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Determinants of Oxygen Consumption and Maximum Oxygen Intake of Bantu and Caucasian Males

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Summary. Oxygen consumptions were measured on 80 Caucasian and 45 Bantu young adult males at a number of different work rates both while stepping on and off a bench and bicycling. In *both* groups gross body weight accounted for 70% of the differences between individuals in this measurement; height was negatively correlated and accounted for 4% of the differences between individuals; lean body mass had no significant influence. However, the Bantu have significantly lower oxygen consumptions, which indicates that they are mechanically more efficient in stepping and bicycling. 70% of the differences between individuals in maximum oxygen intake is in Caucasians due to differences in body weight but only 18% in Bantu recruits. After a period of good food and regular work this figure rises to 50% in the Bantu. The regression line for the Bantu recruits is significantly lower than that for Caucasians, but after the induction period the regression line for the Bantu is not significantly different from that for the Caucasians over most of the weight range.

Introduction

It has long been known from comparative physiology that there is a close quantitative relationship between resting metabolism and body size. Kleiber [8], and Benedict [3] independently demonstrated that the plots of the log of metabolism against the log of body weight fell closely about a straight line. This applies to animals as different in body weight as the elephant and the rat. In man, resting metabolism has also been shown to be related to body size. However, there is a certain amount of controversy as to which parameter of body size should be used. In clinical medicine metabolism is expressed as a function of surface area. Surface area is a function of length and mass. There are physiologists such as Kleiber [9] who feel, however, that metabolism should be related to the two-thirds power of mass.

When man walks or runs he lifts the weight of his body against gravity. The work done against gravity is directly related to gross body weight and hence one would expect the rate of metabolism to be related to gross body weight. However, the linear measurements of the individual, particularly of the lower extremities, influence the mechanics of the movements during walking and running and they might be expected therefore to influence the mechanical efficiency. The maximum rate of aerobic metabolism is determined directly by the muscle mass, which is related to the gross body weight of the individual. There are also non-morphological determinants of the rate of metabolism for a given rate of work, and of the maximum aerobic metabolism. Sex, age and training have all been shown to have a measurable effect [2, 25], but the influence of nutrition and genetic constitution have not been evaluated fully.

This review is confined to one aspect only of the influence of morphology on metabolism. A statistical examination has been made of the effects of certain parameters of body size, such as gross body weight, height, and percentage body fat on the rate of oxygen consumption at submaximal rates of work and on the maximum oxygen intake. These relationships were examined in samples of two ethnic groups, Caucasian and Bantu, who differ greatly in these morphological characteristics, and also in other factors which might be expected to affect these measurements.

Background

The Bantu males studied were all recruits to the gold mines in South Africa. These men are recruited from all over southern Africa. The fertility of the soil varies greatly in different parts of the country, and so does the prevalence and the severity of the endemic diseases. These men differ greatly therefore among themselves and from the Caucasians in their states of nutrition, in the endemic diseases from which they suffer, and in the habitual physical activities upon which they normally engage. These are all factors which are thought to influence metabolism during exercise and also the maximum aerobic metabolism.

The Bantu do not work hard in their homelands as they have a subsistence economy based upon primitive agricultural and pastoral farming. The soil which is cultivated, is tilled by the women with primitive hoes. The Bantu males walk long distances when herding cattle, to visit neighbours (they are a convivial people) and in making their purchases at trading stores. The exercise they take is mainly of an endurance nature and it is intermittent. The staple diet of the Bantu in southern Africa is the mealie, and therefore the content of animal protein and fat in the diet is low by Western standards. Like all primitive peasant populations they are at the mercy of the weather, and a period of drought inevitably brings hunger, as has been the case in the last 5 years in southern Africa.

In the mines the nutritional and exercise habits of these men change greatly. They work a regular 8-hour shift for 6 days a week and, being manual workers in the main, they expend energy at a moderate rate. They are presented with a more than adequate diet of over 4.000 kcal per day/man. The protein content is 120 g, of which 65 is of animal or fish origin. As a result of the change in diet and the regular work in the mine the Bantu gain on the average 3.5 kg [15, 25] in weight.

The sample of Caucasians studied were young recruits into the Army. These men, like the Bantu recruits, are selected after a medical examination. Most of the men stated that they had taken part in some form of organised physical activity at school, prior to joining the army, and in the course of their military training they are subjected to regular daily physical training. The diets of the Caucasians are typical of the more affluent sections of Western countries, being high in animal protein and fat.

The physical characteristics of the two groups are given in Table 1.

Table 1. *Physical characteristics of 80 Caucasian and 45 Bantu males*

	Caucasians	Bantu
Age	17 — 19	Young adult
Weight (kg)	66.3 ± 7.32	58.9 ± 5.86
Height (cm)	174.4 ± 5.82	166.4 ± 6.49
Skinfold (mm)	8.1 ± 2.93	5.3 ± 0.74

The Influence of Gross Body Weight, Height, and Body Composition on Oxygen Consumption during Exercise

A series of studies was carried out to determine the relationship between oxygen consumption and the three body size parameters, gross body weight, height, and fat free mass on two relatively large samples, one comprising fit, young Caucasian army recruits, and the other fit, young Bantu recruits to the gold mines. The aim of the study was to estimate the percentage of the variance in oxygen consumption which is due to differences between individuals in these three morphological characteristics, and also to establish whether there are any systematic differences between the two ethnic groups in this regard which could not be attributed to morphological differences, and which might therefore be considered to be due to differences between the two groups in some factor other than morphology.

Correlation coefficients were calculated between oxygen consumptions and gross body weights, heights, and fat free masses determined by Buskirk and Taylor's method [6], of the 80 Caucasians from data obtained when they walked on a treadmill at 7.26 km/h (4.5 m.p.h.) on the flat and on 45 Bantu while they stepped on and off a bench at a rate of 24 steps/min at two different heights. One height was 30.5 cm (12 inches) (work rate 1), and the other was 37.5 cm (15 inches) (work rate 2). The mean rates of oxygen consumption and their standard deviations are the following:

Group	No.	Mean oxygen consumption	Standard deviation
Caucasian	80	1.92 l/min	0.255 l/min
Bantu (1)	45	1.28 l/min	0.160 l/min
Bantu (2)	45	1.61 l/min	0.192 l/min

The following are the correlation coefficients:

Factors correlated	Caucasians	Bantu (1)	Bantu (2)
Log V. O_2/log weight	0.703	0.618	0.655
Log V. O_2/log height	0.277	0.506	0.595
Log V. O_2/log fat free mass	0.707	0.569	0.583
Log weight/log height	0.581	0.707	
Log weight/fat free mass	0.971	0.936	
Log height/fat free mass	0.605	0.726	

For the 80 Caucasian results a correlation coefficient greater than 0.220 is significant at the 5% level and for the 45 Bantu the critical value is 0.294. It is clear that *all* of the above correlations are significant at the 5% level.

These correlation coefficients are in line with those obtained by other researchers for various physical activities. These are given in Table 2.

It should be borne in mind, however, that the significant correlations between oxygen consumption and each of the three body size parameters independently may be due to the high correlations between the body size parameters themselves. The relative contributions of the three body size parameters can be assessed by calculating partial correlation coefficients in which the influence of weight on the correlations between the other factors is eliminated. The relevant partial correlation coefficients are as follows:

Factors correlated	Caucasians	Bantu (1)	Bantu (2)
Log V. O_2/log weight for constant height	0.693	0.427	0.413
Log V. O_2/log height for constant weight	—0.227	—0.124	—0.245
Log V. O_2/log fat free mass for constant weight	0.143	—0.034	—0.113

Table 2

Authors	Date	Work rate	V. O_2/ weight	V. O_2/ height	V. O_2/fat free mass	V. O_2 l/min
Running and walking						
SELZER [12]	1940	5.6 km/h 8.6% grade	0.77	0.36	—	1.96
MILLER and BLYTH [10]	1955	7.9 km/h 10% grade	0.75	0.32	0.67	—
BROCKETT et al. [5]	1956	5.6 km/h 0 grade	0.75	0.28	0.27 (% fat)	1.06
DURNIN [7]	1958	5.2 km/h	0.68	—	—	—
RASCH et al. [11]	1962	4.4 km/h 1 in 10 gradient	0.65	0.52	0.54	—
WYNDHAM et al. [21]	1964	4.8 km/h 0 grade	0.90	—	—	0.86
WYNDHAM et al. [17]	1966	4.0 km/h 0 grade	0.76	—	—	0.74
Stepping on and off a bench						
WYNDHAM et al. [27]	1966	30.5 cm × 12/min	0.95	—	—	0.93
Climbing stairs or a slope						
DURNIN [7]	1958	4.4 km/h 1 in 10 slope	0.78	—	—	—
WYNDHAM et al. [21]	1964	not given	0.99	—	—	1.74
Pedalling a bicycle or bicycle ergometer						
WYNDHAM et al. [17]	1966	173 kg/min	0.70	—	—	0.61
		346 kg/min	0.57	—	—	0.91
		693 kg/min	—0.30	—	—	1.52
		831 kg/min	—0.62	—	—	1.82
ADAMS [1]	1967	16 km/h	0.76	0.59	0.71	1.17 (approx.)

The critical values for a 5% level of significance are 0.225 and 0.306 for the Caucasians and Bantu groups respectively. From the partial correlation coefficients given above it is clear that the correlation between oxygen consumption and gross body weight with the effect of height eliminated, remains significant at the 5% level. The correlation between oxygen consumption and height becomes negative when the effect of weight is eliminated and, in the case of the Caucasian data, the correlation is significant at the 5% level. In the case of the Bantu data the correlation is significant only at the 10% level at the higher rate of work, but is not significant at the lower rate. The correlation between oxygen consumption and fat free mass is no longer significant when the effect of weight is eliminated. This means that any association between oxygen consumption and fat free mass is entirely due to the significant correlation between gross body weight and fat free mass.

The results of the partial correlations given above are in general agreement with those of other authors in the literature. The partial correlations between oxygen consumption and weight with height removed are 0.71, 0.74 and 0.86 in the results of MILLER and BLYTH [10], BROCKETT et al. [5] and WILLIAMS et al. respectively [17]. There are, however, differences in the literature on the partial correlation between oxygen consumption and height with the effect of weight eliminated. MILLER and BLYTH found that the correlation coefficient fell to —0.04, which is not significant, but BROCKETT et al.'s figure of —0.216 and WYNDHAM et al.'s figure of —0.68 are both significant at the 5% level. On balance therefore it appears that height has a small, negative effect on oxygen consumption from which one can conclude that in two men of equal weight, the taller man would have a lower oxygen consumption than the shorter man. This conclusion is at odds with that of SELZER who used a different statistical technique. He concluded that during submaximal exercise, the shorter, more lateral man would have a lower oxygen consumption. MILLER and BLYTH, and BROCKETT et al. both found that the partial correlations between oxygen consumption and fat free mass, with the effect of weight eliminated, fell to values which are not significant. The general conclusion from this analysis is that the difference between individuals in oxygen consumption at different rates of exercise is largely due to differences in their body weight, the heavier man having a higher oxygen consumption; that differences in height play a small, negative role; and that difference in the percentage body fat is not significant. It is further concluded that these conclusions apply to both Caucasians and Bantu subjects with the effect of height being less significant in the Bantu.

The next question to consider is what percentage of the variation between individuals in oxygen consumption can be accounted for by differences between them in body weight, in height and in fat free mass. It will be clear from the above analysis that while the percentage effect of body weight can be estimated by means of the coefficient of determination ($r^2 \cdot 100$), the percentage effects of the other parameters of body size cannot be estimated from the correlation coefficients because when the effect of body weight is eliminated by partial correlations, these values all become much reduced. The alternative is to calculate the total variance and the "irreducible minimum variance" in oxygen consumption and then to calculate the residual variances about the regressions between oxygen consumption and these three body size parameters. From these different variances it is then possible to estimate the percentage of the variation between individuals in oxygen consumption which is due to differences between the individuals in body weight, height and fat free mass.

The general regression equation used is:

$$y = A + Bx_1 + Cx_2 + Dx_3$$

where $y = \log$ V. O_2, $x_1 = \log$ weight in kg, $x_2 = \log$ height in cm, $x_3 =$ log fat free mass in kg.

The calculations for the 45 Bantu males at the two rates of oxygen consumption are given in Table 3.

Table 3

	Parameters				Residual variance	Accounted for
	A	B	C	D		
			Low work rate			
Total variance	—	—	—	—	0.00275	—
Regression on log weight	—1.246	0.764	—	—	0.00174	76%
Regression on log weight and log height	—1.946	0.649	0.407	—	0.00175	75%
Regression on log weight, log height and log fat free mass	—1.945	0.847	0.482	—0.250	0.00178	73%
Irreducible minimum variance	—	—	—	—	0.00142	—
			High work rate			
Total variance	—	—	—	—	0.00260	—
Regression on log weight	—1.190	0.788	—	—	0.00152	57%
Regression on log weight and log height	—2.557	0.563	0.795	—	0.00146	61%
Regression on log weight, log height and log fat free mass	—2.557	1.032	0.974	—0.591	0.00143	62%
Irreducible minimum variance	—	—	—	—	0.00072	—

From the results given in Table 3 it is clear that at the lower work rate about 75% of the differences between individual Bantu in oxygen consumption can be accounted for by differences between them in body weight. The addition of neither the height nor the fat free mass to the regression equations accounts for more of the variation between individuals in oxygen consumption. At the higher rate of work 57% of the variation between individuals in oxygen consumption can be accounted for by differences in body weight. In this instance adding height to the regression equation accounts for a further 4% of the variation in oxygen consumption, and adding fat free mass a further 1%. These three parameters account therefore for 62% of the variation between individual Bantu in oxygen consumption.

Table 4

	Parameters				Residual variance	Accounted for
	A	B	C	D		
Total variance	—	—	—	—	0.00338	—
Regression on log weight	—1.258	0.845	—	—	0.00173	69%
Regression on log weight and log height	—0.895	0.993	—0.846	—	0.00165	73%
Regression on log weight, log height and log fat free mass	—1.142	0.168	—0.992	0.870	0.00161	74%

The calculations for the 80 Caucasians at one rate of oxygen consumption (1.92 l/min) are given in Table 4. We do not have a figure for the irreducible minimum variance in oxygen consumption on the 80 Caucasians at 7.26 km/h (4.5 m.p.h.), but it is a reasonable assumption that it would be about 0.00100. On this basis the percentage of the variation in oxygen consumption between individuals due to differences in body weight, in height and in fat free mass could be calculated. 69% of the variation between individuals in oxygen consumption can be accounted for by differences in gross body weight. A further 4% can be accounted for by differences in height and another 1% by differences in fat free mass, making a total of 74% of the differences between individuals in oxygen consumption which can be accounted for by differences between individuals in these three parameters of body size.

The results of the above analyses indicate that in physical activities in which the rates of oxygen consumption are between 1.5 and 2.0 l/min, differences in gross body weight in both the fit, young Bantu and Caucasians account for about 70% of the differences between individuals in oxygen consumption. Differences in height account for about a further 4% of the difference in oxygen consumption. Differences in fat free mass make virtually no contribution to the differences between individuals in oxygen consumption. As these two groups of men were very different in their nutrition and habitual exercise, it will be clear that these factors do not make a large contribution to the differences between individuals in oxygen consumption.

Next it is important to determine whether there are differences between the Caucasian and Bantu in oxygen consumption when carrying out the same physical effort in order to establish whether there are differences between the two ethnic groups in this regard which are not attributable solely to differences between them in body size. The following are the means and standard deviations of oxygen consumptions of the two groups when running at 9.66 km/h (6 m.p.h.):

Ethnic group	Mean oxygen consumption	Standard deviation
Caucasians	2.80 l/min	0.312 l/min
Bantu	2.23 l/min	0.252 l/min

The mean weights of the two groups were 66.3 and 58.9 kg respectively, so that comparison of the mean oxygen consumptions is not strictly valid. According to TANNER [13] it is not valid to compare the mean oxygen consumptions of the two groups per kilogram of gross body weight unless the regression lines of oxygen consumption against body

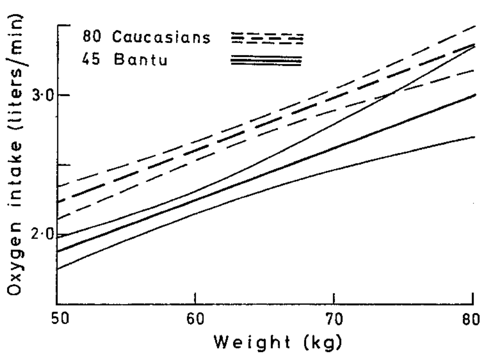

Fig. 1. Comparison of regression of VO_2/weight of Bantu and Caucasians running at 9.66 km/h (6 m.p.h.)

weight of the two groups pass through zero. The only acceptable method of comparing the oxygen consumptions of the two groups is to calculate regressions equations for oxygen consumptions on gross body weight for the two groups and to fit 90% confidence limits. Where adjacent confidence limits do not overlap, one can say that the regression lines, in that region, are significantly different at the 5% level. Regression lines and 90% limits are given in Fig. 1. From this figure it is clear that the oxygen consumptions of the Bantu are significantly lower than those of the Caucasians over the range of body weights in which the two samples overlap. The differences between the two regression lines are approximately 400 ml and this is too great to be accounted for by any difference between the two groups due to basal metabolisms of the Bantu being lower because they are smaller in size. These results on Bantu and Caucasians running at 9.66 km/h (6 m.p.h.) confirm those reported by WYNDHAM et al. [19], who showed that Bantu had lower rates of oxygen consumption than Caucasians in the task of stepping on and off a bench 30.5 cm (12 inches) in height at 6, 12 and 24 times per minute and also in pedalling a bicycle ergometer.

The reasons for the lower rates of oxygen consumption of Bantu are not at all clear. Two possible reasons for the differences between the two ethnic groups in oxygen consumptions suggest themselves. One is the shorter stature of the Bantu for a given weight and the other is some factor in the genetic constitution of the Bantu which makes him mechanically more efficient in physical tasks. Taking the question of stature first, the Bantu male is roughly of the same stature and gross body weight as the Caucasian female. Evidence has been brought forward that the Caucasian female has a lower rate of oxygen consumption than the male when walking, even when differences in weight are taken into account [4]. This finding has been confirmed in this Laboratory for untrained male and female Caucasians when stepping on and off a bench at a work rate of 216 kg m/min (1.560 ft. lb/min). The means and standard deviations of these two groups, together with those of a group of untrained Bantu, are as follows [22, 23]:

Group	N	Height (cm)	Weight (kg)	Skinfold (mm)	Oxygen intake
Caucasian male	30	175.9 ±7.71	70.04 ±7.016	8.04	1.03 ±0.125
Caucasian female	26	163.0 ±6.50	59.40 ±10.022	11.12	0.90 ±0.091
Bantu male	22	165.9 ±6.03	59.09 ±6.079	5.45	0.93 ±0.093

It is clear from the above that the oxygen consumptions of the Caucasian females and the Bantu males are not significantly different, but both are significantly lower (at the 5% level) than the oxygen consumption of the Caucasian males. The similarity of the Bantu male and the Caucasian female in height and weight suggests that the lower oxygen consumption of the Bantu males and Caucasian females are not of genetic origin, but are due to some, as yet unrecognised, factor associated with the smaller body sizes of these two groups, compared with the Caucasian males.

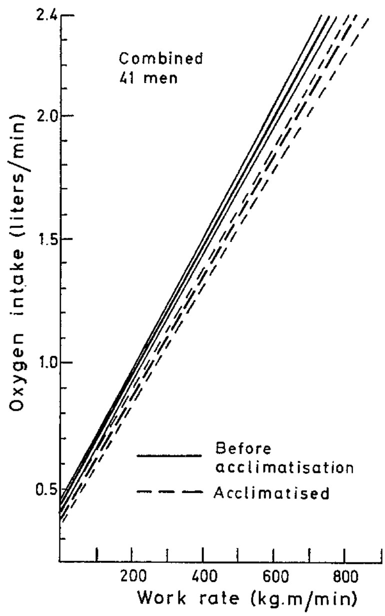

Fig. 2. Oxygen intake vs work rate (90% confidence limits)

One further point needs to be borne in mind in considering the oxygen consumptions of various forms of physical activity. It is the influence of physical training. In Fig. 2 are given regression lines of oxygen consumption on work rate for trained and untrained men stepping on and off a bench at four different rates of work. These are 108, 216, 332 and 431 kg m/min (780, 1,560, 2,400, and 3,120 ft. lb/min). The men were Bantu recruits who were tested on arrival at a gold mine and again after 2 weeks of intensive training during which they worked for the first few days for 4 h each day at 216 kg m/min (1,560 ft. lb/min — oxygen consumption of approximately 1.0 l/min) and in the last few days they worked for 4 h each day at 431 kg m/min (3,120 ft. lb/min — oxygen consumption of approximately 1.6 l/min). 90% confidence limits have been fitted to the regression lines; it is clear that the trained men have significantly lower rates of oxygen consumption (at the 5% level). Similar results were found in Caucasian males who underwent the same regime of training [22].

The general conclusion we reach in this section is that fit, young Bantu males have lower rates of oxygen consumption than fit, young Caucasian males in running, pedalling a bicycle ergometer and stepping on and off a bench at various rates, even when allowance is made for the differences in weight of the two groups by calculating equations for oxygen consumption on body weight. However, within each group the influence on oxygen consumption of gross body weight, height and fat free mass is similar; gross body weight accounting for about 70% of the differences between individuals in oxygen consumption, height accounting for a further 4% and fat free mass having no significant effect.

The Influence of Gross Body Weight, Height and Body Composition on Maximum Oxygen Intake

A series of studies was carried out to determine the influence on maximum oxygen intake of differences between individuals in gross body weight, in height and in fat free mass. The same two samples of 80 Caucasians and 45 Bantu subjects were used.

The maximum oxygen intakes of the 80 Caucasians were measured by the intermittent treadmill technique and for the 45 Bantu, by the step test procedure. The results of these two procedures have been shown by this Laboratory to be closely comparable [24]. The procedures used are described in detail in the paper referred to.

Correlation coefficients were calculated between the maximum oxygen intakes and gross body weight, height and fat free mass. The results are contained in Table 5. For the correlations of the 80 Caucasians, a value

Table 5

Factors correlated	Caucasians	Bantu
Log Max. V. O_2/log weight	0.777	0.383
Log Max. V. O_2/log height	0.340	0.193
Log Max. V. O_2/log fat free mass	0.745	0.296
Log weight/log height	0.581	0.707
Log weight/log fat free mass	0.971	0.936
Log height/log fat free mass	0.605	0.726

greater than 0.220 is significant at the 5% level and for the data on the 45 Bantu, a value of 0.294 is significant at that level. From Table 5 it is clear that *all* the correlations are significant at the 5% level, except that of maximum oxygen intake on height of the Bantu. However, as pointed out in the previous section, significant correlations between maximum oxygen intake and the three body size parameters, independently, may be due to the high correlations between the body size parameters themselves. This possibility can be assessed by calculating partial correlation coefficients in which the influence of weight is eliminated. These are as follows:

Factors correlated	Caucasians	Bantu
Log Max. V. O_2/log weight for constant height	0.756	0.355
Log Max. V. O_2/log height for constant weight	—0.218	—0.119
Log Max. V. O_2/log fat free mass for constant weight	—0.063	—0.192

The critical values of the correlation coefficients for a 5% significance level are 0.225 for the 80 Caucasians and 0.306 for the 45 Bantu. From the above analysis it is clear that weight is more highly correlated with maximum oxygen consumption in the Caucasians than in the Bantu and that the association between maximum oxygen consumption and height is largely due to the high correlation between weight and height. However, the correlation between maximum oxygen consumption and height is significant at the 10% level for the Caucasians, but is not significant for the Bantu. The correlation between maximum oxygen consumption and fat free mass falls away when weight is eliminated.

The literature on this subject is relatively scanty. ASTRAND in his classic monograph [2] gave very high correlation coefficients for the relationships between maximum oxygen intake and either gross body weight or total haemoglobin, being 0.98 for both. Subsequently, ASTRAND and his associates pressed for the use of total haemoglobin as the more important determinant of maximum oxygen intake. However, v. DOBBELN [14] showed that the correlation between maximum oxygen intake and total haemoglobin was spurious because total haemoglobin and gross body weight are highly correlated and when the effect of gross body weight on the correlation between maximum oxygen intake and total haemoglobin is eliminated by partial correlation, the correlation between maximum oxygen intake and total haemoglobin is no longer significant.

BUSKIRK and TAYLOR [6], WELCH et al. [16] and WYNDHAM et al. [26] published detailed analyses of the effect on maximum oxygen intake of differences between individuals in gross body weight, in height, and in fat free mass. In the case of BUSKIRK and TAYLOR, they examined also the effects of "active tissue", cell mass, blood volume and red cell volume in a sample of 54 fit, young men, of which they studied 41 in detail. The sample was specially selected to include 26 sedentary students, 9 football players, gymnasts and wrestlers and 5 cross-country runners. They were also selected "to obtain a wide range in body composition (up to 34% fat) and physical conditions (sedentary students to cross-country runners)." WELCH et al.'s sample of 28 subjects was not specially selected. There was not, however, any difference between the two Caucasian samples in respect to their physical characteristics and maximum oxygen intakes, Table 6. WYNDHAM et al.'s sample of 106 men were Bantu recruits from various parts of southern Africa, coming from as far apart as Angola, Barotseland and Mozambique. Their physical characteristics are also given in Table 6.

Table 6

Group	Age (years)	Height (cm)	Weight (kg)	Fat (%)	Maximum oxygen intake (l/min)
Caucasian	22.1	176.3	77.5	13.9	3.58
(BUSKIRK)	(2.6)	(6.1)	(15.6)	(8.6)	(0.50)
Caucasian	23.1	177.0	75.3	15.1	3.73
(WELCH)	(1.9)	(8.0)	(9.6)	(5.8)	(0.45)
Bantu	—	167.1	59.2	4.2	2.35
(WYNDHAM)	—	(6.1)	(6.6)	(1.1)	(0.44)

For comparison with the correlation coefficients given in Table 5, the correlation coefficients obtained by BUSKIRK and TAYLOR, WELCH et al. and WYNDHAM et al. are as follows:

Authors	Max. V. O_2/ weight	Max. V. O_2/fat free mass	Max. V. O_2/lean body mass
BUSKIRK and TAYLOR	0.63	0.85	0.91
WELCH et al.	0.54	0.64	0.65
WYNDHAM et al.	0.53	0.44	—

The correlation coefficients between maximum oxygen intake and both fat free mass and lean body mass in BUSKIRK and TAYLOR's study were significantly higher than the correlation with gross body weight. This led them to conclude that lean body mass or fat free mass is a more important determinant of maximum oxygen intake than gross body weight.

This conclusion has been widely quoted, but it is not supported by the findings of WELCH et al. and WYNDHAM et al., nor is it supported by the present findings that the influence of fat free mass becomes insignificant when the effect of gross body weight is eliminated by partial correlation. There are two possible reasons for the differences in results between BUSKIRK and TAYLOR and other workers. One is that BUSKIRK and TAYLOR's sample was carefully chosen to include both individuals with a high percentage of body fat and also very fit individuals such as cross-country runners. This selection would undoubtedly have the effect of increasing the correlations with fat free mass and lean body mass. Secondly, they base their conclusion upon the difference in correlation coefficients between maximum oxygen intakes and the individual components of body size. This is very questionable because, as we have shown in Table 5 and MILLER and BLYTH [10] have also done, there is a high correlation between gross body weight and these two components of body composition. It is probable that when the influence of gross body weight is eliminated from the correlations between maximum oxygen intake and both fat free mass and lean body mass in BUSKIRK and TAYLOR's results then the high correlations that they show with fat free mass and lean body mass might no longer be significant.

BUSKIRK and TAYLOR, and WELCH et al. found that when they grouped their subjects into three categories with respect to percentage body fat, i.e. 0 to 10%, 10 to 20% and above 20%, then the mean maximum oxygen intake per kilogram fat free mass was the same in the three groups. This indicates that the fat man minus his fat is comparable to the thin man with respect to maximum oxygen intake. Paradoxically, however, BUSKIRK and TAYLOR found that the differences in maximum oxygen intake between well-trained runners and sedentary students are larger when the values are expressed per kilogram of body weight than when they are expressed per kilogram of fat free mass. BUSKIRK and TAYLOR are also at pains to point out the fact that the regression lines for maximum oxygen intake on gross body weight do not go through zero; the comparison should therefore be made only in terms of the regression equation of maximum oxygen intake on gross body weight. It is strange that in spite of stressing this point BUSKIRK and TAYLOR do not use this statistical procedure when they compare the athletic and sedentary men, but they make their comparisons in terms of maximum oxygen intake per kilogram of either gross body weight or fat free mass.

The mean maximum oxygen intakes of the 80 Caucasians and the 45 Bantu males are as follows:

Group	Height (cm)	Weight (kg)	Skinfolds (mm)	Max. V. O_2/ (l/min)	Max. V. O_2/kg (m/min/kg)
Caucasians	174.4	66.3	8.1	3.15	47.2
	(5.82)	(7.32)	(2.93)	(0.401)	(6.02)
Bantu	166.4	58.9	5.3	2.12	36.2
	(6.49)	(5.86)	(0.74)	(0.309)	(5.32)

Regression equations have been fitted to maximum oxygen intakes for the two groups and 90% confidence limits have been calculated (Fig. 3). From this it is clear that the maximum oxygen intakes of the Caucasians are significantly higher than those of the Bantu over almost the entire weight ranges of the two samples. The Bantu, however, were recruited from all over southern Africa and as we pointed out, they differ in nutrition, in the endemic diseases to which they are exposed and in the habitual activities upon which they engage in the homelands. These are all factors which are considered to influence the maximum oxygen intake.

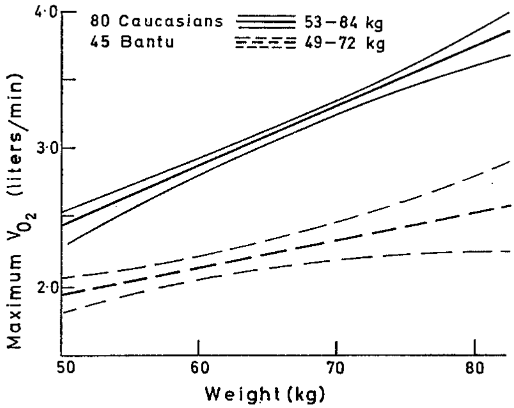

Fig. 3. Regression of maximum VO_2/body weight of Bantu and Caucasians

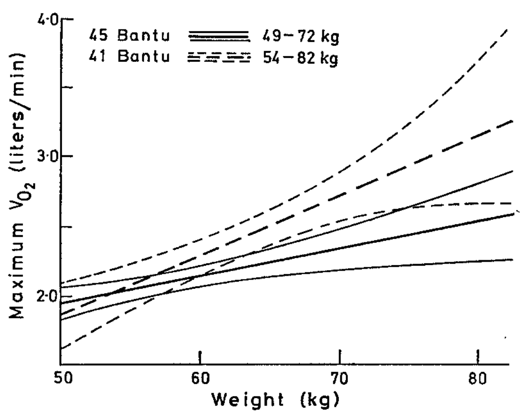

Fig. 4. Regression of maximum VO_2/body weight of two samples of Bantu recruits

We therefore took another group of 41 Bantu recruits and measured their maximum oxygen intakes on recruitment to the mine and again after 2 weeks of intensive physical training which would make them comparable to the 80 Caucasian army recruits. The maximum oxygen intake of the 41 Bantu on recruitment was 2.39 ± 0.558 l/min or 38.75 ± 7.73 ml/min/kg, which is not significantly different from that of the 45 recruits, as shown by regression lines in Fig. 4.

As a result of the intensive training and an excellent diet the mean maximum oxygen intake increased to 2.82 ± 0.705 l/min or 45.1 ± 8.09 ml/min/kg. This is a significant increase in maximum oxygen intake. The regression lines for the 41 Bantu males before and after the period of

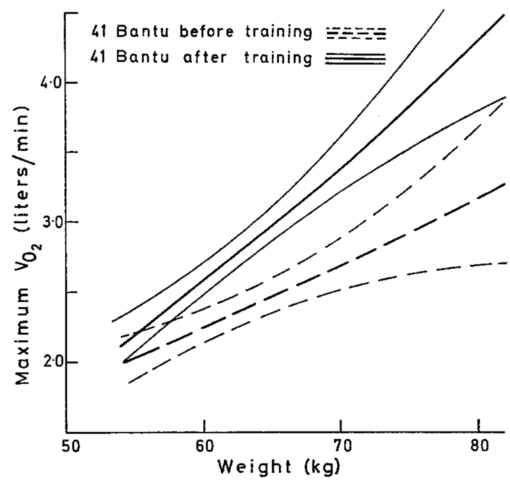

Fig. 5. Regression of maximum VO_2/body weight of 41 Bantu before and after training

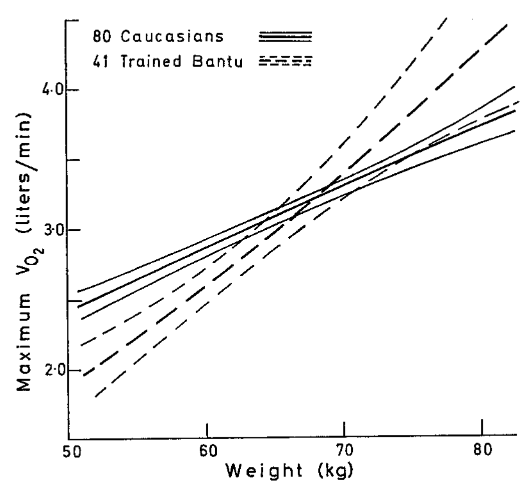

Fig. 6. Regression of maximum VO_2/body weight of Caucasians and trained Bantu

intensive training are given in Fig. 5, which indicates clearly that the maximum oxygen intakes of the men had increased significantly at the 5% level. The maximum oxygen intakes per kilogram of body weight of the Caucasians and Bantu of 47.2 and 45.1 ml/min/kg are not significantly different. However, as we have pointed out repeatedly in this review, comparison of samples of men of different weight in these terms is not valid and the regression lines and 90% limits for the 80 Caucasians and 41 Bantu of maximum oxygen intake on gross body weight are given in Fig. 6. From this it is clear that in men above 60 kg in weight there is no significant difference between Caucasian and Bantu males, but in men below 60 kg the maximum oxygen intakes of the Bantu are significantly lower. The reason for this result is not immediately obvious. However, one possibility is that most of the Bantu gain in weight in the first few weeks [15] and it might be that the men who do not gain in weight are those who weight less than 60 kg. These men might be suffering from a disease, such as chronic malaria or bilharzia, which is endemic in the areas from which they are recruited and which had not been detected in the initial medical examination that all the recruits are subjected to.

The next point examined was the percentage of variation between individuals in maximum oxygen intake which could be accounted for by differences between them in gross body weight, in height and in fat free mass. The samples of Caucasians and Bantu were dealt with separately in this analysis. The statistical procedure was exactly the same as that used in the last section, i.e. multiple regression equations were calculated and from the total variances in maximum oxygen intake, the irreducible minimum variance and the residual variances about the regression lines, estimates could be made of the percentages of the variation between individuals in maximum oxygen intake that could be accounted for by these three body size parameters.

The calculations on the 45 Bantu recruits are given in Table 7 and for the 80 Caucasians in Table 8.

From Tables 7 and 8 it is clear that in the fit, young Caucasian male differences between individuals in gross body weight accounts for 70% of the variation between individuals in maximum oxygen intake; weight and height, and weight, height and fat free mass, a further 1%. In the Bantu the situation is quite different. Only 18% of the variation between individuals in maximum oxygen intake can be accounted for by differences between them in gross body weight and height, and fat free mass does not increase the percentage of the difference in maximum oxygen intake that can be accounted for.

WELCH et al. made estimates of the percentage of the variation in maximum oxygen intake that could be accounted for by certain components of body size, using the coefficient of determination, ($r^2 \cdot 100$). They estimated from their figures that 35% of the variation in maximum oxygen intake could be accounted for by differences in gross body weight and 41% by differences in fat free mass. They calculated from BUSKIRK

Table 7

	Parameters A	B	C	D	Residual variance	Accounted for
Total variance	—	—	—	—	0.00373	—
Regression on log weight	—0.650	0.553		—	0.00326	18%
Regression on log weight and log height	0.342	0.716	—0.577	—	0.00328	17%
Regression on log weight, log height and log fat free mass	0.343	1.323	—0.346	—0.765	0.00326	18%
Irreducible minimum variance	—	—	—	—	0.00110	—

Table 8

	Parameters A	B	C	D	Residual variance	Accounted for
Total variance	—	—	—	—	0.00319	—
Regression on log weight	—1.156	0.908	—	—	0.00127	70%
Regression on log weight and log height	—0.861	1.029	—0.681	—	0.00122	71%
Regression on log weight, log height and log fat free mass	—0.748	1.405	—0.610	—0.397	0.00122	71%
Irreducible minimum variance	—	—	—	—	0.00046	—

and TAYLOR's correlation coefficients that 40% of the variation could be accounted for by differences between individuals in gross body weight; that 72% would be accounted for by differences in fat free mass; and 83% by differences in lean body mass. However, it is not a valid procedure to calculate the coefficient of determination on correlation coefficients which might be highly correlated. Therefore only the percentages they calculated for gross body weight have any meaning. WELCH et al.'s figure of 35% and BUSKIRK and TAYLOR's of 40% for the percentage of difference in maximum oxygen intake that can be accounted for by differences between individuals in gross body weight is considerably less than the figure of 70% of the 80 Caucasians. The higher figure of the 80 Caucasians might be due to the fact that they had all been undergoing a period of intensive physical training and also that their mean percentage of fat and standard deviation was very much less than in the other two Caucasian groups, studied in the U.S.A. [6, 16].

The very low percentage of the variation in maximum oxygen intake that can be accounted for in the Bantu by differences in gross body weight is in line with the findings in this regard from this Laboratory on a sample of 106 Bantu recruits [26]. In that paper the multiple regression equation technique was also used and showed that 27% of the variation could be accounted for by differences in gross body weight and a further 3% by differences in height and that the introduction of fat free mass into the regression equation did not increase this percentage. It was proposed in that paper that the low percentage of the variation between Bantu in maximum oxygen intake that can be accounted for by differences in gross body weight is probably due to the great differences between the men in their states of nutrition, in the endemic diseases from which they may be suffering and in the habitual activities upon which they engage in their homelands. The present results validate those in the paper referred to. That it is probably differences in nutrition and habitual activities, rather than chronic disease, that accounts for this low percentage is suggested in the findings on the sample of 41 Bantu recruits referred to earlier in this section. These men were subjected to a period of 2 weeks of intensive training and the correlation coefficient between log maximum oxygen intake and log weight increased from 0.40 to 0.72 over that period and the men gained significantly in weight in this period. Using the coefficient of determination, it can be estimated that the percentage of the differences in maximum oxygen intake that can be accounted for by differences in weight, increase from approximately 16 to 50%.

These findings are also similar to those reported in 1962 from this Laboratory [18] on a small sample of men who were studied repeatedly over the first 4 months of their period of service in the mines. In that case the correlation coefficients (corrected for contingency) between maximum oxygen intake and gross body weight increased from 0.59 on recruitment to 0.76 after 1 month of service. These findings appear to indicate that differences between individual Bantu in their states of nutrition and physical fitness, due to differences in habitual activities in their homelands, probably account for the low correlation between maximum oxygen intake and gross body weight. As a result of the excellent diet provided by the mine and either an intensive period of training or a month of regular work at a moderate rate in the mine, this correlation increases to a figure which is similar to that found in untrained Caucasians (WELCH et al., and BUSKIRK and TAYLOR's values) but are lower than that of highly trained Caucasians. This suggests, further, that it probably takes more than a fortnight of intensive training and good diet to get these

Bantu into the same homogeneous state that is demonstrated by the fit, young Caucasians.

Certain general conclusions can be drawn about the influence on the maximum oxygen intake of Bantu and Caucasians of gross body weight, height and fat free mass. They are:

1. That mean maximum oxygen intake of the Bantu on recruitment is 2.12 l/min or 36.1 ml/min/kg and this is significantly less than that of the Caucasian value of 3.15 l/min or 47.2 ml/min/kg. However, after a week's intensive training the mean figure for the Bantu is 2.82 l/min, or 45.1 ml/min/kg, which is not significantly different from the mean of the Caucasians. Comparison in this way is not valid. The regression line of maximum oxygen intake on gross body weight of the new Bantu recruit is significantly lower than that of the Caucasian; after one week's intensive training the regression line lies significantly above that of the new recruits and is then not significantly different from that of the Caucasian in the weight range above 60 kg, but below 60 kg the Bantu regression line is significantly lower than the Caucasian's.

2. That the differences between individuals in both groups in maximum oxygen intake is largely attributable to differences between them in gross weight. Differences between individuals in height and in fat free mass contribute little to the differences between them in maximum oxygen intake.

3. That there are marked differences between the Bantu and Caucasians in the percentage of the differences between individuals in maximum oxygen intake that can be accounted for by differences in gross body weight. This figure is 70% for the Caucasians and approximately 20% for the Bantu on arrival from their homelands in various parts of southern Africa. However, after a week's intensive physical training the percentage for the Bantu rises to 50%.

The Influence of Gross Body Weight on Maximum Oxygen Intake and Oxygen Consumption during Exercise of the Same Samples of Bantu and Caucasians

In the earlier sections of this paper it was shown that the differences between individuals in gross body weight determine to an important extent the differences between them both in maximum oxygen intake and in oxygen consumption during physical effort. The correlations are significant and positive; therefore one can state in broad general terms that heavy men have higher maximum oxygen intakes and oxygen consumptions than lighter men. However, what has not been considered up to this point is whether the increase in maximum oxygen intake with rise in body weight is greater or less than the increase in oxygen consumption. If the increase in maximum oxygen intake is greater than the increase in oxygen consumption then heavy men would use a smaller proportion of their maximum oxygen intakes than lighter men do and be under less physiological strain. Conversely, if the increase in maximum oxygen intake with rise in weight is less than the increase in oxygen consumption then the heavy men would use a greater proportion of their maximum oxygen intakes and be under greater physiological strain. These relationships may also be different in the two ethnic groups studied.

These equations can be answered by drawing on the same graph the regression lines for maximum oxygen intake on body weight and oxygen consumption on body weight. These regression lines are shown for the Bantu in Fig. 7. The physical activity was stepping on and off a bench, 30.5 cm in height, at a rate of 24 steps per minute, which gives a mean oxygen consumption of 1.63 l/min. The regression lines for the Caucasians are given in Fig. 8. The physical activity of the Caucasians was walking at 7.26 km/h on the flat which gives a mean oxygen consumption of 1.92 l/min. In the two physical activities the regression lines for oxygen consumption on body weight have a similar slope. It is clear from Fig. 7 and 8 that the slope of the regression lines for maximum oxygen intake on body weight are steeper than those for oxygen consumption on body weight in both the Bantu and Caucasians. From this result it can be concluded that in both ethnic groups the heavy men use a smaller proportion of their maximum oxygen intakes than the lighter men. This point is supported further by considering the regression lines for oxygen consumption on body weight for the men running at 9.66 km/h, also drawn in Fig. 7 and 8. From Fig. 7 it is clear that the light Bantu running at 9.66 km/h, have oxygen consumptions that are very close to their maximum oxygen intakes, but the heavy men have a considerable reserve in oxygen consumption at this rate of running. The situation is similar with the regression lines for the Caucasians (Fig. 8), but the differences between light and heavy men in this regard are not so great as in the Bantu.

The only other comparison in the physiological literature between the regression lines for maximum oxygen intake on gross body weight which we are aware of is that published by WYNDHAM et al. from this Laboratory in 1963 [19]. They compared the regression line for 50% of the maximum oxygen intake (representing the maximum rate of oxygen consumption which the men could employ for endurance efforts) with those for oxygen consumption on body weight when the same men stepped on and off a bench 30.5 cm in height, at 6, 12 and 24 steps per minute. They showed that in the sample of 338 newly recruited Bantu labourers, the regression line for oxygen consumption on body weight for stepping on and off the 30.5 cm high bench at 24 steps per minute lay just above the regression line for 50% of maximum oxygen intake on body weight, i.e. it is similar in slope. The regression lines for oxygen consumption on body weight for the two lower rates of stepping lay well below the regression for maximum oxygen intake on body weight and were lower in slope. The difference between those and the present results lies probably in the fact

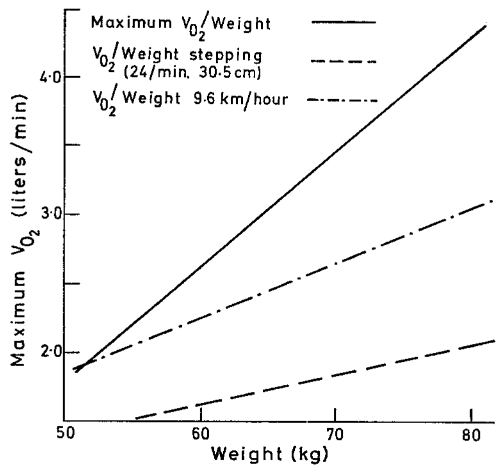

Fig. 7. Comparison of regressions of maximum VO_2/weight and VO_2/weight of Bantu males stepping and running at 9.66 km/h (6 m.p.h.)

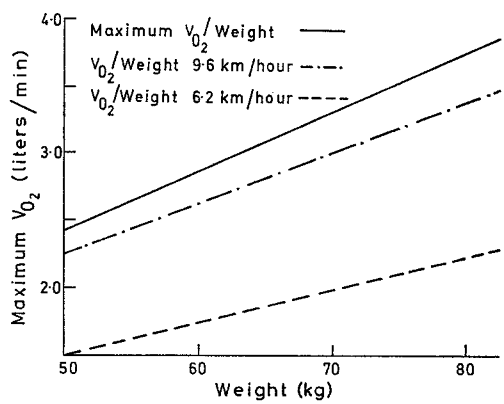

Fig. 8. Comparison of regressions of maximum VO_2/weight and VO_2/weight for 7.26 and 9.66 km/h (4.5 and 6 m.p.h.) of Caucasians

that the present regression line for maximum oxygen intake on body weight is based upon the results from 41 intensively trained men.

Williams et al. in 1966 [17] in a further paper on this subject from this Laboratory demonstrated that for the three tasks, pedalling a bicycle ergometer, shovelling sand an pushing a mine car, the increases in maximum oxygen intake with rise in body weight were greater than the increases in oxygen consumption and that the heart rates of the heavy men were lower than those of the light men, indicating that the heavy men were under less physiological strain.

The general conclusion in this section is that the increase in maximum oxygen intake with increase in body weight is in general greater than the increase in oxygen consumption in tasks such as walking, running, stepping on and off a bench at various rates, pedalling a bicycle ergometer, shovelling sand and pushing a mine car. The heavy man is therefore under less physiological strain than the light man at the same rate of work.

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