AN INVESTIGATION OF THE VALIDITY OF A SECTION OF A THEORETICAL MODEL TO PREDICT WORK PHYSIOLOGY PARAMETERS FROM AGE AND WEIGHT

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ABSTRACT

Work physiology is the study of physiological parameters of the body during work. Two of these physiological parameters are commonly measured to assess the cost of work : oxygen consumption and heart rate.

In 1979 a theoretical model was developed to estimate some ergonomic parameters from age, height and weight. While this model predicted anthropometric, biomechanical and work physiology parameters, the present research was concerned only with the section of the model predicting work physiology parameters of oxygen consumption and heart rate from age and weight.

In this study oxygen consumption and heart rate values were obtained from measurement of seven subjects working on an ergometer. These values were then used to test three of the equations in the predictive model. Two of the equations were found to be unreliable as predictors of oxygen consumption and heart rate for this sample, while one of the equations was found to be reliable. Further research with a larger sample is necessary before any firm conclusions about this section of the model may be made.

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CHAPTER 1

Introduction

"Manual labour, sometimes under adverse environmental conditions, still exists in all countries, and will probably remain an essential part of the society. Furthermore, individuals continue to find satisfaction and enjoyment in their leisure time through sports or other types of muscular activity . . . In a very broad sense, physical performance or fitness is determined by the individual's capacity for energy output (aerobic and anaerobic processes and oxygen transport), neuromuscular function (muscle strength, co-ordination and technique), joint mobility and psychological factors (e.g. motivation and tactics) These factors play a more or less dominating role depending upon the nature of the performance" (Astrand and Rodahl, 1977, 7).

So interest in the physical capacity of individuals to perform, whether at work or leisure, has increased in spite of a corresponding increase in automation in the work place. Indeed Davis (1977) doubts that automation will continue at the exponential level predicted.

Davis (1977) identified three stages of technological progress; Primary (simple), Secondary (complex, non human energy) and Tertiary (fully automatic), and stated that during its formative years ergonomics had concerned itself with looking at Secondary systems. However the need to investigate primary technology is now perceived to be of increasing importance because of the possibility of an initial rise in manual worker availability following the turn of the next century, followed by a rapid fall. The rationale for the perceived need for the redesign and improved knowledge of primary technology is that as energy supplies diminish there will be a need to return to biological energy, but with the present levels of population there is insufficient land to support any large increases in horses or cattle as alternative energy sources. If, therefore, manual labour and other physical activities are to become the focus of future concentration it is necessary that we know as much as possible about work, the physical cost of work, the measurement of that cost, and how work can be efficient within the physical limits of the individual.

The objective of this research report is to test some theoretical models developed to determine physical performance, based on heart rate and oxygen consumption, against direct measures of these parameters.

1.1 Body Work and Energy

The physiology of muscular work and exercise is basically a matter of transforming bound energy into mechanical energy. Many similarities exist between the "human engine" and the combustion engine constructed by human beings. In the combustion engine peteroleum and air are introduced into the cylinder.

The spark from the spark plug initiates the explosive combustion of the gas mixture. Chemical energy is transformed into kinetic energy and heat.

The expansion of the gas forces the piston to move, and a system of mechanical devices can transfer this motion to the wheels. The motor is cooled by fluid or air to prevent overheating. The waste products are expelled with the exhaust. As this motor can work only in the presence of oxygen, its function is aerobic. When the petrol tank is empty, the engine can no longer continue to run, since the operation of the combustion engine is dependent upon a continuous supply of fuel. In a motorcar, the starter motor provides the energy for the first movements of the pistons. This energy comes from the battery which accumulates electrical energy : the starter can thus work in the absence of oxygen, or anaerobically. The stored energy of the battery is quite limited however, so the battery must be frequently recharged.

"Living organisms, like machines, conform to the law of the conservation of energy, and must pay for all their activities in the currency of metabolism (Baldwin, 1967). In the human machine, the muscle fibers (sic) are the pistons. When fuel is available and a spark is introduced to start the breaking down of the fuel, part of the energy which is thus liberated can cause movement of the pistons. Heat and various waste products are produced" (Astrand and Rodahl, 1977, 12).

The energy needs of individuals are satisfied by food which the individual consumes during the course of a day. If the health and activity of individuals are to be maintained then a certain minimum amount of food must be consumed per day.

However, the problem arises of how to measure the amount of food consumed and what proportion of this food is converted into energy and used as such in the human engine.

1.2 Direct Measures of Energy Expenditure

Obviously dietary studies can be made of individual subjects and this has been attempted in the past. The energy expenditure of a variety of occupations was stated after analysing the diets consumed by individuals of know employment (Voit et al, 1955). This method is open to the theoretical objection that it assumes that the diets consumed provide exactly enough energy with no surplus or deficiency (Passmore and Durnin 1955). It provides no direct yardstick or requirement. Indeed, especially in developing countries large numbers of people certainly have an insufficiency of food for health and activity, whereas the high incidence of obesity in Western countries shows that many consume regularly an excess of food over their physical requirements. There is a real difficulty in converting the results of dietary surveys into tables of food requirements. Further, dietary surveys are always difficult and expensive to carry out. This particularly applies to individual surveys which provide so much more information than the less precise family surveys (Passmore and Durnin, 1955).

1.3 Indirect Measures of Energy Expenditure

Alternatively, the use of rates of oxygen consumption as the basis for measuring energy expenditure has become widely used. This method of measuring the metabolic cost of work, along with heart rate, is known as indirect calorimetry and has been increasingly used in field conditions, to a large part due to the development of apparatus which may now be used in field conditions, whereas it was once impracticable to do this because of the cumbersome nature of the apparatus designed for studies in laboratory conditions.

Indirect calorimetry enables the energy expended to be determine while a definite activity is undertaken for a limited period of time, usually measured in minutes. In the past indirect calorimetry and data collected using this method have met with only limited success, mainly due to the practical difficulties of determining oxygen consumption in field settings. The apparatus that was used in earlier attempts to establish energy expenditure at work was the Douglas Bag, the size of which made studies under field conditions very difficult and led to imprecise data collection. The Douglas Bag was more suited to static exercise, or treadmill running in the laboratory. However in the 1940's a light portable respirometer was developed at the Max-Planc-Institut fur Arbeitsphysiologie in Germany. The portable respirometer has several attributes in its favour over the Douglas Bag for experiments under field conditions. It is light, weighs less than four kilograms;

it can be worn on the back like a haversack; it measures the volume of expired air directly while simultaneously diverting a small fraction of the expired air (0.3 - 6%) into a rubber bladder for later analysis (Passmore and Durnin, 1955). Passmore and Durnin (1955) state that first major test of the portable respirometer was a survey of workers in German industry during World War two. Observations were made of individuals only at work in the factories and the mines, but assumptions were made for energy expenditure outside working time and the results were expanded and expressed in terms of daily energy requirements. Subsequent observations were carried out in Britain and from these, tables of energy expenditure for given occupations and activities have been compiled.

It is interesting to note that even though the portable respirometer, and various modifications, has been in use for approximately forty years at the time of writing, there is still a dependence on laboratory work with the Douglas Bag. While it may be assured that the portable respirometer would be technically superior and more accurate than the Douglas Bag, Astrand and Rodahl (1977) disagree. "The classical method for the determination of oxygen uptake, the Douglas Bag method, rests on a very secure foundation. It is theoretically sound, and it is well tested under a wide variety of circumstances. In all its relative simplicity, it is unsurpassable in accuracy" (p. 339).

Examples of the continued use of the Douglas Bag may be seen in the work of Vokac et al (1975), Bergh et al (1976), Goldsmith et al (1978) and Datta et al (1978). On the other hand Aunola et al (1978), Soule et al (1978), Saha et al (1979) and Verma et al

(1979) used a portable respirometer to collect expired air for analysis to determine energy expenditure in their experiments.

It is felt that the measurement of oxygen consumption in order to estimate an individual's energy expenditure can give rise to imprecision. An opinion is (Passmore and Durnin, 1955) that larger errors are likely to arise from a failure to determine corectly the length of time spent in any activity rather than in any assessment of the metabolic cost of that activity. An example of this is that if a man walks to and from his work every day, it is essential to know how long he spends on the journey. When compared with his other activities the exact energy cost of the walking may be comparatively unimportant. Further, one measurement of such an activity is only strictly applicable to the walking while the measurement is being made. An accurate value for an individual's walking, in general, necessitates several estimations under a variety of environomental conditions (Passmore and Durnin, 1955).

For this reason one must seriously consider the implications of the use of oxygen consumption from which to measure individuals' energy expenditure. If, however, the alternative is direct calorimetry through a study of individuals' diets, then the measurement of oxygen consumption is preferable for research purposes. However it must be stressed that no single tool exists than can measure the effects of different kinds of loads on an individual (Davis et al, 1969), which leads to a second physiological variable that must be examined : heart rate.

Hear rate is used to measure energy expenditure indirectly for a variety of reasons. It is less intricate and time consuming than the measurement of oxygen consumption, the use of which has been felt to retard progress in the determination of energy expenditure at work (Leblanc, 1957). Further, oxygen consumption alone is not a reliable indicator of energy expenditure (Maxfield and Brouha, 1963). There is a linear relationship between heart rate and oxygen consumption (Astrand and Rodahl, 1977), and it is felt wise to measure both heart rate and oxygen consumption since oxygen consumption alone would not indicate changes in temperature and humidity in the work environment (Davis et al, 1969). Finally, heart rate has been shown to be sufficiently accurate within the range of most industrial jobs (Ricci, 1967).

However in his research the central concern is the cost of work and the capabilities and limitations of individuals.