment of the presence of additional risk factors, and a determination of the extent of the patient's knowledge of his disease and its therapy (44).

However, recommendations regarding return to occupational activities are difficult to make because of the scarcity of data on the caloric cost of industrial and occupational activities (39, 38). In the absence of these data, the physician's decisions are based on his past experience and the guidelines used by other physicians.

If a patient is returned to a job in which the energy requirement exceeds his present functional capacity serious physical complications may result and the company is burdened with an even greater loss of productive man-hours. It is most probable that a patient will return to work with a functional capacity that is below that enjoyed prior to illness and he may have to be placed in a less demanding job. This is a very important consideration since he is more apt to show improvement if the energy cost of his work is compatible with his functional capacity (1). Whether this decision is made by the physician or a community agency responsible for vocational guidance and placement, precise information regarding the energy cost of specific job tasks is a necessity.

Data which have been published regarding daily energy expenditure and energy cost of various activities have generally been gathered for motives other than that referred to in the preceding paragraphs. Different motives, as well as the development of new equipment and refinement of research techniques have continuously renewed interest in energy expenditure research.

Early studies on the energy cost of physical activity, prior to and immediately after the turn of the century, were based solely on dietary studies. An individual's total energy needs were assessed

by analyzing the food which was consumed. This was done for different occupations with generalizations then being made about the energy expenditure of these occupations. Assumptions about energy expenditure based solely on dietary information have serious limitations as pointed out by Passmore and Durnin (31). In addition to the fact that dietary surveys are difficult and expensive, the main objection is that they provide no definite criterion of energy requirement. One cannot assume that the calories consumed provide exactly enough energy with no excess or deficit. As the use of indirect calorimetry was validated for measuring energy expenditure and as more convenient apparatus was developed for use under a variety of conditions, there was renewed interest in determining the energy cost of various physical activities.

In 1950, a report by a committee of the Food and Agriculture Organization of the United Nations (35) resulted in another stimulus for energy cost measurement. The report summarized the existing physiological knowledge regarding how much energy is provided by food. It stressed the importance of this information as it related to practical problems of rationing in case of a national or world food shortage. The report also identified gaps in our present knowledge concerning the actual energy cost of every-day work activities and stressed the need for further investigation. This provided the impetus for studies concerned more with daily energy expenditure and dietary intake. However, in order to estimate daily energy expenditure, the energy cost of many different every-day activities had to be measured.

It is beyond the scope of this study to review all the research dealing with daily energy expenditure and the energy cost of specific activities. Some very excellent summaries of this work are available. Dill (20) summarized work prior to 1936 and prepared classification levels for work intensity based on metabolic cost. His levels were:

Moderate work--Less than three times the basal metabolic rate;

Hard work--Three to eight times the basal metabolic rate; and

Maximal work--More than eight times the basal metabolic rate.

In the hard work classification he included mining, agriculture, construction work, manual jobs in heavy industry and war activities.

In 1955, Passmore and Durnin (31) published an extensive summary of energy cost studies which covered a myriad of activities and data gathering techniques. The activities whose energy costs were presented included climbing, running, stair climbing, recreational activities, domestic work, light industries, manual labor activities, postal delivery, building, mining, iron and steel industry, agriculture, lumber work, fishing, and soldiering activities.

In 1967, Durnin and Passmore (22) published a book which brought their earlier work up-to-date. They set forth a grading system for industrial work. These classification levels are first described by Christiansen (16) in 1953 and are shown in Table 1. Many studies since Christiansen's work have used the terms light, moderate, or heavy to describe work that fell within the ranges defined in Table 1.

TABLE 1

WORK CLASSIFICATIONS

Work Classification	kcal/min
Light	2.0 - 4.9
Moderate	5.0 - 7.4
Heavy	7.5 - 9.9
Very Heavy	10.0 - 12.4
Unduly Heavy	Above 12.5

Also included in their book are several tables of energy costs for different activities whose values are standardized for a 65 kg man and a 55 kg woman. One must keep in mind that each of their tables was prepared from the compilation of results from several studies. This undoubtedly resulted in values affected by varying sample sizes, subjects' ages, experimental conditions, and data gathering techniques.

A still more recent emphasis on energy cost studies has arisen as a result of The Occupational Health and Safety Act (41) which was passed by the United States Congress in 1971. This act required standards for occupational work to be set and implied that this work must be more carefully evaluated not only in terms of work conditions but also in terms of the level of energy expenditure required for different jobs. The remainder of this review of literature will focus on the most recently published information regarding energy cost studies in different occupational settings.

I. Astrand (5) studied the energy expenditure of housekeeping activities. The average heart rate during work was related to oxygen consumption by individual heart rate-oxygen consumption regressions based on bicycle ergometer work. The energy cost of the variety of activities ranged from 3.7 to 6.9 kcal per minute. The values were measured on the day of the week on which the greatest variety of work was usually done so the values given represent those from a heavy work day and not a typical work day.

The evaluation of physical working ability of male agriculture workers in Central America was studied by F. Viteri et al. (43). The study involved the measurement of total daily energy expenditure so that time-motion studies and dietary evaluations were necessary. To assess the energy cost of the different agricultural activities, expired air was collected in a Kofranyi-Michaelis respirometer and analyzed on a Scholander apparatus. The average caloric expenditure for several different activities ranged from 1.73 kcal per minute for office work and washing the stable with a hose to 7.18 kcal per minute for mowing with a sickle, shoveling heavy material, and harvesting with a machete. Another agricultural study conducted in Central America by Spurr et al. (40) investigated the energy cost of cutting sugar cane. The average energy expenditure was 7.3-7.6 kcal per minute which represents heavy physical labor (16).

A study to determine the energy cost of potential emergency tasks in an industrial setting was conducted by Fors (24) in 1971. Heart rate response to the different tasks was the criterion measure of energy cost. The heart rate data were related to energy cost

(in Mets) by developing individual heart rate-work load calibration curves from work on a treadmill. The average energy cost of the emergency tasks tested ranged from 4.4 Mets to 10.4 Mets and ten of the twelve tasks had an energy cost of over 6.0 Mets. He suggested that further research in the areas of energy cost of industrial or occupational tasks would aid in obtaining maximum efficiency of personnel and would assist in preventive measures for employee health and safety.

Horvath et al. (26) and Raven et al. (33) have studied the energy cost of aluminum smelter workers. Gas was collected with a manually operated "piston-throw" valve as suggested by Maksud (28). Time spent on a particular job and duration of collection time of the sample were measured by a stopwatch. Oxygen content of the expired air was determined on an electronic oxygen analyzer and the volume was measured with a dry gas meter.

Horvath et al. found energy expenditures of up to 8.6 Mets and Raven's values ranged from light (greater than 2.5 kcal/min) to heavy (greater than 7.5 kcal/min) according to Christiansen's (16) classification of energy expenditure. These values were similar to those found by others for somewhat comparable activities (22).

The energy expenditure and climatic exposure of Yemenite and Kurdish Jews in Israel has been investigated by Edholm et al. (23). The majority of the males were engaged in farming activities while the women were primarily housewives. Energy expenditure was calculated from a timed activity survey and measurements of oxygen consumption in a number of tasks. The energy cost of the specific tasks was

determined by (a) actual measurement of oxygen consumption, (b) published values (22), or (c) unpublished values from previous studies by the authors. In the field, a number of measures of oxygen consumption or ventilation volume were obtained by use of the Max Planck respirometer or the Wright flowmeter. Gas samples were analyzed using a Lloyd-Haldane apparatus. The energy cost of the specific tasks ranged from 1.9-9.3 kcal per minute for the men and from 2.0-11.25 kcal per minute for the women. According to Christiansen's (16) classification this ranges up to heavy work for men and very heavy for women.

These recent studies as well as the summaries that were discussed, provide energy cost values for most of the normal activities of recreation, work, and the home. However, there are specific job tasks within many industries and occupational settings that are as yet untested and whose energy cost values must be obtained. It is the purpose of this study to investigate the energy cost of different work tasks performed by The University of Tennessee custodial personnel.

CHAPTER II

METHODS

The subjects in this study were seven male employees (ages 18 to 51) of The University of Tennessee Physical Plant. They were members of the custodial staff which worked the night shift at the Physical Education Building.

Discussions were held with the Building Supervisor and Supervisor of the night crew to identify a number of job tasks that were typically performed by the custodial crew. Task selection was based only on the criteria that the tasks were measurable and were representative of the normal work activities of the crew.

The subjects did not perform every work task either because they never did that kind of work on a regular basis or because only a small crew was used to carry out certain tasks. The following tasks were selected and a description of each is given.

Buffing. Buffing consisted of the operation of an Advance Pacemaker II buffer with buffing pad. This task primarily involved the right to left movement of the machine as the subject backed down a hall or across a floor.

Wet Mopping. This task involved the wet mopping or cleaning of the building floors. It was also performed with a right to left movement as the subject moved across a floor or backed down a hallway. Periodically the mop bucket was pulled down the hall, the mop placed in the bucket for rinsing, and some water squeezed out by the wringer before continuing the task.

Water Vacuuming. In the process of removing old wax from the floor, a stripper was mixed with water and spread generously on the floor. A buffing machine with a stripping pad was then used to remove the old wax after which the excess stripper and water was picked up. An Advance Industrial Hydro-Vac was used to vacuum the water. This process involved a forward and backward movement of the vacuum handle and hose as the subject moved across a room or hall.

Dust Vacuuming. Dust vacuuming was done with a smaller Clarke 500 vacuum cleaner to clean the carpeted main entrances to the building. This also consisted of a forward and backward movement of the vacuum cleaner.

Dust Mopping the Arena. The arena, which is the large gymnasium containing four regulation basketball courts, was cleaned daily with a long handled dust mop with a four foot pad. The process consisted of cleaning one court at a time by pushing the mop from one end of the court to the other.

Wall Washing. The ceramic tile walls of the locker room were periodically washed with a sponge and warm soapy water. The process included primarily arm movement as the wall was washed, some bending or squatting to get to low areas on the wall and periodic rinsing and wringing of the sponge.

Stroking and Feathering. Stroking and feathering are described together since they are two processes involved in applying a varnish finish when refinishing a gym floor. In stroking, a long handled mop with a finish applicator was dipped in a roller-mounted finish container and the finish was then applied to the floor at right angles to the

wood grain. The finish was applied to about a four foot strip all the way across the floor and the finish container was pulled along with the mop as the subject backed across the floor. In feathering, the same type of mop and applicator was used with the objective being to follow behind the stroker and with a somewhat lighter touch on the applicator, remove the excess finish by pulling the applicator with the wood grain. These two processes were carried out all the way across the floor and a full basketball court was completed before the workers were able to stop. Stroking measurements were obtained for refinishing the handball courts as well as the arena floor.

A gas collection system was used to collect expired air from which energy expenditure was determined. The gas collection system consisted of a Daniels valve (19), large diameter, low resistance tubing, a two-way collection valve, and meterological baloons.[1] The system was light and sufficient tubing was used so that the subject's movement while working was not hindered. Figure 1 shows the valve, head gear, and tubing used in the gas collection.

Collection times were measured with a stopwatch and after the test sessions the gas balloons were taken to the laboratory where the gas was analyzed immediately for oxygen and carbon dioxide content. A Beckman E-2 Oxygen Analyzer and a LB-1 Carbon Dioxide Analyzer[2] were used for these measurements. These analyzers were calibrated by a known tank gas whose oxygen and carbon dioxide content had been

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[1]Warren E. Collins, Incorporated, Braintree, Massachusetts.

[2]Beckman Instruments, Incorporated, Palo Alto, California.

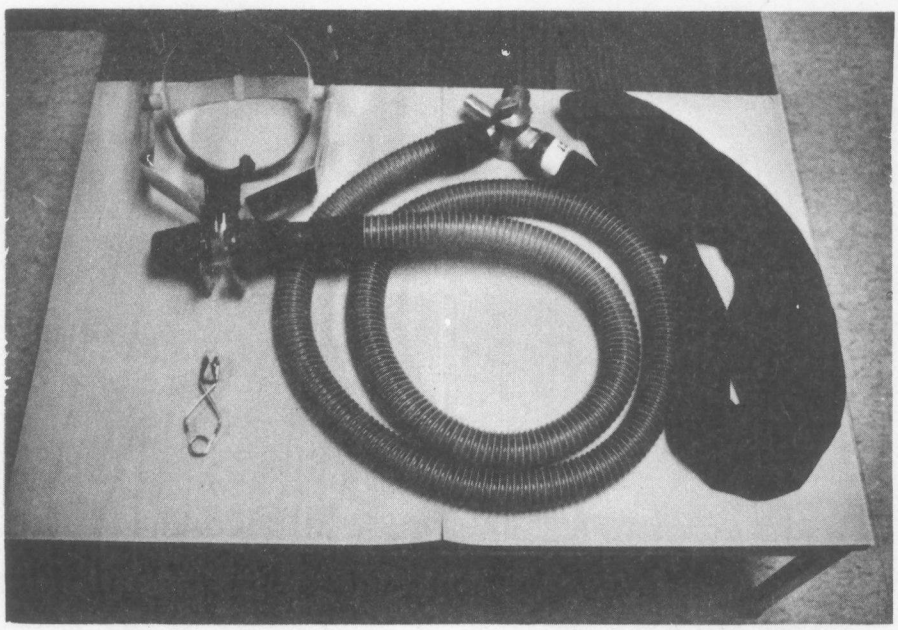


FIGURE 1. Gas collection apparatus.

verified by repeated analyses on the Scholander apparatus (36). Periodically the readings from the electronic analyzers were also compared with values measured on the chemical analyzer. A 50 ml sample was taken from a balloon of expired air and analyzed on the Scholander apparatus. The volume of expired air was determined by passing it through a Parkinson-Cowan dry gas meter[3] which was calibrated against a Collins gasometer[4] each day prior to a test.

Heart rates were obtained using a telemetry-heart rate recording system. The system included an EKEG Model 681 EKG transmitter,[5] a BASF Model 9300 Radio-Recorder,[6] and an electronic beeper-timer.[7] This equipment, including the belt in which the transmitter was carried, is shown in Figure 2.

The electrodes were attached at the manubrium sterni and the fifth intercostal space on the left side. The skin at the site of electrode placement was thoroughly cleaned with a standard alcohol solution. Placement of electrodes and position of the belt and transmitter are shown in Figure 3.

The electronic beeper-timer was used to calibrate the recording tape speed. The timer was set to beep at ten second intervals and was

---

[3]Instrumentation Associates, New Yotk.

[4]Warren E. Collins, Incorporated, Braintree, Massachusetts.

[5]EKEG Electronics Co. Ltd., Vancouver, B. C., Canada.

[6]BASF Systems, Bedford, Massachusetts.

[7]Life Sciences Electronics Services, The University of Tennessee, Knoxville, Tennessee

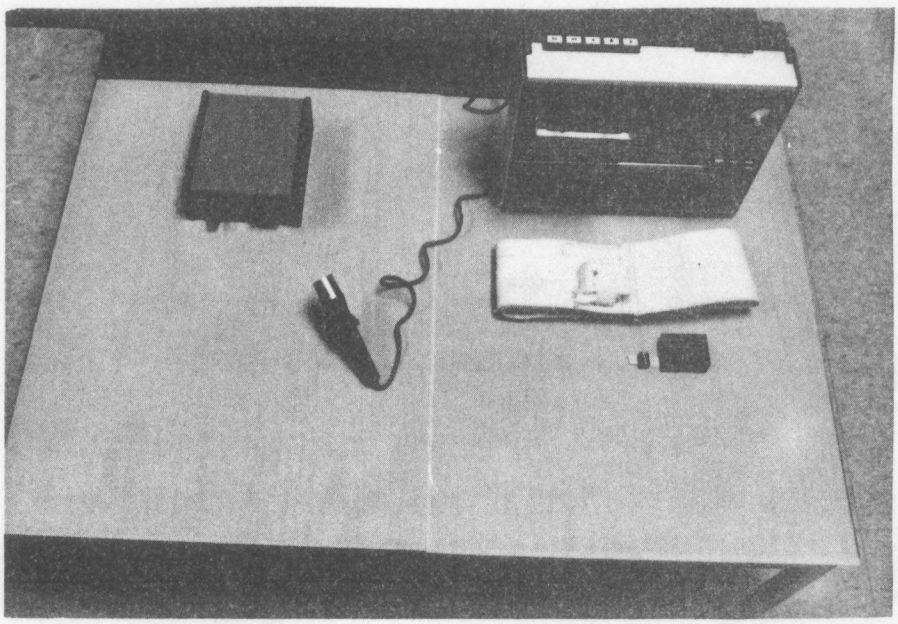


FIGURE 2. Heart rate telemetry recording system.

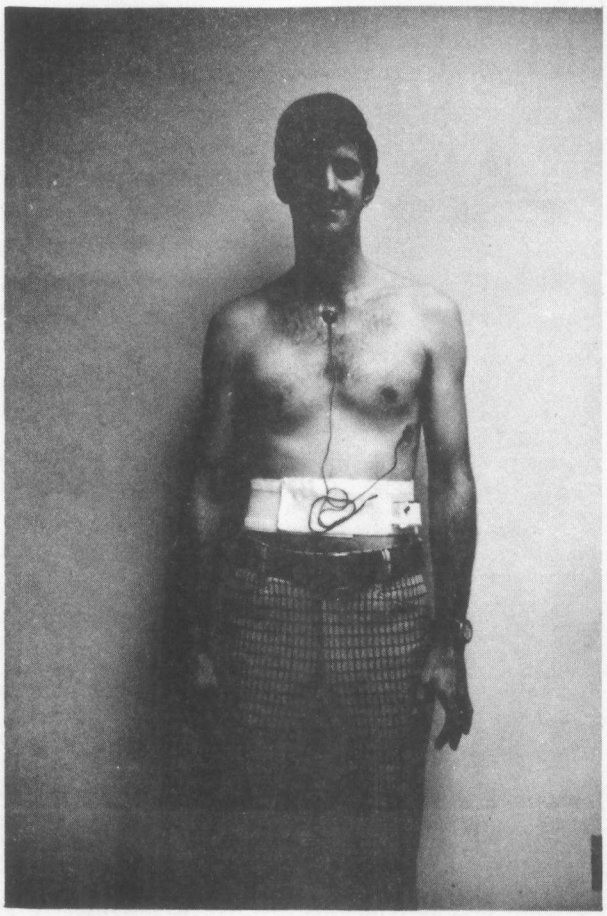


FIGURE 3. Electrode placement and transmitter position.

calibrated with a stopwatch prior to each test session. The microphone for the radio-recorder was activated and positioned in front of the beeper-timer so as to record the ten second beep along with the subjects' heart beats. When the recording was played back, heart beats between the ten second beeps were counted for the two minute test period and an average heart rate for the work task was determined.

Preliminary testing was not necessary because there was no need to determine the subjects' physical capacity to do the work. The tested activities were events they performed every day. The subjects were met at the job site and given an explanation of the test procedures that would be followed. They were instructed to perform the job tasks as routinely as they performed them every day.

In most instances only two subjects were tested per session. They were prepared for the telemetry and gas collection equipment and allowed to work for a three minute period. At the end of this warm-up period the gas collection tubing and meterological balloons were attached to the breathing valve, the subject put on the nose clip and resumed work for a one minute accommodation period. Two consecutive one minute samples of expired air were then collected and heart rates were recorded. The same protocol was followed for each work task except the stroking which took place in the handball courts. In this case, continuous work time was so brief because of the size of the court, that thirty second samples of expired air were collected. Figures 4, 5, and 6 show a subject prepared for data collection for buffing, water vacuuming, and wet mopping, respectively.



FIGURE 4. Subject prepared for buffing.

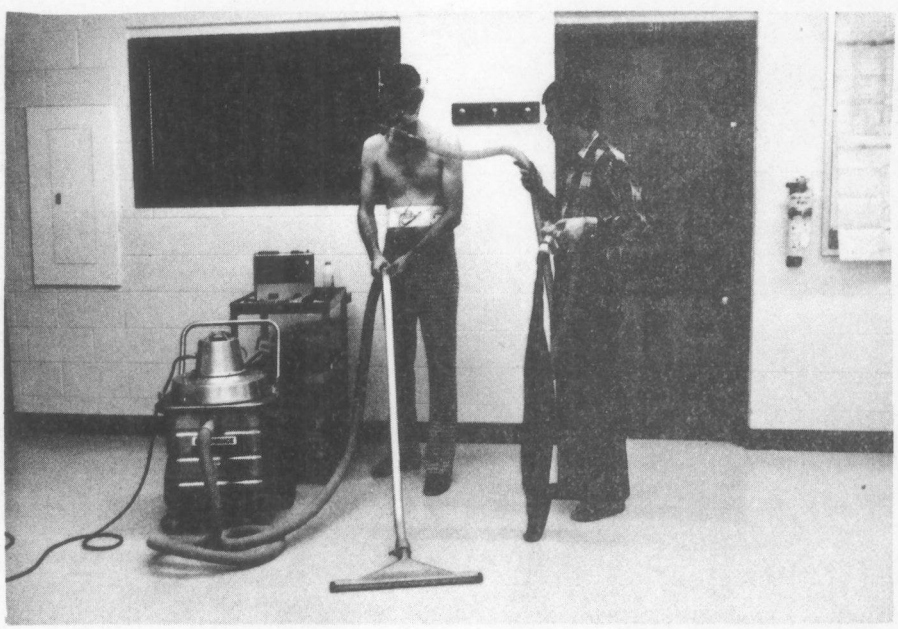


FIGURE 5. Subject prepared for water vacuuming.



FIGURE 6. Subject prepared for wet mopping.

Energy cost values for the work tasks were expressed as milliliters of oxygen per kilogram of body weight per minute (ml/kg per minute), kilocalories per minute (kcal/minute), kilocalories per kilogram of body weight per hour (kcal/kg per hour), and Mets. Mets are multiples of the resting metabolic rate or ratios of work metabolic rate to resting metabolic rate (20). Oxygen uptakes were calculated according to Consolazio et al. (18) and a caloric equivalent of 4.85 kcal per liter of oxygen was used to convert oxygen consumption values to kilocalories of energy expended.

An average respiratory exchange ratio of 0.82 was found for all measures. However, there were three cases in which the subjects hypoventilated producing R's lower than 0.70 and two cases in which the subjects hyperventilated resulting in R's of greater than 1.00. For this reason, the value of 4.85 kcal per liter of oxygen consumed was used to determine energy cost in all cases. This could result in, at most, an error of only 3.5 percent (37).

A set of Continental Health-O-Meter scales[8] calibrated by standard weights were used to obtain the subjects' weights. Temperature and relative humidity of test conditions was determined by using a Bacharach sling psychrometer.[9]

---

[8]Continental Scale Corporation, Chicago, Illinois.

[9]Bacharach Industrial Instrument Company, Pittsburgh, Pennsylvania.

CHAPTER III

RESULTS

Physical characteristics of the seven subjects who participated in the study are presented in Table 2.

TABLE 2

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subjects	Age	Weight (kg)	Height (cm)
RT	23	89.6	185.4
JS	19	75.5	175.2
JI	51	60.9	166.4
ES	22	60.6	161.9
CH	27	70.5	185.4
BW	19	52.6	163.2
MB	36	59.5	185.4

The mean energy requirement and heart rate response for each of the nine work tasks are presented in Table 3. The energy cost values are presented in several different units of measurement to facilitate comparison with previous and future research. A task average for each unit of measurement is also given. The reader should note the consistently higher heart rate response by subject ES for each task and also the higher energy cost in six of the nine tasks for the same subject.

TABLE 3

AVERAGE ENERGY REQUIREMENT AND HEART RATE RESPONSE FOR CUSTODIAL WORK TASKS

Subject	Liters O_2 per minute	ml O_2/kg per minute	Mets[a]	kcal per minute[b]	kcal/kg per hour	H.R. bpm
			BUFFING			
R. T.	.83	9.1	2.6	4.0	2.7	84
J. S.	.59	7.9	2.2	2.9	2.3	81
J. I.	.76	12.2	3.5	3.7	3.6	99
E. S.	.70	11.4	3.3	3.4	3.3	114
B. W.	.59	11.2	3.2	2.8	3.2	99
Task Average	.70	10.0	2.9	3.4	3.0	91
			DUST VACUUMING			
R. T.	.80	9.0	2.6	3.9	2.6	81
E. S.	.74	12.4	3.5	3.6	3.6	126
B. W.	.63	12.0	3.4	3.1	3.5	81
J. S.	.88	11.6	3.3	4.3	3.4	90
C. H.	.73	10.3	3.0	3.5	3.0	78
Task Average	.76	11.2	3.2	3.7	3.2	91
			STROKING (HANDBALL COURTS)			
R. T.	.86	9.8	2.8	4.2	2.9	91
B. W.	.65	11.5	3.3	3.2	3.3	96
E. S.	.75	12.5	3.6	3.6	3.6	111
J. S.	.83	11.1	3.2	4.0	3.2	93
Task Average	.78	11.2	3.2	3.8	3.3	98
			WALL WASHING			
E. S.	.83	13.5	3.8	4.0	3.9	126
J. S.	.71	9.4	2.7	3.4	2.7	84
C. H.	.86	12.1	3.4	4.2	3.5	78
J. I.	.75	12.1	3.5	3.6	3.5	102
B. W.	.83	15.8	4.5	4.0	4.6	102
Task Average	.79	12.6	3.6	3.9	3.6	98

TABLE 3 (continued)

Subject	Liters O_2 per minute	ml O_2/kg per minute	Mets[a]	kcal per minute[b]	kcal/kg per hour	H.R. bpm
			WATER VACUUMING			
R. T.	.98	10.8	3.1	4.8	3.2	96
E. S.	1.16	19.4	5.6	5.6	5.6	153
J. S.	1.29	17.1	4.9	6.2	5.0	117
B. W.	.78	14.8	4.2	3.8	4.3	108
C. H.	.63	8.9	2.6	3.0	2.6	84
J. I.	..73	12.0	3.4	3.5	3.5	99
Task Average	.93	13.9	4.0	4.5	4.0	110
			WET MOPPING			
J. S.	.95	12.5	3.6	4.6	3.7	108
R. T.	1.20	13.2	3.8	5.8	3.8	102
C. H.	.93	13.3	3.8	4.5	3.9	78
J. I.	.82	13.3	3.8	4.0	3.9	102
E. S.	1.13	18.2	5.2	5.5	5.3	132
B. W.	.74	14.1	4.0	3.6	4.1	84
Task Average	.96	14.1	4.0	4.7	4.1	101
			FEATHERING (ARENA FLOOR)			
R. T.	1.06	12.1	3.5	5.2	3.5	105
B. W.	.68	12.9	3.7	3.3	3.8	114
E. S.	1.01	16.9	4.8	4.9	4.9	141
J. S.	1.12	14.9	4.3	5.4	4.3	108
Task Average	.97	14.2	4.1	4.7	4.1	117
			STROKING (ARENA FLOOR)			
R. T.	1.00	11.6	3.3	5.0	3.4	102
B. W.	.85	14.9	4.2	4.1	4.3	102
E. S.	1.16	19.3	5.5	5.6	5.6	174
J. S.	1.04	14.0	4.0	5.1	4.1	97
Task Average	1.02	14.9	4.3	4.9	4.4	119

TABLE 3 (continued)

Subject	Liters O_2 per minute	ml O_2/kg per minute	Mets[a]	kcal per minute[b]	kcal/kg per hour	H.R. bpm
			DUST MOPPING ARENA			
E. S.	1.46	24.5	7.0	7.1	7.1	157
J. S.	1.60	21.0	6.0	7.8	6.1	141
M. B.	1.50	25.2	7.2	7.2	7.3	153
C. H.	1.34	18.9	5.4	6.5	5.5	102
B. W.	1.06	20.0	5.7	5.1	5.8	117
J. I.	.97	16.0	4.6	4.7	4.7	117
Task Average	1.32	20.9	6.0	6.4	6.1	131

[a]Multiples of basal metabolic rate (assuming 1 kcal/kg/hour or 3.5 ml O_2/kg/minute).

[b]Product of liters of oxygen per minute times 4.85 kcal/liter of oxygen.

In order to better compare the mean energy requirements and mean heart rate responses of the various work tasks, the bar graphs in Figures 7 through 10 were constructed. The work tasks are arranged in order of increasing energy requirement and heart rate and standard deviations for each work task are given. Also included in the Appendix is a table presenting the mean, standard deviation, and range of energy cost for each work task. In Figure 7, the reader should note the similarity of energy cost for dust vacuuming and stroking (handball courts) and for water vacuuming and wet mopping and also note the considerably larger energy cost for dust mopping the arena floor. Also, in Figure 10 it is interesting to note the large variability in heart rate in most of the work tasks which is attributed to the unusual response of subject E. S.

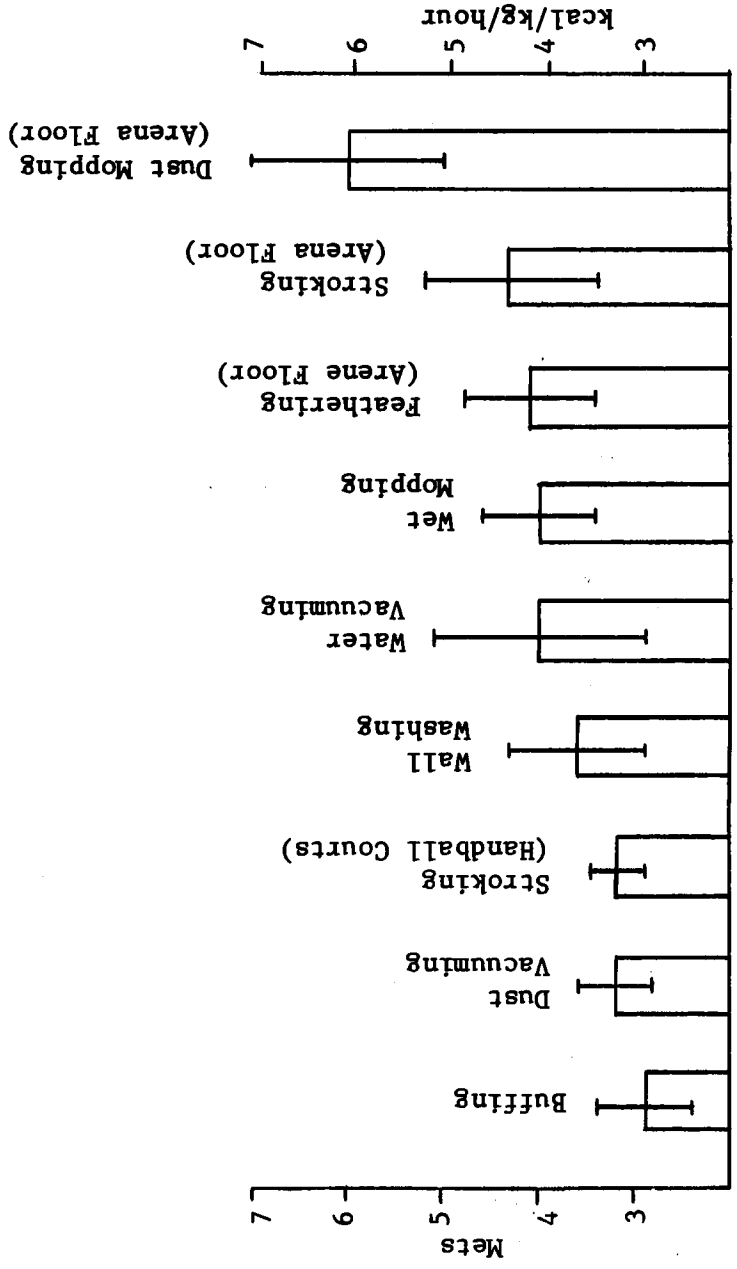


FIGURE 7. Mean and standard deviation of energy requirements for each work task (kcal/kg per hour and Mets).

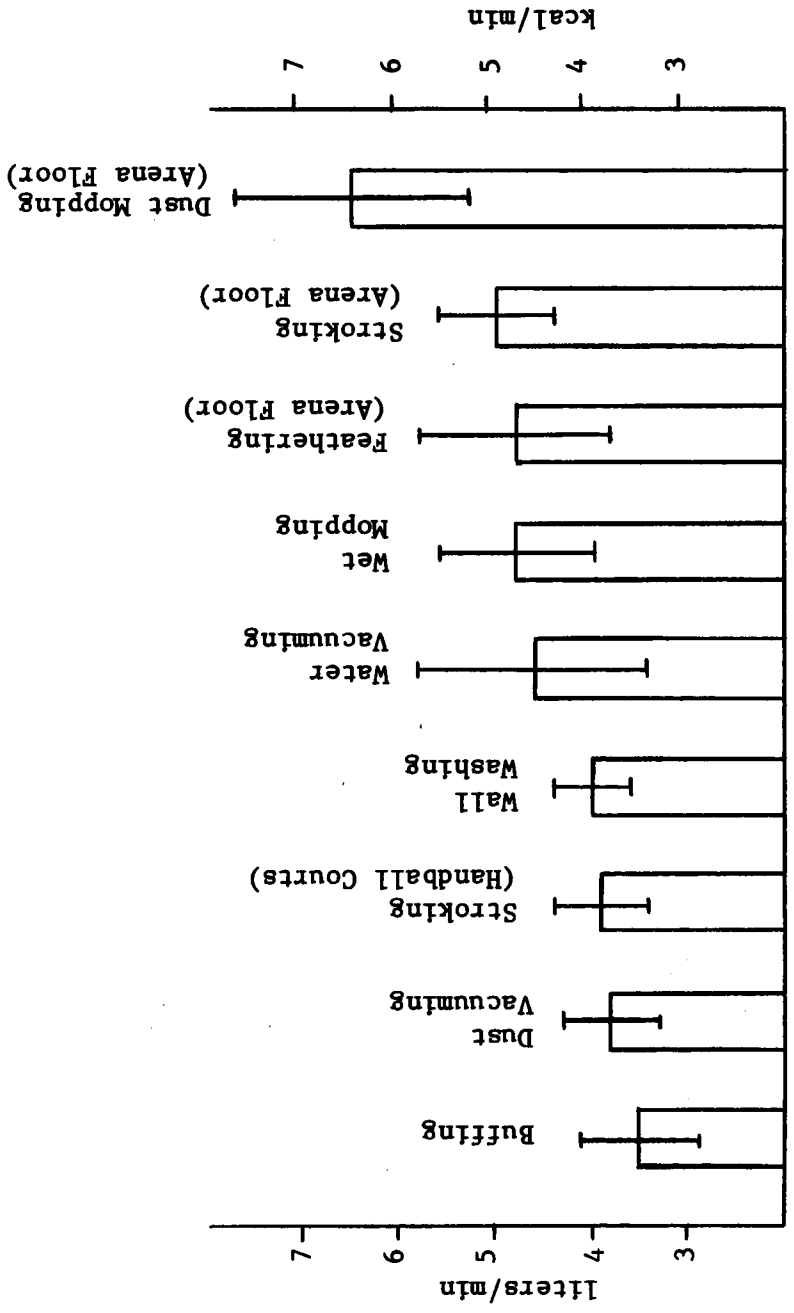


FIGURE 8. Mean and standard deviation of energy requirements for each work task (kcal per minute and liters per minute).

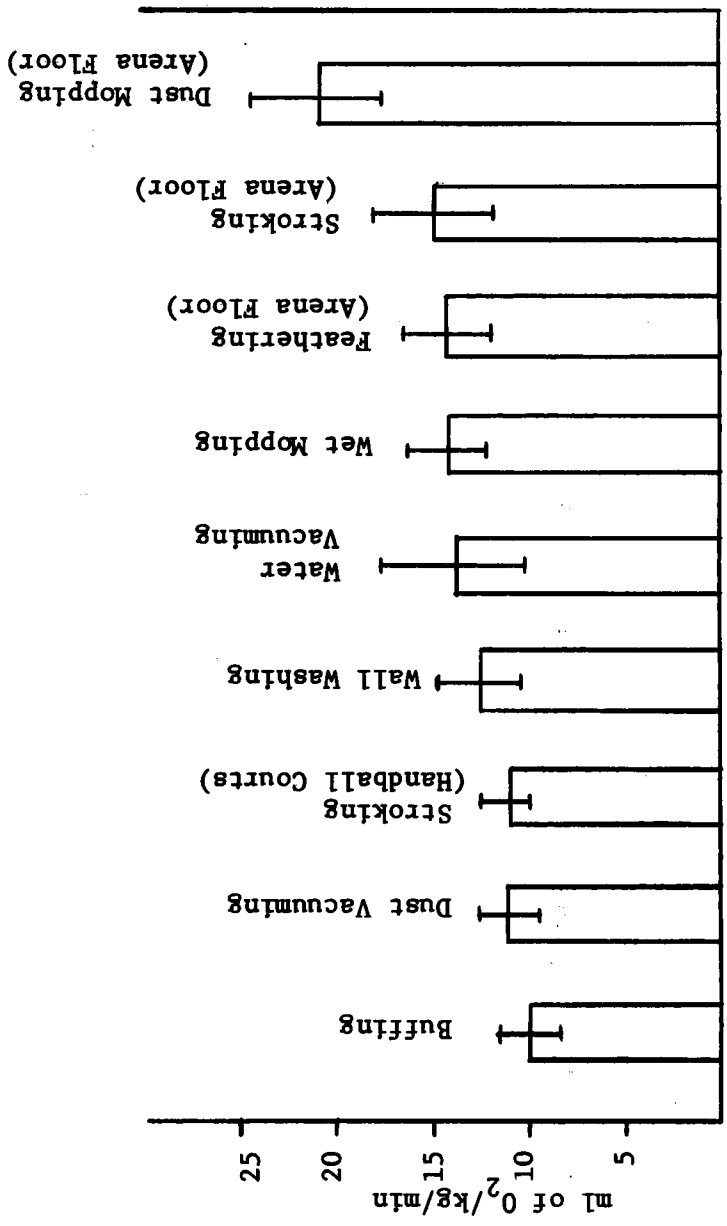


FIGURE 9. Mean and standard deviation of energy requirements for each work task (ml of O_2/kg per minute).

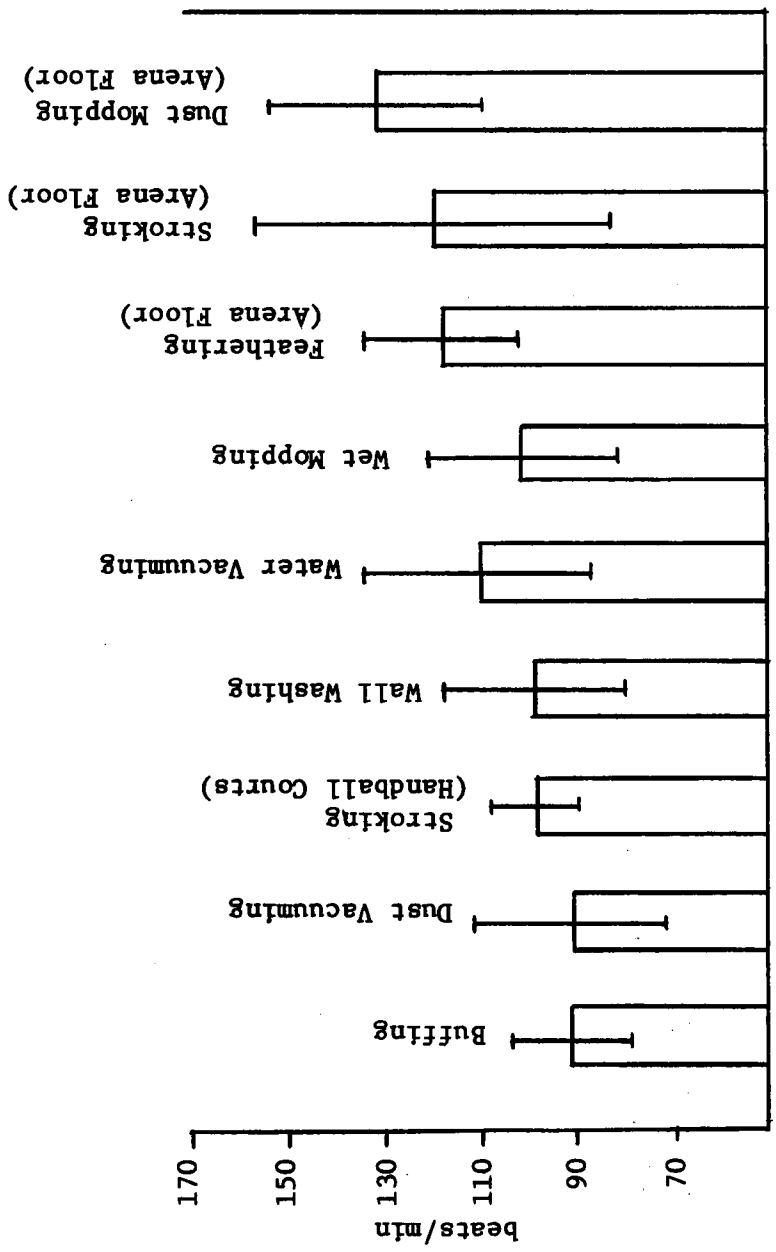


FIGURE 10. Mean and standard deviation of heart rate response for each work task (beats per minute).

CHAPTER IV

DISCUSSION

The consistently higher heart rate response to each work task by subject E. S. was readily seen in Table 3, page 22. This increased heart rate was initially assumed to be due to an anticipatory or emotional response to the experimental apparatus. This was not borne out since heart rate responses in subsequent work tasks were also high and since this subject exhibited the highest energy requirement for six of the nine work tasks. Durnin and Namyslowski (21) found that being apprehensive of experimental apparatus had very little influence on gross metabolism and if it had, there would have been obvious changes in energy expenditure as familiarization and practice increased.

Environmental temperature was also not a factor in affecting the energy cost since the other subjects did not show a similar response under the same environmental conditions. The maximum environmental temperature under test conditions was 29.2 degrees C and the maximum relative humidity was 70 percent. Consolazio and Johnson (17) have reported that only in cases where environmental temperature increases to 30-40 degrees C is it necessary to consider increases in energy requirement due to the temperature.

The lack of effect of these factors on energy cost, however, does not necessarily apply to the heart rate response to a work task. Examination of the data revealed that for wep mopping, E. S. had an energy cost of 18.2 ml/kg per minute with a heart rate of 132 beats

per minute. For feathering, he had a lower energy cost, 16.9 ml/kg per minute, but a higher heart rate, 141 beats per minute. This suggested that factors other than just the energy requirement of the work task were affecting the heart rate.

In order to determine how linear the relationship between heart rate and energy production was for these work tasks, separate graphs were constructed for each individual, plotting their heart rate and oxygen consumption values for each work task. These graphs are shown in Figure 11, demonstrating that there was considerable deviation from linearity in the heart rate-oxygen consumption relationship for each subject.

It is a well established fact that environmental temperature does affect the heart rate response to a set work task (10, 11, 12, 13). Brouha (10) found in his study of man in industry, as did Consolazio (17), that the rate of oxygen consumption for a task was primarily determined by work load and not affected very much by environmental temperature. However, he found that for similar oxygen consumptions, the heart rate increased as the environmental temperature increased. So, differences in ambient temperature for the different work tasks could account for the high heart rate reported for E. S. and for some of the variability seen in the graphs. When heart rate and environmental temperature were plotted for each individual for each work task, no consistent degree of relationship was seen.

To control for metabolic load, heart rate (beats/minute) per unit of oxygen consumption (ml/kg/minute) was plotted against environmental temperature for each individual for each work task. Although

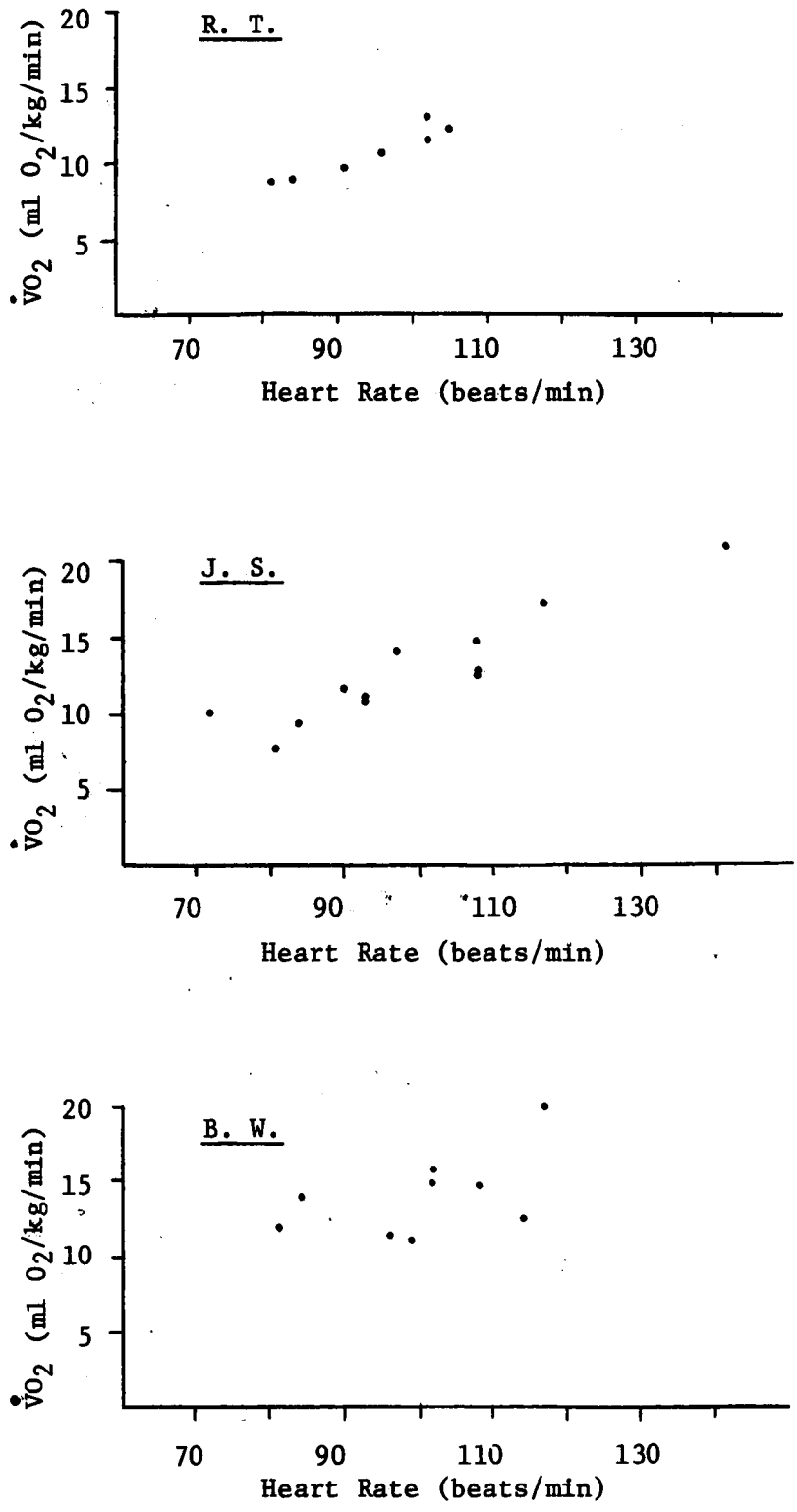
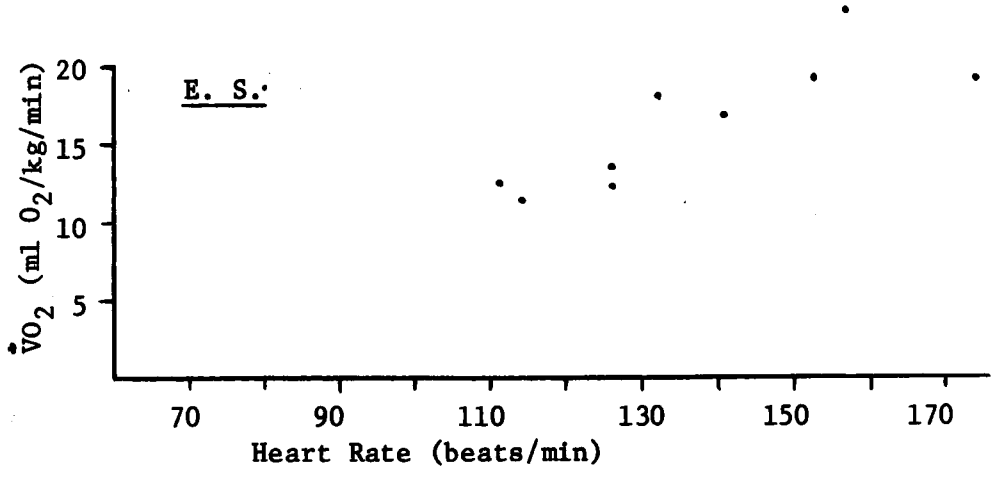
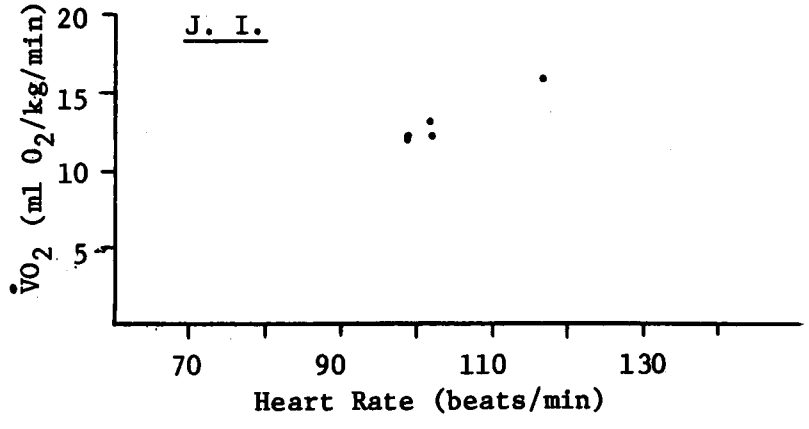


FIGURE 11. Relationship of heart rate to oxygen consumption for each subject.





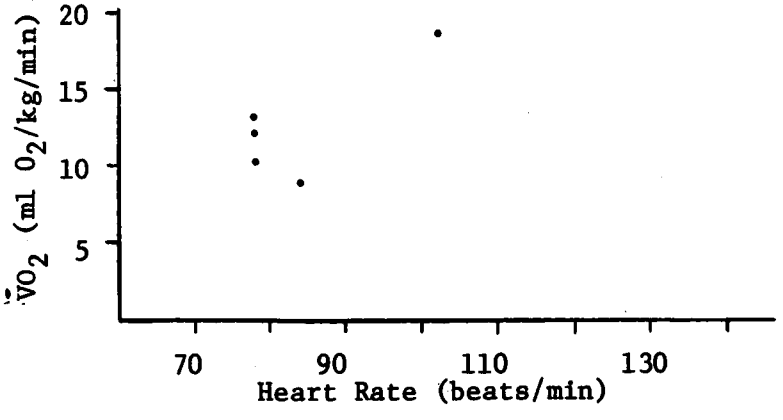


FIGURE 11. (continued)

the variability for this relationship was again large, there were two or three work tasks which seemed to stand out with regard to their heart rate per unit of oxygen consumption responses. Examination of the mechanics of the work tasks led to the possibility that the type of work being done could affect the heart rate or oxygen consumption response and account for some of the variability in this relationship.

When buffing, which is predominantly static work, was compared with dust mopping the arena which is predominantly dynamic work, there was a significantly larger heart rate per unit of oxygen consumption for buffing ($t = 4.12$, $p < .05$). When wall washing, which is primarily an arm activity, was compared to dust mopping the arena, which is primarily leg work, there was a significantly larger heart rate per unit of oxygen consumption for wall washing ($t = 3.65$, $p < .05$). Andrews (2, 3) and others (4, 6) have found that the site of muscular activity (arms versus legs) and the kind of muscular activity (static or dynamic) has a profound effect on the heart rate during work. Working with arms alone or while simultaneously walking, resulted in significantly higher heart rates.

In addition to environmental temperature, the site and kind of muscular activity in a work task, Andrews (2) also lists several other factors which influence the relationship between heart rate and energy expenditure: state of training, state of fatigue, state of absorption, sex, and age. There is also evidence regarding the variation in heart rate response to the same work task for different individuals as well as for the same individual on different days (30). Wyndom et al. (45) reported that it appears possible to train an individual to repeat a

work task from day to day with little variance but very difficult to control the skill or mechanical efficiency with which different individuals perform the same work tasks.

The large number of factors that influence the heart rate-energy expenditure relationship, including the variation that exists between individuals and in the same individual on different days, makes it difficult to pinpoint the cause for the variability in response to some of the work tasks in this study. This response also provides clear evidence as to why errors may result from estimating energy expenditures of occupational work tasks from measurements on one individual. They also attest to the error in estimating energy expenditure from a heart rate measured during a given work task or physical activity. Only when all of the physiological stress is due to the physical work task that is undertaken can the heart rate replace the actual energy expenditure as a means of measuring the work load (30). Bradfield (9) has suggested that heart rate is a good predictor of energy cost of most submaximal activities only if several factors which affect heart rate are held constant. Factors such as size, physical condition, and temperature could be controlled by determining individual heart rate-energy consumption regressions for each subject. Others (7, 8, 29,32) have also suggested separate regression equations for each subject as well as separate regression equations for each type of muscular activity.

In this study, a resting heart rate prior to work was measured on only one occasion. When these resting heart rates were subtracted from the work heart rates for each of the subjects in each of the

tasks, subject E. S. was not very different. So, even though his gross heart rate was unusually high, his net heart rate may have been a valid indication of the metabolic cost of the work task. Since resting heart rates were not taken prior to each test session, this comparison cannot be made.

The work task requiring the largest mean energy requirement was dust mopping the arena floor. Since this task involves several 100-foot excursions up and down a basketball floor, the increased amount of walking as compared to the other tasks, will account for the greater energy cost. The cost of walking on the level at three miles per hour has been reported to be 3.5-3.8 kcal/kg per hour (27, 22). The speed of walking in this task was not experimentally determined but was considerably more brisk than a three miles per hour pace.

Only two of the work tasks could be compared with data from previous research. The energy cost values of vacuuming in this study ranged from 2.6-4.0 kcal/kg per hour. This range was somewhat lower than the 3.5-4.5 kcal/kg per hour as reported by Durnin and Passmore (22). Astrand (5) presented a value of less than 3.7 kcal per minute for women which corresponds closely to the mean of 3.7 kcal per minute for vacuuming in this study; however, her data would result in a higher value when expressed per kilogram of body weight since her subjects had an average body weight of 55 kilograms.

The mean energy cost values for mopping in this study were 4.7 kcal per minute and for means of comparison, 4.1 kcal/kg per hour. Durnin and Passmore (22) reported a range of 3.8-4.9 kcal per minute within which the average value from this study would fall. Astrand's

(5) value of 4.7 kcal per minute is the same as the value from this study but once again would be larger when corrected for body weight. Grandjean's (25) values of 4-5 kcal per minute for women would provide a similar comparison. Consolazio (18) reports a value of 4.0 kcal/kg per hour which compares very favorably with the 4.1 kcal/kg per hour in this study.

The average energy expenditure of the various work tasks in this study ranged from 3.4-6.4 kcal per minute which was similar to the energy cost ranges of other occupations. Astrand (5) reported a range of 3.7-6.9 kcal per minute for housekeeping activities, Viteri (43) a range of 1.7-7.2 kcal per minute for agricultural activities, and Raven (33) a range of 2.5-7.5 kcal per minute for smelter workers. Reddan's (34) energy requirements of 10-16 ml/kg per minute for rubber plant workers compares favorably to the range of 10-20.9 ml/kg per minute found in this study. Fors (24), who measured the energy cost of emergency tasks, reported a range of 4.4-10.4 Mets which was somewhat larger than the 2.9-6.0 Met range found in this study. However, the tasks which he measured involved climbing several flights of stairs, climbing a vertical ladder, and carrying as much as 150 pounds on a rescue stretcher. This would account for the higher Met loads since the custodial work tasks primarily involved movement of the subject's own body weight in a horizontal plane.

The upper and lower limits of the ranges presented are easily affected by the choice of work tasks to be measured. Measuring all work tasks included in a job description or occupation as opposed to

measuring a sample of the work tasks would definitely alter the energy cost range.

The range of energy expenditure for the work tasks in this study, 3.4-6.4 kcal per minute would classify the whole job, according to Christiansen (16), as moderate work. Brown and Crowden (14, 15) have suggested somewhat lower limits for occupational work tasks and would classify the job as heavy work. The Dictionary of Occupational Titles (42) lists the physical demands of 4,000 jobs and classifies janitorial work as being heavy work. However, the physical demands of the jobs in this last survey were determined from information obtained by a job analysis technique which consisted of an observation and an interview and no direct measurements.

As a result of the heart rate data from this study it seems that the heart rate response to a given work task may be a better indicator of the total physiological stress than the energy cost. Brouha (10) has stated that, " . . . oxygen consumption measurements alone may be misleading when attempting to evaluate the physiological cost of a given work load under varying environmental conditions." According to Maxfield (30), the heart rate response to work is a better determiner of the total stress of the task.

The average heart rates for the various work tasks in this study ranged from 91-131 beats per minute. In a classification of work according to heart rate during work, which was devised by Brouha (10), this whole job would be classified as heavy work. The unusually high heart rates exhibited by E. S. in three of the work tasks would classify these tasks as being very heavy work for him.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to determine the average energy cost and heart rate response to a job classified as custodial work. Although energy cost values exist for a large number of physical activities and for some industrial jobs, there are many occupational tasks for which these values need to be determined. The information from this study should be of value to those calculating a daily energy expenditure and should also be of benefit to the physician in determining the ability of a cardiac patient to return to a job requiring the performance of custodial work tasks.

Seven male employees of The University of Tennessee Physical Plant who performed custodial work tasks were the subjects for the study. Nine work tasks that were representative of the normal work activities of the crew were chosen for investigation. Oxygen consumption and heart rate were the two parameters measured for each work task. The energy cost for each task was determined from the oxygen consumption values and was presented in several units for comparison.

The following conclusions were drawn from the results of this study:

1. The average energy requirements of the various work tasks ranged from 3.4-6.4 kcal per minute with the largest value resulting from dust mopping the arena floor. This range of energy costs would classify the whole job as moderate work.

2. The average heart rate response of the various work tasks ranged from 91-131 beats per minute with the largest value again resulting from dust mopping the arena floor. This range of heart rates would classify the whole job as heavy work.
3. This heart rate range as well as the consistently high heart rate response for one individual indicates that the heart rate may be a better measure of the total physiological stress of a particular work task. This should be especially true for the physician who must decide the degree of cardiac strain that this job may represent to a patient.
4. The site of muscular activity (arms versus legs) and the kind of muscular activity (static versus dynamic) seem to definitely be factors contributing to the variability in the heart rate-oxygen consumption relationship in this study.

Also as a result of this study, the following recommendations are made for future study:

1. Daily resting heart rates should be measured in addition to the heart rate response to work so that a net heart rate for each task can be determined. This value should considerably reduce the variability that existed in the heart rate-oxygen consumption relationship in this study.
2. For the same reason stated above, a daily baseline or resting metabolic rate should be established for each

subject prior to testing so that a net energy cost for the task can be determined.

3. Energy cost measures for each subject for each of the work tasks should be repeated on different days so that the degree of day-to-day variation within each subject can be determined.

The degree of physiological stress, including energy cost and heart rate response, needs to be determined for many industrial and occupational jobs. By applying the recommendations mentioned above, considerable contribution to the field of industrial physiology can result.

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APPENDIX

TABLE 4

MEAN, STANDARD DEVIATION, AND RANGE OF ENERGY REQUIREMENTS FOR EACH WORK TASK

Work Task		liters O_2 per minute	ml/kg O_2 per minute	Mets	kcal per minute	kcal/kg per hour	Heart Rate
	$\bar{X}$	.70	10.0	2.9	3.4	3.0	91
Buffing	SD	.12	1.8	.5	.6	.5	13
N=5	R	.55-.92	7.2-12.6	2.1-3.6	2.6-4.4	2.1-3.7	81-114
Dust	$\bar{X}$	.76	11.2	3.2	3.7	3.2	91
Vacuuming	SD	.10	1.5	.4	.5	.4	20
N=5	R	.61-.94	8.8-13.7	2.5-3.9	3.0-4.6	2.6-4.0	78-126
Stroking	$\bar{X}$	.78	11.2	3.2	3.8	3.3	98
(Handball Courts)	SD	.10	1.2	.3	.5	.3	9
N=4	R	.60-.89	9.7-12.7	2.8-3.6	2.9-4.3	2.8-3.7	91-111
	$\bar{X}$	.79	12.6	3.6	3.9	3.6	98
Wall Washing	SD	.07	2.3	.7	.4	.7	19
N=5	R	.63-.87	8.3-16.2	2.4-4.6	3.0-4.2	2.4-4.7	78-126
Water	$\bar{X}$	.93	13.9	4.0	4.5	4.0	110
Vacuuming	SD	.25	3.8	1.1	1.2	1.1	24
N=6	R	.61-1.29	8.8-19.8	2.5-5.7	3.0-6.2	2.6-5.8	84-153
	$\bar{X}$	.96	14.1	4.0	4.7	4.1	101
Wet Mopping	SD	.17	2.1	.6	.8	.6	19
N=6	R	.73-1.22	12.2-19.1	3.5-5.5	3.5-5.9	3.5-5.6	78-132
Feathering	$\bar{X}$	.97	14.2	4.1	4.7	4.1	117
(Arena Floor)	SD	.20	2.3	.7	1.0	.7	16
N=4	R	.71-1.25	10.9-17.2	3.1-4.9	3.2-6.1	3.2-5.0	105-141

TABLE 4 (continued)

Work Task		liters O_2 per minute	ml/kg O_2 per minute	Mets	kcal per minute	kcal/kg per hour	Heart Rate
Stroking	$\bar{X}$	1.02	14.9	4.3	4.9	4.4	119
(Arena Floor)	SD	.13	3.1	.9	.6	.9	37
N=4	R	.78-1.18	11.1-19.7	3.2-5.6	3.8-5.7	3.2-5.8	97-174
Dust Mopping	$\bar{X}$	1.32	20.9	6.0	6.4	6.1	131
Arena	SD	.25	3.4	1.0	1.2	1.0	22
N=6	R	.95-1.67	15.7-26.1	4.5-7.4	4.6-8.1	4.6-7.6	102-157

VITA

Joe Foust Smith was born in Jackson, Tennessee, on May 12, 1942. He attended the city schools in Jackson and was graduated from Jackson High School in 1960. The following September he entered Union University in Jackson and received a Bachelor of Science degree in 1964. The following year he accepted a teaching assistantship at the University of Arizona and received his Master of Education degree in 1965.

He was employed at Treadwell Junior High School in Memphis, Tennessee, for the 1965 school year. From 1966 to 1969 he taught and coached at Shorter College in Rome, Georgia, and performed the same duties at Palm Beach Atlantic College in West Palm Beach, Florida, from 1969 to 1972.

In the summer of 1972 he entered the graduate school at The University of Tennessee. He was an instructor in the Physical Education Department for two years and a graduate assistant for one year. He received the Doctor of Education degree with a major in Physical Education in June of 1975.

He is married to the former Carol Chalhub of West Palm Beach, Florida, and they have two children, Scott and Shannon.