THE EFFECT OF TEMPORAL UNCERTAINITY ON HUMAN ENERGY EXPENDITURE DURING MOD-ERATE EXERCISE

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THESIS

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by

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The Effect of Temporal Uncertainty
on
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by

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ABSTRACT

It is hypothesized that psychological attitudes affect physiological functions in humans. One function that might be affected is energy consumption during work or exercise.

An experiment was conducted to examine the effect of temporal uncertainty about the duration of an exercise period on energy cost. A sample of 13 healthy, young male military officers were tested under controlled exercise routines with and without temporal uncertainty. Results indicated that there is a significant ($\alpha < .05$) difference between similar tasks under temporal uncertainty and certainty. The task under uncertainty required less energy than the other task.

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I. INTRODUCTION

A. NATURE OF THE PROBLEM

Studies of the effects of various physical parameters on human physiological factors are frequently conducted. Chapman and Mitchell [1965], Cooper [1970], and Cotes and Meade [1960] have presented detailed studies of the effects of exercise on human physiology. The effect of heat strain and other environmental conditions on pulse rate, energy consumption, and working efficiency have been reported by many authors (e.g., Brouha [1960], Brouha and Maxwell [1962], Belding and Hatch [1955], Consolazio [1963], and Grandjean [1969]). Most studies of this type have been concerned with work load, work duration, and environmental conditions as they affect physiological parameters such as energy consumption, fatigue, body temperature, pulse rate, etc.

Many other authors (e.g., Gagne and Fleishman [1959] and Yufer [1969]) have attempted to correlate psychological effects on human performance. No known work, however, has been reported that attempted to investigate psychological factors on energy expenditure. Information about conscious or subconscious control over one's sympathetic nervous system and its control over blood pressure, pulse, body temperature, and energy consumption would be of interest from both medical and human engineering viewpoints.

B. EXPERIMENTAL APPROACH

The experiment reported in this thesis investigated the effect of temporal, or time duration, uncertainty on energy consumption. Davies and Tune [1969] reported a significant improvement in vigilance performance when subjects were aware that the end of the task was approaching. They called this phenomenon the end effect. It was postulated that a similar end effect, or other such effects, might influence energy consumption. To test for this effect, energy consumption was measured during two nearly identical moderate exercise tasks--one with subjects having temporal knowledge and the other under temporal uncertainty.

The tasks consisted of pedaling a bicycle ergometer under one of four work/rest conditions. During each of the four tasks subjects exercised during an eight minute work/rest period. Two of the tasks were conducted with subjects having full temporal knowledge of the work and rest period durations. The other two tasks were conducted without this knowledge. Two of the tasks (one with temporal knowledge and one without) consisted of very similar work/rest periods and these two were used to investigate the hypothesis of this thesis.

C. ORDER OF REPORTING

The experimental design and the procedures used in conducting the experiment are discussed in Section II. The results of the experiment and analysis of the data are presented in Section III. Conclusions and recommendations for further study are given in Section IV.

Appendixes A through F present equipment listing, complete compilations of the experimental data, the data analyses, and a discussion of some problems encountered in the experiment.

II. EXPERIMENTAL DESIGN AND PROCEDURE

A. EXPERIMENTAL DESIGN

The principle question investigated in this experiment was whether temporal uncertainty has an effect on human energy consumption. A basic ergometer exercise task was chosen that would be tiring enough to the subject to make termination desirable but not so exhausting as to make repeated measurement impossible. The subjects were required to perform four such tasks--two under temporal uncertainty and two with temporal knowledge. Indirect calorimetry measurements were made and energy expenditure by the subjects were calculated for each subject on each task. Comparisons of the tasks were then made.

1. Mathematical Model

A randomized-block mixed model design was selected for the experiment [Kirk 1969]. Subjects were utilized as blocks and tasks were the treatments. Randomization was accomplished by randomly determining the order of applying treatments to subjects. This model is the desired one when variability among blocks is appreciably larger than the variation among treatments within blocks. It was expected that the energy consumption rates would vary more from subject to subject than from treatment to treatment. A mixed effects model was considered appropriate since the treatments (tasks) were fixed while the blocks (subjects) were considered to be a random sample from a normally distributed population.

It is assumed in this model that a particular measurement X_{ij} is given by

$$X_{ij} = \mu + \beta_i + \tau_j + \epsilon'_{ij} \qquad (1)$$

where μ = grand mean of all observations

β_i = constant associated with block i

τ_j = effect of treatment j

$\epsilon'_{ij} = (\beta\tau)_{ij} + \epsilon_{ij}$; the interaction effect and the true experimental error.[1]

The hypothesis of this model is that $\tau_j = 0$ for all j and $\sigma^2_\beta = 0$.

2. <u>Factors of the Model</u>

a. Subjects

Subjects were male military officers who volunteered to be tested. The age of the group varied between 24 and 31 years. All were in excellent general health and none had any temporary illness at the time of testing. Each subject received a meal one hour prior to starting the tests. This meal was the same for all subjects and was given in an attempt to insure that subjects constituted a homogeneous sample from a normal population. Guyton [1971] discussed the effect of different foods and the amount of time after ingesting them on metabolic rate.

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[1]Since no replications were administered, the interaction effect was inseparable from the true experimental error.

b. Tasks

The subjects were required to pedal a bicycle ergometer for six minutes of eight total task minutes for four different tasks (the remaining two minutes of each task were spent resting on the bicycle). Ergometer friction was set manually to require approximately 330 kilogram-meters per minute[2] at a pedaling speed of 80 revolutions per minute. Energy expenditure was estimated by indirect calorimetry.

The four different tasks required of each subject are given in Table I and are depicted in Figure 1. Comparison of energy consumption during tasks A and D was the primary purpose of this experiment. The total work done in both tasks was the same and the work/rest cycle pattern was very nearly the same. The one major difference was that in task D the subject had no knowledge of the task duration or pattern.

Since task D was so similar to task A, it was necessary to confound the subject by introducing tasks B and C. This was done to prevent the subject from assuming that all tasks would be similar. Further, introduction of task B allowed comparison of a long work period under temporal uncertainty with the standard, task A. Task C gave the opportunity to investigate the effect of frequent starting and stopping of the bicycle.

Task A was chosen as the standard for all tasks. An eight minute total task period was chosen to set the total testing period

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[2] 330 kg-m/min = 73 ft-lb/sec = 54 watts

Table I. EXPERIMENTAL TASKS

Task	Name	Temporal Knowledge?	Work/Rest Cycle Lengths (min:sec) work	rest	work	rest	work	rest	work	rest
A	Standard	yes	2:00	1:00	2:00	1:00	2:00			
B	Extreme	yes	5:00	2:00	1:00					
C	Uniform	no	1:30	:15	:45	:30	3:15	:45	:30	:30
D	Normal	no	2:00	1:00	1:45	1:00	2:15			

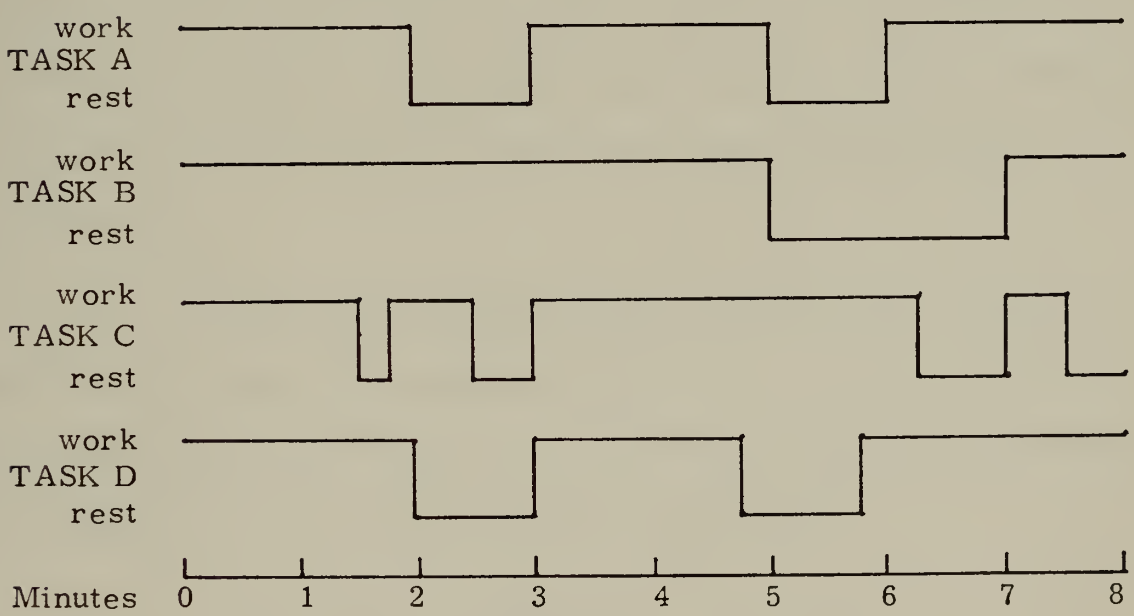

Figure 1. Experimental Task Work/Rest Cycles

for each subject at about one hour. This time included preparation, the actual tasks, and adequate rest periods between tasks.

Task D was developed from a discretized normal distribution based on mean parameters of task A. The durations of the work and rest cycles were based on randomly selected normal variates with means of two minutes and one minute respectively. The computed values were rounded to the nearest 15 second interval. The last work period was predetermined by the others and the requirement for exactly six minutes of work. The desired similarity between tasks A and D was thus achieved.

Task C was developed from a discretized uniform distribution. Work durations were chosen at random from the interval between :15 seconds and 3 minutes :45 seconds rounded to the nearest 15 seconds. Rest durations were selected from an interval between :15 seconds and 1 minute :45 seconds. The mean values of the distribution of work and rest periods were again two minutes and one minute respectively.

Rest periods between tasks were provided to insure that there was no fatigue or oxygen debt carry-over from one task to the next. Grandjean [1969] presents the following formula for determining an adequate rest period as a percent of work time:

$$\text{Rest Time} = \left(\frac{\text{kcal/min}}{4} - 1\right) \times 100.$$

Preliminary investigation indicated that energy expenditure would be less than 6 kcal/min for the required tasks. Thus a rest period of about 50% of the duration of the work period was determined to be adequate. A rest period of about seven minutes (88% of the work period) was actually used in the experiment.

3. Hypotheses

a. Primary Hypothesis

The primary purpose of the experiment was to see if there was a difference in energy expenditure between tasks A and D, the nearly identical tasks--one with and one without temporal knowledge. Thus the model given in Equation (1) was applied with treatments being the type of task performed by the subject. The null hypothesis was,

H_o^1: treatment effect of task A equaled effect of task B.

b. Supplementary Hypotheses

(1) All Tasks. Since an experiment such as the one presented here had not been conducted previously, it was desired to determine what effects, if any, the work/rest cycle pattern of each task had on energy expenditure. The model was applied as with H_o^1 and the null hypothesis was,

H_o^2: treatment effect of any task equaled that of any other task.

(2) Order of Tasks. Analysis was made of the experimental data of the 13 primary subjects considering the actual order of tasks rather than the type of task. That is, energy expenditure values

of each subject's first task were compared with the values of the second, third, and fourth task without regard to the type of task. This was done in order to examine for a trend in the observations indicating a fatigue or learning effect. Thus the same mathematical model was used with the treatments being the order of subjects performing the tasks. The null hypothesis was,

H_o^3: Treatment effect of i^{th} task equaled that of j^{th} task ($i, j = 1, 2, 3, 4; i \neq j$).

(3) Control Subjects. Data was obtained from a group of two control subjects who performed the same experiment as other subjects except that they repeated task A throughout the test. The purpose of these tests was to ascertain whether the results were repeatable. If each control subject consumed about the same amount of energy on repetitions of the same task then it would be concluded that different energy expenditure rates in the primary experiment were due to actual differences in the tasks. Again Equation (1) was applied with the treatments being repetitions of task A. The null hypothesis of this analysis was,

H_o^4: treatment effect of i^{th} repetition of task A equaled that of j^{th} repetition ($i, j = 1, 2, 3, 4; i \neq j$).

B. EXPERIMENTAL PROCEDURE

1. Background

Energy released in the body from both activity and basal metabolism is almost entirely converted into heat [Guyton 1971]. Therefore heat production is a direct indicator of energy consumption.

Several methods of measuring heat production are in use. They are summarized in the following sections.

a. Direct Calorimetry

The most accurate and direct method of measuring heat production is direct calorimetry. The procedure is to take accurate measurements of all the heat liberated from the body. This is normally done with the subject in a large, specially constructed calorimeter. This method is cumbersome and difficult to conduct and although it has the advantage of measuring total metabolic heat production, it is seldom used in physiological experiments.

b. Indirect Calorimetry

Indirect calorimetry is the preferred method of measuring heat production. Since almost all energy expended in the body is derived from the oxidation of food it is possible to relate oxygen consumption to energy consumption. This method was first used in the early twentieth century and has been shown to be in very close agreement with direct calorimetry [Consolazio 1963]. Simply stated, indirect calorimetry consists of measuring the volume and composition of expired gases and calculating energy consumption in kilocalories.[3] The specific experimental procedures used in this study are given in the next subsection. There are several units of measurement available to

[3]The kilocalorie (or large calorie or "Calorie") is the common measure of heat production in physiology. It is the amount of heat required to raise the temperature of one kilogram of water from 14.5°C to 15.5°C.

the experimenter conducting indirect calorimetry experiments. The commonly reported units are shown in Table II.

c. Other Methods

Consolazio [1963] paraphrased Benzinger et al [1958] in describing another method of human calorimetry, the gradient principle. In practice this method is closely related to direct calorimetry and for that reason is probably no more suitable for general experimentation.

Sharkey et al [1966] have attempted to predict oxygen consumption by measuring pulse rate and pulmonary ventilation. Although this method has great advantages in experimental application, the authors cited reported differences of up to 30% between this procedure and standard indirect calorimetry.

2. Method

a. Preparations and Instructions

Each subject was tested about one hour after eating. He was told that he would be required to go through four sessions of work/rest cycles on the stationary bicycle;[4] each session to be followed by a five to ten minute rest period. He was also informed that the entire test would last about one hour. He would be told when to start pedaling and when to stop in all four sessions and, additionally, during two sessions he would be able to observe a clock displaying the work/rest cycles. He was told not to rush to get the cycle speed up to the

[4] A complete listing of the equipment used in the experiment is given in Appendix A.

Table II. UNITS OF MEASUREMENT FOR INDIRECT CALORIMETRY

MEASUREMENT	UNITS COMMONLY REPORTED	REMARKS
Oxygen Consumption	Milliliters of 0_2 per minute (ml/min)	Actually measured in indirect calorimetry. Basis for energy estimates.
Heat Production	Kilocalories (kcal)	Used in reporting total energy for particular activity.
Heat Production Rate	Kilocalories per minute (kcal/min)	Most commonly reported measurement in physiological experiments.
Standardized Heat Production Rate	Kilocalories per minute per square meter body area ($kcal/min\text{-}m^2$)	Tends to standardize energy consumption values over a wide population of subjects.

required 80 rpm but that it should take about 10 seconds to do so and only one or two seconds to stop.

The subject was told to stop the test at any time that he became dizzy or nauseated or needed to remove the mask to sneeze, cough, or vomit. (No such instances occurred throughout this study.) The face mask was fitted on the subject and the bicycle seat height was adjusted. He went through two short practice trials to become accustomed to starting and stopping the bicycle. He was then allowed to rest in an easy chair for about three minutes.

During that rest period the experimenter prepared the equipment for the upcoming task session. The control face of the Lifecycle ergometer was covered except for the RPM indicator dial. An evacuated rubber sample bag was placed on the respirometer and the initial respirometer reading was recorded. A sample of the room air was introduced into a previously evacuated sample bag and this was attached to the flowmeter. When a flow of 50 milliliters per minute was established from the flowmeter it was connected to the oxygen analyzer. To insure correct oxygen analysis the percentage oxygen reading was made four minutes after the sample had been introduced to the analyzer.

b. Actual Testing

Following an initial resting period, the subject mounted the bicycle and fitted the face mask in place. He remained at rest for one to two minutes to drive out gases in the respirometer from the

previous test. He was then informed as to whether or not he would have access to the clock for that task period. On command from the experimenter he began cycling (all tasks began with a work period). At the same time the timer or stopwatch was started and the respirometer was turned on to begin venting a sample of the expired gases into the sample bag.

The experimenter sat to the side and slightly behind the subject and verbally gave the start and stop commands even in the tasks where the clock was visible to the subject. The oxygen analyzer was within reach of the experimenter and room air analysis was recorded during the task. At the end of the task period the respirometer was turned off, the subject stopped cycling, and his face mask was removed. The subject sat in the easy chair and rested prior to the next task session. Meanwhile, the experimenter recorded the final respirometer reading and expired air temperature and introduced the expired gas sample to the oxygen analyzer via the flowmeter. The equipment was then prepared for the next task session. After seven minutes of rest by the subject the procedure was repeated.

One entire experimental session required about one hour and ten minutes excluding the time during and following the meal. At the end of testing, subjects were told the purpose of the experiment and were asked for any pertinent observations that they had.

While most of the experiment was conducted without difficulty it was recognized that a few problems might have existed. These were:

(i) an apparent variation in room air oxygen percentage,

(ii) a possibility of subject variation during the tasks,

(iii) a possibility of subject pattern recognition during the tasks.

These problems are discussed in detail in Appendix F and justification is given for ignoring the possibility of their affecting the results.

c. Data Collection and Calculations

Prior to beginning each experimental session a questionnaire concerning biographical and physical information about the subject was filled out. During the experiment the volume, temperature, and oxygen content of the subject's expired gases and the oxygen content of the inspired air were recorded. Barometric pressure was obtained from the Navy Weather Center at the Naval Postgraduate School. Samples of the questionnaire and data collection form are given in Appendix B.

Calculations were made for each subject on each task of respiration quotient, energy expenditure rate (kcal/min), and standardized energy expenditure rate (kcal/min-m^2). The calculational procedures and a sample calculation are given in Appendix C.

III. RESULTS AND ANALYSIS

A. RESULTS

Complete presentations of the raw and calculated data from the experiment (including the control experiment) are made in Appendix D. Figures 2 and 3 summarize the principle results of the experiment.

Figure 2 shows that the mean energy expenditure rates for the 13 subjects ranged from 5.11 to 5.45 kcal/min. Task C, with the frequent starting and stopping of the ergometer, apparently required the highest energy expenditure. Task A had a fairly high mean value also and task D (similar to task A but conducted under temporal uncertainty) had the lowest mean value.

Figure 3 shows the mean values when considering the order rather than type of task. Here the range was from 5.21 to 5.34 kcal/min with the first task having the highest mean and the third task having the lowest.

B. ANALYSIS

1. Analysis Technique

The common method of analysis of data of a design as presented in the preceding section is analysis of variance (ANOVA). A primary assumption in ANOVA is that errors are normally distributed. If the errors are not normally distributed some degradation of the power of the analysis can be expected. However, Kirk [1969] indicated that

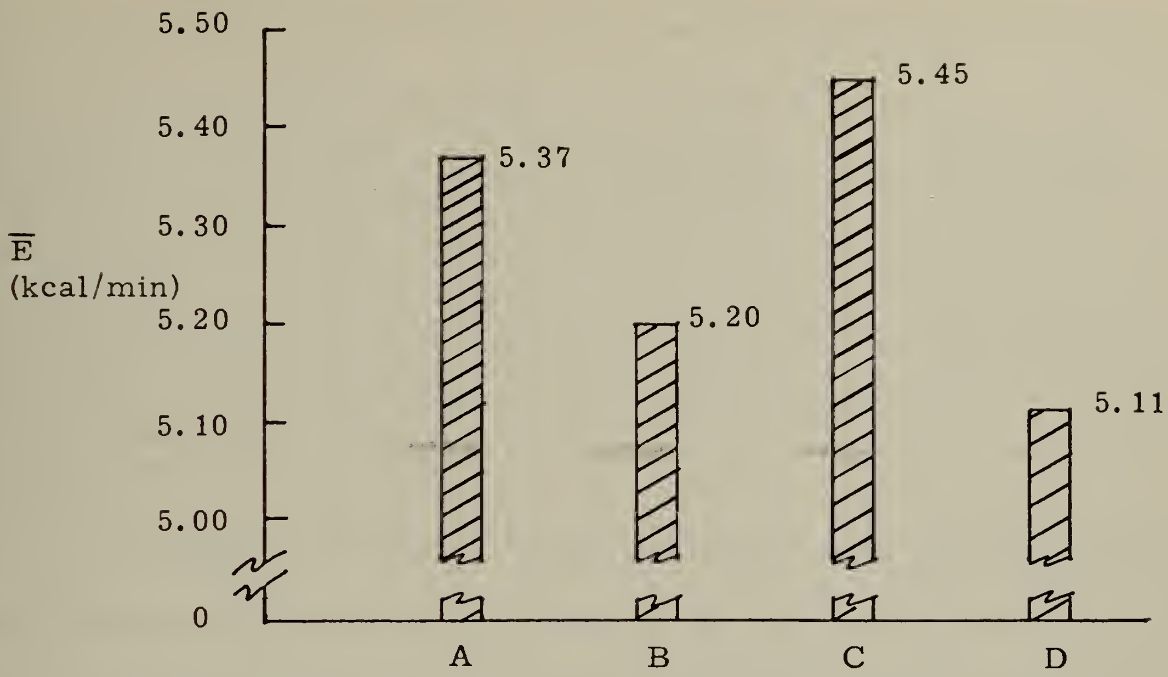

Figure 2. Mean Energy Expenditure Rates by Type of Task

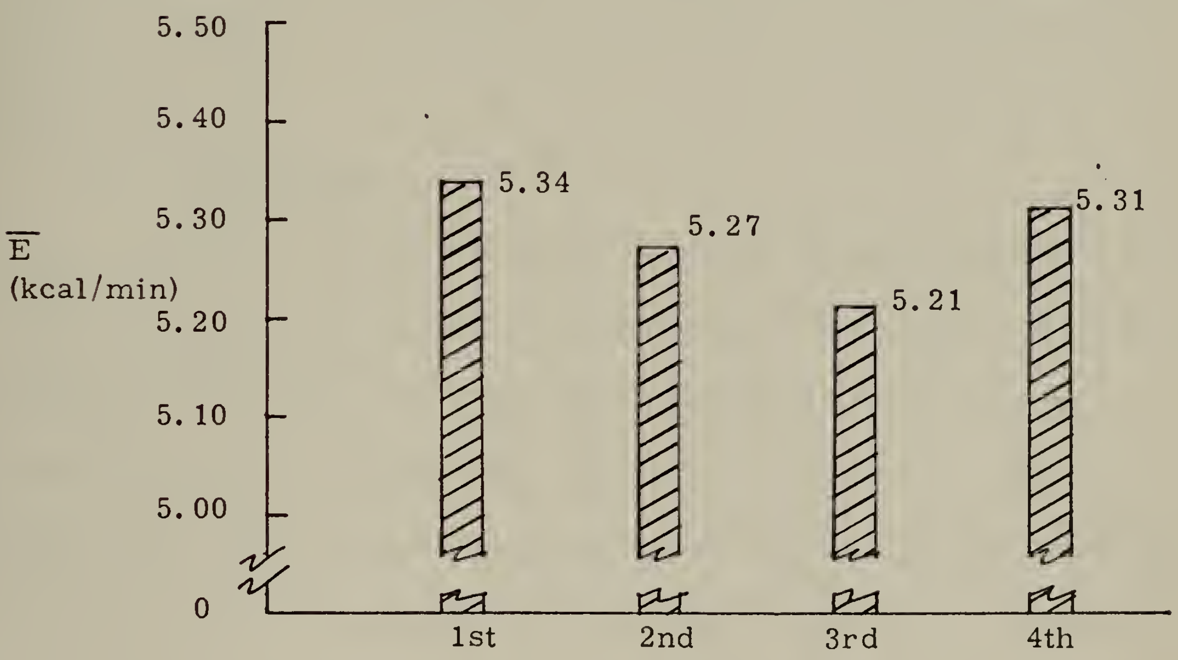

Figure 3. Mean Energy Expenditure Rates by Order of Task

moderate departures from normality is usually not a serious problem and Jones [1971] presented strong evidence that error non-normality should be of little concern relative to degradation of the power of the ANOVA, even in extreme cases. Thus, even though there was no assurity that errors in this experiment were normally distributed, comparison of treatment means was made by analysis of variance techniques.

When the ANOVA procedures indicated significant differences between the means being tested under H_o^1, H_o^2, H_o^3, or H_o^4 various tests were employed to identify those pairs of means that were actually different from one another. The test for comparison of means chosen were Tukey's honestly significant difference (HSD) test, the least significant difference (LSD) test, and Duncan's new multiple range (DMR) test (See Kirk [1969]).

2. Data Analysis

Analysis of variance of the data represented in Figures 2 and 3 was conducted and is presented in Appendix E. The results of these analyses indicated that there was significant (at $\alpha < 0.01$) difference between the type of tasks but not between the actual order of the tasks. That is, one must reject the null hypothesis, H_o^2, that all tasks required the same energy consumption. But one must accept the null hypothesis, H_o^3, that the order of the subjects doing the tasks had no effect on energy consumption.

Analysis of the data from the control group (also presented in Appendix E) led to the conclusion that the results were repeatable under the conditions of the experiment. That is, one must accept the null hypothesis, H_o^4, that subjects repeating the same task had the same energy consumption on all repetitions.

These results in total led to the conclusion that the experiment was a valid test for the hypothesis that temporal uncertainty effects energy consumption. However to test the primary hypothesis, H_o^1, that task A, under temporal knowledge, differed significantly from task D, under temporal uncertainty, it was necessary to compare the mean values of energy consumption rates for the four tasks. This comparison, done by three methods, is presented in Appendix E. The results indicate a significant (at $\alpha < 0.05$) difference between tasks A and D and thus the null hypothesis must be rejected at this significance level.

IV. CONCLUSIONS AND RECOMMENDED FURTHER STUDY

It was concluded, based on the analyses reported in the preceeding section, that there was a significant effect on energy expenditure due to temporal uncertainty. Subjects tended to consume less energy when they were uncertain about the duration of the task cycle. The actual reason for this difference is unknown although it is suggested that some sort of "end effect" at the end of a known work cycle and anxiety preceeding the end of a known rest cycle may cause higher energy consumption.

It was concluded that there was no evidence of fatigue or learning effects on the subjects tested. It was also concluded that subjects tended to consume about the same amount of energy when given repetitions of the same task under the same temporal knowledge.

It is obvious that the results of this study are limited in scope. The controlled, short-term, moderate exercise task, the limited population of subjects, and the other obvious experimental unrealities prevent direct extrapolation to industrial or military applications. However, if the basic premise of an effect on energy consumption by temporal uncertainty can be shown to exist over a wider variety of subjects and task conditions, then it might be possible to affect energy requirements for a particular task by controlling temporal knowledge.

It is recommended that further studies investigate this phenomena under the following conditions:

(i) greater and lesser energy rate requirements,

(ii) longer work periods,

(iii) larger, more varied subject population, and

(iv) actual work conditions rather than exercise tasks.

APPENDIX A: EQUIPMENT

1. Bicycle Ergometer - "Lifecycle," set manually at 330 kg-m/min @ 80 rpm, manufactured by Lifecycle Incorporated, Concord, California.

2. Facemask and Fittings - Sanborn metabolism mask with two-way breathing valves, manufactured by the Monaghan Company, Denver, Colorado.

3. Respirometer - Max Plank Institute respiration test meter, set to withdraw 0.3% sample, sold by Instrumentation Associates Incorporated, New York, New York.

4. Flowmeter - Gas manometer, manufactured by Matheson Company, Newark, California.

5. Oxygen Analyzer - Model C2, manufactured by Beckman Instruments, Fullerton, California.

6. Clock - Universal timer, manufactured by Dimco-Gray Company, Dayton, Ohio.

7. Stopwatch - Manufactured by Heuer Company.

APPENDIX B: SAMPLE DATA COLLECTION FORM

NAME C.L. DATE 31 JAN 72 BARO PRESSURE 759 mm

OCCUPATION USMC OFFICER SEX M AGE 31

HEIGHT 66½" WEIGHT 142# SMOKER ? NO

GENERAL HEALTH EXCEL. PRESENT HEALTH PROBLEMS NONE

SUBJECTIVE EVALUATION OF PHYSICAL CONDITION 1 (2) 3 4 5
(best) (worst)

ACTUAL ORDER OF TASKS B C D A

TASK

	A	B	C	D
OXIN[5]	20.50	20.40	20.50	20.50
OXOUT[6]	15.50	15.75	15.70	15.70
RI[7]	36267	35727	35915	36103
RF[8]	36444	35915	36103	36267
T[9]	26	26	26	26

[5] Percentage oxygen in room air.

[6] Percentage oxygen in expired gases.

[7] Initial respirometer reading.

[8] Final respirometer reading.

[9] Temperature of expired gases in °C.

APPENDIX C: CALCULATIONS

A. CALCULATIONAL FORMULAS

This section presents the formulas used to estimate energy expenditure during the experiment. The formulas were discussed in more detail by Consolazio [1963] and Chaffin [1967].

The following abbreviations are used in the formulas:

OXIN - Oxygen content of inspired air in percentage

OXOUT - Oxygen content of expired gases in percentage

RI - Initial respirometer reading in liters

RF - Final respirometer reading in liters

T - Temperature of expired gases in degrees centigrade

B - Barometric pressure in millimeters of mercury

HGTC - Subject height in centimeters

WGTK - Subject weight in kilograms

The following calculations were made for each run of the experimental tasks:

1. Respiration Quotient, R.Q. - R.Q. is defined as the volume ratio of carbon dioxide production to the oxygen consumption,

$$R.Q. = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}} .$$

This is required in estimating the conversion from oxygen consumption to energy consumption. An empirically derived estimation that does not require a CO_2 gas analysis is,

$$R.Q. = \frac{(15.60 - 0.7051 \times OXOUT) - 0.03}{OXIN - OXOUT} .$$

2. Energy per Liter of Oxygen, K - The conversion factor is estimated from R.Q. by,

$$K = 3.9 + (1.1 \times R.Q.) \qquad [kcal/liter]$$

3. Volume of Air, V and V_{STP} - The average volume rate of air expired during the eight minute task is given by,

$$V = \frac{RF - RI}{8} \qquad [liters/min]$$

This is corrected to a dry, standard temperature and pressure by,

$$V_{STP} = V \times \frac{B - 23.76}{760.0 \times (1.0 + 0.00367 \times T)} \qquad [liters/min]$$

4. Energy Expenditure Rate, E - The average energy expenditure rate is then estimated by,

$$E = V_{STP} \times K \times \frac{OXIN - OXOUT}{100} \qquad [kcal/min]$$

5. Subject Body Surface Area, A - Human body surface area in square meters is estimated by the empirical formula,

$$A = (WGTK)^{0.425} \times (HGTC)^{0.725} \times 0.007184 \qquad [m^2]$$

6. Standardized Energy Expenditure Rate, E_a - The standardized rate is then given by,

$$E_a = E/A \qquad [\text{kcal/min-m}^2]$$

B. SAMPLE CALCULATION

This section gives an example of the calculations made with the formulas presented in the preceding section. The sample is from the data given in Appendix B.

1. $$R.Q. = \frac{(15.60 - 0.7051 \times 15.50) - 0.03}{20.50 - 15.50} = \underline{\underline{0.928}}$$

2. $$K = 3.9 + (1.1 \times 0.928) = \underline{\underline{4.92}} \text{ kcal/liter}$$

3. $$V = \frac{36444 - 36267}{8} = \underline{\underline{22.1}} \text{ liters/min}$$

$$V_{STP} = 22.1 \times \frac{759.0 - 23.76}{760.0 \times (1.0 + 0.00367 \times 26)} = \underline{\underline{19.6}} \text{ liters/min}$$

4. $$E = 19.6 \times 4.92 \times \frac{20.50 - 15.50}{100} = \underline{\underline{4.81}} \text{ kcal/min}$$

5. $$A = \left(\frac{142 \text{ lbs}}{2.20 \text{ lbs/kilo}}\right)^{0.425} \times (66.5 \text{ in} \times 2.54 \text{ cm/in})^{0.725}$$

$$\times\ 0.007184 = \underline{\underline{1.74}} \text{ m}^2$$

6. $$E_a = 4.81/1.74 = \underline{\underline{2.76}} \text{ kcal/min-m}^2$$

APPENDIX D: EXPERIMENTAL RESULTS

A. EXPERIMENTAL DATA

Table D.1 presents the data obtained during the experiment and includes the 13 primary subjects and the two control subjects.

Table D.1. EXPERIMENTAL DATA

SUBJ	AGE (yrs)	HGT (in)	WGT (lbs)	TASK ORDER	TASK	OXIN (%)	OXOUT (%)	RI (l)	RF (l)	T (°C)
1-JM	25	69	180	ACBD	A	20.60	16.50	30140	30395	23
					B	20.50	16.25	30638	30882	24
					C	20.50	16.20	30395	30638	24
					D	20.55	16.25	30882	31113	24
2-BZ	29	68	195	DCAB	A	20.45	15.50	31538	31752	24
					B	20.45	15.70	31752	31976	24
					C	20.50	15.50	31319	31538	23
					D	20.55	15.40	31113	31319	23
3-RK	32	72	185	ABCD	A	20.55	15.65	32864	33069	23
					B	20.55	15.80	33069	33267	23
					C	20.55	15.75	33267	33486	23
					D	20.55	15.65	33486	33677	23

Table D.1. (Continued)

SUBJ	AGE (yrs)	HGT (in)	WGT (lbs)	TASK ORDER	TASK	OXIN (%)	OXOUT (%)	RI (1)	RF (1)	T (°C)
4-PG	24	72	203	CBAD	A	20.50	15.80	32409	32634	24
					B	20.45	16.00	32184	32409	24
					C	20.50	15.85	31976	32184	24
					D	20.40	15.85	32634	32864	24
5-ER	31	71	185	ADBC	A	20.55	16.10	33678	33896	23
					B	20.50	16.80	34096	34299	23
					C	20.55	16.75	34299	34517	23
					D	20.40	16.70	33896	34096	23
6-JF	24	70	155	DABC	A	20.80	15.75	35204	35379	25
					B	20.70	15.50	35379	35550	25
					C	20.70	15.40	35550	35727	25
					D	20.75	15.75	35031	35204	24
7-CL	31	66-1/2	142	BCDA	A	20.50	15.50	36267	36444	26
					B	20.40	15.75	35727	35915	26
					C	20.50	15.70	35915	36103	26
					D	20.50	15.70	36103	36267	26
8-JB	31	73	190	DBCA	A	20.35	15.35	38276	38481	25
					B	20.40	15.35	37850	38054	25
					C	20.30	15.65	38054	38276	25
					D	20.30	15.55	37654	37850	25

Table D.1. (Continued)

SUBJ	AGE (yrs)	HGT (in)	WGT (lbs)	TASK ORDER	TASK	OXIN (%)	OXOUT (%)	RI (1)	RF (1)	T (^oC)
9-HS	31	75	188	CADB	A	20.65	16.15	39686	39906	26
					B	20.40	16.25	40116	40333	26
					C	20.55	16.25	39446	39686	26
					D	20.40	15.90	39906	40116	26
10-MP	28	70	149	CDAB	A	20.60	16.00	40725	40920	26
					B	20.55	16.10	40920	41124	26
					C	20.65	15.90	40333	40531	26
					D	20.55	16.00	40531	40725	26
11-BT	28	75	195	ACBD	A	20.40	15.25	42014	42206	26
					B	20.45	15.50	42411	42607	27
					C	20.45	15.35	42206	42411	27
					D	20.50	15.65	42607	42822	26
12-DP	31	72	180	BDAC	A	20.45	16.15	43278	43492	26
					B	20.55	16.40	42822	43057	26
					C	20.50	16.10	43492	43741	26
					D	20.55	16.20	43057	43278	26
13-DB	30	66	145	ABCD	A	20.65	16.10	43741	43958	26
					B	20.65	16.15	43958	44168	26
					C	20.60	16.05	44168	44373	26
					D	20.60	16.15	44373	44572	26

Table D.1. (Continued)

CONTROL GROUP

SUBJ	AGE (yrs)	HGT (in)	WGT (lbs)	TASK ORDER	TASK	OXIN (%)	OXOUT (%)	RI (1)	RF (1)	T (°C)
C1-BS	31	74	200	AAAA	A	20.25	15.45	38675	38872	25
					A	20.25	15.35	38872	39065	25
					A	20.25	15.30	39065	39255	25
					A	20.25	15.30	39255	39446	25
C2-PG	24	72	203	AAAA	A	20.45	15.70	41124	41350	26
					A	20.50	15.55	41350	41571	27
					A	20.40	15.60	41571	41794	27
					A	20.35	15.55	41794	42014	27

B. EXPERIMENTAL RESULTS

Table D.2 presents the calculated data for the 13 primary experimental subjects and the two control subjects..

Table D.2. EXPERIMENTAL RESULTS

SUBJ	AREA(m^2)	TASK	R.Q.	E(kcal/min)	E_a(kcal/min-m^2)
1-JM	1.95	A	0.96	5.85	2.96
		B	0.97	5.79	2.93
		C	0.96	5.85	2.96
		D	0.96	5.53	2.80
2-BZ	2.02	A	0.94	5.82	2.88
		B	0.95	5.86	2.90
		C	0.93	6.02	2.90
		D	0.91	5.82	2.88
3-RK	2.06	A	0.93	5.53	2.68
		B	0.93	5.18	2.52
		C	0.93	5.79	2.81
		D	0.93	5.15	2.50
4-PG	2.14	A	0.94	5.81	2.71
		B	0.96	5.53	2.58
		C	0.94	5.32	2.48
		D	0.97	5.83	2.72
5-ER	2.04	A	0.95	5.37	2.63
		B	1.01	4.21	2.06
		C	0.99	4.62	2.27
		D	1.03	4.16	2.04
6-JF	1.87	A	0.88	4.83	2.58
		B	0.89	4.87	2.60
		C	0.89	5.13	2.74
		D	0.89	4.75	2.54
7-CL	1.74	A	0.93	4.80	2.76
		B	0.96	4.78	2.75
		C	0.94	4.91	2.82
		D	0.94	4.28	2.46

Table D.2. (Continued)

SUBJ	AREA(m^2)	TASK	R.Q.	E(kcal/min)	E_a(kcal/min-m^2)
8-JB	2.11	A	0.95	5.60	2.66
		B	0.94	5.62	2.67
		C	0.98	5.67	2.69
		D	0.97	5.11	2.47
9-HS	2.14	A	0.93	5.41	2.53
		B	0.99	4.99	2.33
		C	0.96	5.67	2.65
		D	0.97	5.21	2.44
10-MP	1.84	A	0.93	4.90	2.66
		B	0.95	4.98	2.70
		C	0.92	5.12	2.78
		D	0.94	4.83	2.62
11-BT	2.17	A	0.94	5.39	2.48
		B	0.94	5.27	2.43
		C	0.93	5.67	2.61
		D	0.94	5.68	2.62
12-DP	2.04	A	0.97	5.05	2.48
		B	0.96	5.35	2.62
		C	0.96	6.00	2.94
		D	0.95	5.26	2.58
13-DB	1.74	A	0.93	5.41	3.10
		B	0.93	5.18	2.97
		C	0.94	5.12	2.94
		D	0.94	4.87	2.79
CONTROL GROUP					
C1-BS	2.17	A	0.97	5.20	2.39
		A	0.97	5.19	2.38
		A	0.97	5.16	2.37
		A	0.97	5.14	2.36
C2-PG	2.14	A	0.95	5.87	2.74
		A	0.93	5.87	2.74
		A	0.95	5.84	2.72
		A	0.96	5.77	2.69

C. DATA SUMMARIES

Table D. 3 summarizes the energy expenditure data from Table D. 2 and places the data in the randomized-block design format. Table D. 4 summarizes the same data but with respect to actual order of tasks rather than type of task. Table D. 5 is a summary of the data from the control group of two subjects.

Table D. 3. SUMMARY OF ENERGY RATES BY TYPE OF TASK

	TASK				
SUBJ	A	B	C	D	Mean
1	5.85	5.79	5.85	5.53	5.76
2	5.82	5.86	6.02	5.82	5.88
3	5.53	5.18	5.79	5.15	5.41
4	5.81	5.53	5.32	5.83	5.62
5	5.37	4.21	4.62	4.16	4.59
6	4.83	4.87	5.13	4.75	4.89
7	4.80	4.78	4.91	4.28	4.69
8	5.60	5.62	5.67	5.11	5.50
9	5.41	4.99	5.67	5.21	5.32
10	4.90	4.98	5.12	4.83	4.96
11	5.39	5.27	5.67	5.68	5.50
12	5.05	5.35	6.00	5.26	5.42
13	5.41	5.18	5.12	4.87	5.15
Mean	5.37	5.20	5.45	5.11	Grand Mean = 5.28

Table D.4. SUMMARY OF ENERGY RATES BY ORDER OF TASK

SUBJ	TASK 1st	2nd	3rd	4th	Mean
1	5.85	5.85	5.79	5.53	5.76
2	5.82	6.02	5.82	5.86	5.88
3	5.53	5.18	5.79	5.15	5.41
4	5.32	5.53	5.81	5.83	5.62
5	5.37	4.16	4.21	4.62	4.59
6	4.75	4.83	4.87	5.13	4.89
7	4.78	4.91	4.28	4.80	4.69
8	5.11	5.62	5.67	5.60	5.50
9	5.67	5.41	5.21	4.99	5.32
10	5.12	4.83	4.90	4.98	4.96
11	5.39	5.67	5.27	5.68	5.50
12	5.35	5.26	5.05	6.00	5.42
13	5.41	5.18	5.12	4.87	5.15
Mean	5.34	5.27	5.21	5.31	Grand Mean = 5.28

Table D.5. SUMMARY OF ENERGY RATES OF CONTROL GROUP

SUBJ	TASK A_1	A_2	A_3	A_4	Mean
C1	5.20	5.19	5.16	5.14	5.17
C2	5.87	5.87	5.84	5.77	5.84
Mean	5.53	5.53	5.50	5.46	Grand Mean = 5.50

APPENDIX E: ANALYSES

A. ANALYSIS OF VARIANCE

Tables E.1, E.2, and E.3 give the results of ANOVAs conducted on the data from Tables D.3, D.4, and D.5 respectively.

Table E.1. ANOVA OF ENERGY EXPENDITURE BY TYPE OF TASK

SOURCE	df	SUM OF SQUARES	MEAN SQUARES	$F_{observed}$	α_{reject}*
Subjects	12	7.7285	0.6440	10.72	0.0005
Tasks	3	0.9291	0.3097	5.15	0.005
Error	36	2.1649	0.0601		
Total	51	10.8225			

Table E.2. ANOVA OF ENERGY EXPENDITURE BY ORDER OF TASK

SOURCE	df	SUM OF SQUARES	MEAN SQUARES	$F_{observed}$	α_{reject}*
Subjects	12	7.7285	0.6440	7.82	0.0005
Tasks	3	0.1241	0.0413	0.50	0.80
Error	36	2.9699	0.0824		
Total	51	10.8225			

Table E.3. ANOVA OF ENERGY EXPENDITURES BY CONTROL GROUP

SOURCE	df	SUM OF SQUARES	MEAN SQUARES	$F_{observed}$	α_{reject}*
Subjects	1	0.9316	0.9316	7.48	0.0005
Tasks	3	0.0134	0.0045	3.59	0.25
Error	3	0.0037	0.0012		
Total	7	0.9488			

---

* α_{reject} implies that this is the significance level at which the appropriate null hypothesis could be rejected. That is, $P[F>F_{observed}] = \alpha_{reject}$.

B. COMPARISON OF MEANS

This section analyzes the differences among means of energy expenditure rates by subjects on the four tasks indicated by the analysis of variance presented in Table E.1 of the preceeding section. The differences are compared by the following techniques:

(i) Tukey's honestly significant difference (HSD) test,

(ii) Least significant difference (LSD) test, and

(iii) Duncan's new multiple range (DMR) test.

These tests were discussed in detail by Kirk [1968].

Table E.4 lists the mean values of energy expenditure rates by type of task. (This is depicted in Figure 2 of Section III.) Table E.5 summarizes the differences and indicates significance when comparing the differences by the tests mentioned.

Table E.4. MEAN ENERGY EXPENDITURE RATES FOR EXPERIMENTAL TASKS

TASK	$\overline{E}$ (kcal/min)
A	5.37
B	5.20
C	5.45
D	5.11

Table E.5. DIFFERENCES AMONG MEANS

	$\overline{E}_D$	$\overline{E}_B$	$\overline{E}_A$	$\overline{E}_C$
$\overline{E}_D$	--			
$\overline{E}_B$	.09	--		
$\overline{E}_A$	.26$^{h, l, d}$	.17	--	
$\overline{E}_C$	.34$^{h, l, d}$	.25$^{l, d}$	.08	--

h: indicates significant ($\alpha < 0.05$) difference by HSD test
l: indicates significant ($\alpha < 0.05$) difference by LSD test
d: indicates significant ($\alpha < 0.05$) difference by DMR test

APPENDIX F: PROBLEMS ENCOUNTERED DURING EXPERIMENT

1. Room Percentage Oxygen Variations

Despite the fact that the experiment was conducted in a large, well-ventilated room, the analysis of room air indicated variations up to 0.25% oxygen during a one hour period. Chaffin [1967] reported variations up to 0.4% while using the same type of equipment. However, he attributed those variations to the fact that his measurements were made over five hour periods and in a small, closed room.

This experimenter felt that the variations encountered were due to one or more of the following:

(1) There may have been an actual variation in oxygen content of the air during the test sessions.

(2) There is some inherent inaccuracy of the oxygen analyzer. The instrument specifications indicate accuracy of $\pm$ .08% oxygen ($\pm$ 1% of full scale) on the model used. Reproducibility is listed at $\pm$ .04% oxygen.

(3) There may have been reading errors. The scale of the instrument is so small that the best that could be read was the closest 0.05%.

Although this variation was disconcerting the experimenter felt that averaging the values of room oxygen over the test period might possibly have introduced error rather than eliminated it. For that reason the four individual room oxygen values were used in the calculations of energy consumption during the four tasks.

2. Subject Variation During the Test

There existed a real possibility that a subject might have changed his method of exercising from task to task thereby affecting his mechanical efficiency and thus varying the basic energy required to complete the tasks. Of course a variation like that would have been interpreted as being caused by the difference in tasks. Although this possibility was recognized prior to experimentation, no "coaching" of the subjects was done for fear of introducing adverse effects.

3. Subject Pattern Recognition

It was recognized that subjects might correctly guess both the total length of each task and the ratio of work to rest based on observations of tasks A and B when one or both were given prior to the tasks under uncertainty. This problem could have been eliminated by giving tasks C and D first to each subject. However, this non-random sequencing would violate the assumption necessary for the analysis of the randomized block design used. Subjects guessing the patterns correctly would tend to perform more nearly the same on all tasks and would thus tend to support the null hypothesis that there was no difference between the tasks. The presence of this effect would give a smaller probability of rejecting a true null hypothesis (Type I error) thus making the actual analysis conservative.

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3. ABSTRACT

It is hypothesized that psychological attitudes affect physiological functions in humans. One function that might be affected is energy consumption during work or exercise.

An experiment was conducted to examine the effect of temporal uncertainty about the duration of an exercise period on energy cost. A sample of 13 healthy, young male military officers were tested under controlled exercise routines with and without temporal uncertainty. Results indicated that there is a significant ($\alpha < .05$) difference between similar tasks under temporal uncertainty and certainty. The task under uncertainty required less energy than the other task.

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