MEASUREMENT OF PHYSICAL WORK-LOADS A SUITABLE FIELD TECHNIQUE

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RINGKASAN

Ukuran tenaga yang digunakan oleh pekerja-pekerja telah menjadi suatu perkara yang diragukan oleh beberapa penyelidik-penyelidik. Sungguhpun ada cara-cara atau teknik amali untuk menyelidikinya tetapi didapati sukar hendak disesuaikan di tempat kerja mereka.

Dalam kertas kerja ini, kesan dan keyakinan serta teknik mudah boleh dibuat di tempat kerja telah diselidiki.

Teknik ini berasaskan kepada pengukuran detik jantung pekerja-pekerja di tepat kerja masing-masing dengan mengguna alat 'telemetric cardiogram'. Keputusan ini dibandingkan dengan nilai oksigen yang digunakan.

ABSTRACT

Measurement of physical energy expanded by the workers has been the concern of many researchers. Although there exists some laboratory techniques, their field applications are usually found difficult to execute.

In this paper the effectiveness and reliability of a simple technique which could be used in field studies, is investigated.

The technique is based on the measurement of the heart rate variation of subjects by a telemetric cradiogram and the result are compared with oxygen consumption values.

1. Introduction

The nature of manual work has changed to a great extent over the last century. Due to the invention of new power sources, and modern production techniques, the human energy requirements for most of the jobs have been reduced: yet, even today, a great number of heavy industrial or agricultural tasks have to be performed manually, either because of the high cost of automation or because of the lack of technical know-how. As long as the need for manual power exists, the question of how much physical work load should be given to a worker without hazarding his/her health and performance has to be answered by those involved in the work design.

The physical work-load of a task can be measured by the amount of energy expanded while performing it. Physiologists agree that 5 k cal/min is the maximum allowable limit of energy which can be expanded by a worker for an 8 hour working day (Murrell). Hence, in order to decide whether a certain task is suitable for manual work, energy requirement for that task should be compared with the physiologically acceptable limit. In cases where energy demanded by the tasks exceeds the 5 k cal/min level, redesign of task must be considered.

1.1 Methods for Measuring Physical Work Load.

A brief review of some of the energy measurement techniques is presented here:

– Direct Calorimetry: (Herbert and Vries) This method is based on the measurement of the heat dissipated by the human body as a result of metabolic activity. The method is not suitable for field studies because of the difficulties in the preparation of the experimental setting.

– Indirect Calorimetry: (Suggs and Splinter) The energy disspated by the oxidation of the fats, carbohydrates and proteins, taken as food, is calculated from the equations of chemical reactions.

– Oxygen Consumption: (Astrand and Rodah 1) The amount of energy expanded during the work is closely related to the amount of oxygen consumed while doing it. For every 8 k cal of human energy 1 lt of oxygen is consumed. Therefore by measuring the amount of oxygen consumption, energy expenditure can be calculated.

– Heart Rate: (Vos, Potkonjak) Heart rate readings are used to estimate the 0_2 consumption, which in turn is used to estimate the energy expenditure.

2. Objective

The aim of the study is to test the effectiveness and realibility of an energy measurement technique which can be used in field studies with comfort and ease.

2.1 Method

In the laboratory experiments the subjects are asked to ride a bicycle ergometer for 15 minutes at a specified speed and pedal friction. Before each test the basal heart Rate (HRo) and oxygen consumption (Vo2 basal) are measured at testing position. Working heart rate (HR) and oxygen consumption values (Vo2) are recorded during the 15 minutes of cycling.

2.2 Subjects

Sixty-four, 20–45 years old, healthy, male subjects are tested during the experiments. The summary of some of the physiological properties of the subjects are given in Table 1.

Table 1: Physiological parameters of the Subjects (n-61 subjects)

The physiological parameter	Min value	Max value	Average	Standard deviation
Age (years)	20	45	29.13	6.59
Resting Heart Rate (beats/min)	55	115	79.23	12.16
Resting 0_2 consumption (1t/min)	0.13	0.46	0.25	0.08
Height (cm)	160	190	174.81	6.51
Weight (kg)	49	90	70.53	9.96

2.3 Equipment

Bicycle ergometer: The different levels of physical work-load are generated by applying friction to the pedals of a Monark Bicycle ergometer. The levels of physical work load are presented in Table 2. The pedalling speed is kept constant at 18km/hr for the test period.

Table 2: Levels of physical work load and corresponding pedal friction on bicycle ergometer.

Level of Physical Work Load	Pedal Friction kpm	watt
0	0	0
1	150	25
2	300	50
3	450	75

Oxycon: The oxygen consumption of the subjects is measured by a Mijnhard portable oxycon system, which automatically records the percentages and the volumes of oxygen in inspired and expired air. The expired air is breathed into a gas mask connected to a receiver, which is carried on the back of the subjects while riding the bicycle; meanwhile the oxygen consumption is displayed digitally on the static part of the equipment. An illustration of the system is given in fig. 1.

Telemetric cardiogram: The heart rate values of the subjects are recorded by a Hellige Telemetric cardiogram which operates on UHF frequency band and utilizes a double frequency modulation system.

3. Results

In the experiments of each level of physical work load, 16 different subjects are tested. The summary of the recorded values of heart rate and oxygen consumption and their variation are presented in table 3.

Table 3: The average values of oxygen consumption and heart rate changes at different levels of physical work load.

Physical work load	HR	ΔHR (1)	VO_2	ΔVO_2(2)
0	84	6	0.238	0.027
1	102	23	0.697	0.412
2	124	44	0.853	0.666
3	139	59	1.352	1.105

1) $\Delta HR = \frac{(HR - HR_o)}{n}$

2) $VO_2 = \frac{(VO - VO_2 \text{ base})}{n}$

The graphical relationship between these variables are presented in figures 2 and 3. From these graphs oxygen consumption corresponding to any heart rate can be estimated, and the energy equivalent of a certain volume of oxygen can be calculated by using (1 k cal $\approx$ 5 lt O_2) as conversion factor.

Table 4 shows the energy equivalents of the measured levels of O_2 consumptions together with the energy equivalents of the O_2 values estimated from figures 2 and 3.

4. Discussions

Figures 2 and 3 indicate a strong linear relationship between heart rate and oxygen consumption during the physical activity. This is an important finding as far as the measurement of energy expenditure in field studies is concerned. It has been mentioned that the energy expenditure can directly be estimated by measuring oxygen consumption during work, but even the most sophisticated equipment used for this purpose requires either a mouth-piece or a gas-mask and both of these are uncomfortable to wear while working. Therefore in field studies, it is desirable to adopt a technique which does not cause any discomfort or inconveniences while performing the task. In this respect heart rate measurement is prefered to O_2 consumption measurement because in the former the subject carries a light receiver on his back and three electrodes on his chest which do not interfere with his work. The recording of the heart rate can be done at a remote station to avoid the psychological stresses which might be felt if the subject was observed from a near distance.

The analysis of Table 4 indicates that, when the physical load exceeds 5 k cal/min (maximum allowable work load) both heart rate and its variation tend to under estimate the energy expenditure. For the work load level "3" the direct measurement of oxygen consumption gives 5.35 k cal/min while estimates from HR and HR values give 4.85 and 4.45 k cal/min respectively.

But at moderate work loads (2-4 k cal/min) Heart rate variation (ΔHR) gives better estimates than the heart rate (HR). As mentioned before HR is calculated by using the following formula.

$$\Delta HR = HR_{working} - HR_{basal}$$

By the use of above equation the deviations which may be caused by the individual basal heart rates of the subjects are eliminated and the change of heart rate caused by the work is taken as a basis.

Another observation from table 4 is that, the human body wastes a considerable amount of energy while working. To overcome the friction loads of 0.36 – 1.08 k cal/min human body spends 1.90 – 5.55 k cal/min, in other words, only about 20% of the human energy expenditure could be utilized in useful work. Since food is the only fuel that the human body uses, the source of human energy is rather expensive, and men as a source of power are quite inefficient.

5. Conclusions

The following conclusions can be drawn from the previous discussions:

a) To measure the energy expanded during various types of work (industrial, agricultural, office etc.) heart rate variation can be used as a safe estimator.

b) Both heart rate variation (Δ HR) and heart rate (HR) can be used to estimate the energy expenditure, but the former gives better estimates especially at moderate work-loads.

c) Only about 20% of human energy expanded during work is utilized as useful work.

Table 4: The Energy Equivalents of Measured and Estimated values of O_2 Consumption at different levels of physical work load.

Applied level of Physical work load Level	Energy equivalent (4) k cal/min	VO_2 measured by oxycon 1t/min	(1) Energy equivalent k cal/cm	Heart Rate variation HR beats/min	Energy (2) equivalent k cal/min	Heart Rate HR beats/min	Energy (3) equivalent k cal/min
0	0	0	0	6	0.55	83	0.05
1	0.36	0.38	1.90	23	1.95	102	4.55
2	0.72	0.69	3.45	44	3.60	124	3.25
3	1.08	1.07	5.35	59	4.85	139	4.45

(1) VO_2 read from oxycon is multiplied by conversion factor (5)

(2) VO_2 estimated from figure

(3) VO_2 estimated from figure

(4) Energy equivalent of pedal friction of the bicycle ergometer.

Figure 3: Relationship between variation in oxygan consumtion and Heart Rate (ΔHR)

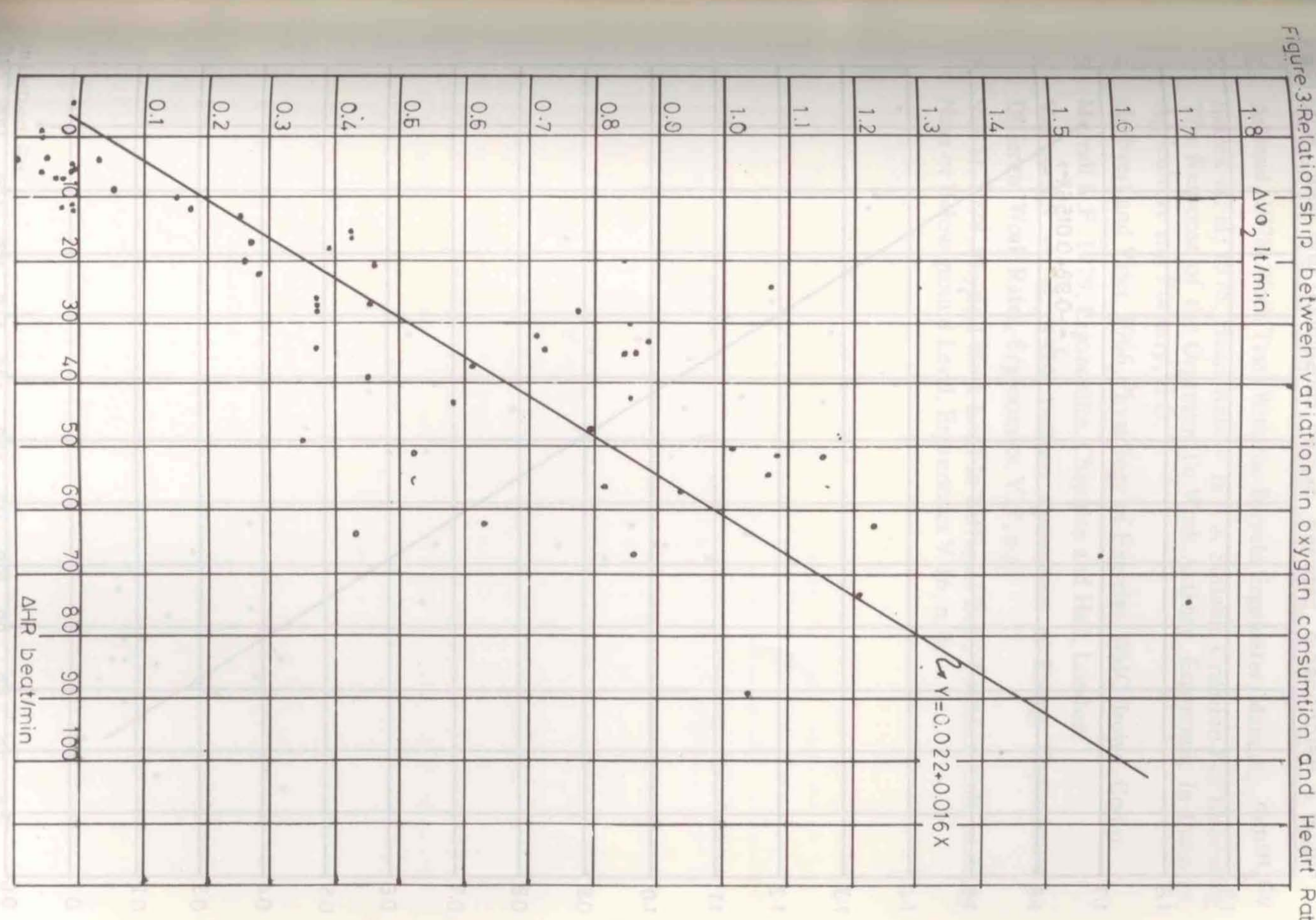
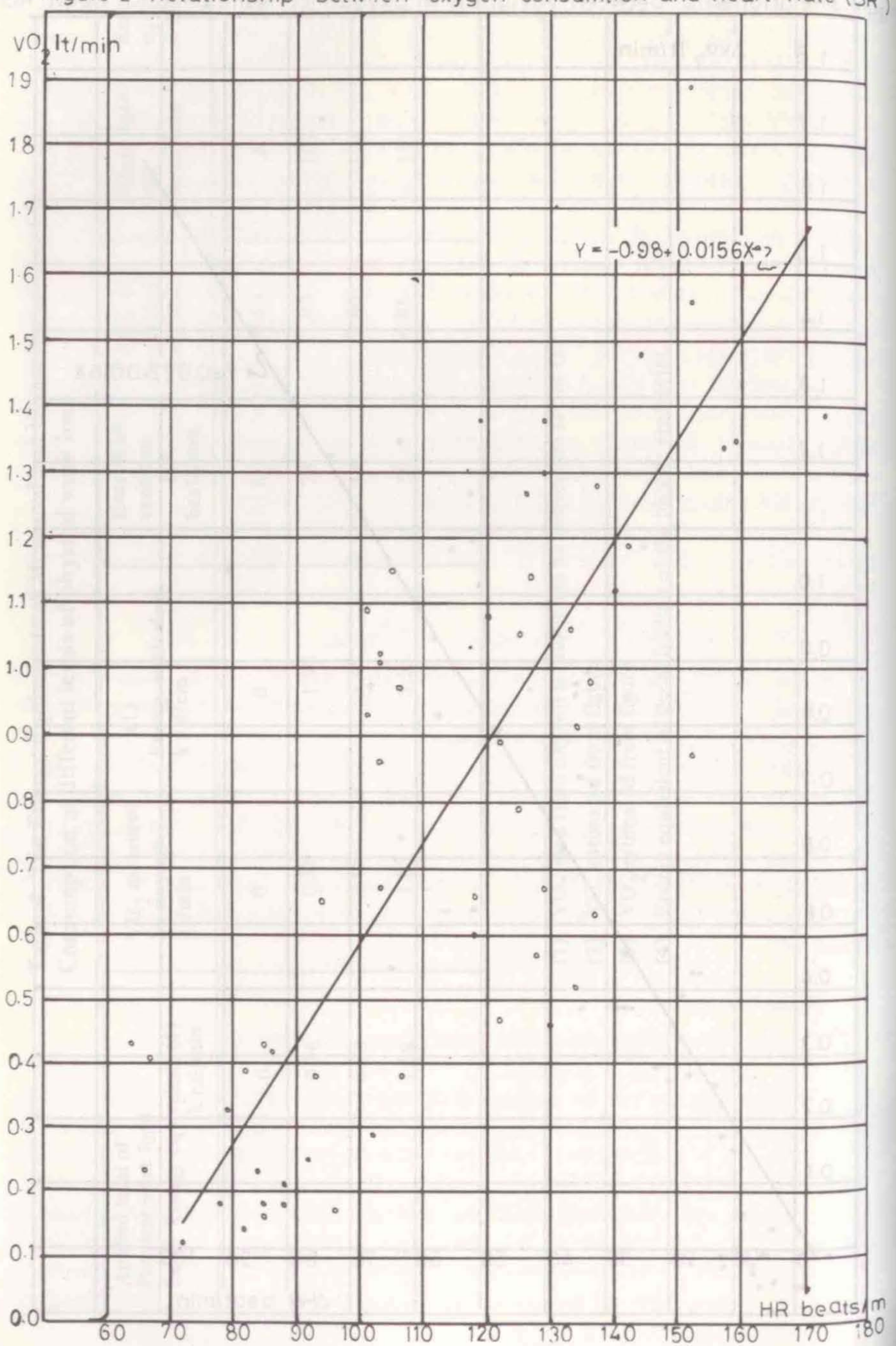


Figure 2: Relationship between oxygen consumtion and heart Rate (3R)



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