WORK CAPACITY: METHODOLOGY IN A TROPICAL ENVIRONMENT

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INTRODUCTION

The tropical habitat currently faces strong pressures. In many parts of Africa, the current growth rate for human populations is 4.5–5.0% per annum, compared with the world average of 1.7%. While there remains some disagreement on minimal nutritional requirements (Rivers & Payne, 1982; Weymes, 1982), the expanding deserts of the sub-Saharan poverty belt threaten starvation to many peoples of this region. At the same time, large parts of the African continent have very few inhabitants. In the "Decade of the Tropics" much thus depends on human ability to exploit the African habitat, producing a surplus of food that can nourish rapidly expanding cities.

One important determinant of the ability to colonize any harsh environment is the individual's physiological working capacity (Harrison & Walsh, 1974; Shephard, 1978), the "ability to perform muscular work satisfactorily" (Andersen et al, 1971). In this review, particular attention will be paid to developments since completion of the International Biological Programme (I.B.P., Worthington, 1978). The changing nature of work capacity will be discussed in a tropical context, along with issues such as sampling bias, technical problems of measurement in a hot environment, and procedures for allocating variance between constitution and environment. The effect of changes in body size, nutrition and health will also be considered briefly.

THE CHANGING NATURE OF WORK CAPACITY

The physiological characteristics appropriate to successful colonization of a given habitat depend on (i) population pressures, (ii) the amount of physical work necessary for survival, and (iii) available technology (Breymeyer & Van

Dyne, 1979). Each of these factors is currently changing. An ever-increasing proportion of tropical inhabitants are living in large cities. In a few countries, such as Singapore, high technology has made rapid strides, although 80% of the population still work in "cottage" type situations, building components for the automated factories. Elsewhere, the movement is from primitive agriculture to labour-intensive industry. Thus in American Samoa (Greksa & Baker, 1982), 55% of the population now engage in paid manual labour, at an energy cost of 12-16 kJ/min; 8% are still agriculturalists, spending 30-32 kJ/min; and the remaining 37% have become office workers. In countries where conditions are less "advanced", the gross domestic product remains very small, increasing in real value by less than 1% per annum, while limited education precludes the drastic infusion of new technology. The burden of feeding a growing population in such regions rests not on the export-earnings of the industrial workers but on the physical efforts of rural peasants using at best intermediate levels of agricultural technology (Brandt, 1980). Attempts to improve productivity raise important social and economic questions (Collins, 1982). Is the optimal approach to enhance the work capacity of the peasant, through better nutrition and the control of disease (Davies, 1974), or should investment be concentrated on the methodology of farming (improvement of crops, livestock, and tools; Andreano, 1976; Collins, 1982)? Economic cost-benefit analysis is complicated by the fact that the harvesting of cash crops generally provides short-term employment, while improvements of nutrition and health are likely to have a more long-term impact upon work capacity (Bliss & Stern, 1982).

Tropical food-producers do not face the extreme climatic changes encountered in the circumpolar regions, and more specialization of economic activity is thus possible. Nevertheless, there is no single "tropical environment" to which biological adaptation can be made. Indeed, settlements are often located at the junction of two or more ecosystems in order to provide a variety of food (Harris, 1982). In recent years, traditional work requirements have been further complicated by interactions with the economy of "white" migrants. Some tropical peoples still live on small islands where strength in paddling and skill in various forms of spear fishing are major assets. Others, in the dusty sub-Saharan region, use simple hand tools to grow millet, sorghum and tubers (Richards, 1982). Swampy flat land or rugged hillsides may also be cultivated (Ferro-Luzzi, 1982). A few of the tropical peoples still run after game or walk long distances searching for nuts and berries (Harris, 1982). It is most unlikely that any one set of physiological characteristics would confer a selective advantage in exploiting all of these varied techniques of survival at both wet and dry seasons. A more general evaluation of human work capacity is required.

THE I.B.P. CONCEPT OF WORK CAPACITY AND HUMAN ADAPTABILITY

The I.B.P. evaluation of working capacity (Shephard, 1978) included data on standing height, body mass, body fat, muscle strength, lung volumes, anaerobic capacity and power. Nevertheless, it was argued that the main determinant of the ability to perform most types of daily work was the maximum oxygen intake ($\dot{V}_{O_2}$ max; Shephard, 1977). This was sometimes expressed in absolute terms (l/min), but where the daily activity required a displacement of body mass, relative units (ml/kg/min) were more appropriate. Expression of $\dot{V}_{O_2}$ max as a ratio to lean body mass was shown not to increase the quality of the information, and indeed in the context of comparing people of widely differing builds, it could be frankly misleading (Gitin et al, 1974).

Much agricultural activity remains quite hard endurance work, whether pursued at a primitive or an intermediate level of technology (Shephard, 1985), and in such situations a large maximum oxygen intake might be thought advantageous. However, whether searching for game, foraging for nuts, or attempting to grow vegetables in unpromising soil, the yield of food depends more on technique than on brute force. Moreover, if the population is self-employed, a relative abundance of food (or poor prices for cash crops) may hold the average person's production far below the physiological potential (Lee, 1969; Ekblom & Gjessing, 1968; Harris, 1982). In New Guinea, a combination of hunting and the tending of cash crops occupy the Kaul for 3.0-3.5% and the Lufa for 6.0-7.5% of the day (Norgan & Ferro-Luzzi, 1978). Nevertheless, the apparently light occupational demands of such a society are supplemented by a need for domestic labour that is avoided in a more highly developed economy (Hawkes & O'Connell, 1981). Thus Clark and Haswell (1964) observed that African and Indian peasants not only spent 17-34 hours working in the field each week, but also carried out such activities as building and repairing houses, making shoes and furniture, spinning, sewing, and grinding corn.

A further difficulty in the interpretation of data is that in some regions any adaptations to a high environmental temperature become confounded with physical demands imposed by the cultivation of a hilly terrain (Patrick & Cotes, 1971, 1978).

Collation of I.B.P. results for various tropical populations (Table 1) provided no evidence for the emergence of physiologically well-adapted variants, either within specific tropics regions, or relative to other populations that have exploited a temperate or a cold habitat. The body mass of the tropical societies was generally very low relative to sedentary "white" standards, and with a few

Table 1: Physiological variables affecting working capacity of labourers in a tropical environment. Range of data reported during IBP studies (from Shephard, 1978). All relate to males, unless otherwise specified.

Variable	Range	Location of low and high extremes
Excess body mass (Kg)	-13.0 to 2.5	Ethiopia, Yemenite-Israelis
Skinfold thickness (mm)	4.5 to 10.6	Kalahari bushmen to Trinidadian East Indians
Muscle strength:		
handgrip (N)	339 to 417	Ethiopia, Warao, Venezuela
knee extension force (N)	288 to 364	Ethiopia, Warao, Venezuela
Anaerobic power (ml/kg/min)	125*	Values for East Africans only.
capacity (ml/kg)	-	No data
Aerobic power (ml/kg/min)		
Male	37.6 to 57.2	Rural Bantu, "active" Tanzanians
Female	27.3 to 41.0	Jamaicans, East African-Dorobo

*This calculation has followed Margaria (1966) in assuming a 25% mechanical efficiency for the staircase sprint. In fact, resynthesis of phosphagen does not occur within the period of observation, so that the equivalent oxygen consumption may be substantially larger than postulated by Di Prampero (1972).

exceptions, skinfold thicknesses averaged less than 7 mm. Muscle strength and anaerobic power were only about 75% of the figures found in Europeans, but partly because of a low body mass, most tropical populations had a relative anaerobic power at least as large as their European counterparts.

DEVELOPMENTS IN METHODOLOGY

There have been several technical developments in the measurement of work capacity since completion of the I.B.P. project.

Body Mass

Young women and the elderly of both sexes have increasingly demanded access to heavy employment, particularly in more sophisticated societies. Physiologists have recognised that lifting is an important component of the ability to perform heavy work and that body mass provides a simple indication of the individual's potential in this regard (Nottrodt & Celentano, 1984). In part because of a negative correlation between body mass and cigarette smoking

Table 2: Discrepancy of body mass between male Indian athletes (I) and competitors at the Montreal Olympic Games (O). Based in part on data accumulated by Sodhi and Sidhu (1984).

Event	Mass $(\frac{I-O}{O}\%)$	Height $(\frac{I-O}{O}\%)$	Event	Mass $(\frac{I-O}{O}\%)$	Height $(\frac{I-O}{O}\%)$
Jumping	-18.5	-9.3	400 m	-16.0	-11.4
Pole vault	-11.5	-5.8	800 m, 1500 m	-17.0	-11.6
Discus	-10.5	-9.6	Marathon	-9.3	-11.2
Javelin	-23.8	-11.8	110 m hurdles	-16.7	-11.0
100 m, 200 m track	-15.0	-11.1	400 m hurdles	-9.6	-6.0

(Garrison et al, 1983), the Metropolitan Life Assurance Company (1983) has proposed an upward revision of the actuarial "ideal" body mass. However, the concept that low-income tropical societies have a low body mass relative to their height remains unchallenged. Thus Indian athletes still show a deficit of 5.6 to 22.9 kg (9.6 to 23.8%) relative to "white" competitors, only about a half of this difference being attributable to their shorter stature (Sodhi & Sidhu, 1984; Table 2). Nigerian basketball players are even smaller than their Indian counterparts (Mathur, 1982). It remains unclear whether any of this mass deficit is constitutional, and whether the life expectancy of the tropical groups would be improved by a substantial weight gain.

Body fat

Controversy continues over methods of estimating body fat. There have been renewed suggestions that at least in a well-nourished population, the body mass index (mass/height^2) provides the best simple field index of fatness (Baecke, 1982). One important practical lesson from the I.B.P. was that this index loses its validity if muscle mass is increased by heavy physical work, or is decreased by chronic malnutrition. The interpretation of skinfold data may also be complicated in poorly nourished populations; apparently, "essential" trunk fat is conserved, while fat is lost from the arms (Bogin & MacVean, 1981; Johnston et al, 1984). There are many additional problems in trying to convert skinfold readings to estimates of body fat, including possible differences in the distribution of body fat between superficial and deeper body depots, and a two-fold variation in fat estimates according to the choice of prediction formulae (Shephard, 1978; Lohman, 1981; Cureton, 1983). In the tropics, the "normal" variation in density of the several body compartments is often enhanced by a lack of bone mineral and increases of tissue water content secondary to malnutrition. Jones & Corlett

(1980) demonstrated a correlation between total limb width and the mineral content of the femur among Indians; the fat-free density of the Ghurkas was 0.003 above the standard value, leading to a 15% error in the calculated fat-free mass.

Muscle strength

Interest in muscle strength as a factor limiting the employment of women and elderly men has led to the development of an incremental lifting task (Nottrodt & Celentano, 1984); however, to date, this and other tests of muscle strength have yielded little more information about work capacity than that provided by a determination of body mass. Many exercise physiology laboratories now supplement "static" measurements of muscle strength with isokinetic or isotonic data, recorded from Cybex and Ariel dynamometers respectively. The equipment is expensive, not readily portable, and does not yet appear to have been applied to tropical populations. Fortunately, there seems to be a fairly close correlation between isokinetic data and the corresponding isometric readings (Kofsky, Davis & Shephard, 1985); on the other hand, the isokinetic data bears little relationship to the scores for tests of explosive strength (such as a vertical jump, Genuerio & Dolgener, 1980). In theory, lean body mass is an attractive indicator of muscularity, since little cooperation is required from the subject (Forbes, 1974). Low values confirm poor muscular development (Miller et al, 1972), but most available methods of estimating lean mass suffers from the problems of varying body composition already discussed.

The weak muscles of an undernourished, tropical resident are plainly a disadvantage in either agricultural or industrial tasks that call for substantial strength, but because of the small amount of body fat, the overall handicap may be less than force measurements suggest (Petrofsky & Phillips, 1981). Difficulty in perfusing weak muscles may also limit heavy aerobic effort (Kay & Shephard, 1969).

Muscle biopsy

A further, important development in the evaluation of muscle function has been a perfection of needle biopsy techniques. New information has been obtained on the distribution of muscle fibre-types, on local stores of water, minerals and metabolites, and on muscle enzyme activities. This approach should be of particular interest in monitoring human adaptability to the tropical habitat, since there is solid evidence that immediate environmental conditions (including hard physical work) cannot convert a slow-twitch fibre to a fast-twitch fibre, or vice-versa (Saltin et al, 1977).

Anaerobic power and capacity

I.B.P. estimates of anaerobic power and capacity were based on scores for a staircase sprint (Margaria, 1966) and determinations of blood lactate (DiPrampero, 1971) respectively. East Africans, in common with many "primitive" groups, fared poorly on these tests. However, it was unclear whether the problem was anatomical (differences in geometry of the limb muscles), physiological (deficiency of muscle mass or of phosphagen due to malnutrition) or experimental (including difficulties of communication with the subjects, their lack of experience with the required test procedures, and an absence of competitive spirit in the societies under evaluation). It is tempting to attribute much of the functional deficit to a nutritionally based limitation of muscular development (Malina, 1984). However, malnutrition also begets inactivity and thus loss of physical condition, while the power output that can be demonstrated in a staircase sprint varies to some extent with the mass that is to be lifted (Caiozzo & Kyle, 1980). Alternative, cycle-ergometer field tests of anaerobic capacity and power are now available (Bar Or, 1983), although it has yet to be demonstrated that a tropical villager finds the fast pedalling of a cycle ergometer any easier than the task of sprinting up a flight of stairs. Indeed, unless ergometer loadings are adjusted for the small leg volume of tropical residents, it seems likely that misleading answers will be obtained (Lavoie et al, 1984).

Some investigators continue to use performance tests as measures of anaerobic work capacity. Procedures have included a 50 metre run (Ruskin, 1978; U.S. Sports Academy, 1983), a 256 metre run (Thompson, 1981), a medicine ball throw and a vertical jump (Ghesquiere & Eckles, 1984). The last authors plotted their data against body mass, in an attempt to overcome the well-recognized effects of body size upon performance test scores. The results obtained in a tropical milieu are also depressed by lack of test experience, a hot environment, poor track conditions and the absence of a sense of competition (Strydom, 1978).

Aerobic power

Much additional investigation has substantiated the I.B.P. concept that the maximum oxygen intake measured by uphill treadmill running provides a generalisable measure of aerobic power that cannot be materially exceeded (Thys et al, 1979; Shephard, 1982, 1984). It has been repeatedly confirmed that maxima are at least 3-4% smaller when stepping, and 7-8% smaller during cycle ergometry. However, much of the deficit encountered in a cyclist can be corrected by the use of a racing design of cycle, with optimal gear ratios and drop handlebars (Faria et al, 1978), rat-trap pedals (King et al, 1982) and standing on the pedals (Kelly et al, 1980). Irrespective of the mode of exercise that is adopted, the quality control of data is of great importance (Jones & Kane, 1979). Under field conditions, the validity of data is best assured by the regular testing of a panel of volunteers with known characteristics.

In Canada, a step test developed for the field-testing of aerobic power has found extensive application in population surveys and self-administered fitness evaluation (Bailey et al, 1976; Fitzgerald et al, 1980). The concept of using music to set the rhythm of stepping evolved during our studies of the Inuit, but with an appropriate adjustment of instrumentation, music could also provide a useful method of teaching and motivating tropical populations during step-testing. One point to check for a tropical population is the mechanical efficiency of step-climbing; possibly as a part of their heat acclimatisation, indigenous populations are sometimes more efficient than those from cooler regions (Wyndham, 1966).

Other designs of step test (Wyndham & Sluis Cremer, 1968; Robertshaw et al, 1984) continue to find industrial field application both in South Africa and the U.K. All-out cycle ergometer tests have also been extrapolated to the oxygen consumption at the presumed maximal heart rate ($\dot{V}O_{2,195}$: Collins, 1982). All-out runs over distances of 402-8050 metres have not had thorough evaluation as a simple method of predicting PWC170 (Table 3). There is some concern regarding the safety of prolonged, unsupervised running in older populations, and in general, correlations with the directly measured maximum oxygen intake are only moderate. Scores depend greatly upon motivation, knowledge of pacing, and environmental conditions (Shephard, 1982), with the largest coefficients of correlation being reported over distances of 2000-3000 metres.

Anaerobic threshold

One final aspect of work performance that has attracted much attention over the past decade has been the relative intensity of effort at which significant amounts of lactate accumulate in the blood stream - the so-called "anaerobic threshold". It has been suggested that well-trained and well-muscled individuals can operate at a large fraction of their maximum oxygen intake without a significant build-up of lactate, and this apparently gives them an advantage in tasks calling for sustained endurance (Ready & Quinney, 1982; Powers et al, 1983). In general, determinations of both the aerobic threshold (where Type I muscle fibres are heavily recruited and an imbalance develops

Table 3: Coefficients of correlation between directly measured maximum oxygen intake and running speed (based on reports tabulated by Shephard, 1982).

Distance	Coefficient of correlation	Number of reports
402 m	0.22-0.31	2
549 m	0.27-0.67	6
805 m	0.04-0.73	6
1610 m	0.25-0.79	5
9 min	0.71-0.81	2
12 min	0.28-0.90	11
3220 m	0.47-0.86	3
4830 m	0.43	1
8050 m	0.38	1

between pyruvate formation and oxidation), and the anaerobic threshold (above which large amounts of lactate accumulate in the blood stream) have required access to a laboratory with facilities for on-line determinations of gas exchange. However, the second and more clearly identified breakpoint in the gas exchange curve can be estimated from its correlation with the time to exhaustion on a simple cycle ergometer test (Jacobs et al, 1983), with the perception of "somewhat hard" work on the Borg scale of perceived exertion (Purvis & Cureton, 1981), with absolute heart rate (Parkhouse et al, 1982), and with a non-linearity in the relationship between heart rate and work rate (Conconi et al, 1982).

Collins (1982) has illustrated some of the difficulties encountered when translating these physiological and psycho-physical measurements into estimates of productive work. In a commercial situation such as a sugar plantation, bonuses and experience of cane-cutting are generally more important variables than any estimate of physiological work capacity.

MEASURING WORK CAPACITY IN A TROPICAL ENVIRONMENT

Both techniques of testing and the interpretation of data may need modification in the tropical environment.

Sampling problems

Sampling presents many practical problems. Identification of names and ages becomes imprecise when these have not been recorded by the government (Sinnett & Whyte, 1973; Davies et al, 1974). In some studies, sampling appears to have been fairly complete; for example, Goldrick et al (1970) examined 95% of the 1,500 member Enga clan in the New Guinea highlands. Other reports give no indication of the proportion of the total population that has been sampled.

By analogy with the circumpolar data, incomplete sampling usually leads to over-representation of the fit, and under-representation of the diseased (Shephard, 1978). This has serious implications for population estimates of working capacity in countries where conditions such as malnutrition and anaemia (Fleming, 1977), and diseases such as malaria, schistosomiasis, hookworm, filariasis and amoebic infections are endemic (Davies & Van Haaren, 1974; Huizinga & Hooijen Bosma, 1980; Weymes, 1982; Collins, 1982; Ghesquiere & Eekels, 1984; Van Ee, 1985).

Other, more general problems of sampling can also arise in the tropics. Volunteers display their need of peer approval by out-performing randomly selected individuals and exaggerating their normal performance both in questionnaire responses and in field measurements of energy expenditure (Arnett & Rikli, 1981). Urban samples are further biased by a limited recruitment of smokers and alcoholics.

Body build

Despite the supposed advantages of heat loss conferred by a linear body form, a wide range of statures is encountered in the tropics, from the pygmy Twa (average height 144 cm) to the inhabitant of the arid sub-Saharan region (average height, 171 cm; Hiernaux, 1966; Austin et al, 1979). This immediately raises the vexing issue of proportionality in measurements of working capacity. For example, if maximum oxygen intake varied as height$^{3.0}$, a Saharan man would have a 67% advantage of oxygen transport over the Twa. However, if the exponent were $H^{2.0}$, the advantage would drop to 41%. Details of proportionality theory (Von Döbeln, 1966; Ross et al, 1978) are unfortunately not borne out by experimental data collected over the period of normal growth (Table 4), and it seems rather improbable that such calculations can adjust for differences of size between adult populations.

A further complication is that a secular trend associated with greater hybridisation and changes of nutrition has increased the body size of many groups over recent years; for example, the Twa are now 10-16 cm taller than the classical figure (Ghesquiere, 1971; Austin et al, 1979). Socioeconomic and/or nutritional gradients of stature have been described in India (Malhotra, 1966), Tunis (Pařízková et al, 1972), Samoa (Greksa & Baker, 1982), and Kinshasa (Ghesquiere & Eekles, 1984). The authors of the last study commented that when the results of several field performance tests were expressed relative to body mass (approximately an $H^{3.0}$ correction), the poorer segment of the