THE CAPACITY FOR MAXIMUM PHYSICAL EFFORT OF CAUCASIAN AND BANTU ATHLETES OF INTERNATIONAL CLASS

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Astrand in Sweden,[1,2] Hollman in Germany[3] and the Human Sciences Laboratory in South Africa[4-7] have made striking advances in the last decade in the understanding of the physiology of exercise. Physiologists can accurately measure the maximum rate at which a man can expend energy under conditions where the energy is derived predominantly from aerobic metabolism. This measurement is termed the 'maximum aerobic capacity' by Astrand or the 'maximum oxygen intake' in our laboratory, and is expressed in litres/min. of oxygen consumption. We also know that the maximum rate of oxygen consumption is limited by the ability of the respiratory system to transfer atmospheric oxygen to the pulmonary capillary blood and by the capacity of the heart, as a pump, to deliver this blood to the exercising muscles through the circulatory system. Certain factors which limit the rate of diffusion of oxygen from capillary blood to exercising muscle cells, such as the extent of the capillarization of the muscle, the rate of blood flow, etc., are also of importance.

Maximum oxygen intake is assessed by measuring the oxygen consumption of the testee while he pedals a bicycle ergometer or runs on a treadmill in a succession of increasing rates of work. When he reaches the point at which a further increase in rate of work causes no further increase in the rate of oxygen consumption the individual has reached 'maximum oxygen intake'. The maximum rate of oxygen consumption sets the limit to the maximum rate at which the individual can carry out 'endurance' exercise, such as middle-distance running, or cycling, or rowing. The individual can exercise at higher rates of work than that which produces his maximum rate of 'aerobic' metabolism, but the additional work is done on 'anaerobic' metabolism and is associated with a rapid increase in lactic and pyruvic acid concentrations in the blood. When this occurs the individual can only continue to exercise for a limited period before becoming exhausted. Sprinting is an

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example of a form of exercise which is carried out, essentially, on 'anaerobic' metabolism.

It is also possible to assess the capacity of an individual for anaerobic metabolism. This is done by measuring the concentrations of lactic and pyruvic acid during maximal work, and calculating the 'excess lactate' from these concentrations by Huckabee's method,[8] and by measuring the oxygen debt incurred.

Although the maximum capacity for aerobic work limits the maximum rate at which any individual can carry out endurance exercise it is, theoretically, possible that in two men of equal maximum oxygen intake, one might be mechanically more efficient than the other and require less oxygen for the same rate of work. The second man would reach his maximum oxygen intake at a higher rate of work than the first and, in consequence, run faster at his maximum oxygen intake. Astrand has shown that there are no significant differences in running between athletes and non-athletes in mechanical efficiency.[1] There might, however, be significant differences in this regard in other forms of sport—e.g. cycling and rowing, where the acquisition of skill requires long and arduous training—and also differences between Caucasian and Bantu, but this has not been studied fully.

In this paper we report the results of a study of the maximum oxygen intakes of a number of South African international and national athletes of both Caucasian and Bantu origin. These results can be compared with those reported overseas on international class athletes so that conclusions can be drawn on the question of whether the Republic's top athletes have sufficient 'horse-power' to compete with the world's best. Comparison can also be made with the results of similar studies of young, fit males of both Caucasian and Bantu origin.

Although the sample sizes of the two groups of athletes are rather small these results are reported because this is the first scientific study in the Republic of the capacity for endurance effort of male athletes and of fit, young men, and also the first in which Caucasian and Bantu athletes have been compared in this regard.

All of these studies were made in Johannesburg at an altitude of nearly 6,000 ft. The effect of altitude on the pulmonary ventilation during exercise will be demonstrated. Studies have also been made on the mechanical efficiencies of Caucasians and Bantu while climbing at various rates and the results will be reported.

SUBJECTS AND METHOD

The subjects arrived at the working place about 2 - 3 hours after a light breakfast. Heights and weights were recorded and each subject was allowed to rest for about 30 minutes while the aims and objectives of the study were outlined to him. Each subject was allowed to walk on the treadmill for a short period as a warm-up, and to accustom himself to the equipment in use.

An Edward's rubber face mask was fitted to each subject about 5 - 10 minutes before the first experimental work rate. This was connected to a modified low resistance Max Planck breathing valve on each side. Each breathing valve was connected to a corrugated rubber tube 1 inch in diameter, which carried the expired air to a standard rubber-lined canvas Douglas' bag. The Edward's face mask was carefully secured with tapes to prevent leakage of expired air.

In each case work started at an easy and obviously submaximal work rate. Subsequent work rates were chosen so that the graph of oxygen intake plotted against work rate clearly demonstrated that the subject had carried out work to the point at which no further increase in oxygen intake was possible. Each subject was permitted to choose his own rest interval between work rates, but no more than 7 work rates were completed each day. Most work rates were carried out at least twice.

Submaximal work was carried out for 6 - 10 minutes as a rule, gas being collected during the final 2 minutes of exercise. Once the subject's pulse rate exceeded 160 beats/minute, immediately after exercise, work was limited to 3 minutes only. Gas was then collected during the final minute of exercise. Gas samples were collected and analysed by a standard method of the Human Sciences Laboratory.

Pulse rates were recorded by palpating the left subclavian artery during the 15-second period immediately after exercise. We have demonstrated to our satisfaction that, in comparable groups of men, there is no significant difference between pulse rates recorded in this way and by electrocardiograph during exercise.

Studies of fit, young men. The methods used to determine the maximum oxygen intakes, the mechanical efficiencies and the pulmonary ventilations of 35 Caucasians and 88 Bantu are given in another paper from the Laboratory.[7]

RESULTS

Maximum Oxygen Intakes

International athletes of Caucasian and Bantu origin. Caucasian athletes were significantly taller than the Bantu, with mean heights of 177·9 cm. and 167·7 cm. respectively (Table I). The Caucasians were also significantly heavier with a mean weight of 67·5 kg. compared to the 58·4 kg. of the Bantu (Table I).

TABLE I. CAUCASIAN AND BANTU ATHLETES COMPARED WITH FIT YOUNG MEN

	Age years	Height cm.	Weight kg.
Caucasian athletes			
1. Richard C.	18	172·1	68·2
2. John V.	20	176·5	72·3
3. Wilhelm O.	28	179·0	62·3
4. Perry L.	24	184·1	67·3
Mean	23	177·9	67·5
Bantu athletes			
5. Daniel M.	33	—	50·5
6. John Q.	24	167·5	58·9
7. Benoni M.	23	177·7	69·6
8. Bennet M.	29	166·8	55·0
9. Humphrey K.	26	163·2	61·4
10. Thomas K.	23	163·2	55·2
Mean	25	167·7	58·4
Fit, young men			
Caucasian (N = 35)	19	175·9	71·8
Bantu (N = 88)	Young adults (No registration of births)	165·9	59·1

The mean maximum oxygen intake of the Caucasians was 4·13 l./min. and this is significantly greater than the mean of the Bantu athletes, 3·69 l./min. However, when these figures are expressed per kg. of body weight—the correct basis for comparing samples of different weight—the mean maximum oxygen intakes of Caucasians and Bantu athletes are similar, being 61·1 and 63·2 ml./kg./min. respectively.

The mean ventilations (BTPS) and heart rates of the 2 groups at the maximal levels of exercise are not significantly different.

Comparison of international athletes with fit, young men. The mean height of the fit, young Caucasians was 175·9 cm. and of the Bantu 165·9 cm., and the mean weights of the 2

TABLE II. BANTU AND CAUCASIAN ATHLETES COMPARED

Subjects	Max. HR (beats/min.)	Pulmonary ventilation l./min.	Pulmonary ventilation BTPS	Max. oxygen l./min.	Max. oxygen ml./kg./min.	Performance
1. Richard C.	192	—	140·8	4·07	59·6	Fastest 500 yard swim at 6,000 ft. altitude.
2. John V.	192	—	163·2	4·31	59·6	½ mile—1 min. 53 sec.
3. Wilhelm O.	168	—	143·3	3·97	63·7	1 mile—4 min. 8 sec. 2 miles—8 min. 53 sec. 3 miles—13 min. 38 sec.
4. Perry L.	190	—	152·3	4·16	61·9	1 mile—4 min. 11 sec. 3 miles—14 min. 28 sec.
Mean	186		149·9	4·13	61·2	
5. Daniel M.	190	—	141·6	3·40	67·3	3 miles—14 min. 11 sec. 6 miles—29 min. 23 sec.
6. John Q.	192	—	151·4	3·84	65·2	½ mile—1 min. 52 sec. 1 mile—4 min. 12 sec.
7. Benoni M.	192	—	160·5	3·90	60·4	½ mile—1 min. 48·7 sec.
8. Bennet M.	204	—	142·6	3·37	61·3	2 miles—9 min. 14·8 sec. 3 miles—14 min. 14·7 sec.
9. Humphrey K.	204	—	163·8	3·46	56·4	½ mile—1 min. 48·7 sec.
10. Thomas K.	204	—	135·9	3·80	68·7	2 miles—9 min. 20 sec. 3 miles—14 min. 19·8 sec.
Mean	198		149·5	3·69	63·2	

groups were 71·8 kg. and 59·1 kg. respectively. The athletes of both groups were slightly taller and lighter than the young, fit non-athletic men.

The mean maximum oxygen intakes of the fit, young Caucasians was 3·47 l./min., which is significantly higher than the mean of fit, young Bantu, 2·85 l./min. When body weights are taken into account these figures are 48·3 ml./kg./min. and 47·7 ml./kg./min. respectively for Caucasians and Bantu, which is not significantly different.

The maximum oxygen intakes of the athletes are about 25 - 30% higher than those of the young, fit men.

Mechanical Efficiencies

Data are not available on these 2 groups of men for running, but oxygen consumptions have been measured on 35 Caucasians and 88 Bantu while they were stepping on and off a stool, 1 ft. in height, at 4 different rates, giving a range in oxygen consumption from about 0·6 - 1·7 l./min. Separate regression lines have been fitted to the plots of oxygen consumption against work rate for each of the 2 groups and these are given in Fig. 1, together with 83% confidence limits.

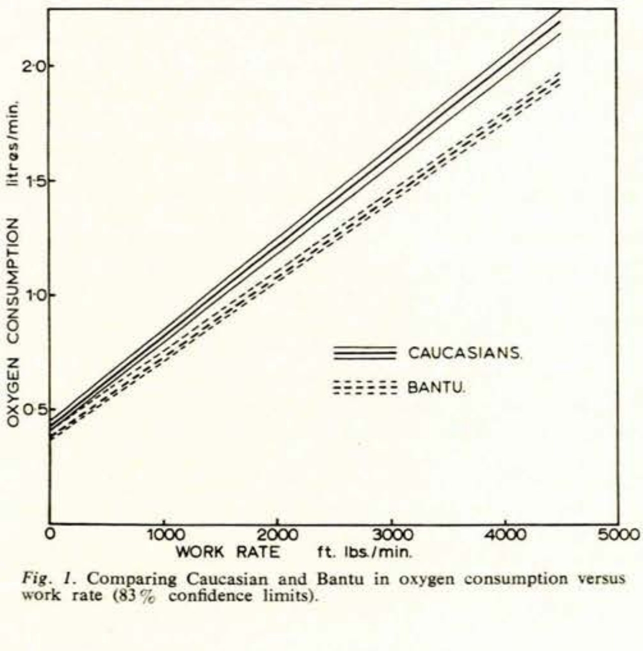

Fig. 1. Comparing Caucasian and Bantu in oxygen consumption versus work rate (83% confidence limits).

From these limits it can be said that where the adjacent limits do not overlap, the 2 regression lines are significantly different at the 95% level of confidence. Judged on this basis the oxygen consumptions of the Caucasians are significantly higher than those of the Bantu. This means that in terms of 'gross mechanical efficiency' the Bantu are mechanically more efficient than the Caucasians at this task.

Pulmonary Ventilation

The pulmonary ventilations in l./min. (BTPS) of the same 35 Caucasians and 88 Bantu who carried out the step test at 4 rates, were plotted against oxygen consumptions. Separate regression lines were fitted to the data for the Caucasians and the Bantu and these lines are given in Fig. 2. The 83% confidence limits are relatively wide, compared with those fitted to the regression lines of oxygen consumption against work rate, and overlap throughout, so that it can be concluded that the pulmonary ventilations of Caucasians and Bantu during physical effort at an altitude of 6,000 ft. are not significantly

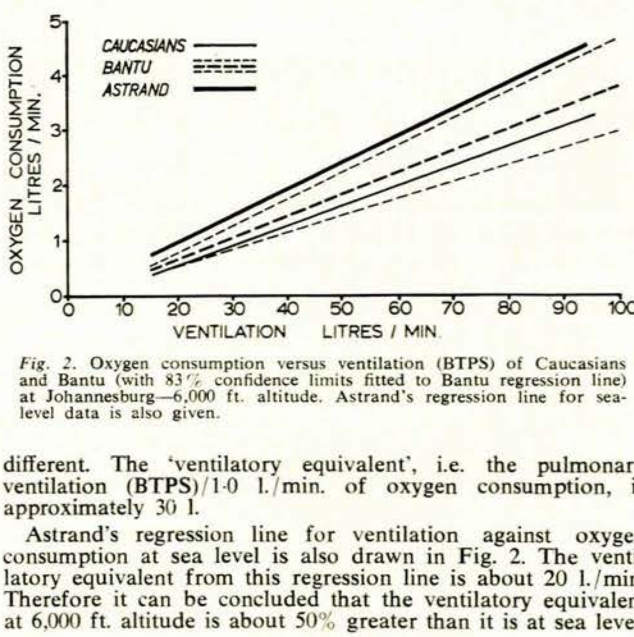

Fig. 2. Oxygen consumption versus ventilation (BTPS) of Caucasians and Bantu (with 83% confidence limits fitted to Bantu regression line) at Johannesburg—6,000 ft. altitude. Astrand's regression line for sea-level data is also given.

different. The 'ventilatory equivalent', i.e. the pulmonary ventilation (BTPS)/1·0 l./min. of oxygen consumption, is approximately 30 l.

Astrand's regression line for ventilation against oxygen consumption at sea level is also drawn in Fig. 2. The ventilatory equivalent from this regression line is about 20 l./min. Therefore it can be concluded that the ventilatory equivalent at 6,000 ft. altitude is about 50% greater than it is at sea level.

DISCUSSION

Maximum Oxygen Intakes

Comparison of the maximum oxygen intakes, expressed as ml./kg., of the Caucasian and Bantu international and national class 'middle-distance' athletes shows no significant difference between the two groups. The values, 61·1 and 63·2 ml./kg. respectively for the Caucasian and Bantu athletes compare unfavourably, at first sight, with the mean of 72·8 ml./kg. given by Astrand for 5 international class athletes, including Landy who was one of the first 4-minute milers. The relevant details of Astrand's study on the 5 athletes are given in Table III for comparison with our results.

TABLE III. MEASUREMENTS OF FIVE INTERNATIONAL CLASS ATHLETES

Subjects	Ht. cm.	Wt. kg.	Max. HR beat/min.	Pulm. V l./min.	Max. oxygen l./min.	Max. oxygen ml./kg./min.	Best time for 1,500 metres
Eriksson	181	77·5	184	131	5·29	68·1	3 min. 44·3 sec.
Landy	179	66	194	133	5·04	76·6	3 min. 41·8 sec.
Bergkvist	177	65	191	119	4·81	74·0	3 min. 46·6 sec.
Karlsson	172	62	200	119	4·53	73·0	3 min. 44·2 sec.
Ericsson	177	60	200	96	4·37	72·4	3 min. 45·2 sec.

It must be remembered that Astrand's study was made at sea level and ours at an altitude of 6,000 feet. In Fig. 2 it was shown that ventilation is markedly increased during physical effort at an altitude of 6,000 ft. For example, from Fig. 2, it can be estimated that a man with a maximum respiratory ventilation of 100 l./min. will have a maximum oxygen intake of about 4·0 l./min. at sea level, whereas at 6,000 feet altitude his maximum oxygen intake for the same respiratory ventilation will be about 3·0 l./min. Astrand[9] and others consider that the maximum oxygen intake is reduced by about 10 - 15% at 6,000 feet altitude. This gives a mean figure for the Caucasian and Bantu athletes of approximately 70 ml./kg./min., which is closely comparable to the mean of Astrand's 5 international class athletes.

We may therefore conclude that a fair number of Caucasian and Bantu athletes in the Republic are physiologically equal to the world's best athletes.

The maximum oxygen intakes of the young, fit men of Caucasian and Bantu origin are very similar when expressed as ml./kg./min. Their values, 48·3 and 47·7 ml./kg./min. respectively, are lower than that given by Astrand for fit, young Swedes which is 58·6 ml./kg./min.[1] However, when account is taken of the effect of altitude the Caucasian and Bantu figures would be approximately 55 ml./kg./min., which is similar to that of Astrand's Swedes. The maximum oxygen intakes of the young, fit men in both the Republic and in Sweden are about 25 - 30% less than those of international class athletes in these 2 countries.

The maximum oxygen intakes, corrected for altitude, of the fit, young men in the Republic of both Caucasian and Bantu origin are significantly higher than the 69 US Army recruits of Taylor *et al.*[10] and the 8 White share-croppers in the Southern states of the USA of Robinson *et al.*,[11] where the figures are 48·3 and 49·6 ml./kg./min. respectively.

Mechanical Efficiencies

Astrand[1] showed that there are no significant differences between athletes and fit, young men in the rates of oxygen consumption when running on a treadmill at the same submaximal speed. In Fig. 1 there are clear and significant differences in gross mechanical efficiency between Caucasians and Bantu on the task of stepping on and off a stool at various rates of oxygen consumption. This means that for a given rate of oxygen consumption the Bantu can exercise at a higher work rate. Translated into athletics, the Bantu would be able to run a little faster for the same rate of oxygen consumption. We do not know whether in fact the Bantu has a greater mechanical efficiency in running, but this question clearly needs to be investigated.

Pulmonary Ventilation at Altitude

The manner in which the increased pulmonary ventilation during exercise at high altitude affects the maximum oxygen intake of the individual has been discussed. This is, of course, the explanation of the fact that middle-distance running times are worse in Johannesburg and Pretoria than they are at sea level and also of the fact that athletes complain of respiratory distress in these 2 inland centres when they try to reproduce their usual sea level times. To take an example, if an athlete requires 4·0 l./min. of oxygen consumption to run a mile at the coast in, say, 4 minutes, he would have a pulmonary ventilation of about 100 l./min. If he tries to run his race at the same rate in Johannesburg, requiring therefore 4·0 l./min. oxygen consumption, then he has to increase his pulmonary ventilation to at least 130 l./min. The extra ventilatory volume per minute might occasion acute pulmonary distress and force the man to reduce his speed. It might be argued that since the air is less dense at an altitude of 6,000 feet, the man could therefore increase his pulmonary ventilation without experiencing distress. Careful studies of pulmonary ventilation and maximum oxygen intakes at sea level and at altitudes such as those of Johannesburg, Denver City, Mexico City, etc., on the same athletes have not, as far as we are aware, been carried out. Pugh *et al.*[12] studied these 2 parameters of maximal exercise at relatively high altitudes and there is evidence in their results that the maximum pulmonary ventilation during exercise increases with increase in altitude but maximum oxygen intake decreases.
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Physiological and Psychological Requirements to Win International Middle-distance Events

It will be clear from these results and the above discussion that men must have certain minimum physiological requirements if they are to reach, say, an Olympic final. For middle-distance running it is possible to specify these minimum requirements. The individual must have a maximum oxygen intake of at least 70 ml./kg./min. measured at sea level. The higher his maximum oxygen intake is above this level, the greater is the chance that the individual can match the speed of his rival and still be running below his maximum oxygen intake, i.e. he would be running mainly on aerobic metabolism for the major part of the race. He would enter the final straight without any significant accumulation of lactic and pyruvic acids and would therefore be able to sprint the last 100 yards or so without difficulty. It is feasible, theoretically, to assess the maximum rate at which a potential Olympic finalist could run for the major part of the race while remaining within his aerobic capacity. Further, it is also possible to estimate the length of the final sprint the man could make without reaching such a high level of anaerobic metabolism that he would be forced to slow down. Good coaches assess these facts by intuition, but by using modern physiological techniques the element of chance could be eliminated. Both the maximum capacity for aerobic metabolism and for anaerobic metabolism of an athlete can be measured accurately with modern physiological techniques and can be related, in the case of the aerobic capacity, to the maximum rate the man can run for 3 or 4 laps without utilizing anaerobic metabolism and, in the case of anaerobic capacity, to the maximum speed and length of the final sprint.

Measuring the individual's maximum capacities for aerobic and for anaerobic metabolism will tell us whether he has the 'horse-power' to be a top-class international athlete, but it will not tell us whether the individual will have the determination or motivation to drive himself to the point of complete physical exhaustion which is generally needed in order to win an Olympic title. This often includes the mental capacity to stand severe pain in the legs and respiratory system. Very little systematic study with modern experimental psychological methods has been carried out to assess the temperament and motivation needed in winning an international event. This laboratory has recently measured the concentrations of lactic and pyruvic acids in blood after young, fit men had run to exhaustion at a speed of 1 m.p.h. above that at which their maximum oxygen intakes were reached. There is a good correlation between the levels of these products of anaerobic metabolism and the length of time they forced themselves to run. Electroencephalograms and psychological tests of motivation were also made for us by the National Institute for Personnel Research and the results are being correlated with the physiological findings. Studies along these lines, involving the joint efforts of the experimental physiologists and psychologists, can be expected to throw light on this most difficult but interesting aspect of exercise, i.e. when the individual drives himself to the limit of his mental and physiological capacities.

The Need for a National Programme of Research into the Physiology and Psychology of Exercise

We have today sufficient knowledge of the factors which set a limit to the maximum aerobic and anaerobic capacities, and of the techniques of measuring these capacities, to undertake a systematic programme of research on athletes with the object of selecting those men who have the 'horse-power' to reach Olympic finals, and of training them to reach the limits of these capacities in competition.

It is also clear that there is a gap in our understanding of the psychological factors which are important in motivating athletes to make the maximum use of these physiological capacities under the stress of competition. Basic research is needed in this field.

The Republic has some physiologists and psychologists with a knowledge of this field of research, and with experience in the experimental techniques, to make an outstanding contribution to scientific knowledge, provided the financial resources are made available for them to concentrate on these researches. Moreover, the knowledge gained from a study of international class athletes can be applied to the study of other groups in the populations in the Republic who are less fit, and to a study of the effects of age and of chronic illnesses, such as the cardiorespiratory diseases. In this way a contribution can be made to the general improvement of the capacity for exercise of the population as a whole and thereby of its state of well-being and contentment. For such a programme to succeed it will need adequate financial support. Many countries in the Western world, notably Western Germany, are today supporting research in exercise physiology.

At an international level, the International Council of Scientific Unions is planning an International Biological Programme, one section of which is Human Adaptability. One of the important research projects in the Human Adaptability section is on 'Growth and fitness'. Methods for measuring physical working capacities of populations in different parts of the world have been discussed at a number of meetings, which one of us (C.H.W.) attended, and agreement has been reached on methodology. If the Republic is to keep a place in this field of research it is important that it formulate its plans and obtain the necessary finance for research in exercise.

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