Work Capacity, Thermal Responses and Lung Function: United Kingdom Studies in the I.B.P.

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Work capacity, thermal responses and lung function: United Kingdom studies in the I.B.P.

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Results of physiological studies from some ten U.K. Human Adaptability projects are presented. U.K. investigators made major contributions in developing and adapting techniques for the assessment under field conditions of work capacity, heat tolerance and respiratory function. The various ethnic studies of work capacity revealed the special role of body size and muscularity, as well as training, in determining the observed inter- and intra-population variance. The results on samples from U.K., New Guinea, the Caribbean, Israel, West and East Africa and the Ethiopian highlands gave no indication that genetic differences were significant in determining population differences. Differences in heat tolerance reflect in general the intensity of heat exposure, especially when combined with hard physical work. Indigenous peoples in Africa and New Guinea show some modification in sweating responses which do not appear to be genetically determined but are in some way, as yet not clearly established, attributable to long continued residence in tropical climates. In renal function the desert Bedouin show no special adaptations. Successful adaptation for life in hot regions imposes changes in way of life as well as in dietary intake, particularly of salt and water, as shown by studies in the Sudan and Tanzania. Lung function of some seven ethnic groups were analysed in terms of lung volume bellows function, gas exchange and responses to exercise and carbon dioxide. The relative importance of genetic and non-genetic factors was examined.

1. Introduction

The International Biological Programme adopted as its general aim the world-wide, coordinated study of 'the biological basis of productivity and of human welfare'. The fulfilment of the second objective 'the biological basis of human welfare' was the task accorded to the Human Adaptability Section. In the detailed planning (Weiner 1969) emphasis was placed on the biology of human communities exposed to the more demanding environments of the world, notably in the circumpolar, high altitude and tropical regions. Studies of harsh habitats gave promise of deepening our insight into the processes of adjustment needed for survival, fitness and welfare (physiological as well as nutritional, genetic, demographic and hygienic). Many of the populations in these habitats are, or were, relatively small and homogeneous and, despite difficulties of access, would be to that extent easier to sample.

Many laboratory findings had been accumulated on physiological responses to extreme climates and on the physiological assessment of 'fitness', but their significance in everyday life had been little studied. The proposed H.A. field work was therefore not only scientifically timely but also carried tangible practical implications. Because these regions remain relatively underpopulated before beginning to undergo development, it was useful to establish what biological limitations were set by 'natural' environmental conditions to working efficiency, and to provide biomedical 'base-lines' of the fitness, nutritional status and health of the inhabitants.

A final consideration for adopting this line of work was that it entailed, in accordance with the principles of the I.B.P., a whole series of comparable national projects, in many cases carried out (as they were) by multi-national teams. Of course populations in other ecological situations, those in urban and rural areas in developed countries and in temperate zones, all found a place in the H.A. programme both in their own right but also for comparative purposes (Weiner 1969).

The United Kingdom's contribution fitted very well into this framework. Communities in all these habitats (except the circumpolar) were in fact studied by U.K. teams and in most instances on a bilateral or multilateral national basis.

This paper deals with the three major physiological themes within the Human Adaptability Section and is based on the results obtained in some ten U.K. projects. These three themes comprise: (1) The assessment of the physiological work capacity of groups in a variety of habitats. Dr J. Cotes and Dr M. Davies were responsible for most of this work. (2) The physiological responses which underly successful adjustment to hot climates. Professor R. A. McCance, Dr R. H. Fox and Dr O. G. Edholm were largely responsible for these studies. (3) The factors affecting respiratory functioning and efficiency, for which Dr J. Cotes took responsibility. Dr Cotes has kindly provided a brief review of this aspect.

It should be added that these three topics will form the subject matter of one of the five international H.A. synthesis volumes to be published by the Cambridge University Press.

The three themes have a good deal in common. They are all concerned with the elucidation of regulatory and adaptive processes and with the involvement of genetic and non-genetic factors in determining the range and variability of observed responses, and they all carry implications for human welfare and efficiency.

2. Studies on work capacity

Exercise tolerance was assessed in many H.A. studies in order to ascertain the level of fitness attained by various communities under different living and working conditions, for example in agriculture and industry, at high altitudes or in extreme climates, and in relation to nutritional or health status. Studies of such factors, incidentally, enabled the significance of ethnic differences to be examined.

The principle of the assessment of exercise tolerance widely adopted in H.A. studies is shown in figure 1. The subject is required to perform work at increasing levels of intensity up to the maximum which he can sustain. This enables the relation between the heart rate and the oxygen usage for each subject to be established. It is this linear relation which provides the criteria for specifying the subject's work capacity. At sub-maximal levels of work one such criterion is to determine the heart rate at an agreed O_2 uptake, either 1.0 or 1.5 l/min, obtained by interpolation from the linear relation. Another criterion – the maximal work capacity – is specified as the O_2 utilization (or $V_{O_2,\max}$) where the work reaches its maximum limit. This maximum generally occurs when the heart rate reaches about 190 beats/min ($f_{h,\max}$). The variability of the $f_{h,\max}$ of individuals in a population around the population mean is sufficiently small for the population mean to be used, by extrapolation, to derive the $V_{O_2,\max}$. The reproducibility and validity of these criteria, as well as the feasibility of obtaining them, were thoroughly examined

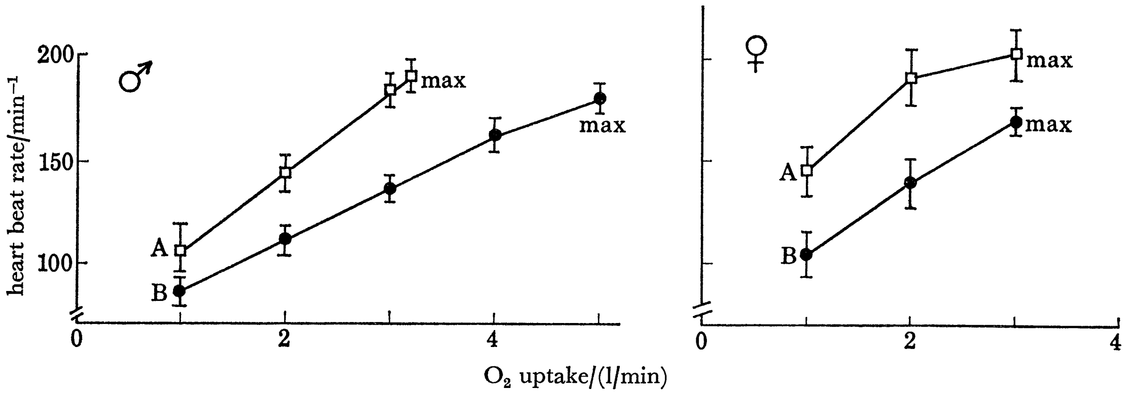

FIGURE 1. Heart rate during submaximum and maximum exercise in young adult (20–30 years) men and women, showing sex differences and variations between A, sedentary (unfit) subjects and B, athletic (fit) subjects. (Based on Hermansen & Lange Andersen 1965.)

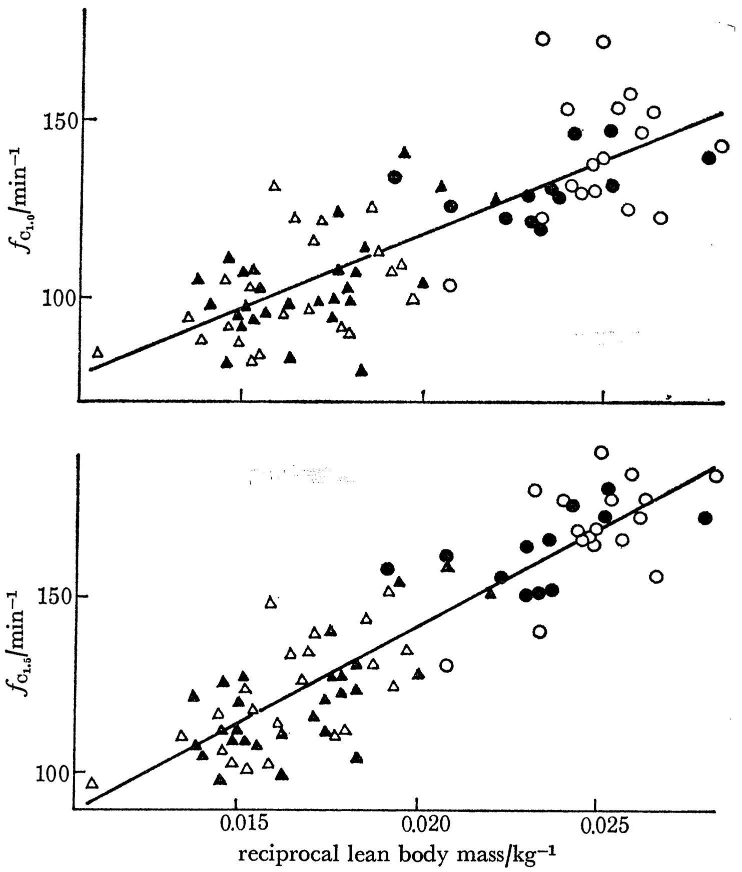

FIGURE 2. Relationship to lean body mass of cardiac frequency during submaximal exercise at the oxygen uptakes of 1.0 and 1.5 l min⁻¹ ($f_{\mathrm{C}_{1.0}}$ and $f_{\mathrm{C}_{1.5}}$ respectively). The circles and triangles refer respectively to women and men; group A subjects are open symbols and group B subjects closed symbols. The regression line is constructed using equation (2). (Cotes, Berry *et al.* 1973.)

in the preparatory phase of I.B.P. by a multinational team in Canada. The agreed procedures are set out in I.B.P. Handbook no. 9 (Weiner & Lourie 1969).

That the very considerable intra- and interpopulation variation in aerobic capacity is related to age, sex (figure 1) and body size is well documented (Åstrand & Rodahl 1970). As a factor in this variation, U.K. H.A. teams were much interested in the specific role of muscle mass in determining the rate of oxygen utilization – a matter which had received very little attention. Dr Cotes and his colleagues (Cotes *et al.* 1973) examined the relationship of the cardiac frequency during submaximal exercise to various indices of body muscle. In figure 2 the values for cardiac frequency at interpolated oxygen intakes of 1.0 and 1.5 l min^{-1} are shown in relation to lean body mass and in figure 3 in relation to total body potassium. These findings show clearly that muscle mass is closely related to the intensity of the submaximal exercise responses and that difference between males and females is dependent on this bodily component.

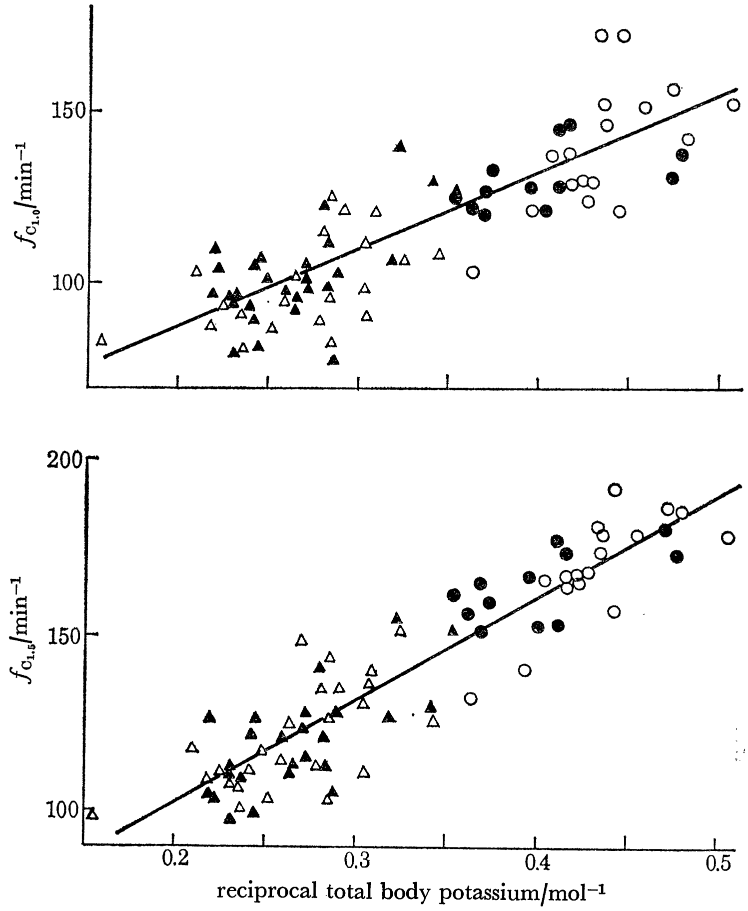

FIGURE 3. Relationship to total body potassium of cardiac frequency during submaximal exercise at the oxygen uptakes of 1.0 and 1.5 l min^{-1} ($f_{C_{1.0}}$ and $f_{C_{1.5}}$ respectively). The symbols are as for figure 2. The regression line is constructed using equation (2). (Cotes, Berry *et al.* 1973.)

Differences in work capacity between ethnic groups are clearly related to differences in the amount of muscle mass as shown in figure 4 from a number of pilot studies in New Guinea and the Caribbean. Cotes, Berry *et al.* (1973) conclude from these results that another factor determining interpopulation differences is the difference in habitual activity.

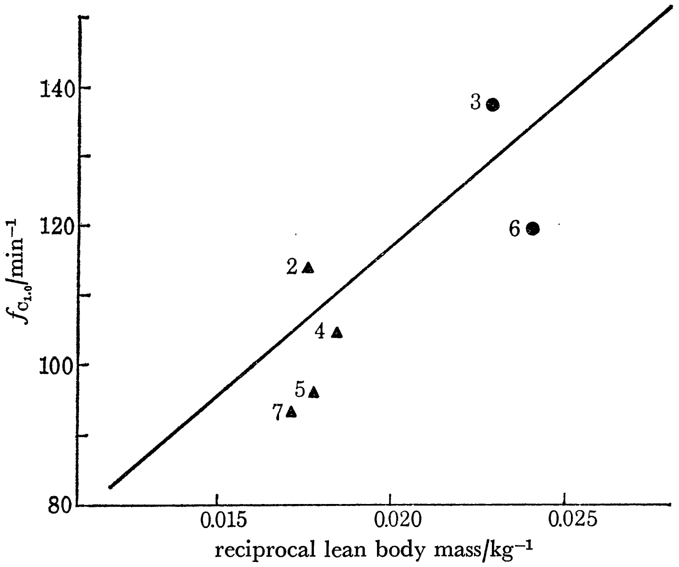

FIGURE 4. Relation of exercise cardiac frequency ($f_{C_{1.0}}$) to lean body mass for the subjects (from figure 2) and mean data for groups of subjects having higher or lower levels of habitual activity;

		▲ men	● women
Caribbean	sedentary	2	3
	hill farmers	4	—
New Guinea	highlanders	5	6
U.K.	cyclists	7	—

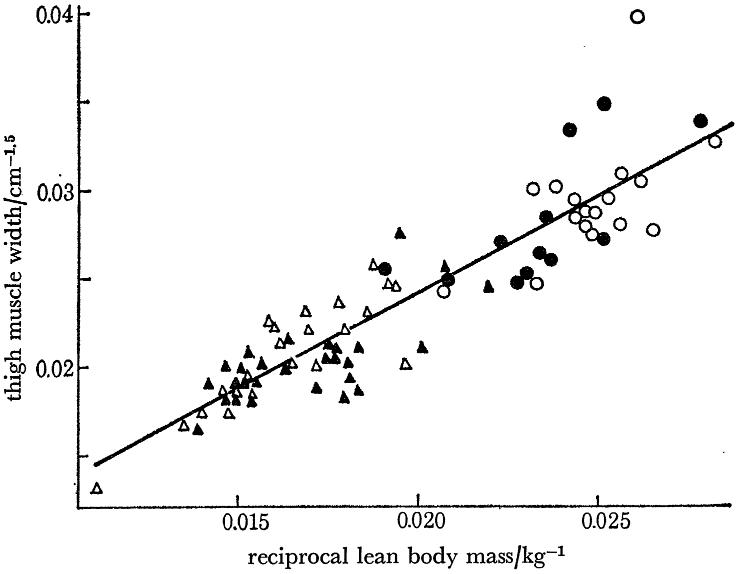

FIGURE 5. Relation of thigh muscle width to lean body mass. The symbols are as for figure 2. The regression line is constructed by using equation (3). (Cotes, Berry *et al.* 1973.)

These issues were taken up on larger samples in further H.A. studies in West and East Africa. Cotes, Berry *et al.* (1973) had also demonstrated a close relation between whole body muscle and thigh muscle (figure 5) and with this in mind Davies, Mbelwa, Crockford & Weiner (1973) assessed the maximum aerobic power in relation to various indices of body physique, including weight, skinfold thickness and leg volume (estimated by anthropometry). The $V_{O_2\,\max}$ of 26 East African male and 30 female subjects did not show a single linear relations to lean body mass (figure 6), in contrast to submaximal responses mentioned above. When these results on Africans are compared with previous findings on healthy Europeans of both sexes, adults as well as boys and girls, it becomes apparent (figure 7) that $V_{O_2,\max}$ is related to the effective muscle mass used to perform the work of cycling on a stationary bicycle ergometer, namely the leg muscles. The lower $V_{O_2,\max}$ of African men and women is in large part a function of their smaller muscle mass.

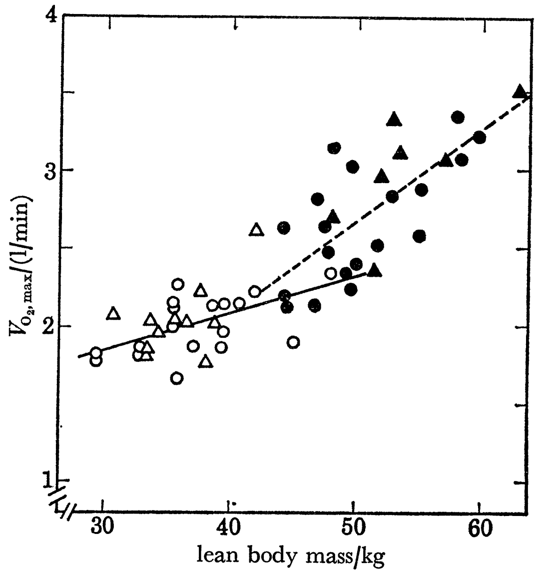

FIGURE 6. Maximum aerobic power ($V_{O_2,\max}$) in relation to lean body mass in African subjects. ●, male industrial workers; ▲, male students; ○, female village workers; △, female nurses.

It is evident that even with these relations (the correlation coefficient in figure 7 is 0.90) a good deal of variance remains. Deliberate physical training will of course improve muscular performance (figure 1), and some of the observed intra- and interpopulation variance must be attributable to differences in training and habitual activity.

In the Nigerian/U.K. H.A. study (Ojikutu, Fox, Davies & Davies 1972) the maximum aerobic power was first ascertained, by means of the direct method, on a small number of subjects. The results (table 1) show clearly that the sedentary and light subjects had a $V_{O_2,\max}$ well below those of workers in heavy industry who in turn performed somewhat less well than those of British subjects, but those differences make no allowance for body size. The importance of this sample lies however in the determination of the 'population' maximum cardiac frequency which is about 190 beats/min. This enabled the indirect extrapolatory method to be applied to larger samples with the results shown in table 2. Here the predicted $V_{O_2,\max}$ is expressed in terms both of body mass and lean body mass. The workers in heavy industry have the largest $V_{O_2,\max}$ followed by the agricultural villagers and then the male students and workers from light industry. Thus even when body size is taken into account the 'heavy industrial' workers were clearly in a better state of fitness presumably due to the training effect of their habitual occupations.

It is apparent that when ethnic or genetic comparisons are made the influence of level of habitual activity as well as body size must be taken into account. In the U.K./Israel H.A. project aerobic work responses were studied in two genetically very different groups – Kurdish and Yemenite Jews. There was, however, no discernible difference in mean $V_{O_2,\max}$ between these groups (Samueloff, Davies & Schvartz 1973). This would appear to reflect the fact that the level of habitual activity as judged by the daily energy expenditure was the same for both groups.

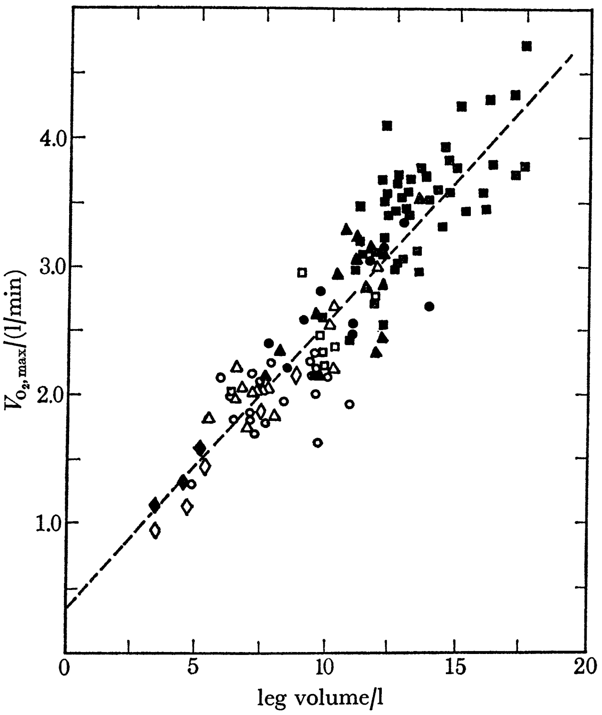

FIGURE 7. Maximum aerobic power ($V_{O_2,\max}$) in relation to leg volume for African and European subjects. The regression equation is of the form:

$$V_{O_2,\max}\ (\mathrm{l\ min^{-1}}) = 0.36 + 0.22\ \text{leg volume (l)}$$
$$r = 0.90.$$

The positive intercept of 360 ml may be interpreted as representing resting metabolism but it will also undoubtedly include a postural component of work. Thus it may be more correctly envisaged as the energy expended while seated on the bicycle pedalling at a frequency of 60 pedals/min against zero load. Symbols as for figure 6 with the addition of: ■, European adult males; □, females; ◆, European children males; ◇, females.

In a review of their results on four distinct ethnic groups – Europeans, Yoruba (Nigerians), and Kurdish and Yemenite Jews – Davies *et al.* (1972) concluded that the responses to exercise were essentially similar in the four groups. The males in particular were able to reach similar values of maximum ventilation, cardiac frequency, and aerobic power output. When standardized for body size and composition (ml per kilogram lean body mass per minute) the $V_{O_2,\max}$ for each paired group (Caucasian-Yoruba, and Kurd-Yemenite) was identical. It was concluded that, if differences in aerobic power output exist between ethnic groups, they must be small and therefore of doubtful biological significance – they are certainly less than the large intersubject variations which exist between members of the same race.

The U.K. contribution to the world-wide study of high altitude peoples was made in the Ethiopian highlands – the first time that populations in this region at altitudes of 3000 m (9000 ft) had been examined. It is to be expected that the reduced oxygen tension would have a profound effect on work performance at these high altitudes. This is indeed the case when the responses of newcomers are compared with their previous sea-level values. A reduction in maximal aerobic power of 2 % per 1000 ft (300 m) of altitude has been reported (Åstrand & Rodahl 1970). It is of course well established that a process of acclimatization sets in and the cardiovascular and respiratory functioning of the new arrivals gradually improves. There is some uncertainty however whether the $V_{O_2,\,\mathrm{max}}$ is fully regained at the end of this acclimatization period of several weeks.

TABLE 1. PHYSIOLOGICAL RESPONSES TO MAXIMAL EXERCISE

(Maximum aerobic power ($V_{O_2,\,\mathrm{max}}$); maximum minute ventilation ($V_{\mathrm{E,\,max}}$); and maximum cardiac frequency ($f_{\mathrm{H,\,max}}$). (♂ mean data ± s.d.))

group		$\dot{V}_{\mathrm{E,\,max}}$ l/min	group comp. P	$f_{\mathrm{H,\,max}}$ bts/min	$\dot{V}_{O_2,\,\mathrm{max}}$ l/min	group comp. P
non and light industrial $n = 6$	(1)	111.87 ± 24.01	1v3*	192.00 ± 3.94	2.92 ± 0.48	1v3*
heavy industrial $n = 9$	(2)	133.95 ± 16.73		190.22 ± 8.01	3.28 ± 0.40	
British $n = 31$	(3)	133.14 ± 18.04		193.26 ± 6.74	3.39 ± 0.43	

Significance * $P < 0.05$.

TABLE 2. PREDICTED MAXIMUM AEROBIC POWER ($V_{O_2,\,\mathrm{max}}$) IN ABSOLUTE (l/min) AND RELATIVE (ml kg^{-1} min^{-1} BODY MASS AND LEAN BODY MASS) TERMS

($V_{O_2,\,\mathrm{max}}$) (mean data ± s.d.)

		predicted $\dot{V}_{O_2,\,\mathrm{max}}$					
group		l/min	group comp. P	ml kg^{-1} min^{-1} (body mass)	group comp. P	ml kg^{-1} min^{-1} (l.b.m.)	group comp. P
heavy industry $n = 24$	(1)	3.35 ± 0.57	1v2** 1v5**	54.6 ± 6.8	1v2** 1v3** 1v4** 1v5**	65.0 ± 10.0	1v2** 1v4** 1v5**
light industry $n = 15$	(2)	2.55 ± 0.34	2v3** 2v4** 2v5**	47.2 ± 7.0	2v5**	56.4 ± 8.2	2v5**
villagers $n = 7$	(3)	2.99 ± 0.38	3v5**	48.5 ± 4.1	3v5**	61.2† ± 3.3	3v5**
♂ students $n = 17$	(4)	3.03 ± 0.52	4v5**	44.8 ± 7.5	4v5**	56.0 ± 10.4	4v5**
♀ students $n = 8$	(5)	1.69 ± 0.30		31.6 ± 3.7		40.5 ± 5.1	

† $n = 3$, significance * $P < 0.05$, ** $P < 0.01$.

That indigenous people at high levels attain levels of $V_{O,\max}$ quite comparable to those at low levels seems clear (figure 8) from the Ethiopian results obtained by Lange Andersen (1972). No genetic difference was involved in the comparison of high altitude and low altitude Ethiopians. In Nepal the findings were the same. Baker, Pawson & Weitz (1975) report that 'the relationship between age or activity pattern and the responses to maximum exercise does not appear to be significantly affected by differences in altitude; and indeed, is generally similar to that observed among comparable active sea level populations tested at low altitude'.

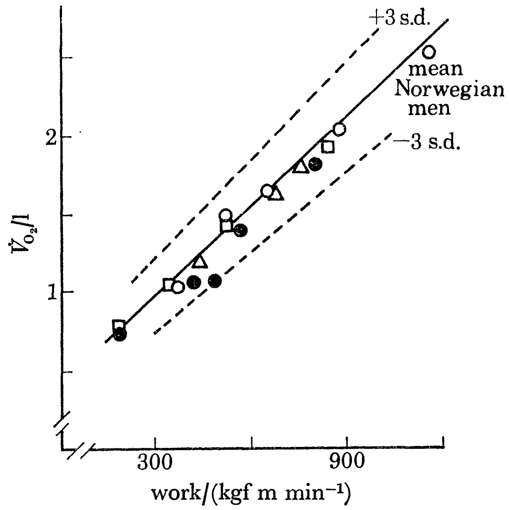

FIGURE 8. Oxygen uptake during submaximal bicycle riding in relation to work performed. Figure gives individual data of two subjects from different altitude habitats. Standard for mean and s.d. is taken from a study by Hermansen & Lange Andersen (1965). ●, □, altitude dweller nos. 24 and 50; ○, △, lowlander dweller nos. 91 and 51.

This quite superficial account of this aspect of the U.K./H.A. physiological studies is sufficient to show that substantial additions to our knowledge of the muscular fitness of populations in a variety of working habits were made; especially in relation to body size, muscularity and genetic constitution. It may be asked, in terms of the I.B.P. objectives, whether this work has any bearing on 'human welfare'. In fact work capacity assessments are increasingly used for monitoring the health and nutritional status of adults and children, for selecting men for heavy work and athletic proficiency. In Tanzania, as a follow-up of the H.A. work, Davies showed that malnutrition in children, and anaemia in both adults and children (Davies 1973, 1974; Davies, Chukweumeka & van Haaren 1973), had measurable effects on working capacity but that marked improvement followed appropriate treatment. The aerobic power measurement could be used to assess the effects of such tropically debilitating diseases as bilharzia, malaria and hookworm. As Davies *et al.* (1973) write, 'In developing countries where a highly trained manpower is required for physically demanding tasks requiring a high (aerobic) power output the nation's productivity will depend in part on the health and fitness of its labour force. Both training and nutrition are concomitants of increased power output and they must be borne in mind in programmes designed to increase productivity in labour intensive activities.'

3. ADJUSTMENTS TO HOT CLIMATES

Long before the H.A. programme was launched many studies of human responses to hot dry and hot humid climates had of course been carried out in laboratory-based climatic chamber conditions. From these, important applications had been made in the selection and acclimatization of men for deep mining (Weiner 1972) and military operations in hot climates (Edholm 1969). But the significance of this work for the everyday life of peoples in the tropics and sub-tropics and arid zones had been largely neglected. The I.B.P. provided a strong incentive to remedy this deficiency, despite the daunting technical difficulties of physiological work of this kind in the field. The principal lines of investigation on peoples living in hot climates pursued by the H.A./U.K. teams were concerned with the study of heat regulatory processes and of water and salt balance.

Heat tolerance

In the preparatory phase of I.B.P. attention had to be given to finding a test of heat tolerance which could be standardized, be sufficiently portable, and not too complex for intensive use on short field visits on samples of 30 or so subjects. Techniques were proposed by physiologists from a number of countries, culminating in a multinational assessment of the different procedures in Cincinnati in 1966 (Henschel 1967). Although two main tests were agreed on (I.B.P. Handbook, Weiner & Lourie 1969), most of the U.K. work was carried out using the test devised by Fox as described in the Handbook. Briefly, the equipment consists of a specially designed air-conditioned bed in which the air flow from a blower can be partitioned between hot and cold heat-exchangers so as to maintain any required temperature between 15 and 55 °C. The air flow is distributed over the whole of the subject's body, except the head, by wrapping a double-layered plastic sheet, formed into ducts with holes on the inner surface, around the subject lying on the bed. Deep body temperature is monitored from both ears using thermistor thermometers with the ears and head well insulated from the external air temperature. Mean skin temperature from eight body sites is measured with thermistor thermometers attached to the sweat-collecting suit. To measure the rate of sweating, the subject is dressed in a thin plastic suit which seals at the neck and from which the sweat is withdrawn under negative pressure, measured, and samples taken for subsequent biochemical analysis. Peripheral blood flow could also be recorded from one hand using a venous occlusion plethysmograph.

Sweating capacity

It has long been known from heat-loading tests in chambers that continued exposure to high air and radiant temperatures, with or without work, activates or 'trains' the sweat glands. Each gland becomes more responsive to the heat stimulus and for a given heat stimulus (as in the bed test) with progressive acclimatization each gland produces more sweat for evaporative heat loss. In the Nigerian study (Ojikutu *et al.* 1972) subjects showed the effect of habitual heat exposure very clearly. In figure 9, the sweat response of European males before and after deliberate acclimatization is compared to that of the two groups of Nigerian industrial workers. The sweat losses were measured during the 40-min period of controlled hyperthermia at 38.0 °C at 10 min intervals, and the initial sweat losses were used to give a measure of the sweating capacity. Each group was tested for a possible correlation between body size and initial sweat loss. No correlation was found so the results have been expressed as ml/min.

The light industrial workers had a significantly lower sweat loss ($P < 0.01$) than heavy industrial workers (figure 9). The industrial workers, and especially the heavy industrial group, had higher sweat rates than both the male students and villagers. Compared with the European males before and after artificial acclimatization to heat, the Nigerians were partially acclimatized, but the heavy industrial workers did not reach the sweating capacity of the acclimatized Europeans.

Nigerian female villagers gave a larger response than unacclimatized European females,

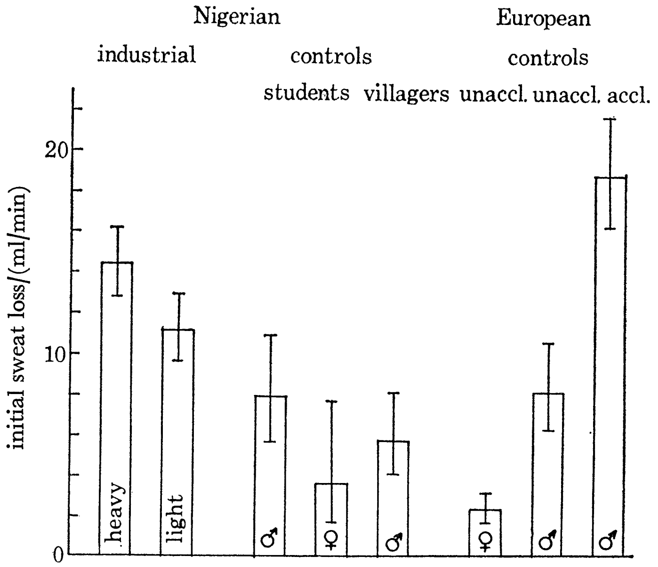

Figure 9. A comparison of the initial sweat losses (ml/min) of the heavy and light industrial workers, the three Nigerian groups and also European control groups.

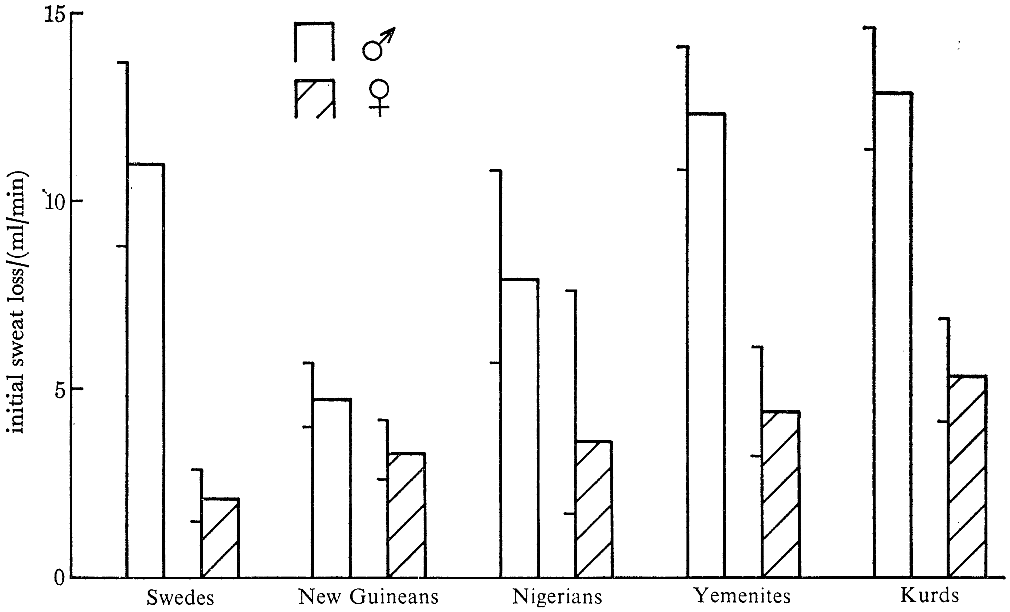

Figure 10. A comparison of the maximum sweating capacity measured in the New Guineans with those found in previous studies on Swedes, Nigerians, Yemenites and Kurds.

reflecting presumably the agricultural work under warm conditions required of the Nigerian women. The maximum sweating capacity of females is much less than males.

The results of the Nigerian study have been brought together with those in New Guinea and in Israel (Fox *et al.* 1974). Acclimatized Swedes are used as a reference group (figure 10).

The sweat rates of the Europeans on Karkar Island of New Guinea were closely comparable with the level for the artificially heat-acclimatized Swedes, and much higher than those of the New Guinea indigenes. The male New Guineans had sweat rates similar to the unacclimatized European (figure 10), whereas the females in New Guinea were somewhat higher than their European counterparts. The low sweating capacity of the New Guinea people is comparable to that of Nigerians tested in the same way. By using different tests, similarly low values were found in South African Bantu (Wyndham *et al.* 1964; Wyndham 1970) and in Uganda by McCance and Purohit (1969). There is as yet no satisfactory explanation for the marked differences in the sweating response of the newly well-acclimatized Caucasian compared with the indigenes of hot countries. The differences are unlikely to be genetically determined. The two ethnic groups of the Israeli study, the Kurds and Yemenites, differ in many of their serogenetic characters yet they show closely similar sweating responses. Moreover the tropical indigenes who show a reduced acclimatized sweating capacity include groups as genetically diverse as South African and Ugandan Bantu, New Guinean Melanesians, Singapore Asians and Indians. It seems more likely that these groups share a common factor related to their prolonged period of hot climate exposure. I have suggested elsewhere that this common factor may reside in the lower body mass combined with the slimmer limbs and trunk generally characteristic of hot climate populations, since this bodily physique could have the effect of imparting a higher overall coefficient of evaporative heat loss than that of heavier built individuals. This would make for more economical sweating when the skin is maximally wetted. This suggestion has not been tested. An alternative hypothesis, again based on the factor of prolonged residence, arises from observations by Macpherson (1960) in Singapore (figure 11). His findings indicate that the first acclimatization period, with high and probably wasteful

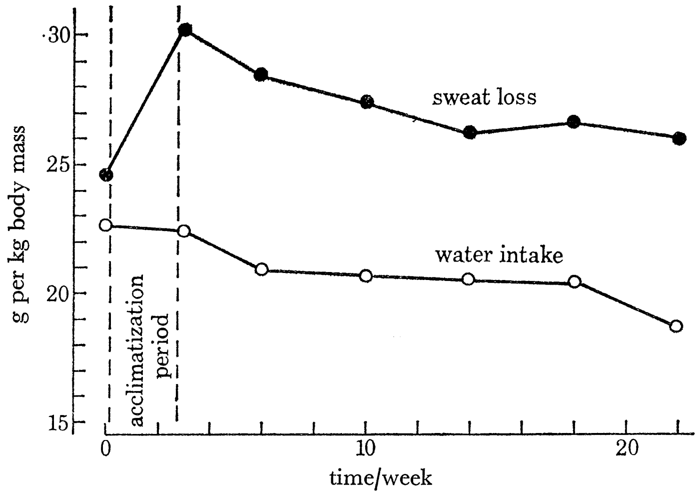

FIGURE 11. Uniformity trials. Mean sweat loss and mean water intake for each heat exposure.

sweating and a large water turnover, is succeeded by a gradual long-term reduction in water intake which is associated, probably causally, with a diminution of sweating. Tropical dwellers' requirement for sweating may also be somewhat reduced by their lower basal metabolic rate (Collins & Weiner 1968; Mason & Jacob 1972) and an acquired economy of muscular movement.

Water and salt balance

Life in hot climates requires major adjustments in the heat regulatory system, and this in turn affects the functioning of the cardiovascular, metabolic, nutritional and endocrinological systems and has repercussions on behavioural responses. Some of these aspects were examined in a number of U.K./H.A. investigations by McCance and his colleagues in Sudan and Israel, by Johnston and colleagues in Jordan and by Weiner and his team in Tanzania.

The study in Khartoum (McCance *et al.* 1971) comprised in reality a description of the 'life-style' of native Sudanese students compared to that of simultaneously observed, recently arrived Cambridge students during their first eight days' stay in Khartoum. The reverse situation, a comparison in Cambridge of these same two groups, was also part of the study. Only a few points can be mentioned here. The unacclimatized status of the newly arrived Europeans was reflected in their lower sweat output compared to that of the resident Sudanese; in both groups water expenditure was markedly greater in Khartoum than in Cambridge but while the groups had a similar water turnover in the U.K. in Khartoum that of the Sudanese was greater than that of the newly arrived group. The daily pattern of activity was such that all the subjects ate less and expended less energy in Khartoum than in Cambridge. Whereas the Sudanese subjects gained mass in Cambridge the Cambridge students lost mass in Khartoum. Of particular interest was the finding that whereas both groups had an average intake of about 13 g of salt in Cambridge they took only about half this amount in Khartoum. McCance showed that this amount provided not only for palatability but also a sufficient safety margin above the daily obligatory urine loss. This finding indicates very clearly, in keeping with laboratory studies (Collins & Weiner 1968), that the body has a well developed capacity, mediated through the kidney and sweat glands, for maintaining the salt balance steady in hot climates even on intakes which are often much lower than that in temperate climates. A similarly low intake of salt has been recorded, for example, in Australian desert aborigines. In the Tanzanian–U.K. study (Wheeler, El-Neil, Willson & Weiner 1973) the subjects were subjected to large changes in intake of protein and therefore in dietary palatability, and there were changes also in daily work load and water intake over the 6 week period. The salt intake was freely chosen but remained remarkably steady at a mean value of about 10 g/day. One of the objectives of the Tanzanian study was to ascertain whether the loss of nitrogen and of iron in the sweat was of significance for people in the tropics subsisting on poor diets. It was found that the nitrogen loss was not of practical importance but the iron losses could be a factor when iron intake was low. Incidentally, the Tanzanian study served to establish for subjects undergoing large changes in diet and water intake the limits of homeostatically controlled water balance. This is of the order of ±1% of body mass (Doré, Weiner, Wheeler & El-Neil 1975).

The functioning of the kidney in hot climates was a subject of investigation both in Jordan and Israel. In cooperation with local workers it was possible to carry out tests of kidney function on Bedouin in both these countries. The question asked was 'Have the Bedouin a special desert physiology?'. From tests of sweat responses but particularly of the concentrating power of the kidney, the answer to this long-standing question was in the negative. As in the Israel study by

McCance *et al.* (1974), Corbett & Johnson (1968*a*, *b*) in Jordan found that during 24 h of complete water deprivation the Bedouin Arabs showed no greater ability to conserve fluid than Europeans.

4. Lung function

(*contributed by Dr J. Cotes*)

The study of the function of the lungs was included in the U.K.'s contribution to I.B.P. on account of both its relevance for work capacity and tentative evidence that it varied between as well as within ethnic groups. Internationally agreed techniques suitable for population studies were available through the activities of respiratory physiologists backed up by the International Labour Organization; they were in use in most countries to study the prevalence of respiratory disease. For application to the I.B.P., it seemed appropriate to relate the findings to the physiological response to exercise. This led to the development of the socially acceptable submaximal exercise test (Cotes, Berry *et al.* 1973) referred to above. The results were analysed separately for the lung volume, including the bellows function of the lung, the gas exchange function and the ventilation during both exercise and rebreathing carbon dioxide (Cotes 1975). The first two aspects are related directly to stature and inversely to age so the results were first standardized to common values for these two variables (e.g. in the case of men an age of 25 and height 1.7 m). The subjects with the greatest pulmonary capacity for ventilation and gas exchange turned out to be those men and women who had low exercise cardiac frequencies relative to their muscularity, including U.K. amateur cyclists, physically active men from the foothills of the Himalayas, including Nepal (Gurkhas) and Bhutan (Cotes *et al.* 1975), and also men and women from the highlands of New Guinea (altitude 1800 m). Those with the least pulmonary capacity were subjects living at sea level in the tropics, including Jamaicans (Miller *et al.* 1972; Edwards, Miller, Hearn & Cotes 1972), South Indians and New Guineans (Cotes, Saunders *et al.* 1973; Patrick & Cotes 1974). The differences were to some extent related to the physiological response to exercise and hence probably to the level of habitual activity. In the case of the gas-exchanging function of the lung, the differences also related to the blood concentration of haemoglobin; after allowing for this and the response to exercise there was no significant association with ethnic group. In the case of the size and the bellows function of the lung the effect of exercise and/or habitual activity was superimposed on an underlying ethnic difference, with people of European descent having larger lungs than those of other ethnic groups. The ventilatory responses to exercise and to rebreathing carbon dioxide seemed to be determined in part by the underlying pulmonary capacity but in the case of the New Guineans, after allowing for vital capacity, the response to carbon dioxide was less than in the other groups of subjects (Cotes, Anderson & Patrick 1974).

These findings have important applications for the detection of respiratory impairment due to disease or to atmospheric pollution, including occupational pollution and personal pollution by tobacco smoke. They also suggest that the development of the lung may be influenced by the level of habitual activity during adolescence; on this account there may be a case for seeing that children, both in the U.K. and elsewhere, have the opportunity to take more exercise than many of them do at present.

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