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DEPARTMENT OF THE SCIENTIFIC ADVISER TO THE ARMY COUNCIL

UNLIMITED

# ARMY OPERATIONAL RESEARCH GROUP

## REPORT No. 4/56

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# THE METABOLIC COST OF LOAD-CARRYING – A DISCUSSION OF EXPERIMENTAL FINDINGS.

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FEBRUARY 1956

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# THE METABOLIC COST OF LOAD-CARRYING - A DISCUSSION OF EXPERIMENTAL FINDINGS



Study No. 193

Requested by SA/AC

86/Research/256

Report prepared by:

J.W.T. Redfearn
Capt. R.F. Crampton, R.A.M.C.
Capt. T.D. Williams, R.A.M.C.
B. Mitchell

Approved by:

A/Chief Superintendent, AORG.

ARMY OPERATIONAL RESEARCH GROUP

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# THE METABOLIC COST OF LOAD-CARRYING - A DISCUSSION OF EXPERIMENTAL FINDINGS

Prepared by:- J.W.T. Redfearn
Capt. R.F. Crampton, RAMC*
Capt. T.D. Williams, RAMC**
B. Mitchell

## ABSTRACT

This paper presents a brief historical review of physiological work on load-carrying. The pooled experimental results of a number of workers in this field are discussed and subjected to statistical analysis and the following major conclusions are derived:

(a) An approximately linear relationship exists between the calorific expenditure on the one hand, and the weight of subject plus load on the other (Fig. 9). The 'slope' of this relationship varies considerably with the rate of marching. For a velocity of horizontal marching at 90 metres per minute (about 3½ mph) the slope is in the region of 0.05 kilogram-calories per kilogram.

(b) The relationship between velocity of marching and calorific expenditure is non-linear, and is such that the latter increases rapidly for increases in velocity above about 80 metres per minute (3 mph).

(c) Curve-fitting procedure has been carried out on the entire data collected from the literature. An equation relating energy expenditure to load, body weight, and velocity of marching has been evolved for men marching on a flat horizontal surface.

(d) The quantities involved in the above relationships show that, in general, it is metabolically more economical to carry heavy loads at a low velocity than light loads at a high velocity. It is important to remember, however, that energy expenditure is not necessarily at all synonymous with 'fatigue'.

(e) Experimental work towards finding a militarily desirable method of carrying loads so as to involve the least energy expenditure has been fragmentary, unsystematic, and inconclusive.

(f) There are insufficient data on the effect of different gradients, terrains, meteorological conditions and psychological states to enable any realistic assessment to be made of the energy cost of marching under military conditions.

*Present address: Department of Physiology, University of Birmingham.
**Present address: Department of Physiology, University of Bristol.

(g) There is insufficient evidence regarding the expenditure which can be kept up for various periods of time to warrant any such maximum reasonable outputs to be adopted for planning purposes.

(h) There are virtually no quantitative data on the activities of soldiers in battle, on which to base any reasonable plans for an optimum weight for fighting order.

It is recommended that:

As the rate of production of human physical energy is limited, more attention should be paid to its conservation, particularly in battle. For example, a slow rate of marching will result in a longer day's march, and may be metabolically a more economic preposition. Reducing the velocity of movement is even more important than reducing the load on the soldier. When military training is under review, consideration might be given to this.

Further research is necessary before recommendations can be made regarding optimum or maximum loads and it is suggested that such research should proceed along the following lines:-

(a) The linearity of the relationship between body weight plus load, and calorific expenditure, should be submitted to further experimental enquiry. The cost for various speeds should also be determined. During such investigations method of carriage and other experimental conditions should be standardized and specified. This may be best done on a treadmill but the relative cost of treadmill and road walking should be determined.

(b) Experimental work should proceed towards providing a rational basis for recommending the manner in which loads should be carried.

(c) The effects of different gradients, terrains, meteorological, psychological and training conditions should be investigated.

(d) Research should be initiated aimed at finding out whether it is possible to recommend a maximum level for energy expenditure in marching and in running, beyond which the soldier should not, as far as planning is concerned, be expected to exert himself.

(e) Metabolic studies are needed of soldiers on manoeuvre and under marching and fighting conditions which are as realistic as possible.

It is suggested that for most purposes the use of simple units of energy expenditure is preferable to the more abstract criteria of efficiency which have often been used.

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## THE METABOLIC COST OF LOAD-CARRYING - A DISCUSSION OF EXPERIMENTAL FINDINGS

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## INTRODUCTION

1. This report is not intended to deal comprehensively with the whole subject of load-carrying and the design of load-carrying equipment. Excellent comprehensive reviews of scientific work on load-carrying and of the history of military load-carrying are those of Lothian (1921) and Renbourn (1954).

2. From the strictly physiological point of view, however, it is felt that the time is opportune to review more critically previous researches upon the metabolic cost of load-carrying, some of which, for example, purport to prove that the optimum load for a soldier is about one-third of his body weight. It is the purpose of this report to enquire more carefully into the substance of these and similar assertions.

3. Before this can be done, it is necessary to review briefly the research which has been done, and to study the criteria of load-carrying efficiency which previous writers have employed. The experimental data from previous work can then be re-presented so as to combine the results available in the literature into a more meaningful pattern than would otherwise be possible.

4. To this end the experimental data of previous authors have been pooled and the results presented both fully in tabular form (Appendix A) and graphically (Figs. 1-14). The considerations which arise out of this treatment of the data in the literature are brought forward in the section entitled 'Factors affecting Energy Expenditure in Load-Carrying' (paras 28-78). Curve-fitting yields a simple equation from these data relating energy expenditure with body weight, load and velocity.

## HISTORICAL

5. The classical work in the field under review is that of Zuntz and his co-workers Schumburg, Durig, Kolmer, and others, in the early years of the present century. Zuntz and Schumburg (1896, 1901) in human and animal work, showed that calorific expenditure at normal rates of walking increased in proportion to the load carried, except for very heavy loads (e.g. 50 Kgm) when the cost was disproportionately high. The cost also increased as velocity was increased. They showed that fatigue increases the cost of exercise. They started investigations into the effect of different methods of carrying the same load, e.g. in the hand as opposed to on the back, and demonstrated increased cost in cases where the load was not balanced.

6. In a small number of experiments on the calorific cost of marching up slopes they found that if the cost of marching horizontally is subtracted from the actual calorific cost, the cost of raising one pound of body weight or load one foot is relatively constant.

7. Zunts and his school expressed the "costliness" of load-carrying in terms of calories per horizontal kilogram-metre. The calories represented the net calorific expenditure in excess of basal calories, and the units of mass referred to the mass of subject plus his load. They showed that for speeds below about 80 metres per minute (3 mph), costliness measured in the above units remained fairly constant at about 0.52 gram-calories per horizontal kilogram-metre. Other workers of the school obtained similar values and the discrepancies of Douglas and his co-workers are explicable in terms of their use of a basal rate relating to the standing position instead of lying-down (see Brezina and Kolmer (1912)).

8. For rates of walking in excess of 80 m/min, which he called the 'maximal economic speed', Durig (1911) claimed to show that the uptake in gram-calories per kilogram-metre increased as an exponential function of the speed in excess of maximal economic speed. The rapid rise in the cost of walking above speeds of about 3-3½ mph was an important finding.

9. Brezina and Reichel (1914) claimed to confirm Durig's findings for a range of loads carried, and also studied the effect of various loads on the metabolic efficiency of load-carrying. Plotting load against gram-calories per kilogram-metre, they showed a minimum value for the latter at a load of 19 Kgm. For walking speeds below 80 m/min, the energy cost expressed as calories per horizontal kilogram-metre for loads in excess of 18 Kgm was approximately proportional to the square of that excess. Their actual experimental figures show a minimum value at 14 Kgm although the figure of 19 Kgm corresponds to the minimum on the curve which they derive theoretically from their data.

10. Cathcart and Orr (1919) and Cathcart, Richardson and Campbell (1923) repeated the work of Brezina and his co-workers, with similar results. They agreed on a maximum economic velocity of about 80 metres per minute (3 mph), and also studied the effect of various loads, carried with standard British Army webbing equipment, on the cost of transport in gram-calories per kilogram-metre per square metre of body surface. Measured in these units in two subjects, the "costliness" of carriage fell when the load was increased from 25% of the body weight until the load reached 40% of the body weight, and thereafter rose steeply. These authors conclude that although 40% of body weight may be the most economical load when carried under laboratory conditions, the traditional figure of one-third of the body weight is probably best for rough and sloping terrains; but no experimental data were presented for such conditions.

11. Bedale (1924) studied the effect of carrying loads in different ways by women, and found that a yoke placed across the shoulders was the most economical method of carriage of the six methods tried. A study of the photographs in Bedale's paper suggests that, other things being equal, the least costly method of carriage is that in which the normal centre of gravity of the body is maintained. This later received some confirmation from the electromyographic work of Lippold and Naylor (1950), who found that there was much less electromyographic activity in the muscles of trunk, back, and shoulder girdle during walking if the load were carried in a balanced fashion, and if the weight of the load was transmitted to the ground via the body skeleton rather than via muscles which have to do useless work to support the load.

12. There is some rather inconclusive evidence (Cheyne, 1926, Daniels et al, 1953) that less energy is expended in carrying a load in the "high back" position than in the "low-back" position. The nature of the problem of how best to carry a load of given mass makes it difficult to design crucial experiments or to evaluate the work of others. It is quite possible that factors such as comfort of fitting, and amount of permitted movement or

'jogging' during carriage, are of importance in determining metabolic cost, and it is very difficult to control these factors. For example, it is difficult to design a method of carrying loads on a belt (Daniels et al, 1953) which would not cause discomfort or permit movement of parts of the load with the limbs.

13. As is to be expected, unidimensional factors such as load, body weight, and speed of marching are given prominence in the scientific literature but unfortunately quantitative work on optimum loads, velocity, and body weight has involved carriage of the load on the back with differing forms of harness the characteristics of which have not always been adequately specified. This fact no doubt accounts for a certain amount of the variability in the results reported by different workers.

## THE USE OF CRITERIA OF METABOLIC EFFICIENCY IN LOAD-CARRYING RESEARCH

14. A hypothesis implicit in much of the research under review, is that there is an optimal or most economically carried load, and also an optimal or most economically maintained velocity at which to carry it. These are to be determined by ordinary costing principles. On the debit side is the metabolic cost of a particular piece of load-carrying work. On the credit side is the end-product of this work.

15. The metabolic cost of the work is taken as the difference between the calorific expenditure during the work and the basal metabolism under the same dietary and environmental conditions, the units "working-calories" being used as a measure of this difference.

16. In a task where the end-product can be measured as real physical work, such as climbing, or performing on an ergometer, a convenient criterion of muscular efficiency is at hand. This is expressed as the ratio of external work done to the metabolic cost of that work. During the carriage of loads on a horizontal plane, no useful physical work is done, so a simple ratio will not suffice.

17. However, external work is a product of force (usually weight) and displacement. As if by analogy, it has been a common practice, since the work of Durig, to calculate the quantity of end-product by multiplying the total weight of subject plus load by the horizontal displacement. The index of the "costliness" of the work is expressed as the ratio of working calories expended to the product of total weight times distance travelled. This index represents the reciprocal of efficiency, and is measured as gram-calories per horizontal kilogram-metre.

18. It is worth emphasizing that this evaluation of the end-product of load-carrying is quite different from that which would appeal to the economist or production engineer. In a measure of load-carrying efficiency, it is at first sight illogical to include the weight of the vehicle as a worth-while part of the load transported. Using these units, a heavy goods train carrying a small parcel would appear to be working as economically as a train carrying its full load. From a practical point of view, the weight of the vehicle may be considered as "dead weight". Similarly, in human load-carrying, the stevedore is concerned with carrying a given amount of material from A to B with the least possible energy expenditure, or, if on piece-work, with carrying the greatest amount of material from A to B for a given expenditure of energy. It is merely unfortunate that on each trip he makes he has to carry himself as well as his load. In forming a judgement of the optimum load for a stevedore, therefore, the concept of calories per kilogram-metre, (the kilograms referring to total weight of subject plus load) is irrelevant. If, however, the kilograms refer to load only, the concept becomes relevant, and may be optimized against load. (See Fig.6). When the data are plotted in this way, it becomes clear that, for the stevedore, large loads might well be preferable.

19. Such-like abstractions from experimental data must always, of course, be interpreted with reserve. In this case, for example, it would be necessary to keep the absolute rate of working within certain limits so as not to place undue strain upon the body.

20. If one comes to consider another example of human load-carrying, that of the soldier marching with his pack, the weight of the soldier cannot be regarded as dead weight. The transportation of the body of the soldier is the major aim. The use of the units "calories per horizontal kilogram-metre (total weight of subject plus load)" is therefore not entirely inappropriate.

21. To use these units without specifying load or velocity it would be necessary to assume, firstly, that metabolic cost is directly proportional to velocity of marching, and secondly, that metabolic cost is directly proportional to total weight of man plus load. It will be seen later how far these assumptions are justified.

22. Attempts have been made (Brezina and Reichel, 1914, and Cathcart et al, 1923) to optimize load against some such criterion as the above. Even if the experimental results supported this, the procedure cannot give a militarily optimum weight for the soldier's equipment. Such a procedure implicitly assumes that each kilogram of load is of equal military value to each other kilogram, and to each kilogram of soldier. It is clear, however, that if the naked soldier were clothed and accoutred item by item, his military value would not rise steadily as more weight was added, but would rise sharply as he was given his rifle plus a few rounds of ammunition, and much less steeply as he was given a second spare pair of boots.

23. And just as it is not easy to optimize load against calories per horizontal kilogram-metre, neither is it easy to optimize velocity against the same index of costliness of effort. Supposing we were to optimize the velocity of a cat against calories per horizontal kilo-metre, the result would be that the cat would never catch a mouse. It were better to optimize velocity against calories per mouse caught. Very similar considerations might apply to a man facing an enemy, whether he were advancing or retreating.

24. From a purely physiological point of view, the relevance of these criteria of metabolic efficiency, even if they could be used in a logical manner, should not be taken for granted. It is often the case that an engine is working under the best conditions from many other points of view when it is working most economically, and that a rise in fuel consumption per unit of output betokens something amiss. The same state of affairs might often apply to the human muscular system, but a more precise justification for these and similar abstractions is seldom possible.

25. At present therefore, it would seem both wise and convenient in load-carrying work, to make as few abstractions from the experimental data as possible. The use of the units of working-calories per minute is often sufficient and is certainly convenient. Furthermore, working-calories per minute can be said, at a first approximation at least, to represent real physiological cost in terms of what the lungs and circulation have to provide in the way of oxygen and metabolities, in order that the work should be done. For work involving the massive use of musculature, such as load-carrying, these factors may be the limiting ones, as Muller (1953) suggests. Metabolic research may therefore be successful in determining limiting values for load, velocity, or environment. But it is only with the above reservations that it would be helpful in laying down optimal values, for the simple reason that it is not usually sufficient to measure physiological or any other cost in terms of calories, and not usually possible to state the precise end-product whose cost is to be assessed.

26. With these important reservations, however, it is still of great potential interest to present the data of previous workers in common forms, so that the results of one worker may be compared with those of another, and so that a coherent picture may be obtained. It will be found that the assumptions underlying the use of the units of calories per horizontal kilogram-metre are in part well-founded, and that a case can be made out for their use on occasions, provided that velocity at least is specified.

27. Such a treatment of the data of previous workers is attempted in the following section.

## POSSIBLE FACTORS AFFECTING THE ENERGY EXPENDITURE OF LOAD-CARRYING

28. It is clear that many variables have to be considered in assessing the energy expenditure of load-carrying. These variables include:-

(1) The weight of the load carried.

(2) The body weight of the individual.

(3) The velocity of walking.

(4) The method of carrying the load.

(5) The length of time for which the load is carried.

(6) The effect of training.

(7) Variations in terrain, e.g. level road, slope, rough and smooth surfaces.

(8) Meterological conditions, e.g. temperature, humidity, wind velocity.

(9) Clothing.

(10) "Psychological" factors, e.g., comfort, morale, fatigue, nervous tension, interest.

29. Because of the time involved in metabolic studies, individual physiological workers in this field have only found it possible to examine the effect of a few of these factors on a very limited number of subjects. For this reason it has been attempted here to combine all available previous experimental data (Appendix A). Since compiling these results and the graphs (Figs 1 to 14) therefrom, a few further data (e.g. Hill et al (1924-5), Ogasawara (1934), and Liljestrand and Stenstrom (1920)) have been found, but the data here presented were all that were available at the time of the study, and were not selected in any way except by virtue of their accessibility.

30. It has been thought desirable, in the graphical presentation, to show which experimental results were obtained by which authors. In this way experimental bias on the part of a particular author might the more readily become apparent. At the same time, in so far as each result from a particular author forms a control for each other result (as certain of his experimental errors will remain constant throughout his work) the results of each author may be studied in isolation from all other authors.

31. All the data collected were from healthy male subjects walking on the level in a temperate environment (not always adequately specified by the authors concerned). The only treadmill data included are the results of Daniels et al (1953). Although these workers stated that a significant difference exists between the metabolic cost of treadmill and ordinary walking, it will be seen from the graphs that their pooled results show in themselves very much less scatter than do the results of all authors combined. For this reason there seemed no point in excluding the treadmill data from the graphs.

**Weight of the Load Carried**

32. The rates of energy expenditure, expressed as working kilogram-calories per minute, for different loads are shown for three separate velocities in Figs 1-3. All experimental results are included regardless of the body weight of the subjects. The question of body weight is dealt with later (paras 38-40). The evidence is most complete in Fig.1 for 90 metres per minute (3½ mph). At least as a first approximation it would seem that the energy expenditure varies directly with the load carried. The slope of the straight line is 0.052 kilocalories per kilogram, which agrees well with the relationships obtained from the whole of the experimental data in Appendix B (see paras. 45-50).

33. It appears from Figs 2 and 3, and it is confirmed in Appendix B, that the relationship for other speeds is also linear, the slope varying according to the velocity.

34. The discussion of Brezina and Reichel (1914) and of Cathcart et al (1923) centred around the question of an optimal load, expressed in terms of calories per horizontal kilogram-metre. As there is a linear relationship between energy expenditure and load, these discussions lose much if not all of their former interest, as they are in fact concerned merely about whether there are slight deviations from linearity or not.

35. Plotting calories per horizontal kilogram-metre (the kilograms being the total weight of subject plus load) against load, Brezina and Reichel found a minimum cost at 19 Kg load. The results however apply to a series of experiments on a single subject, and it would be regarded nowadays as foolhardy to derive such sweeping generalizations as did Brezina and Reichel from such a small number and variety of experimental results. They did not determine the variation from one subject to another, from one method of carriage to another, from one environment to another, and so on. Their conclusions, therefore, are based upon insufficient evidence. Other criticisms in that the authors assumed an arbitrary basal value for the series, and did not specify the environmental conditions such as temperature, humidity, and air velocity, are quite minor in comparison.

36. In order to test the conclusion of Brezina and Reichel, data from other workers are presented in Fig.4, in which the same co-ordinates are used as were used by these authors. This manner of presenting the data is only justified when the velocity is known and constant, because, as will be seen later, the relationship between velocity and calorific expenditure is not linear. The velocity of about 90 metres per minute (3½ mph) is again chosen. It is seen that Brezina's postulated minimum at around 15 or 20 kilograms is not borne out. The data when plotted in this way seem to present a horizontal straight line. If the relationship between load and metabolic cost is linear, and the cost in terms of calories per horizontal kilogram-metre for a given velocity does in fact remain constant, as appears to be the case in Fig. 4, then it can be concluded that the relationship between body weight and metabolic cost must also be linear, with approximately the same slope in calories per kilogram. It will be seen later (paras 45-50) that this does seem to be the case. But for the moment it is sufficient to note that any minimum there may be in Fig. 4 is certainly not a striking one.

37. Cathcart, Richardson and Campbell (1923) used two subjects, Richardson and Campbell. Loads over a wide range were carried at a constant velocity of just over 90 metres per minute (3½ mph). The load as a percentage of the body weight was plotted against metabolic cost in calories per horizontal kilogram-metre per square metre of body surface, and a minimum value found for the load of 40% of the body weight. This method of presenting the data has been repeated for all the workers in Fig.5. While it could not be said to lend very definite support to Cathcart's hypothesis, it can be argued that when the load reaches a very large percentage of the body weight, the cost of carriage increases disproportionately. This would indicate certain obvious limitations to the linear relationship postulated from Fig.1 (para 32). The large scatter of the results precludes firm conclusions, and is perhaps an indication of the doubtful validity of presenting the data in this way.

## Body Weight

38. If the velocity is kept constant, and the load is kept constant, it should be possible to study the effect of body weight on metabolic cost. If this is done, (Fig.7) there are insufficient data from any one load or velocity for any firm conclusions. The only data on which conclusions can be based are those of Passmore et al (1953), and these also have been plotted in Fig. 7. It is important to note that whereas the other data refer to a velocity of 90 m./min, and a load of 20 Kg, Passmore's data refer to a velocit of 80 m./min, and were obtained from unloaded subjects. Passmore's data can be represented quite well by a straight line passing through the origin, with a slope of 0.047 kilogram-calories per Kgm. It is likely that the slope for 90 metres/minute would be very close to 0.052 kilocalories/kgm, which is the slope in Fig. 1 for 90 metres/minute.

39. To summarise the effects of body weight and load, the data allow the hypothesis that at a normal walking pace, round about 85 metres per minute (3¼ mph) every increase of 10 Kg (22 lbs) in total weight (body plus load) will increase calorific output by about 0.5 kilogram-calories/min., whether the increase is in body weight or load.

40. In Fig. 9 it is seen that such a working hypothesis would lead to no great errors, but the relationship departs from linearity for small values of body weight plus load. The departure is by virtue of the results of one author (Cathcart (1919)), so that two possibilities remain. Either Cathcart's results in 1919 were consistently high, or else the calorific output of men under 60 Kgm weight is disproportionately high. The figures of Passmore et al lend no support to the latter possibility, but do not exclude it as no very lightweight persons are included in their data.

## Velocity of Progression

41. Several observations have been recorded on the effect on energy expenditure of varying the velocity of walking while carrying a load. The data of Brezina and Reichel (1914) indicate that load carriage is most economical at speeds below approximately 80 m/min. These data, and those of other workers have been presented in Fig. 14; and from this, when the results of each worker are considered separately, it could be argued that above a velocity of 80-90 m/min metabolic efficiency decreases rapidly.

42. It may be that the curve is S-shaped, and that cost does not rise so rapidly above speeds of 160-180 m/min. This would confirm the finding of Durig (1911). It would not be at all unexpected, for at such velocities, running or a special style of walking would tend to occur, and for these higher velocities running is probably more efficient than walking (Ogasawara, 1934). Even if Durig's subject were walking with an ordinary style throughout, and had not altered his style of walking for the higher speeds, a limit to the capacity of the heart and circulation to supply more oxygen will occur around this value, and figures for oxygen intake as opposed to total oxygen requirement commence to be unreliable (Hill, Long, and Lupton, 1924-5).

43. Regarding Fig.14, it seems justifiable to pool various loads and various body weights in view of the fact that cost in calories per horizontal kilogram-metre does not vary much either with load (Fig. 4) or with body weight (Fig. 8). In Figs 10 to 13, the effect of velocity of walking on energy expenditure (in Working Cals. per min) when carrying constant loads is shown. Each of these graphs does show a suggestion of a more rapidly increased rate of energy output above a velocity of 80-90 m/min, and if this point of inflexion in the curve is confirmed by further work it would substantiate the claim of Brezina and Reichel that such a velocity is optimal for metabolic efficiency.

44. Estimates have been made of the maximum rate of calorific expenditure which can be maintained indefinitely when working 8 hours per day. Lehmann (1953), has given this value as 5.2 working kilocalories per min and Muller (1953) gives 4.0 working kilocalories per min. Lehmann (personal communication) agrees with Muller's maximum as the more practical value. If Muller's figures are used to determine the maximum velocity for which different loads may be carried indefinitely for 8 hours each day (by reference to Figs 10 to 13), then for zero load, the maximum velocity is 100 m/min (3.7 mph), and for a load of 33-34 Kg, 77 m/min (3 mph). A more accurate estimation of this maximal calorific expenditure for periods varying from say a day to a year would enable maximal velocities at which loads could be carried to be predicted, assuming a 'working-day' of approximately eight hours. (See para. 49).

<u>An equation relating energy expenditure, load, body weight, and velocity of horizontal progression</u>

45. It is seen from the preceding paragraphs that a linear relationship probably exists between calorific expenditure on the one hand and both load and body weight on the other, and that some form of curvilinear relationship holds for velocity.

46. Curve-fitting procedure (see Appendix B) was carried out on the entire data tabulated in Appendix A. The best equation so far evolved relating the variables is as follows:-

$$wC = 0.0083(10 + W + L)e^{V/50}$$

where wC is the energy expenditure above the basal metabolic rate in working kilocalories per minute, W is the weight of the man in kilograms, L is the load in kilograms, and V is the velocity of walking in metres per minute. e is the exponential constant and is equal to 2.72. Predicted expenditures for various loads, speeds, and body-weights are presented for convenience in Figs 15-18. If not known, basal metabolism may be predicted from body weight (see Fig.19) by means of the regression

$$Y = 0.56 + 0.0091\ W$$

where Y is the basal metabolism in kilocalories per minute and W is the body weight in kilograms. In this study basal metabolism and working metabolism have been kept separate in view of predominant usage, although it is probable that equally accurate prediction, with some saving of labour, would have resulted if basal values had been disregarded entirely and total metabolism had been substituted for working metabolism.

47. This equation incorporates quite successfully the relationships between load, body weight, and energy expenditure developed in paras. 32-40. It shows that a simple exponential function describes quite well the relationship between energy expenditure and velocity for the velocity range over which the data were collected, say about 50 to 120 metres per minute (2-4.5 mph). At very low and very high speeds there is no reason to assume that this simple exponential relationship holds.

48. When using this formula it should of course be remembered that the scatter of individuals' energy expenditure is so wide that prediction is not practicable for the single individual. For 90% certainty of prediction the range is approximately 1 kilocalorie both above and below the predicted value. It is quite clear that a large proportion of this uncertainty is due to experimental errors and differences in technique, and so we may look to the future for considerable improvements in the certainty of prediction. Even then it may confidently be assumed that substantial individual variations will be shown to exist.

49. It was Bresina who first suggested that in marching it is more important, from the point of view of energy cost, to keep the velocity down to 3 mph or below than to reduce the load to very small values. We have seen that each kilogram of load adds to energy expenditure about the same figure as each kilogram of body weight. The energy cost of a march will therefore vary directly with load, so that there is no "optimum" value for load except zero. Let us now see how the cost of a march varies as a function of velocity.

The energy expenditure per minute above basal is given by

$$wC = 0.0083\ (10 + W + L)\ e^{V/50} \ \ldots\ldots \text{(para. 46)}$$

The time taken to march a distance D is $D/V$ minutes. Therefore the energy expenditure, E, above basal, in marching a distance D is given by

$$E = 0.0083\ (10 + W + L)\ e^{V/50} \cdot \frac{D}{V}.$$

The most economical value of V is clearly that which minimizes E, i.e.

$$\frac{dE}{dV} = 0.0083\ \frac{D}{V^2}\ (10 + W + L)\ e^{V/50}\ \left(\frac{V}{50} - 1\right) = 0$$

This yields a value of V = 50 metres per minute, or 1.85 mph. We have therefore the interesting finding that, for minimising the total energy cost of a march, the optimum velocity is in the region of 2 mph. It can be seen from Figs 15–18 that at this velocity even very large loads, in excess of a hundredweight, can be carried continuously without exceeding Muller's upper workaday limit of 4 working kilocalories per minute (see para.44). This optimum velocity is independent of load, body weight, and distance marched. The comparative cost of a march at other velocities, expressed as a percentage of the minimal cost at 1.85 mph, is shown in graphical form in Fig.20 (which is essentially a condensed and smoothed form of Fig.14). For the convenience of the military reader, the graph has been marked off at several velocities corresponding to Muller's upper limits of 4 working kilocalories per minute, for different loads (assuming an average man of about 70 kg). These would, according to Muller, be the velocities which could be kept up for an 8-hour day, day in and day out, more or less indefinitely.

50. In those occupations where the load carried is of prime importance, the weight and velocity would no doubt be adjusted towards high weights and low velocities. From a military point of view, it may be that in some circumstances, it is the man and not the load which is of critical importance and in this case a reduction of load would be necessary to effect any desired increase in velocity.

Method of Load Carriage

51. The upright posture does not require very much energy expenditure because no muscles have to work very hard in order to maintain it. What work is done is presumably expended either:-

(a) in maintaining parts of the body rigid. This may entail the continuous action of agonists and antagonists against each other, or the action of muscles e.g. those of the shoulders against externally applied force e.g. webbing equipment,

(b) in rectifying errors of positioning which, if allowed to remain uncorrected, would lead to greater errors of position. In other words, in balancing.

52. In marching, the above items are undoubtedly increased. In addition work is done:-

(c) in raising and lowering the limbs, and the body as a whole (Benedict and Murschhauser 1915),

(d) in accelerating and decelerating the limbs,

(e) in overcoming friction and wind resistance.

53. Carrying the load on the lower limb is obviously uneconomical as it increases item (a). Compared with loads carried on the back, there is a significant increase of energy expenditure even if the load is carried on the thigh (Daniels et al, 1953) and of course even greater increases occur when the load is carried on the feet (Russell and Belding 1946; Turrell and Robinson, 1943 cit, Russell and Belding 1946).

54. Carrying loads in the hand or under one arm is also in general uneconomical (Zuntz and Schumburg 1901, Bedale 1924) as is any method of grossly unbalanced carriage, as this increases items (a) and (b) unnecessarily (Lippold and Naylor 1950).

55. Head carriage, and yoke carriage, although efficient, may be dismissed in this short discussion as usually impractical from a military point of view. Another point which does not require discussion is that the load should be disposed as close to the body as possible, in order to lessen the turning moments required to turn the body when such movements are required, and so that unbalance should be reduced to a minimum.

56. At first sight it must seem obvious that the load should be properly balanced from side-to-side and also fore-and-aft. However the weight which can be placed on the front of the body without unduly encumbering the soldier may be limited, and it has usually been found desirable to increase the weight on the back. This is necessarily counteracted by slight stooping the desirability or otherwise of which is not yet clear. There has been a certain amount of controversy as between "high-back" loading and "low-back" loading and claims have been made (Cheyne, 1926) that high-back carriage reduces metabolic cost by as much as 10%. However, many other alterations were made to the high-back pack designed by Cheyne, and it is not known what contribution was made by these other factors.

57. In order to retain perspective in the matter of where the load should be placed, it should be pointed out that, apart from the increases which could occur from placing the entire load on the feet or on some other moving part, the differences involved are not large. Experiments in progress at AORG show, for example, that the extra cost of placing a load not only entirely on the back, but removed six inches posterior to the surface of the back by means of a suitable harness, as compared with the cost of a perfectly balanced load, is unlikely to exceed about 5%, and may be appreciably less, so long as the load does not exceed about 60 lbs. Here it should perhaps be re-emphasized that energy expenditure and 'fatigue' are not synonymous.

58. The work of Daniels et al (1953) suggests that there is probably not much difference in the metabolic cost of high-back carriage and low-back carriage. High-back carriage probably entails slightly less stooping, and more use of the muscles of the back.

59. Lippold and Naylor (1950) suggest that in order to save muscular effort, the weight of the load should be placed as far as possible on bony structures whence it can be transmitted directly to earth. Personal experience indeed suggests that many webbing equipments cause severe and unnecessary work on the part of the shoulder muscles, and that if a load can be made to sit on the hips or pelvis as does the Bergen rucksack, it can be carried more easily. The method of achieving this no doubt lies in the skilful design of the pack, rather than in attaching the load round the belt, as Daniels et al attempted. Suspending the load from a belt may easily cause chafing, undue movement of the load, and restriction of thigh movement.

60. Marching at attention would undoubtedly entail higher expenditure of energy than marching or walking in a more relaxed manner, but the size of the increase has not been investigated. All the data in Appendix A may be taken to appertain to a fairly relaxed gait. Until further data become available it is perhaps reasonable to expect that, a further 5% or 10% or occasionally even more might be added for marching at attention, depending on the rigidity of posture.

Length of Time for which a Load is Carried

61. With feet and lower limbs aching after a severe march of 50 Km, two subjects of Zuntz and Schumburg (1901) showed an increased energy consumption of the order of about five percent for the same marching task. A similar or even smaller increase was demonstrated by these workers on several occasions.

62. After a rapid eight-mile march "to exhaustion" with heavy packs, the two subjects of Cathcart, Richardson and Campbell showed no such increase, in spite of aching or blistered feet and aching shoulders.

63. It is clear that any effect there may be is small, and might be accounted for by changes in posture and in the rigidity with which parts of the body are held.

64. Some work on rest pauses was done by Cathcart et al (1923). The subjects had to cover a certain distance in an hour, either by marching the whole time slowly, or by marching for 40, 45, 50, or 55 minutes during the hour, correspondingly faster, and resting during the remainder of the time. When the distance which had to be covered in the hour was only 3.5 Km., the cost of the march remained roughly constant. But when the distance was 5 Km., it was better to march for 55 minutes or even for the whole hour rather than attempt the higher velocities. The work of Muller (1953) however, makes it appear probable that if the rest pauses had been spaced more frequently, the higher velocities might have been attained at less total cost. But rest pauses every few minutes would be difficult to organise on the march, and it is common experience that it is preferable to keep up an even pace rather than to march very quickly for a minute or two, then rest.

Training

65. Although several subjects have been investigated over many periods of exercise, no training effects seem to have been noted in the literature. It therefore seems reasonable to expect that, if training effects exist, they will not prove to be very great. The reduction in exhaustion, in blisters and in the aching of limbs consomitant with training would be expected to cause a reduction in the metabolic cost of the same order as the increase due to these factors mentioned in the previous Section (para 61), i.e. about five per cent. Larger reductions than this occur during the period of training in the wearing of the apparatus, and particularly in the first few experiments on the treadmill (Durig, 1911). The effect of training on metabolic efficiency seems to vary with the extent to which a person has to learn new movements. For example, there are large training effects in swimming, rock-climbing, timber-felling and knitting.

Variations in Gradient and Terrain

66. A few observations by Zuntz and Schumburg (1896) and by Durig (1911) suggested that the cost of uphill progression for gradients up to about 1 in 5 or 6 over and above the cost of the horizontal component amounts to 7 or 8 calories per metre-kilogram (total weight of man plus load), in temperate weather.

67. In Durig's results there were marked individual variations.

68. A few results of Daniels et al (1953) suggested a 14% increase in metabolism for each degree of slope. This increase is of the same order as those of the German workers. Estimates from figures quoted by Lehmann (1953, page 149) are also in substantial agreement, the estimated extra cost varying between about 5 and about 8 gram-calories per metre-kilogram.

69. Finally, the two subjects of Durnin (1955) gave similar results, the extra cost of the vertical component (after subtracting basal metabolism and the cost of the horizontal component, as before) being about 8 gram-calories per metre-kilogram. These subjects were ascending a gradient of about one in five at the rate of 2,000 feet per hour.

70. Very few figures indeed can be given for the cost of downhill walking. A few results of Asmussen (1953) suggest that for downhill gradients of up to 1 in 6 there may be a reduction in expenditure with a maximum reduction of 10% at a gradient of 1 in 10, compared with horizontal walking. At steeper gradients the cost of horizontal walking is exceeded somewhat.

71. Little reliable information is available on the effect of terrain of different kinds. Daniels et al produce a few results which at first sight suggest that treadmill walking is roughly 10% less costly than cinder-track walking, but differences in environmental conditions (the treadmill experiments were conducted at 70°F, the track experiments at an unspecified temperature) might possibly account for a discrepancy of this size. Spitzer's figures, quoted by Lehmann (1953, page 148) for unladen walking at 4 Km. per hour, suggest that walking on firm grass may increase energy expenditure by about 50% as compared with walking on a good road surface. Walking across a ploughed field may cause increases of the order of 100% or even 150%, depending upon conditions.

Meteorological Conditions

72. It is probable from the work of Durig (1911) that wintery as opposed to summery conditions in Europe may increase the cost of uphill progression by 50% or more, but the effects of the surface and climatic conditions cannot be disentangled. No further information is available. Furthermore, an increase in cost due to low environmental temperatures may have a different significance from that of a similar increase caused by actual work. No data have been found of the cost of load carriage under tropical conditions.

Clothing

73. Although a good deal of work has been done, particularly in the USA, on the heat stress effects of different clothing assemblies on men doing moderate work, none seems to have dealt with the effect of clothing on the metabolic cost of load carriage. The report of Lippold and Naylor (1950) deals briefly with the problem of adequate ventilation in the design of load-carrying equipments. Some methods of load-carriage e.g. battle jerkins, desirable in many other respects, seem to have encountered opposition from users on the grounds of thermal discomfort, but sensible perspiration rather than heat stress is no doubt responsible for the complaints.

Psychological Factors

74. It seems likely that discomfort, aching, overstraining small muscles, and all the results of poor design of equipment, or overwork, or insufficient training, would increase unnecessary movements and increase muscle tone locally or generally, resulting in an increase in the metabolic cost of the work. No experimental data have been collected on this point.

75. Individuals in a state of "nervous tension" and neurotics would undoubtedly work less efficiently than normal individuals on account of their tendency to contract both agonists and antagonists simultaneously (Bishop and Clare 1949), and on account of the impairment of their oxygen-carrying capacity. Jones (1949) found that neurotic subjects with effort-intolerance had an increased post-exercise oxygen uptake. He discusses some of the factors - muscular, autonomic, and others - involved in the greater cost of muscular exercise in these neurotic patients.

76. In a state of pronounced muscular fatigue, muscles adjacent to the ones necessary for a voluntary movement tend to contract (Ash, 1914). This would also increase the cost of the work.

77. The magnitude of these probable effects is unknown. It is possible that fear may have more profound effects on muscular activity, but this is also a matter for investigation.

78. Prolonged sleep deprivation, muscular or mental activity, negative attitudes towards items of equipment or towards the situation and many other psychological factors may interfere with the desire to perform work, much more than with the metabolic cost of any work that may be performed. Although such factors are not strictly relevant to the present discussion, they may nevertheless be of profound practical importance in equipment design and in determining the load which should be carried.

DISCUSSION

79. Certain conclusions have already been drawn in the foregoing paragraphs. In the first place the metabolic costliness of velocity has been stressed. If total available energy is limited, and there is some evidence that it is, then if any appreciable distance is involved, marching speeds should be kept under 3 mph. In war even this speed is probably rarely attained in practice, but in view of the atomic threat, much emphasis is being placed on mobility, so that it may be worth while considering the cost of higher speeds. Marching at 5 mph across country in fighting order will expend about 13 working kilo-calories per minute or 780 working kilo-calories per hour. Marching at 4 mph would cost about 7 working kilo-calories per minute or 420 working kilo-calories per hour. Lehmann's suggested maximum expenditure for one hour (attained by only one in 25 German industrial workers) is 600 working kilo-calories in the hour. It follows that although an average speed of 5 mph across country in battle order may on favourable occasions be attainable, the tremendous cost of an extra one mile per hour should be realized. It is perhaps worth mentioning that maximum overall mobility would not necessarily result from soldiers proceeding at an exhausting pace earlier in the course of a battle, only to have t take much longer periods of rest shortly afterwards. The race would literally not be to the swiftest.

80. As regards the proper load for the soldier, we have seen that there is no critical figure, but that energy expenditure increases linearly with load. Some basis has been provided for estimating the energy expenditure for various loads at various speeds. Experimental data are still needed for various gradients uphill and downhill, for various terrains, and for different climatic conditions and possibly different psychological states, before any reality can be achieved in an estimate of the metabolic cost of marching.

81. Even when it becomes possible to make an accurate estimate, it will also be necessary to know what is the maximum calorific output to be expected from, say, 95% of average infantry soldiers. The relationship between energy expenditure and subjective and objective fatigue is still not clear.

82. According to Muller (1953), the maximum output which can be expected of the industrial worker working 8 hours per day, 300 days per year, year in and year out, is 4 working kilogram-calories per minute during working hours. At 90 metres per minute a load of only 4 kgm could be carried 8 hours per day if we are to accept this figure. Until the maximum reasonable output for marching, can be assessed more accurately it is obviously not possible to recommend any particular load, either for prolonged of short-term carriage.

83. If we were to remain content with a slow rate of marching, say 70 metres per minute (2.5 mph), large loads could be carried without exceeding this figure of 4 wor ing kilocalories per minute.

84. Recommendations of the maximum output to be expected from men, such as those of Lehmann and Muller, can only apply to the "average worker" or some such hypothetical man. It is not known how this maximum level varies with factors such as the physique and size of the individual, but it seems reasonable to assume that such factors are very important.

85. Before any reasonable maximum output can be arrived at, it is necessary to know for how long this output must be maintained. It is obvious that the maximum effort which can be kept up for a day or a week could not be kept up continuously for a year.

86. The above remarks apply mainly to the load which the soldier carries while marching. The load to be carried in battle is even less likely to be decided from purely metabolic considerations. However, let us see where such considerations lead. How would this load affect his mobility?

87. Let it be assumed that in battle a man puts out an energy expenditure which he could only keep up for a week, i.e. (according to Lehmann) 3000 kilocalories per day. Part of his activity will include walking and running. Let us suppose he has 2000 working kilocalories available for walking and running, and let us suppose he has to do 4 hrs walking or running. What will his average speed be for various weights of load? (battle order etc. including rifle and clothing).

| Load in Kg | Maximum speed which could be kept up for 4 hrs. m/min (approx.) |
|---|---|
| 0 | 145 (5.4 mph) |
| 20 (44 lbs) | 115 (4.3 mph) |
| 33 (73 lbs) | 108 (4 mph) |

88. It is, of course, very doubtful that when a soldier has done all the other things he has to do in battle (for which no data are available at present), he will have as much as 2000 kilocals to expend on running. But, in any case the figures illustrate that from the scanty data at present available we have no reason to say that there is a critical weight for battle order beyond which mobility is drastically reduced.

89. If the Army, on the basis of sound research, could state what minimum level of mobility was required, it would be possible to state the maximum load for battle order; but it is first necessary to ascertain representative patterns of battle activity. Metabolic and other studies of men on manoeuvre might well provide some guidance.

90. It is necessary to remember that the data we have discussed (paras.28-78) do not in fact apply to running but to fast walking. It seems likely that at the speed at which one naturally breaks into a trot, running is less costly than walking at the same speed. The relationship between load and metabolic cost may possibly be of a different sort for running as opposed to walking, although there would seem to be no reliable evidence on this point.

91. It is in battle that the effects of psychological stress may have such profound physical effects, namely, upon the pituitary-adrenal system. From work which has been done (Davis and Taylor, 1954), it is certain that soldiers who have lived through a battle are highly "stressed". Maximum metabolic output, or at least metabolic reserves, are probably greatly affected in such states. It is the common experience of men undergoing parachute training that 'physical exhaustion' prevents more than two or at the most three jumps per day during the training period, although the actual physical work done is probably not at all large. Here again the inference can be drawn that maximum metabolic output is reduced by virtue of the psychological stress.

92. From all these considerations it is obvious that the physiologist is not at present in a position to recommend any particular load, although the historian may be in a better position to do so (Lothian, op. cit.). The lesson of history is that a soldier's load tends to increase gradually as he or his superiors cater for more and more remote contingencies. Then, by virtue of catastrophic defeat by a more lightly equipped and fleeter enemy, or some revolution in thought, he virtually strips, and casts off all but the bare necessities, and the process is then repeated.

## CONCLUSIONS

93. The following are the major conclusions:-

(a) A re-appraisal of the experimental data of previous workers indicates that there is an approximately linear relationship between the calorific expenditure on the one hand, and the weight of subject plus load on the other (Fig.9). The 'slope' of this relationship varies considerably with the rate of marching.

(b) The relationship between velocity of marching and calorific expenditure is non-linear, and is such that the latter increases rapidly for increases in velocity above about 3 mph.

(c) Analysis of all individual experimental data which could be gathered from the literature shows that the relationship between energy expenditure, load, body weight and velocity of horizontal marching is best described by the following equation:-

$$wC = 0.0083\,(10 + W + L)\,e^{V/50}$$

Where

wC = energy expenditure in working kilocalories (kilocalories above basal)

W = body weight in kilograms

L = load in kilograms

e = 2.72

V = rate of marching in metres per minute.

(d) The quantities involved in the above relationships show that, in general, it is metabolically more economical to reduce velocity than load. It is important to remember however that calorific expenditure is not necessarily at all synonymous with 'fatigue'.

(e) Experimental work towards finding a militarily desirable method of carrying loads so as to involve the least energy expenditure has been fragmentary, unsystematic, and inconclusive.

(f) There are insufficient data on the effect of different gradients, terrains, meteorological conditions and psychological states to enable any realistic assessment to be made of the energy cost of marching under military conditions.

(g) There is insufficient evidence regarding the maximum calorific expenditure which can be kept up for various periods of time to warrant any such maximum reasonable outputs to be adopted for planning purposes.

(h) There are virtually no quantitative data on the activities of soldiers in battle, on which to base any reasonable plans for an optimum weight for fighting order.

## RECOMMENDATIONS

94. As there are some indications that human physical energy is limited, it is considered that more attention should undoubtedly be paid to its conservation, particularly in battle. A slow rate of marching may well result in a longer day's march, for example. Reducing the speed of movement is even more important than reducing the load of the soldier, at least from the point of view of energy consumption. When military training is under review, this aspect might be thought worthy of consideration.

95. Further research is necessary before recommendations can be made regarding optimum or maximum loads and it is suggested that such research should proceed along the following lines:-

(a) The linearity of the relationship between body weight plus load, and calorific expenditure, should be submitted to further experimental enquiry. The cost in terms of energy expenditure for various speeds should also be determined. During such investigations method of carriage and other experimental conditions should be standardized and specified. This may be best done on a treadmill but the relative cost of treadmill and road walking would have to be determined.

(b) Experimental work should proceed towards providing a rational basis for recommending the manner in which loads should be carried.

(c) The effect of different gradients, terrains, meteorological, psychological and training conditions should be investigated.

(d) Research should be initiated, aimed at finding out whether it is possible to recommend a maximum level for energy expenditure in marching and in running, beyond which the soldier should not, as far as planning is concerned, be asked to exert himself.

(e) Metabolic studies are needed of soldiers on manoeuvre and under marching and fighting conditions which are as realistic as possible.

96. This review seems to indicate that the use of simple units of energy expenditure is often preferable to the more abstract criteria of "efficiency" which have often been used.

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(N.B. The above reports from the Environmental Protection Branch have been referred to as "Daniels et al, 1953" in the text.)

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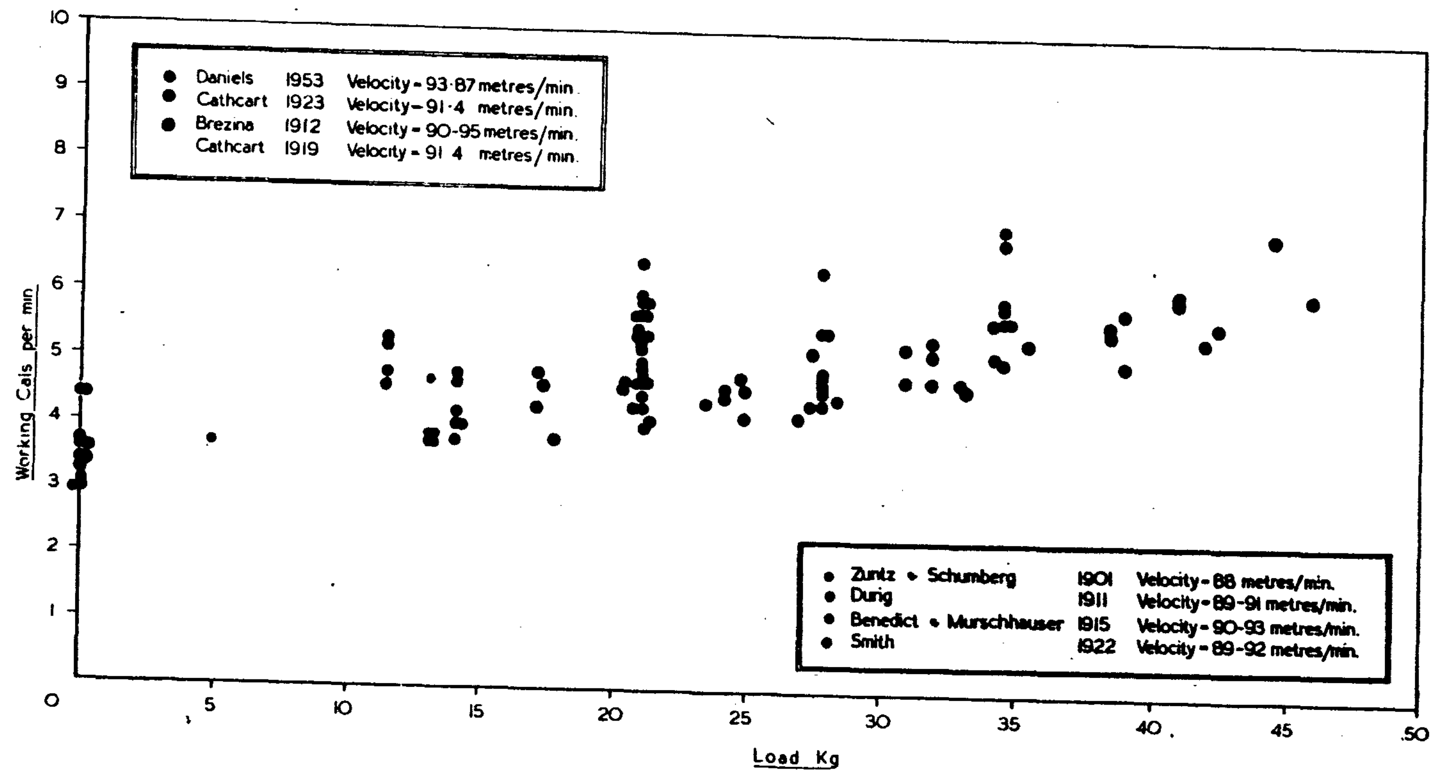


Daniels 1953 Velocity - 93·87 metres/min.
Cathcart 1923 Velocity - 91·4 metres/min.
Brezina 1912 Velocity - 90-95 metres/min.
Cathcart 1919 Velocity - 91 4 metres/min.
Zuntz + Schumberg 1901 Velocity - 88 metres/min.
Durig 1911 Velocity - 89-91 metres/min.
Benedict + Murschhauser 1915 Velocity - 90-93 metres/min.
Smith 1922 Velocity - 89-92 metres/min.
Working Cals per min
Load Kg
0
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25
30
35
40
45
50


FIG. I

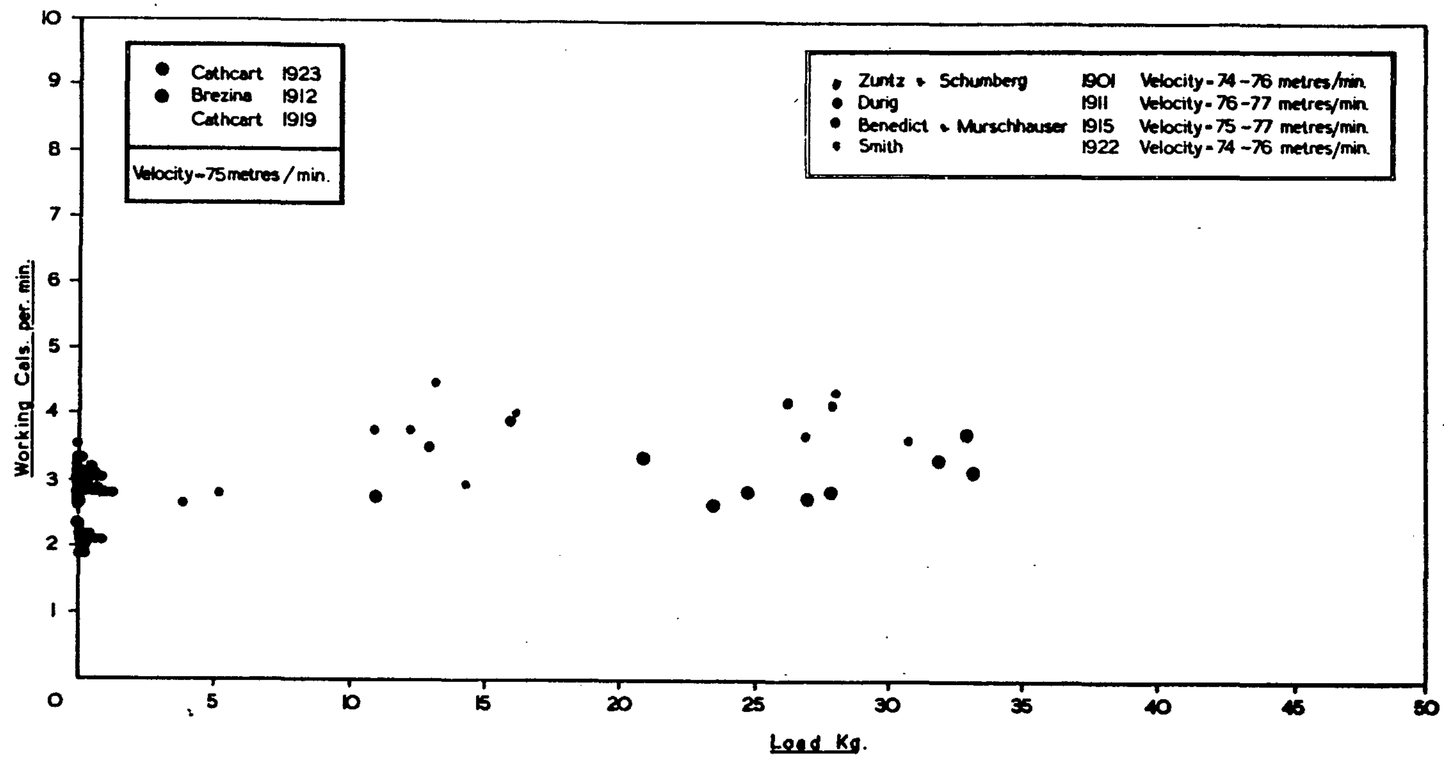

Cathcart 1923
Brezina 1912
Cathcart 1919
Velocity-75 metres / min.
Zuntz + Schumberg 1901 Velocity - 74 - 76 metres/min.
Durig 1911 Velocity - 76 - 77 metres/min.
Benedict + Murschhauser 1915 Velocity - 75 - 77 metres/min.
Smith 1922 Velocity - 74 - 76 metres/min.
Working Cals. per. min.
Load Kg.

**FIG. 2**

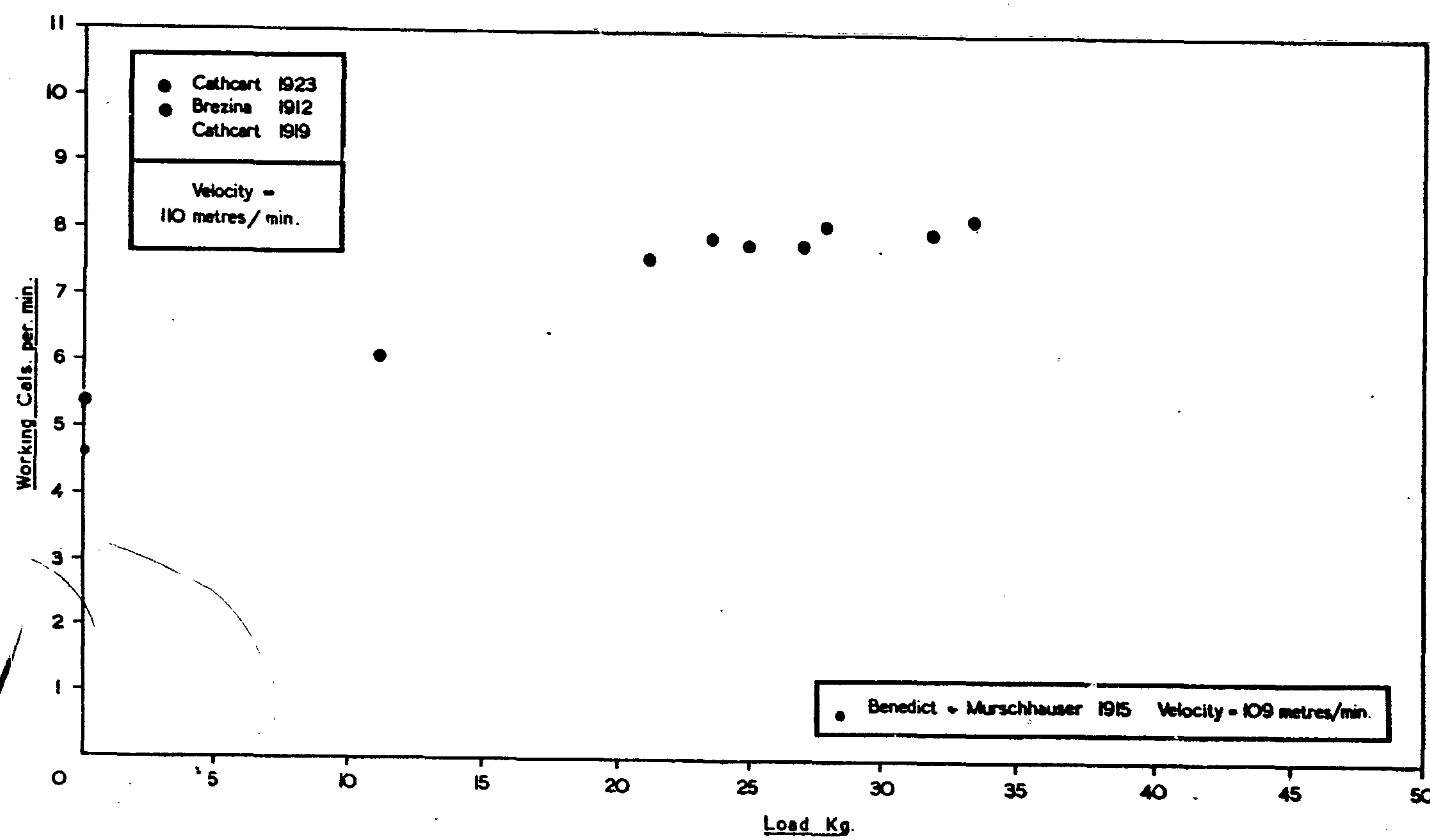
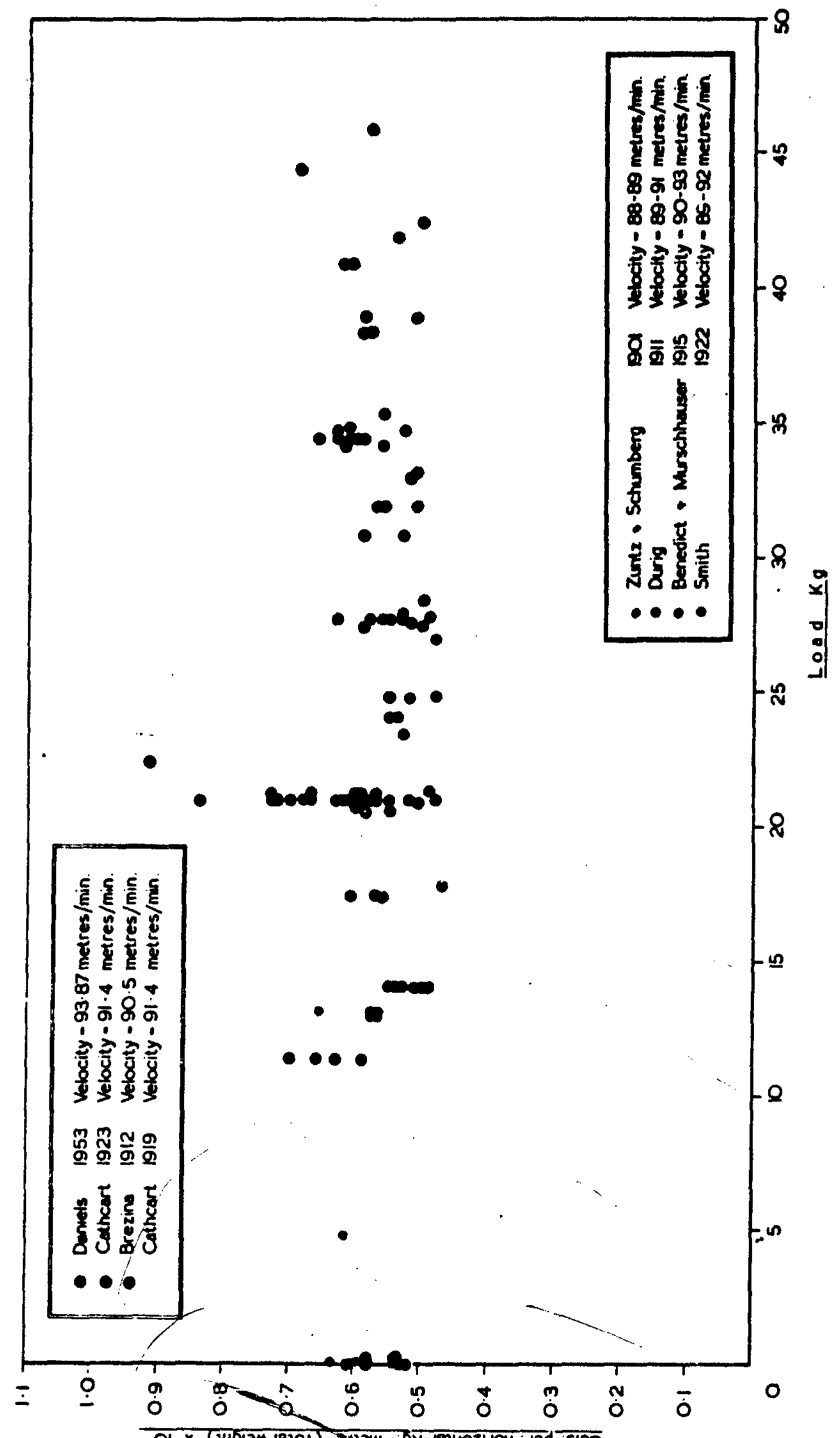

Cathcart 1923
Brezina 1912
Cathcart 1919
Velocity = 110 metres/min.
Benedict + Murschhauser 1915 Velocity = 109 metres/min.
Working Cals. per. min.
Load Kg.
0
1
2
3
4
5
6
7
8
9
10
11
5
10
15
20
25
30
35
40
45
50

FIG. 3

FIG. 4


Daniels 1953 Velocity - 93·87 metres/min.
Cathcart 1923 Velocity - 91·4 metres/min.
Brezina 1912 Velocity - 90·5 metres/min.
Cathcart 1919 Velocity - 91·4 metres/min.
Zuntz + Schumberg 1901 Velocity - 88-89 metres/min.
Durig 1911 Velocity - 89-91 metres/min.
Benedict + Murschhauser 1915 Velocity - 90-93 metres/min.
Smith 1922 Velocity - 85-92 metres/min.
Cals. per horizontal Kg.-metre (Total weight) x 10
Load Kg

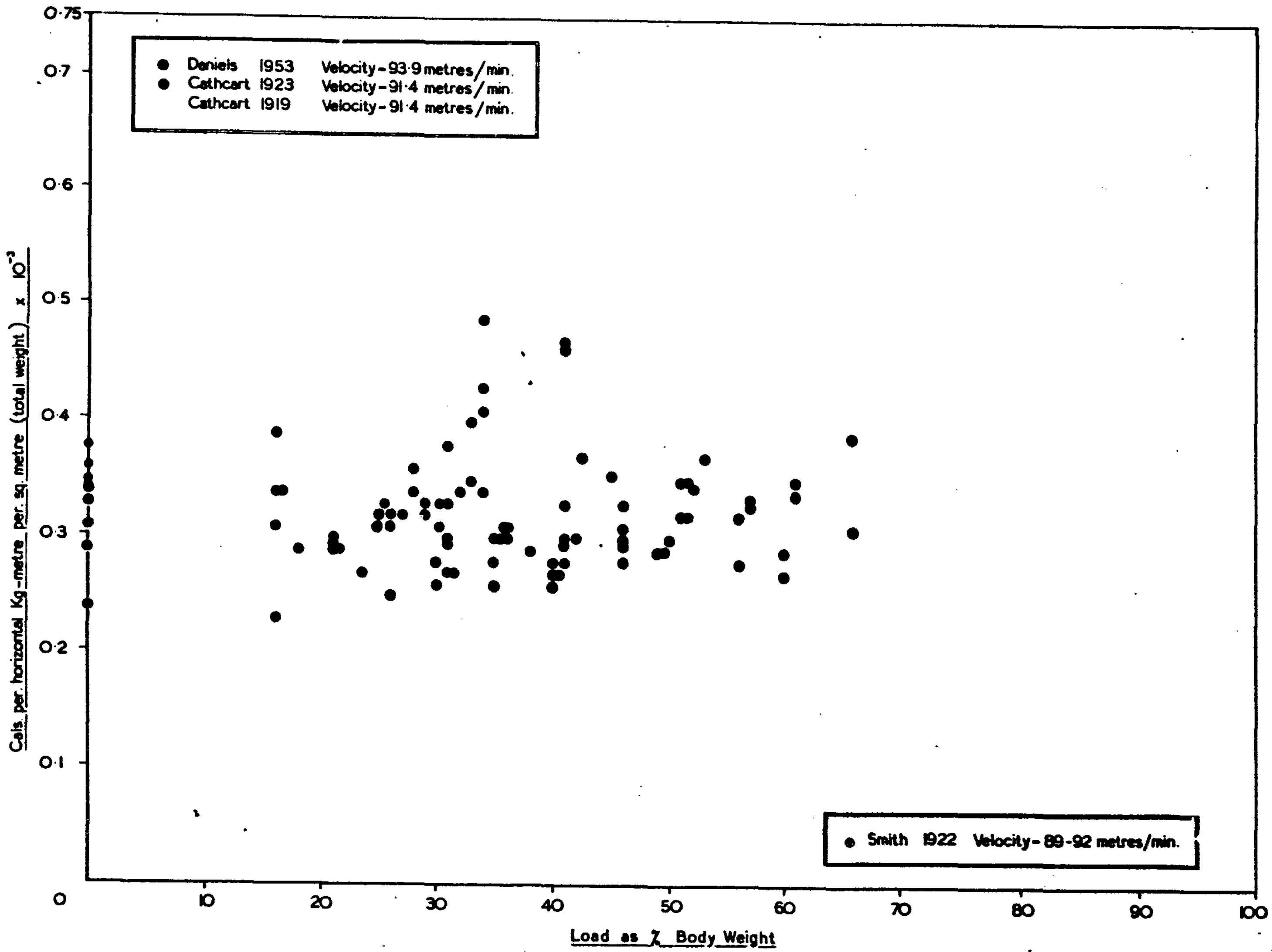
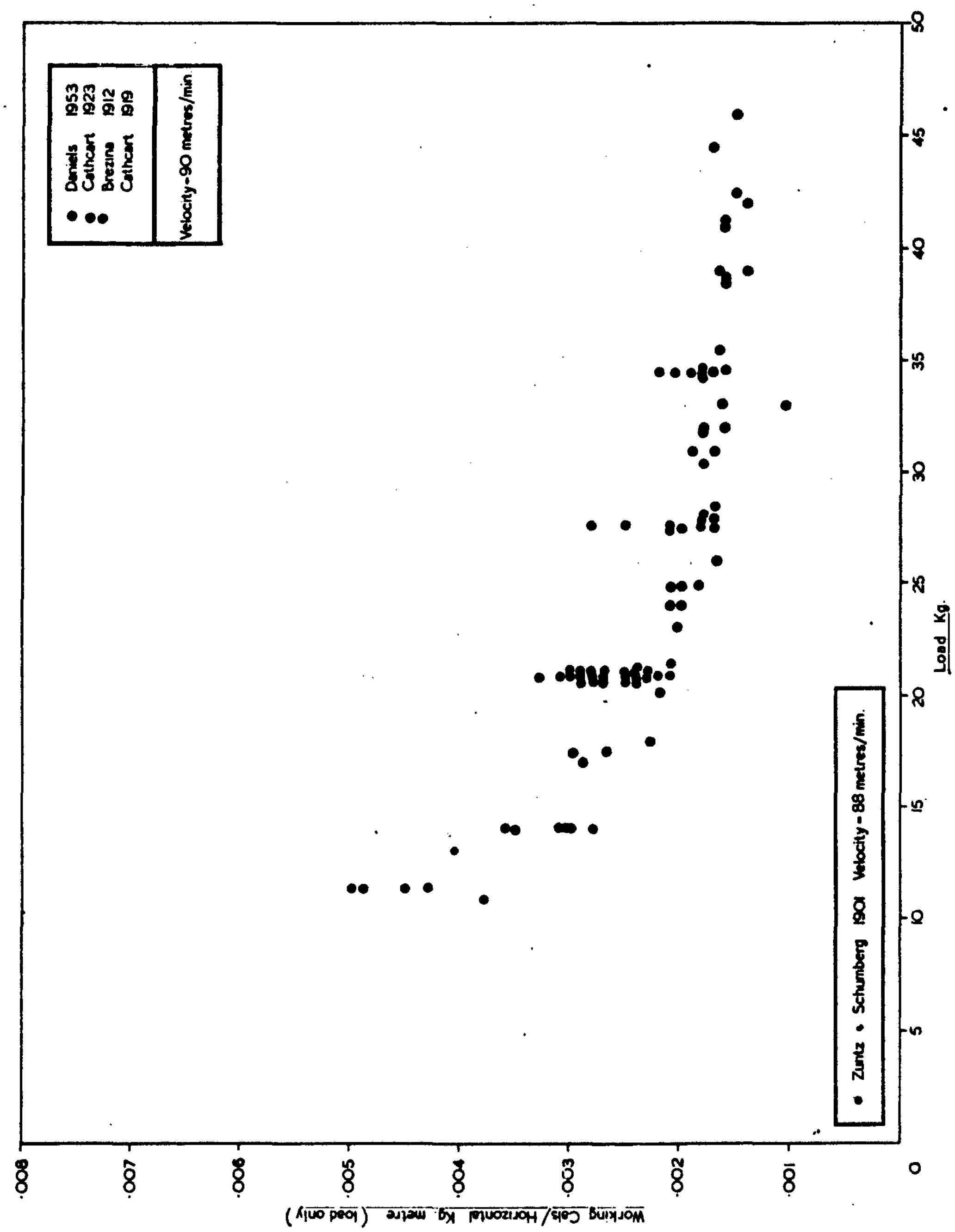
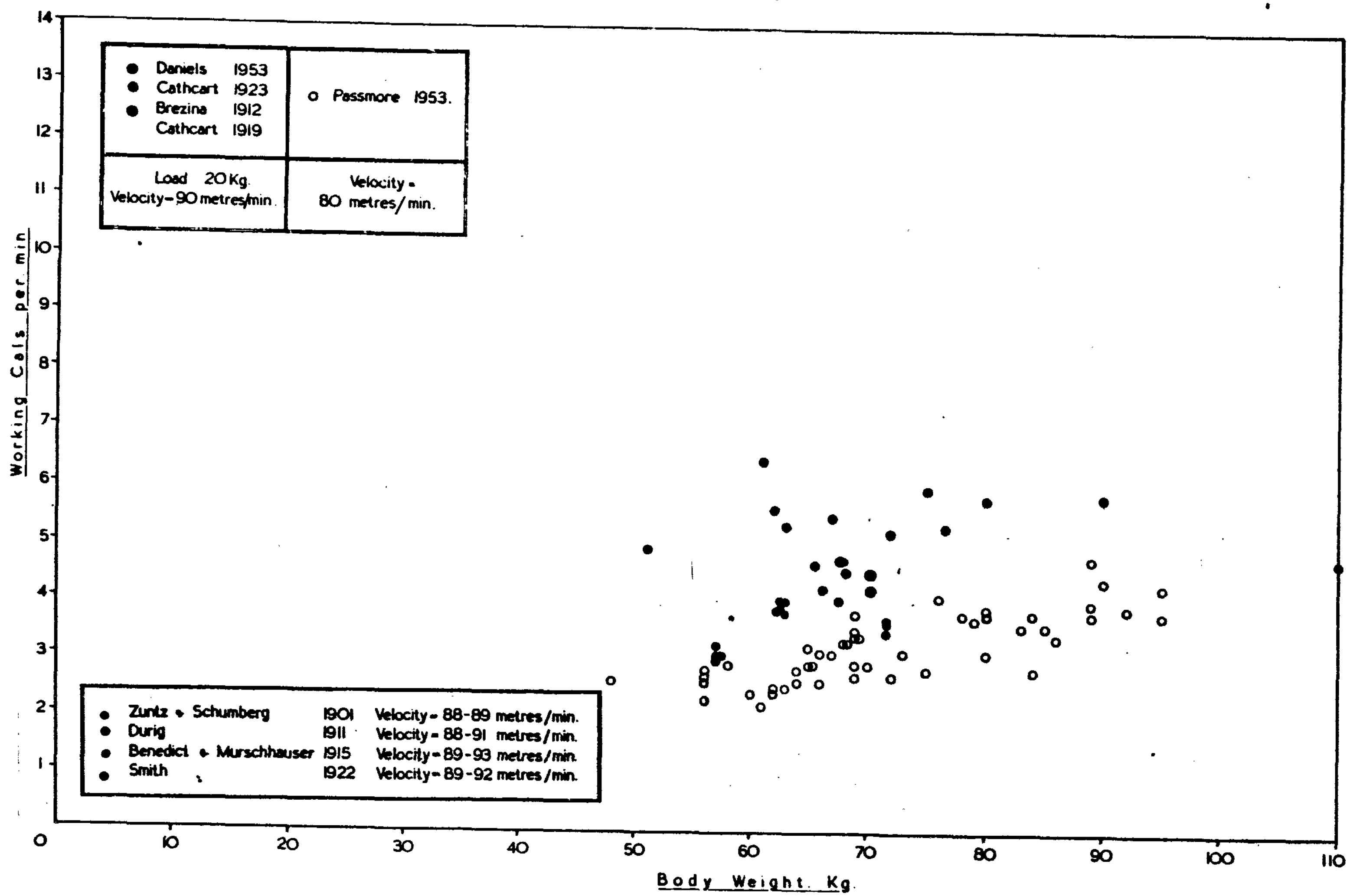

Daniels 1953 Velocity - 93·9 metres/min.
Cathcart 1923 Velocity - 91·4 metres/min.
Cathcart 1919 Velocity - 91·4 metres/min.
Smith 1922 Velocity - 89-92 metres/min.
Cals. per. horizontal Kg-metre per. sq. metre (total weight) x 10⁻³
0·75
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
10
20
30
40
50
60
70
80
90
100
Load as % Body Weight

FIG. 5

FIG. 6

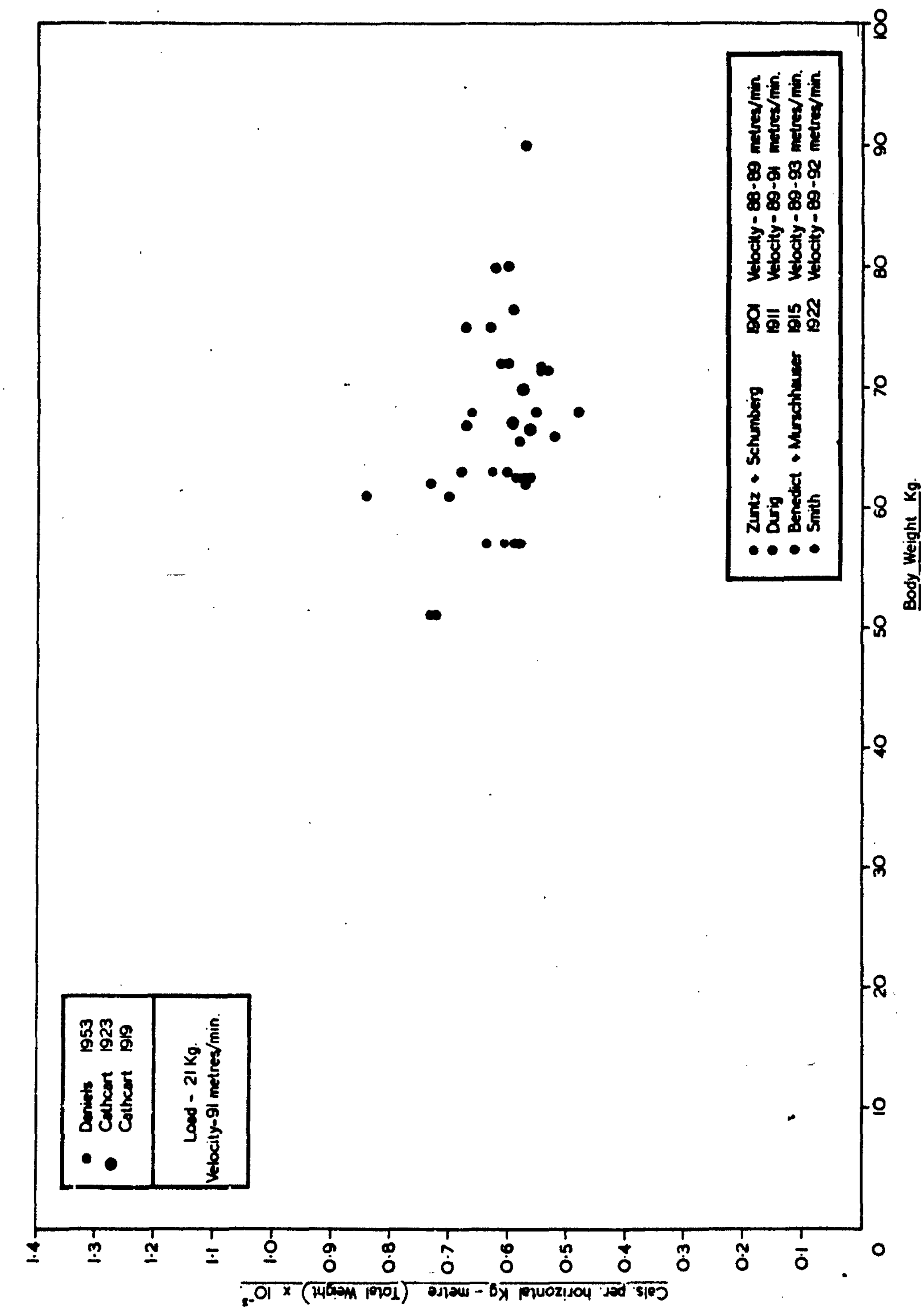

Daniels 1953
Cathcart 1923
Brezina 1912
Cathcart 1919
Velocity-90 metres/min.
Zuntz • Schumberg 1901 Velocity-88 metres/min.
Load Kg.
Working Cals/Horizontal Kg. metre (load only)
0
5
10
15
20
25
30
35
40
45
50
·001
·002
·003
·004
·005
·006
·007
·008



Daniels 1953
Cathcart 1923
Brezina 1912
Cathcart 1919
Load 20 Kg.
Velocity - 90 metres/min.
o Passmore 1953.
Velocity = 80 metres/min.
Zuntz + Schumberg 1901 Velocity = 88-89 metres/min.
Durig 1911 Velocity = 88-91 metres/min.
Benedict + Murschhauser 1915 Velocity = 89-93 metres/min.
Smith 1922 Velocity = 89-92 metres/min.
Working Cals per min
Body Weight. Kg.
0
10
20
30
40
50
60
70
80
90
100
110
1
2
3
4
5
6
7
8
9
10
11
12
13
14


FIG. 7

FIG. 8



Daniels 1953
Cathcart 1923
Cathcart 1919
Load - 21 Kg.
Velocity-91 metres/min.
Zuntz + Schumberg 1901 Velocity - 88-89 metres/min.
Durig 1911 Velocity - 89-91 metres/min.
Benedict + Murschhauser 1915 Velocity - 89-93 metres/min.
Smith 1922 Velocity - 89-92 metres/min.
Cals. per. horizontal Kg - metre (Total Weight) x 10^-3
Body Weight Kg.

FIG. 9

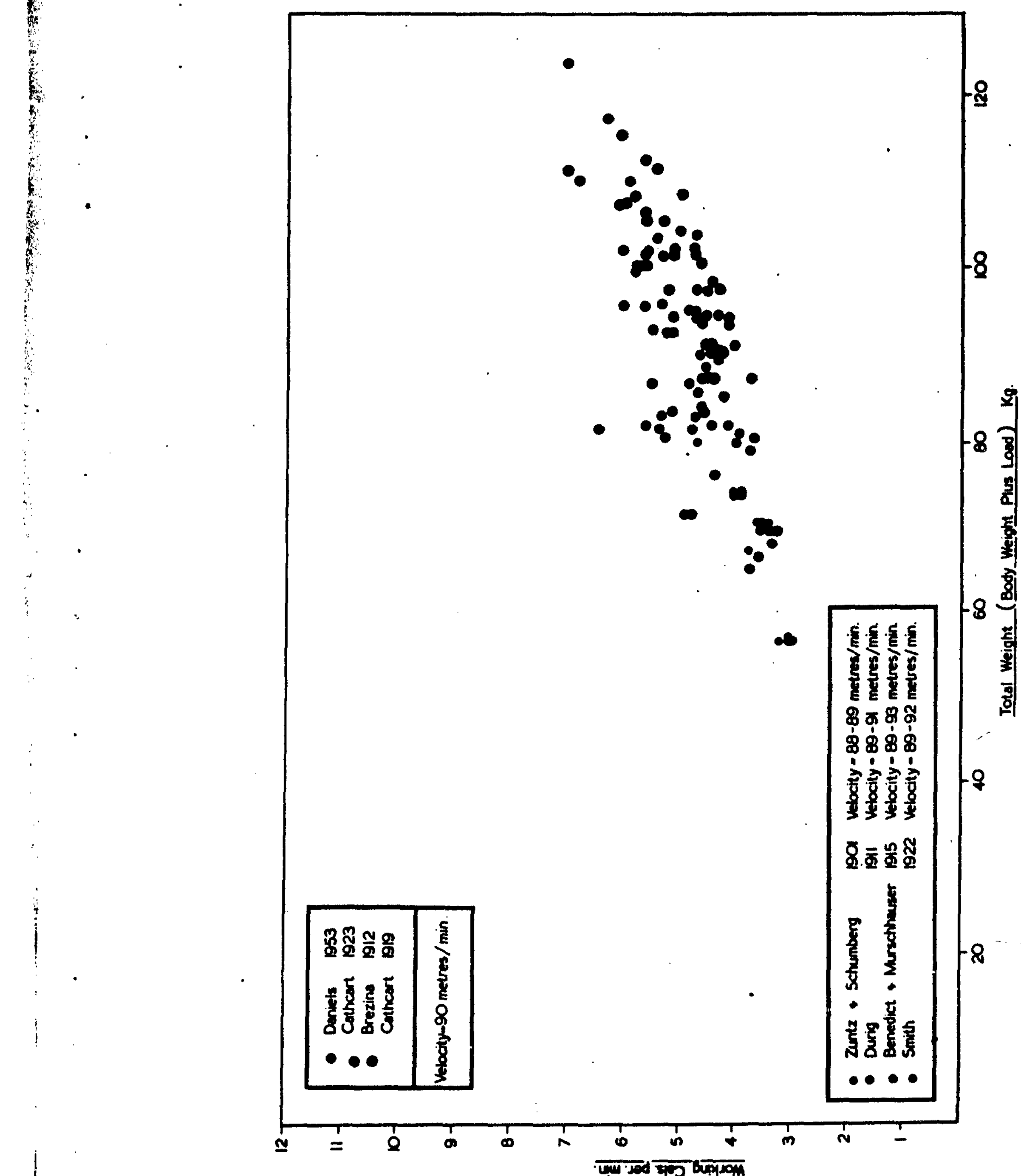

Daniels 1953
Cathcart 1923
Brezina 1912
Cathcart 1919
Velocity-90 metres/min.
Zuntz + Schumberg 1901 Velocity - 88-89 metres/min.
Durig 1911 Velocity - 89-91 metres/min.
Benedict + Murschhauser 1915 Velocity - 89-93 metres/min.
Smith 1922 Velocity - 89-92 metres/min.
Working Cals. per. min.
1
2
3
4
5
6
7
8
9
10
11
12
20
40
60
80
100
120
Total Weight (Body Weight Plus Load) Kg.

FIG. 10

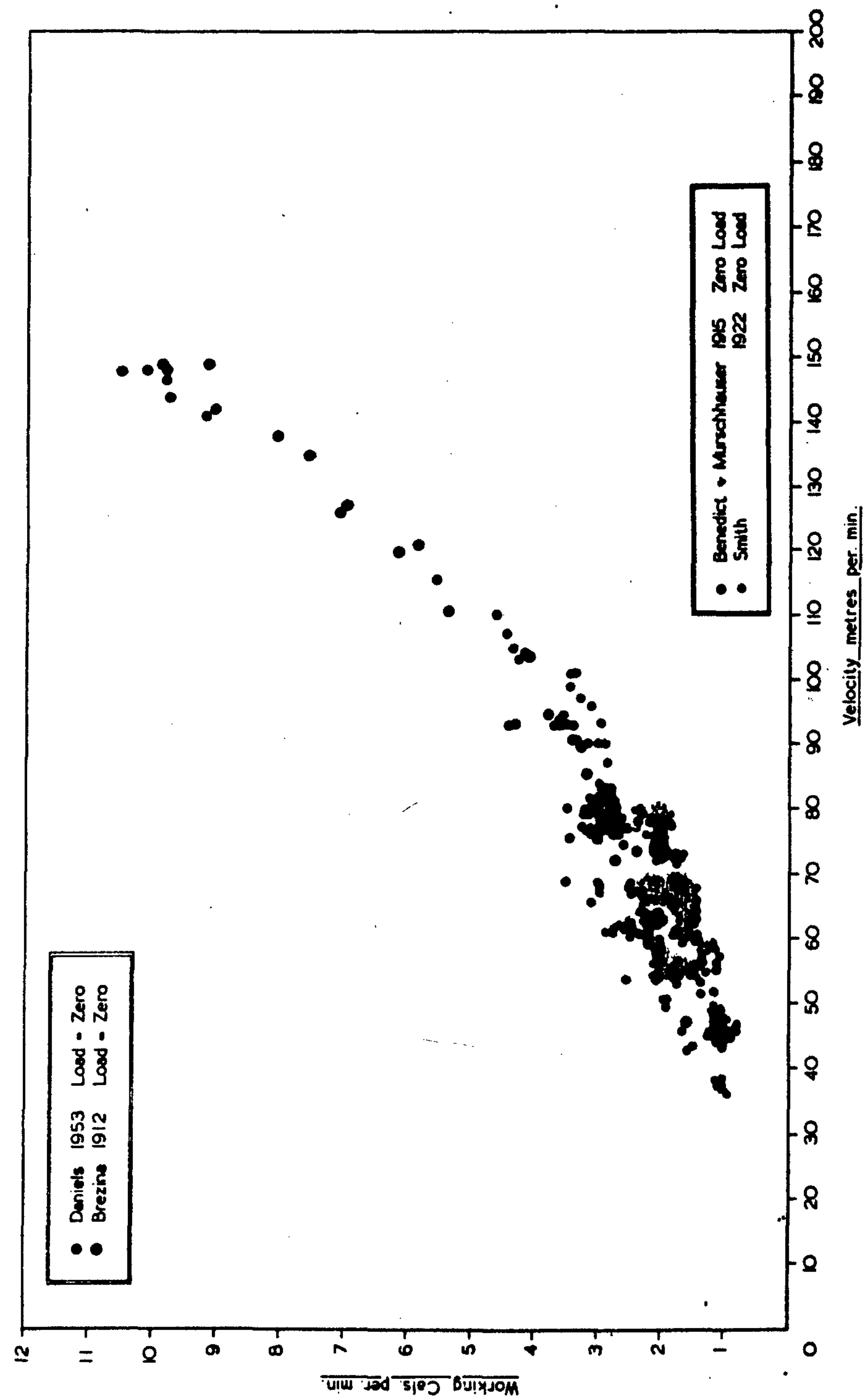
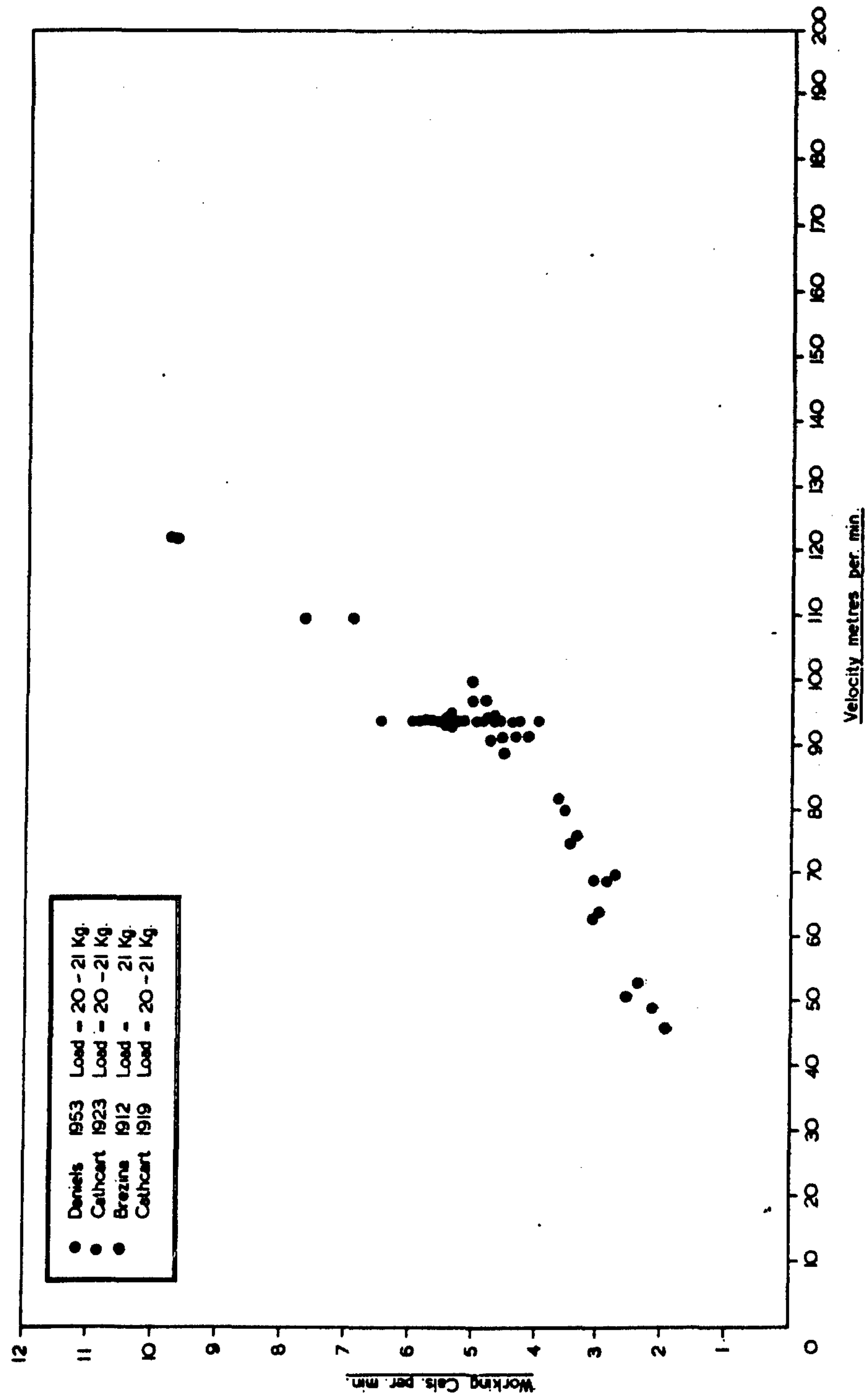

Daniels 1953 Load - Zero
Brezina 1912 Load - Zero
Benedict + Murschhauser 1915 Zero Load
Smith 1922 Zero Load
Working Cals. per min.
Velocity metres per min.

FIG. 11



Daniels 1953 Load = 20-21 Kg.
Cathcart 1923 Load = 20-21 Kg.
Brezina 1912 Load = 21 Kg.
Cathcart 1919 Load = 20-21 Kg.
Velocity metres per min.
Working Cals. per min.
0
1
2
3
4
5
6
7
8
9
10
11
12
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

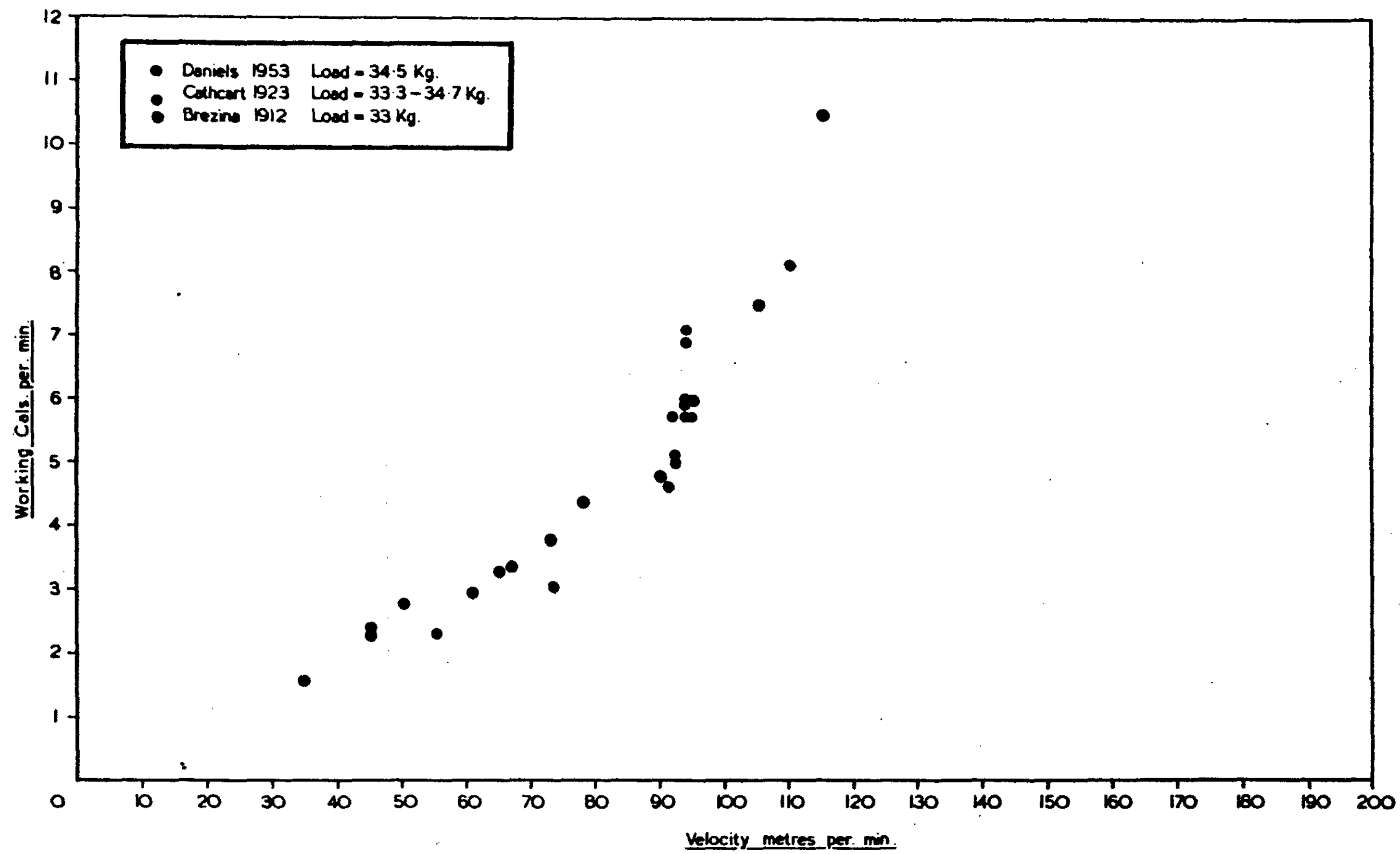

Daniels 1953 Load = 34·5 Kg.
Cathcart 1923 Load = 33·3 – 34·7 Kg.
Brezina 1912 Load = 33 Kg.
Working Cals. per. min.
Velocity metres per. min.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
1
2
3
4
5
6
7
8
9
10
11
12

FIG. 12

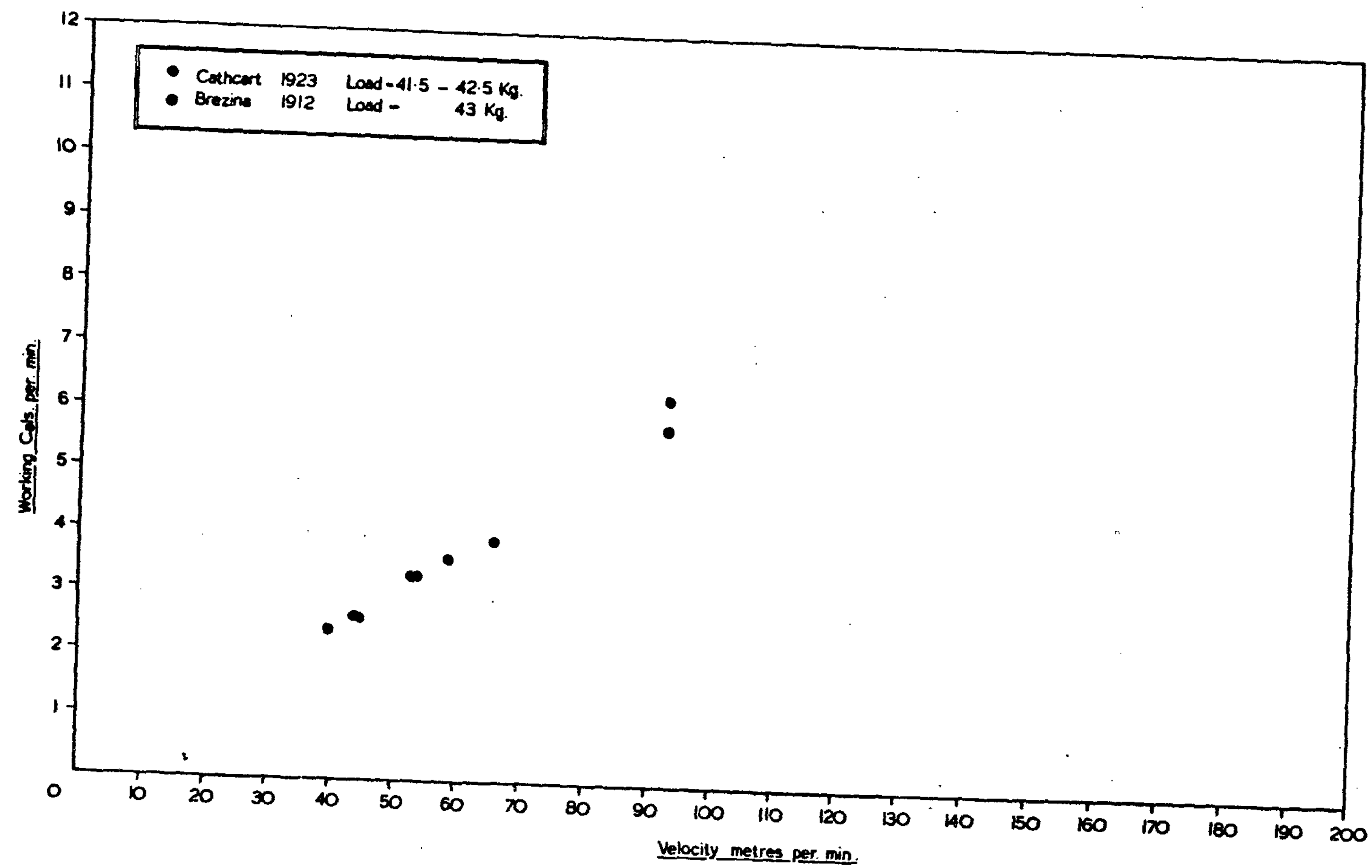
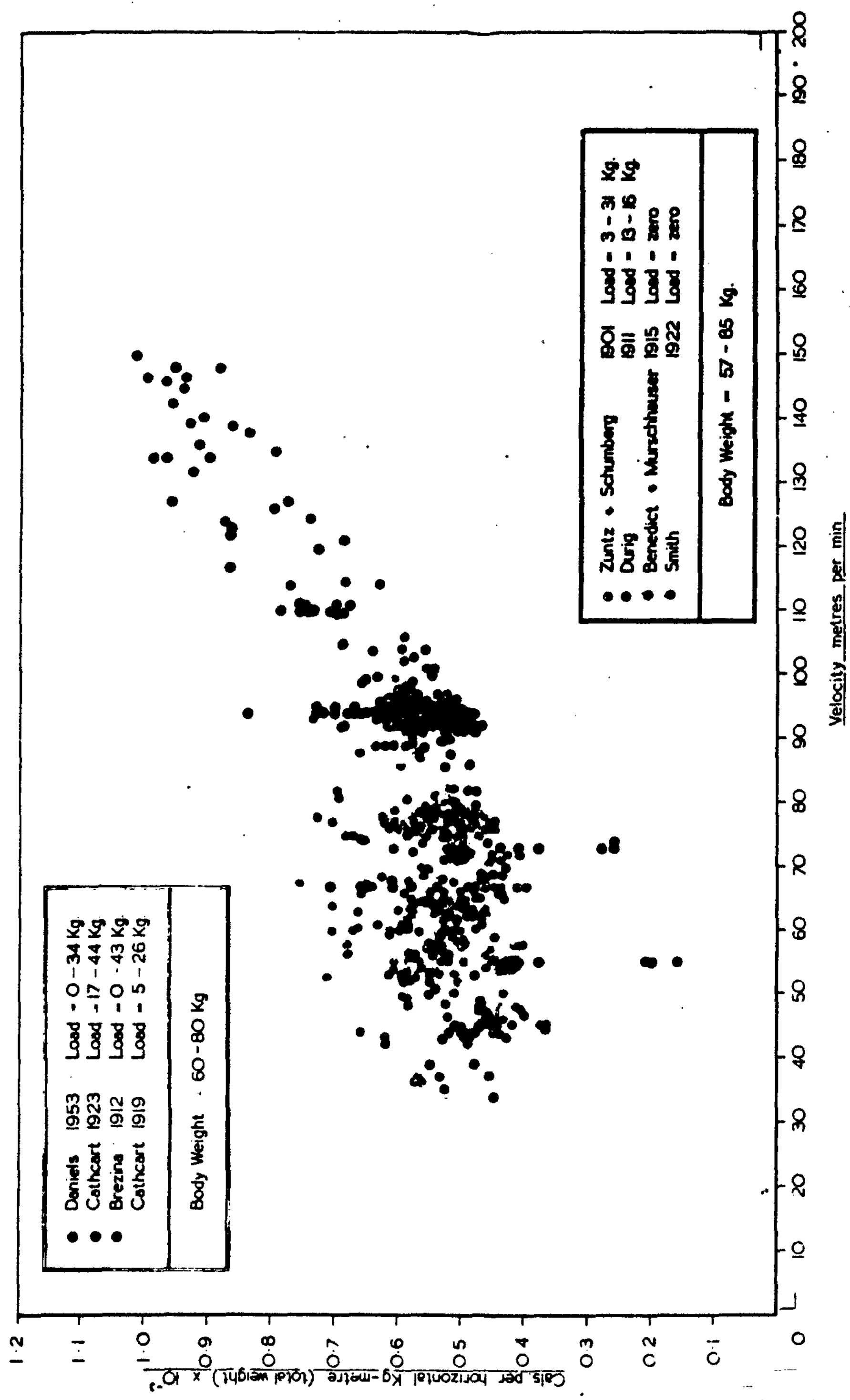

Cathcart 1923 Load - 41·5 – 42·5 Kg.
Brezina 1912 Load - 43 Kg.
Working Cals. per. min.
Velocity metres per. min.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
1
2
3
4
5
6
7
8
9
10
11
12

FIG. 13

FIG. 14



Zuntz + Schumberg 1901 Load - 3 - 31 Kg.
Durig 1911 Load - 13 - 16 Kg
Benedict + Murschhauser 1915 Load - zero
Smith 1922 Load - zero
Body Weight - 57 - 85 Kg.
Daniels 1953 Load - 0 - 34 Kg
Cathcart 1923 Load - 17 - 44 Kg
Brezina 1912 Load - 0 - 43 Kg
Cathcart 1919 Load - 5 - 26 Kg
Body Weight . 60-80 Kg
Velocity metres per min
Cals per horizontal Kg-metre (total weight) x 10⁻³
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2

## Predicted energy expenditure for a 50 Kilogram man walking on a horizontal track

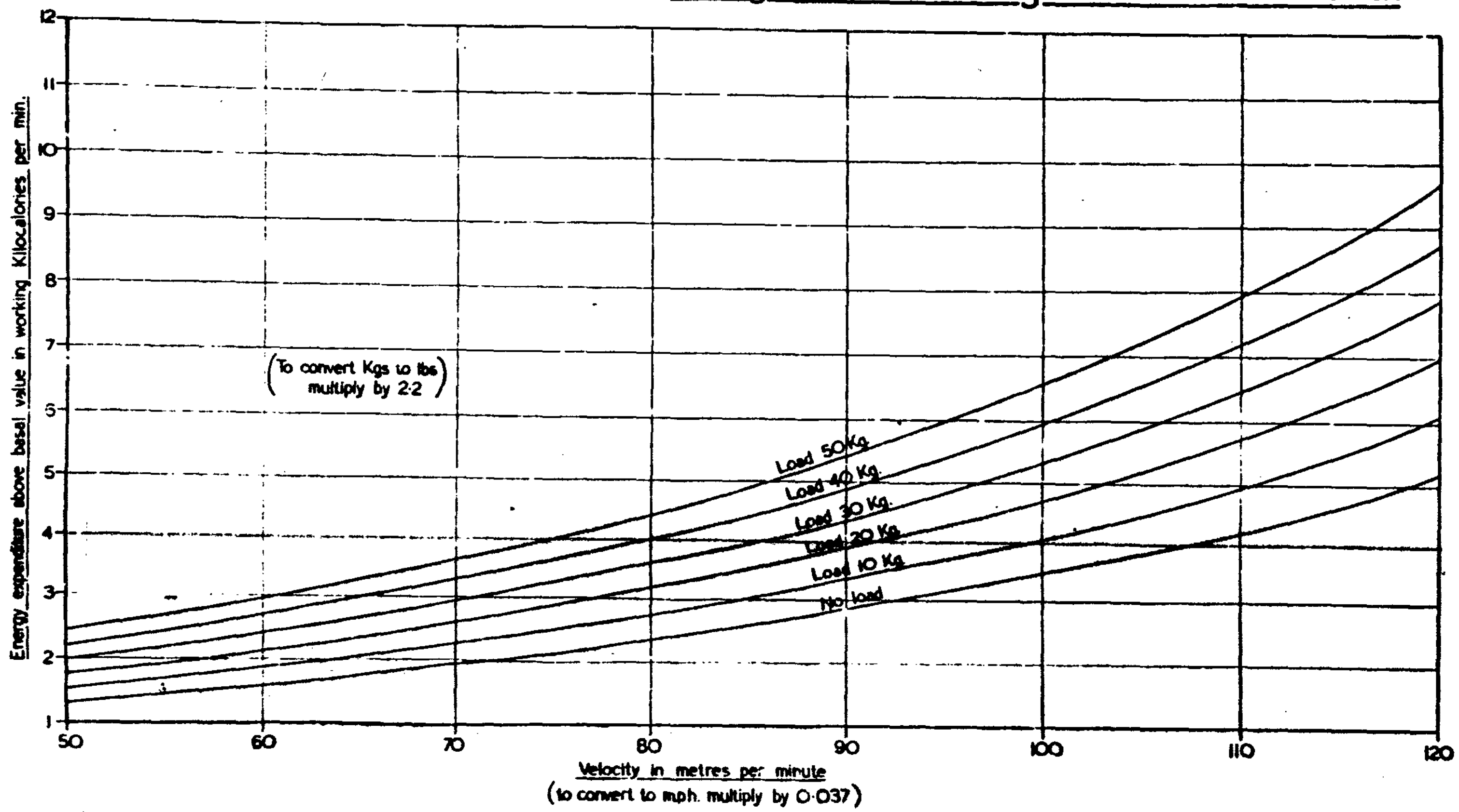



FIG. 15

## Predicted energy expenditure for a 60 Kilogram man walking on a horizontal track

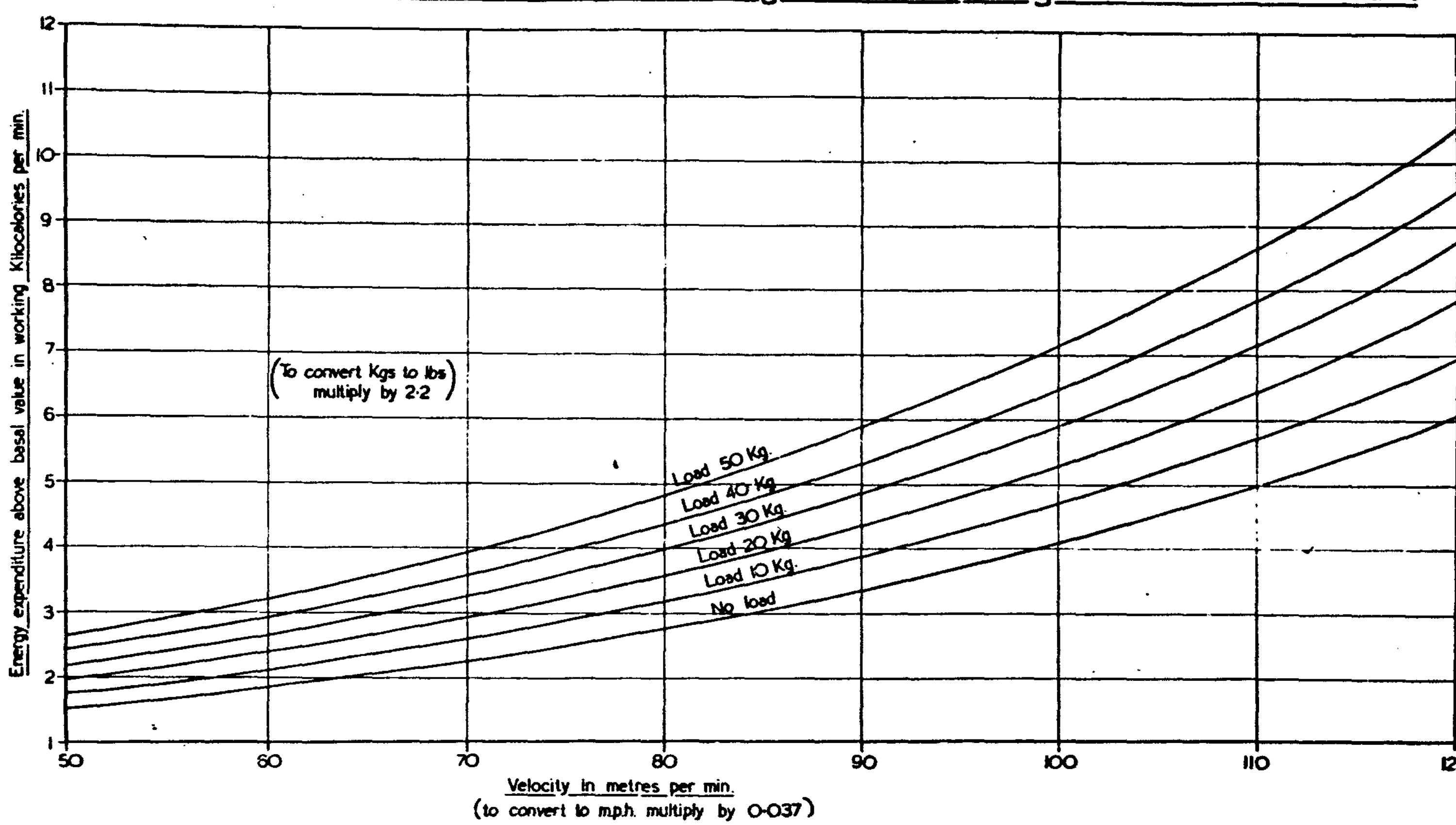
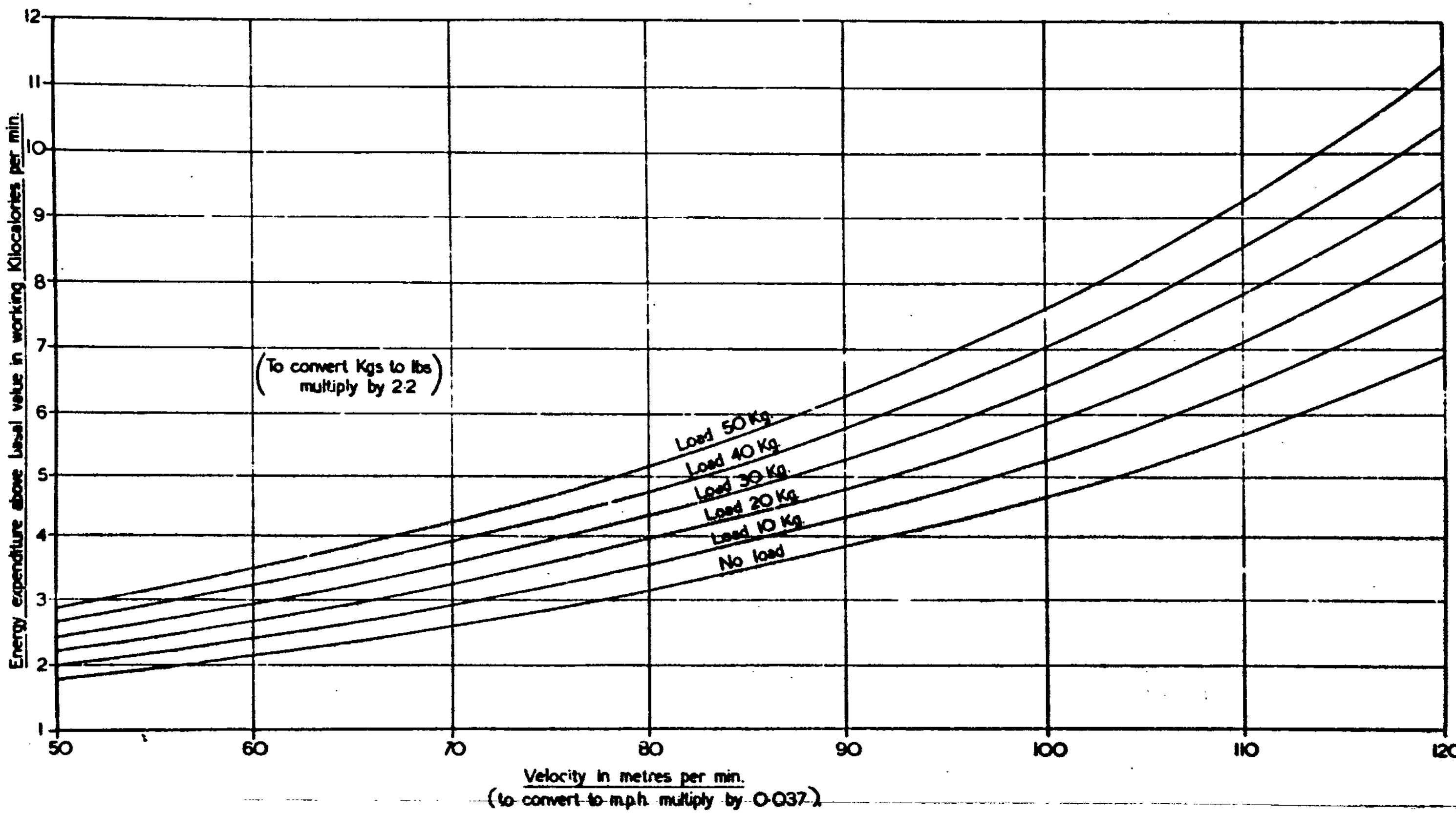



FIG. 16

FIG. 17

## Predicted energy expenditure for a 70 Kilogram man walking on a horizontal track



## Predicted energy expenditure for a 80 Kilogram man walking on a horizontal track

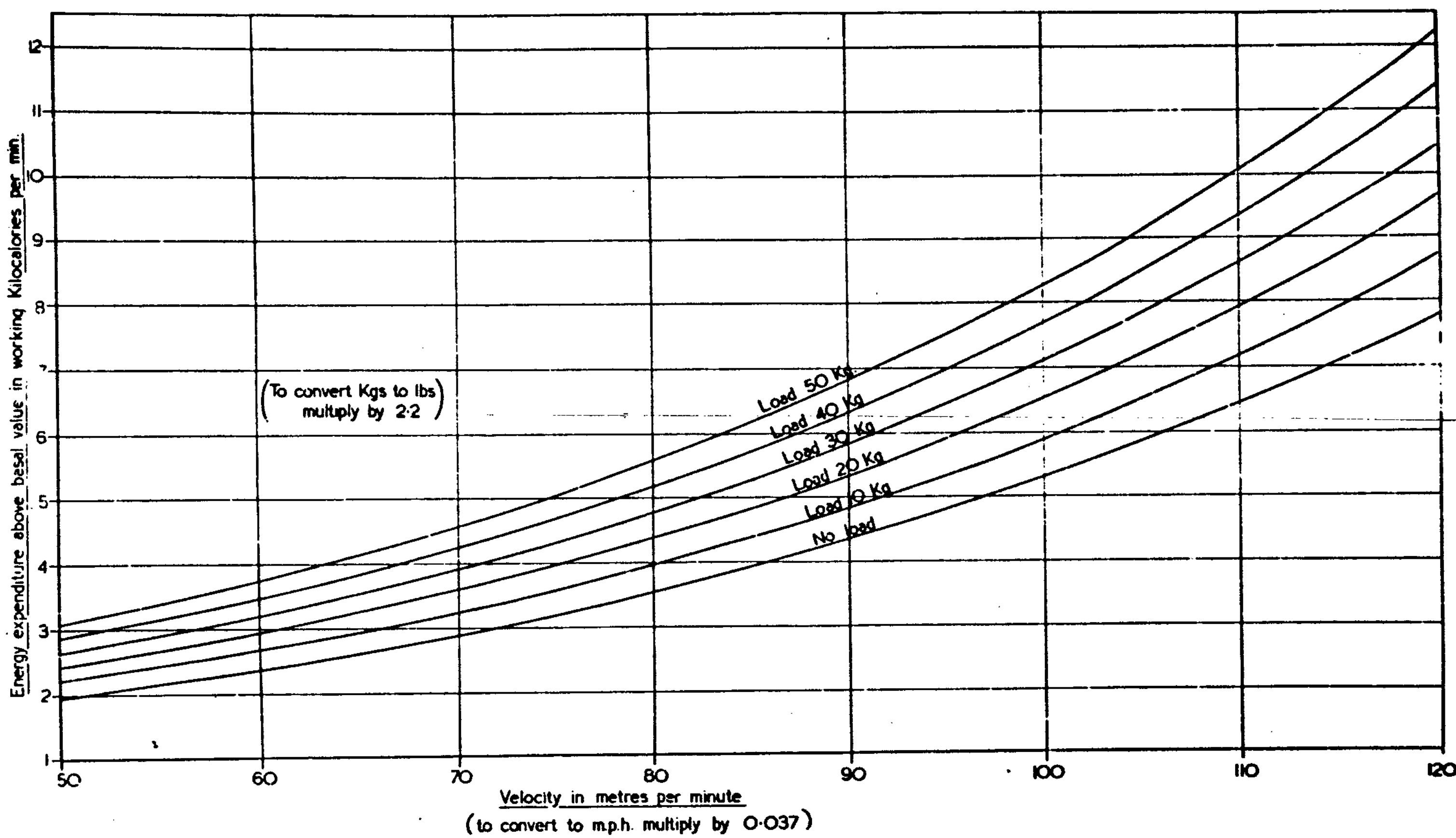



FIG. 18

FIG. 19

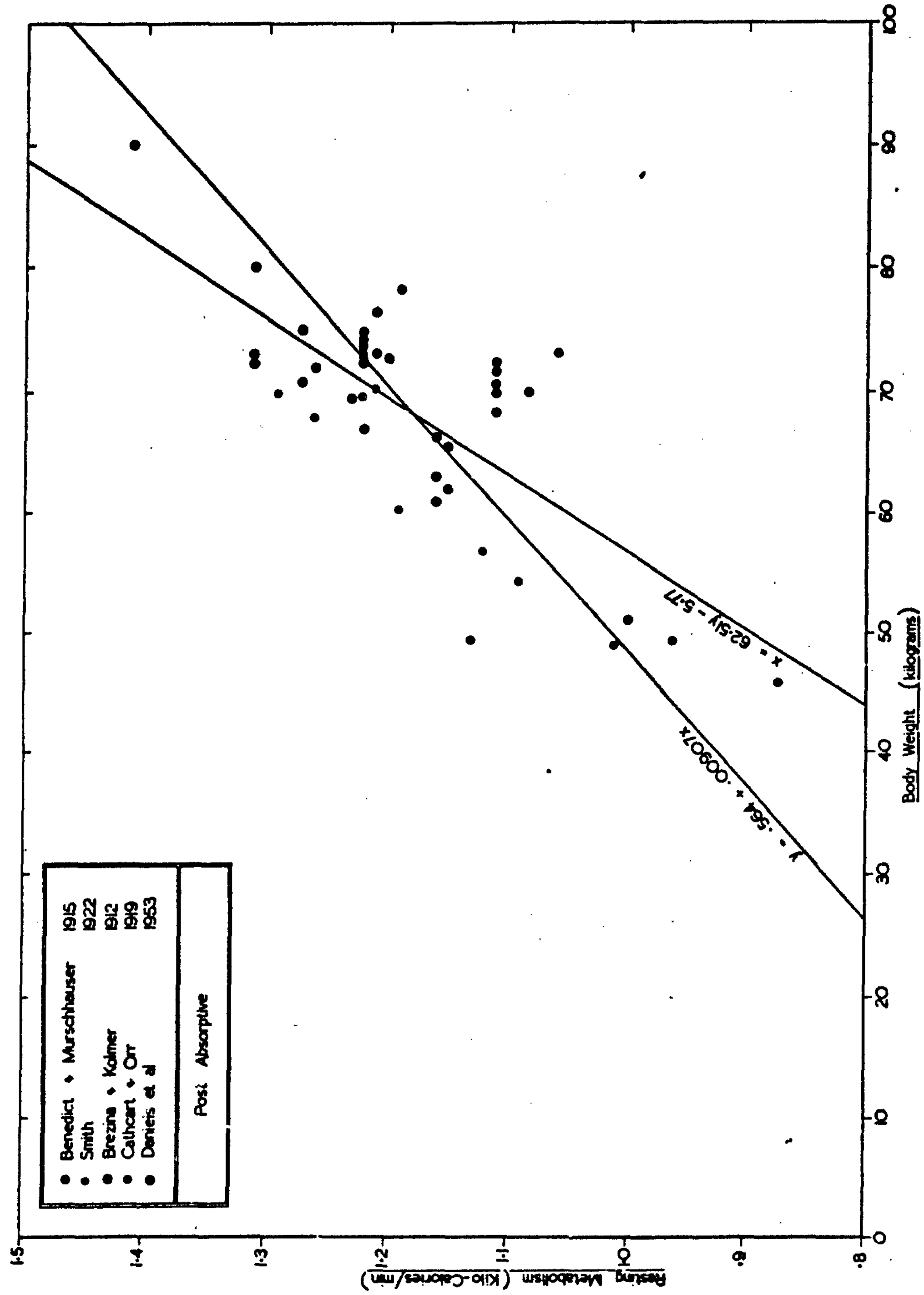
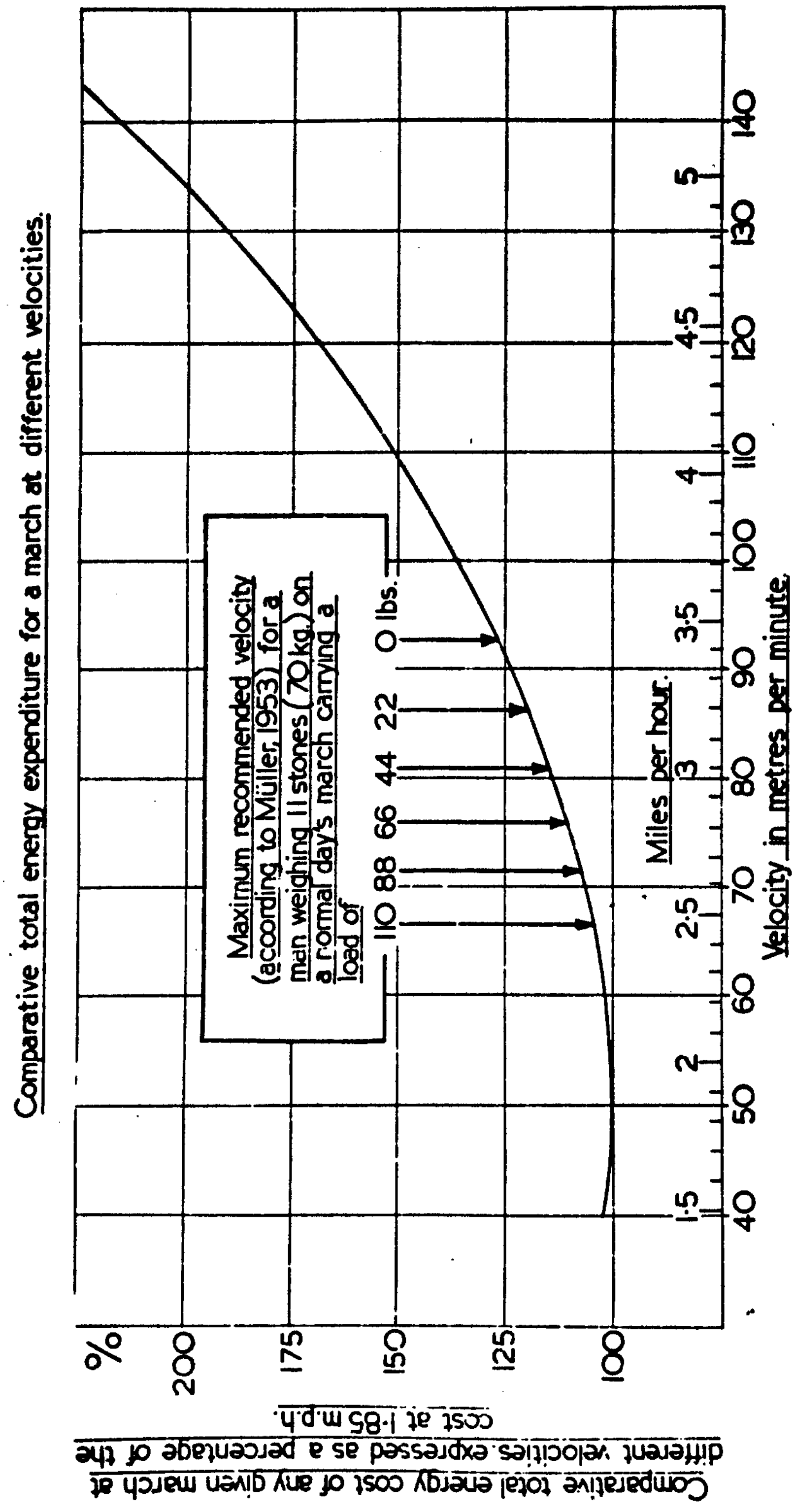

Benedict + Murschhauser 1915
Smith 1922
Brezina + Kolmer 1912
Cathcart + Orr 1919
Daniels et al 1953
Post Absorptive
y = ·564 + ·00907x
x = 62·51y − 5·77
Body Weight (kilograms)
Resting Metabolism (Kilo-Calories/min)

FIG. 20.



Comparative total energy expenditure for a march at different velocities.
Comparative total energy cost of any given march at different velocities expressed as a percentage of the cost at 1·85 m.p.h.
%
200
175
150
125
100
Maximum recommended velocity (according to Müller, 1953) for a man weighing 11 stones (70 kg.) on a normal day's march carrying a load of
110 88 66 44 22 0 lbs.
Miles per hour.
1·5
2
2·5
3
3·5
4
4·5
5
40
50
60
70
80
90
100
110
120
130
140
Velocity in metres per minute.

## Appendix A

### Summary of Experimental Data of Various Authors

A.1. This Appendix contains in tabular form the experimental results which have been presented graphically elsewhere in this report and which were used in the curve-fitting procedure outlined in Appendix B.

A.2. The data are unselected except that one or two authors have been omitted because their results were unknown to the writers at the time the present study was made.

A.3. All the experiments were made in temperate climates on adult male human subjects walking on the level, loads being carried on the back.

Appx. A

SUMMARY OF THE EXPERIMENTAL DATA

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting metabolism Kilo calories /min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Brezina & Kolmer 1912 | Brezina | 70 | nk | nk | 1.083≠ | Level rd. open air | 39.31 | 11.0 | PA+ |
| | | " | " | " | " | " | 43.54 | " | " |
| | | " | " | " | " | " | 46.97 | " | " |
| | | " | " | " | " | " | 58.96 | " | " |
| | | " | " | " | " | " | 69.01 | " | " |
| | | " | " | " | " | " | 76.96 | " | " |
| | | " | " | " | " | " | 82.12 | " | " |
| | | " | " | " | " | " | 86.21 | " | " |
| | | " | " | " | " | " | 88.36 | " | " |
| | | " | " | " | " | " | 97.36 | " | " |
| | | " | " | " | " | " | 97.38 | " | " |
| | | " | " | " | " | " | 99.2 | " | " |
| | | " | " | " | " | " | 111.0 | " | " |
| | | " | " | " | " | " | 124.0 | " | " |
| | | " | " | " | " | " | 131.87 | " | " |
| | | " | " | " | " | " | 135.54 | " | " |
| " | " | 70 | nk | nk | 1.083≠ | Level rd. open air | 38.92 | 43.0 | PA + |
| | | " | " | " | " | " | 43.16 | " | " |
| | | " | " | " | " | " | 44.08 | " | " |
| | | " | " | " | " | " | 52.25 | " | " |
| | | " | " | " | " | " | 52.69 | " | " |
| | | " | " | " | " | " | 57.89 | " | " |
| | | " | " | " | " | " | 65.26 | " | " |
| " | " | 70 | nk | nk | 1.083≠ | Level rd. open air | 34.5 | 33.0 | PA+ |
| | | " | " | " | " | " | 44.82 | " | " |
| | | " | " | " | " | " | 45.28 | " | " |
| | | " | " | " | " | " | 49.76 | " | " |
| | | " | " | " | " | " | 61.45 | " | " |
| | | " | " | " | " | " | 64.60 | " | " |
| | | " | " | " | " | " | 67.22 | " | " |
| | | " | " | " | " | " | 72.85 | " | " |
| | | " | " | " | " | " | 77.71 | " | " |
| | | " | " | " | " | " | 90.34 | " | " |
| | | " | " | " | " | " | 95.21 | " | " |
| | | " | " | " | " | " | 105.10 | " | " |
| | | " | " | " | " | " | 116.98 | " | " |
| | | | | nk = not known | ≠ Assumed; an arbitrary level based on exp. results | | | | + 1 Cup of tea |

| (9) R.Q. | (10) Rate of total energy expenditure Kilo-calories /min | (11) (15 ÷ 3) Working-Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working-Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7 \times 6)}\right)$ Working-gram-calories per horizontal metre - Kilogram (Total weight of body plus load) | (14) $\left(\frac{15}{7 \times 6}\right)$ Working-Kilo-calories per horizontal metre - Kilogram (Load only) | (15) (10 - 4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| .73 | 2.613 | nk | .0219 | 0.48 | .0035 | 1.53 |
| | | | | | | |
| .82 | 2.843 | " | .0252 | 0.50 | .0037 | 1.76 |
| .83 | 2.833 | " | .0250 | 0.46 | .0034 | 1.75 |
| .73 | 3.233 | " | .0307 | 0.45 | .0033 | 2.15 |
| .76 | 3.603 | " | .0360 | 0.45 | .0033 | 2.52 |
| .72 | 3.893 | " | .0402 | 0.45 | .0033 | 2.81 |
| .74 | 4.273 | " | .0456 | 0.48 | .0035 | 3.19 |
| .74 | 4.503 | " | .0489 | 0.49 | .0036 | 3.42 |
| .73 | 4.803 | " | .0532 | 0.52 | .0038 | 3.72 |
| .74 | 5.733 | " | .0664 | 0.59 | .0043 | 4.65 |
| .78 | 5.733 | " | .0664 | 0.59 | .0043 | 4.65 |
| .75 | 5.743 | " | .0666 | 0.58 | .0043 | 4.66 |
| .74 | 7.193 | " | .0873 | 0.68 | .0050 | 6.11 |
| .78 | 9.923 | " | .1263 | 0.88 | .0065 | 8.84 |
| .79 | 10.413 | " | .1333 | 0.93 | .0064 | 9.33 |
| .94 | 11.183 | " | .1442 | 0.92 | .0068 | 10.10 |
| | | | | | | |
| .78 | 3.503 | nk | .0346 | 0.55 | .0015 | 2.42 |
| | | | | | | |
| .81 | 3.663 | " | .0369 | 0.53 | .0014 | 2.58 |
| .76 | 3.673 | " | .0370 | 0.52 | .0014 | 2.59 |
| .79 | 4.333 | " | .0464 | 0.55 | .0015 | 3.25 |
| .80 | 4.353 | " | .0467 | 0.55 | .0015 | 3.27 |
| .83 | 4.683 | " | .0514 | 0.55 | .0015 | 3.60 |
| .72 | 4.993 | " | .0559 | 0.53 | .0014 | 3.91 |
| | | | | | | |
| .79 | 2.682 | nk | .0228 | 0.45 | .0014 | 1.599 |
| | | | | | | |
| .77 | 3.433 | " | .0336 | 0.51 | .0016 | 2.35 |
| .83 | 3.414 | " | .0333 | 0.50 | .0016 | 2.331 |
| .76 | 3.903 | " | .0403 | 0.55 | .0017 | 2.82 |
| .80 | 4.053 | " | .0424 | 0.47 | .0015 | 2.97 |
| .74 | 4.413 | " | .0475 | 0.50 | .0016 | 3.33 |
| .76 | 4.473 | " | .0485 | 0.49 | .0015 | 3.39 |
| .76 | 4.913 | " | .0548 | 0.51 | .0016 | 3.83 |
| .73 | 5.483 | " | .0628 | 0.55 | .0017 | 4.40 |
| .77 | 5.923 | " | .0692 | 0.52 | .0016 | 4.84 |
| .78 | 7.063 | " | .0855 | 0.61 | .0019 | 5.98 |
| .85 | 8.553 | " | .1067 | 0.69 | .0022 | 7.47 |
| .96 | 11.563 | " | .1497 | 0.87 | .0027 | 10.48 |

Appx. A

| Reference | Subject | (1) Weight<br>Kgm | (2) Height<br>Cm | (3) Surface Area<br>Square metres | (4) Resting Metabolism<br>Kilo calories/min | (5) Conditions | (6) Rate of walking<br>Metres/min | (7) Load<br>Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Brezina & Kolmer 1912. | Brezina | 70 | nk | nk | 1.083/ | Level rd open air | 48.4 | ZERO | PA+ |
| | | " | " | " | " | " | 59.67 | " | " |
| | | " | " | " | " | " | 61.93 | " | " |
| | | " | " | " | " | " | 73.37 | " | " |
| | | " | " | " | " | " | 74.25 | " | " |
| | | " | " | " | " | " | 75.61 | " | " |
| | | " | " | " | " | " | 85.95 | " | " |
| | | " | " | " | " | " | 90.08 | " | " |
| | | " | " | " | " | " | 90.74 | " | " |
| | | " | " | " | " | " | 94.41 | " | " |
| | | " | " | " | " | " | 95.43 | " | " |
| | | " | " | " | " | " | 103.60 | " | " |
| | | " | " | " | " | " | 110.90 | " | " |
| | | " | " | " | " | " | 120.30 | " | " |
| | | " | " | " | " | " | 121.1 | " | " |
| | | " | " | " | " | " | 126.1 | " | " |
| | | " | " | " | " | " | 127.4 | " | " |
| | | " | " | " | " | " | 134.8 | " | " |
| | | " | " | " | " | " | 137.8 | " | " |
| | | " | " | " | " | " | 147.6 | " | " |
| | | " | " | " | " | " | 148.1 | " | " |
| " | " | 70 | nk | nk | 1.083/ | Level rd open air | 45.62 | 21.0 | PA+ |
| | | " | " | " | " | " | 49.38 | " | " |
| | | " | " | " | " | " | 50.54 | " | " |
| | | " | " | " | " | " | 53.04 | " | " |
| | | " | " | " | " | " | 62.84 | " | " |
| | | " | " | " | " | " | 64.37 | " | " |
| | | " | " | " | " | " | 68.89 | " | " |
| | | " | " | " | " | " | 69.23 | " | " |
| | | " | " | " | " | " | 69.75 | " | " |
| | | " | " | " | " | " | 74.81 | " | " |
| | | " | " | " | " | " | 76.46 | " | " |
| | | " | " | " | " | " | 80.00 | " | " |
| | | " | " | " | " | " | 81.58 | " | " |
| | | " | " | " | " | " | 88.78 | " | " |
| | | " | " | " | " | " | 96.58 | " | " |
| | | " | " | " | " | " | 96.87 | " | " |
| | | " | " | " | " | " | 99.64 | " | " |
| | | " | " | " | " | " | 110.0 | " | " |
| | | " | " | " | " | " | 110.30 | " | " |
| | | " | " | " | " | " | 121.60 | " | " |
| | | " | " | " | " | " | 121.60 | " | " |
| | | | nk = not known | | /Assumed, arbitrary | | | | +1 Cup of tea |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 5) | (15 ÷ 1) | $\left(\frac{15}{(1+7)x6}\right)$ | $\left(\frac{15}{7 \times 6}\right)$ | (10 - 4) |
| R.Q. | Rate of total energy expenditure Kilo-calories /min | Working-Kilo-calories per square metre per minute | Working-Kilo-calories per Kilogram of body weight | Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | Working-Kilo-calories per horizontal metre-Kilogram (Load only) | Working-Kilo-calories expended per minute |
| .78 | 2.673 | nk | .0227 | 0.47 | ∞ | 1.59 |
| .78 | 3.253 | " | .0310 | 0.52 | " | 2.17 |
| .74 | 3.293 | " | .0316 | 0.51 | " | 2 21 |
| .74 | 3.753 | " | .0361 | 0.52 | " | 2.67 |
| .80 | 3.473 | " | .0342 | 0.46 | " | 2.39 |
| .70 | 4.103 | " | .0432 | 0.57 | " | 3.02 |
| .67 | 4.273 | " | .0456 | 0.53 | " | 3.19 |
| .76 | 4.423 | " | .0477 | 0.53 | " | 3.34 |
| .75 | 4.513 | " | .0490 | 0.54 | " | 3.43 |
| .73 | 4.653 | " | .0510 | 0.54 | " | 3.57 |
| .71 | 4.893 | " | .0544 | 0.57 | " | 3.81 |
| .73 | 5.143 | " | .0540 | 0.56 | " | 4.06 |
| .74 | 6.513 | " | .0776 | 0.70 | " | 5.43 |
| .75 | 7.233 | " | .0879 | 0.77 | " | 6.15 |
| .74 | 6.933 | " | .0836 | 0.69 | " | 5.85 |
| .84 | 8.143 | " | .1008 | 0.80 | " | 7.06 |
| .74 | 8.043 | " | .0994 | 0.76 | " | 6.96 |
| .78 | 8.633 | " | .1079 | 0.80 | " | 7.55 |
| .84 | 9.183 | " | .1157 | 0.84 | " | 8.10 |
| .85 | 11.003 | " | .1417 | 0.96 | " | 9.92 |
| .89 | 10.313 | " | .1319 | 0.89 | " | 9.23 |
| .77 | 2.992 | nk | .0273 | 0.46 | .0020 | 1.909 |
| .76 | 3.193 | " | .0301 | 0.47 | .0020 | 2.11 |
| .77 | 3.563 | " | .0354 | 0.54 | .0023 | 2.48 |
| .78 | 3.403 | " | .0331 | 0.48 | .0021 | 2.32 |
| .73 | 4.053 | " | .0424 | 0.52 | .0023 | 2.97 |
| .73 | 4.013 | " | .0419 | 0.50 | .0022 | 2.93 |
| .73 | 3.843 | " | .0394 | 0.44 | .0019 | 2.76 |
| .73 | 4.043 | " | .0423 | 0.47 | .0020 | 2.96 |
| .79 | 3.813 | " | .0390 | 0.43 | .0019 | 2.73 |
| .71 | 4.483 | " | .0486 | 0.53 | .0022 | 3.40 |
| .79 | 4.353 | " | .0467 | 0.48 | .0020 | 3.27 |
| .75 | 4.573 | " | .0499 | 0.48 | .0021 | 3.49 |
| .79 | 4.723 | " | .0520 | 0.49 | .0021 | 3.64 |
| .73 | 5.603 | " | .0646 | 0.56 | .0024 | 4.52 |
| .73 | 6.093 | " | .0716 | 0.57 | .0025 | 5.01 |
| .83 | 5.843 | " | .0680 | 0.54 | .0023 | 4.76 |
| .86 | 6.073 | " | .0713 | 0.55 | .0024 | 4.99 |
| .82 | 8.693 | " | .1087 | 0.76 | .0033 | 7.61 |
| .79 | 8.01 | " | .0990 | 0.69 | .0030 | 6.93 |
| .85 | 10.713 | " | .138 | 0.87 | .0038 | 9.63 |
| .83 | 10.713 | " | .138 | 0.87 | .0038 | 9.63 |

Appx. A

| Reference | Subject | (1) Weight | (2) Height | (3) Surface Area | (4) Resting metabolism | (5) Conditions | (6) Rate of walking | (7) Load | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| | | Kgm | Cm | Square metres | Kilo-calories/min | | Metres /min. | Kgm | |
| Cathcart & Orr 1919 | A | 78.2 | 174.6 | 1.94 | 1.19 AM (Lying) | Level road | 91.4 | 15.3 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| " | C | 46.0 | 153.0 | 1.40 | .872PA | Level road | 91.4 | 20.5 | PA |
| | | " | " | " | 0.872 | " | " | " | PA |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 0.872 | " | " | 25 | PA |
| | | " | " | " | 0.872 | " | " | " | PA |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| | | " | " | " | 1.01 | " | " | " | AM |
| " | E | 73.2 | 176.5 | 1.89 | 1.06PA | Level road | 91.4 | 20.5 | PA |
| | | " | " | " | 1.3 | " | 91.4 | " | AM |
| | | " | " | " | 1.3 | " | 91.4 | " | AM |
| | | " | " | " | 1.06 | " | 91.4 | 25.0 | PA |
| " | D | 64.1 | 173.4 | 1.77 | 1.28AM | Level road | 91.4 | 20.5 | AM |
| | | " | " | " | " | " | 91.4 | " | AM |
| " | G | 70.5 | 173.4 | 1.88 | 1.60AM | Level road | 91.4 | 20.5 | AM |
| " | F | 49.5 | 163.2 | 1.52 | 0.96PA | Level road | 91.4 | 20.5 | PA |
| | | " | " | " | 1.13AM | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | 25 | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| " | H | 60.0 | 168.2 | 1.68 | 1.15PA | Level road | 91.4 | 15.3 | AM |
| | | " | " | " | 1.31AM | " | " | " | AM |
| | | " | " | " | " | " | " | 20.5 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 25.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |

| (9) R.Q. | (10) Rate of total energy expenditure Kilocalories/min | (11) (15 ÷ 3) Working-Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working-Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7)x6}\right)$ Working-gram-calories per horizontal metre - Kilogram (Total weight of body plus load) | (14) $\left(\frac{15}{7 \times 6}\right)$ Working-Kilo-calories per horizontal metre - Kilogram (Load only) | (15) (10 - 4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| 0.77 | 6.56 | 2.77 | 0.069 | 0.63 | .00384 | 5.37 |
| 0.84 | 5.96 | 2.46 | 0.061 | 0.56 | .00341 | 4.77 |
| 0.73 | 7.34 | 3.17 | 0.079 | 0.61 | .00269 | 6.15 |
| 0.74 | 6.64 | 2.81 | 0.070 | 0.54 | .00239 | 5.45 |
| 0.82 | 7.22 | 3.11 | 0.077 | 0.59 | .00264 | 6.03 |
| 0.76 | 6.89 | 2.94 | 0.073 | 0.56 | .00249 | 5.70 |
| .82 | 5.10 | 3.02 | 0.092 | 0.70 | .00226 | 4.23 |
| .83 | 4.28 | 2.44 | 0.074 | 0.56 | .00182 | 3.41 |
| .85 | 5.47 | 3.19 | 0.097 | 0.73 | .00238 | 4.46 |
| .92 | 4.58 | 2.55 | 0.078 | 0.59 | .00191 | 3.57 |
| .91 | 5.52 | 3.22 | 0.098 | 0.74 | .00241 | 4.51 |
| .92 | 5.46 | 3.18 | 0.097 | 0.73 | .00237 | 4.45 |
| .94 | 4.69 | 2.63 | 0.080 | 0.61 | .00196 | 3.68 |
| .82 | 5.52 | 3.32 | 0.101 | 0.72 | .00204 | 4.65 |
| .85 | 7.32 | 4.61 | 0.140 | 0.99 | .00282 | 6.45 |
| .90 | 5.81 | 3.43 | 0.104 | 0.74 | .00210 | 4.80 |
| .93 | 5.74 | 3.38 | 0.103 | 0.73 | .00207 | 4.73 |
| .90 | 6.05 | 3.60 | 0.110 | 0.78 | .00221 | 5.04 |
| .90 | 5.01 | 2.86 | 0.087 | 0.62 | .00175 | 4.00 |
| .88 | 7.78 | 4.84 | 0.147 | 1.04 | .00296 | 6.77 |
| .90 | 5.91 | 3.50 | 0.107 | .796 | .00214 | 4.90 |
| .86 | 6.06 | 3.61 | 0.110 | .821 | .00221 | 5.05 |
| .84 | 6.12 | 3.65 | 0.111 | .829 | .00224 | 5.11 |
| 0.80 | 5.89 | 2.56 | 0.66 | 0.56 | .00258 | 4.83 |
| 0.89 | 5.84 | 2.40 | 0.62 | 0.53 | .00242 | 4.54 |
| 0.90 | 5.83 | 2.40 | 0.62 | 0.53 | .00242 | 4.53 |
| 0.84 | 6.15 | 2.69 | 0.70 | 0.57 | .00223 | 5.09 |
| 0.95 | 5.60 | 2.44 | 0.67 | 0.56 | .00231 | 4.32 |
| 0.96 | 5.83 | 2.57 | 0.71 | 0.59 | .00243 | 4.56 |
| .94 | 7.15 | 2.95 | 0.079 | 0.67 | .00296 | 5.55 |
| .90 | 5.79 | 3.18 | 0.098 | .755 | 0.0258 | 4.83 |
| .91 | 5.94 | 3.28 | .101 | .781 | 0.0267 | 4.98 |
| .90 | 5.88 | 3.24 | .099 | .772 | 0.0264 | 4.92 |
| .91 | 5.72 | 3.13 | .096 | .747 | 0.0255 | 4.76 |
| .88 | 6.19 | 3.44 | .106 | .820 | 0.0280 | 5.23 |
| .89 | 7.22 | 4.12 | .126 | .923 | 0.0275 | 6.26 |
| .91 | 6.70 | 3.78 | .116 | .846 | 0.0252 | 5.74 |
| .88 | 6.61 | 3.72 | .114 | .833 | 0.0248 | 5.65 |
| 0.87 | 5.871 | 2.71 | .076 | 0.66 | .0033 | 4.56 |
| .93 | 5.871 | 2.71 | .076 | 0.66 | .0033 | 4.56 |
| .95 | 6.09 | 2.85 | .080 | 0.65 | .0026 | 4.78 |
| .95 | 6.311 | 2.98 | .083 | 0.68 | .0027 | 5.00 |
| .94 | 6.211 | 2.92 | .082 | 0.63 | .0021 | 4.90 |
| .94 | 6.211 | 2.92 | .082 | 0.63 | .0021 | 4.90. |
| .95 | 6.111 | 2.86 | .080 | 0.62 | .0021 | 4.80 |
| .94 | 6.180 | 2.90 | .081 | 0.63 | .0021 | 4.87 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Square metres | (4) Resting metabolism Kilo calories /min | (5) Conditions | (6) Rate of walking Metres /min | (7) Load Kg m | (8) Post absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Cathcart & Orr 1919 | M | 63.2 | 174.6 | 1.76 | 1.29AM | Level road | 57.15 | 5.0 | AM |
| | | " | " | " | " | " | " | 5.0 | AM |
| | | " | " | " | " | " | " | 10.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 15.0 | PA |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 20.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | 73.5 | 5.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 10.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 15.0 | AM |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | 20.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | 91.44 | 5.0 | PA |
| | | " | " | " | " | " | " | 10.0 | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | 15.0 | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | " | PA |
| | | " | " | " | " | " | " | 5.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| " | " | " | " | " | " | " | " | 10.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 15.0 | AM |
| | | " | " | " | " | " | " | 20.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | 100.58 | 5.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 10.0 | AM |
| | | " | " | " | " | " | " | " | AM |
| | | " | " | " | " | " | " | 15.0 | PA |
| | | " | " | " | " | " | " | " | AM |

| (9)<br>R.Q. | (10)<br>Rate of total energy expenditure<br>Kilo-calories/min | (11)<br>(15 ÷ 3)<br>Working-Kilo-calories per square metre per minute | (12)<br>(15 ÷ 1)<br>Working-Kilo-calories per Kilogram of body weight | (13)<br>$\left(\frac{15}{(1+7)x6}\right)$<br>Working-Gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | (14)<br>$\left(\frac{15}{7 \times 6}\right)$<br>Working-Kilo-calories per horizontal metre-Kilogram (Load only) | (15)<br>(10 - 4)<br>Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| .91 | 3.62 | 1.32 | .037 | .598 | .0081 | 2.33 |
| .90 | 4.09 | 1.59 | .044 | .718 | .0098 | 2.80 |
| .87 | 3.64 | 1.34 | .037 | .562 | .0041 | 2.35 |
| .86 | 3.39 | 1.19 | .033 | .502 | .0037 | 2.10 |
| .86 | 3.76 | 1.40 | .039 | .590 | .0043 | 2.47 |
| .76 | 3.82 | 1.44 | .040 | .566 | .0029 | 2.53 |
| .95 | 3.92 | 1.49 | .042 | .588 | .0031 | 2.63 |
| .94 | 4.05 | 1.57 | .044 | .580 | .0024 | 2.76 |
| .83 | 3.88 | 1.47 | .041 | .545 | .0023 | 2.59 |
| .86 | 4.37 | 1.75 | .049 | .614 | .0108 | 3.08 |
| .87 | 4.31 | 1.72 | .048 | .602 | .0106 | 3.02 |
| .92 | 3.21 | 1.09 | .030 | .357 | .0034 | 1.92 |
| .83 | 4.13 | 1.61 | .045 | .528 | .0050 | 2.84 |
| .73 | 4.83 | 2.01 | .056 | .658 | .0062 | 3.54 |
| .74 | 4.76 | 1.97 | .055 | .645 | .0061 | 3.47 |
| .85 | 4.46 | 1.80 | .050 | .589 | .0055 | 3.17 |
| .96 | 4.60 | 1.88 | .052 | .576 | .0039 | 3.31 |
| .74 | 4.82 | 2.01 | .056 | .614 | .0041 | 3.53 |
| .94 | 4.81 | 2.00 | .056 | .576 | .0031 | 3.52 |
| .82 | 4.58 | 1.87 | .052 | .538 | .0029 | 3.29 |
| .76 | 5.51 | 2.40 | .067 | .677 | .0148 | 4.22 |
| .77 | 5.49 | 2.39 | .066 | .608 | .0073 | 4.20 |
| .76 | 5.85 | 2.59 | .072 | .660 | .0080 | 4.56 |
| .77 | 5.66 | 2.48 | 0.069 | .611 | .0051 | 4.37 |
| .78 | 6.35 | 2.88 | 0.080 | .708 | .0059 | 5.06 |
| .73 | 5.78 | 2.55 | 0.070 | .628 | .0052 | 4.49 |
| .85 | 5.34 | 2.30 | .064 | .649 | .0142 | 4.05 |
| .92 | 5.26 | 2.26 | .063 | .636 | .0139 | 3.97 |
| .81 | 6.28 | 2.84 | .079 | 0.76 | .0055 | 4.99 |
| .76 | 6.28 | 2.84 | .079 | 0.76 | .0055 | 4.99 |
| .88 | 5.54 | 2.41 | .067 | 0.63 | .0046 | 4.25 |
| .90 | 5.18 | 2.21 | .061 | 0.58 | .0043 | 3.89 |
| .89 | 5.58 | 2.44 | .067 | 0.65 | .0047 | 4.29 |
| .86 | 5.38 | 2.32 | .065 | 0.61 | .0045 | 4.09 |
| .84 | 5.71 | 2.51 | .070 | 0.66 | .0048 | 4.42 |
| .94 | 5.63 | 2.47 | .069 | 0.61 | .0032 | 4.34 |
| .93 | 6.18 | 2.78 | .077 | 0.64 | .0026 | 4.69 |
| .82 | 6.28 | 2.84 | .079 | 0.66 | .0027 | 4.99 |
| .87 | 6.13 | 2.75 | .070 | 0.71 | .0096 | 4.84 |
| .89 | 6.31 | 2.85 | .079 | 0.73 | .0100 | 5.02 |
| .88 | 6.37 | 2.89 | .080 | 0.69 | .0051 | 5.08 |
| .86 | 6.47 | 2.38 | .034 | 0.70 | .0051 | 5.18 |
| .79 | 6.74 | 3.10 | .086 | 0.70 | .0036 | 5.45 |
| .96 | 6.50 | 2.96 | .082 | 0.66 | .0035 | 5.21 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilo-calories/ min | (5) Conditions | (6) Rate of walking Metres/ min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Cathcart & Orr 1919 | M (contd.) | 63.2 | 174.6 | 1.76 | 1.29 | Marching | 100.58 | 20.0 | AM |
| | | " | " | " | " | level | " | " | " |
| | | " | " | " | " | road | 109.72 | 5 | " |
| | | " | " | " | " | " | " | 10 | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | 15 | " |
| | | " | " | " | " | " | " | 20 | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | Doubling | 146.30 | 10.0 | " |
| | | " | " | " | " | level | " | " | " |
| | | " | " | " | " | road | " | 15.0 | " |
| | | " | " | " | " | " | 182.88 | 5.0 | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | 10.0 | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | " | " |
| | | " | " | " | " | " | " | 15.0 | " |
| " | O | 66.4 | 184.2 | 1.86 | .98AM | level | 54.86 | 26 | " |
| | | " | " | " | " | road | " | 9 | " |
| | | " | " | " | " | " | 82.29 | 26 | " |
| | | " | " | " | " | " | " | 9 | " |
| | | " | " | " | " | " | 109.72 | 26 | " |
| | | " | " | " | " | " | " | 9 | " |
| " | N | 60.0 | 160.1 | 1.67 | 1.19AM | " | 54.86 | 26 | " |
| | | " | " | " | " | " | " | 9 | " |
| | | " | " | " | " | " | 82.29 | 26 | " |
| | | " | " | " | " | " | " | 9 | " |
| | | " | " | " | " | " | 109.72 | 9 | " |
| Cathcart et al 1923 | Campbell | 67.4 | 168 | 1.77 | nk | Marching level floor lab. | 91.4 | 23.59 | AM |
| | | " | " | " | " | " | " | 26.96 | AM |
| | | " | " | " | " | " | " | 33.3 | AM |
| | | " | " | " | " | Marching level floor lab | 109.7 | 23.59 | AM |
| | | " | " | " | " | " | " | 26.96 | AM |
| | | " | " | " | " | " | " | 33.3 | AM |
| | | " | " | " | " | " | 73.15 | 23.59 | AM |
| | | " | " | " | " | " | " | 26.96 | AM |
| | | " | " | " | " | " | " | 33.3 | AM |
| | | | | nk = not known | | | | | |

| (9) R.Q. | (10) Rate of total energy expend-iture Kilo-calories /min | (11) (15 - 3) Working-Kilo-calories per square metre per minute | (12) (15 - 1) Working Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7)x6}\right)$ Working-gram-calories per horizont-al metre-Kilogram (Total weight of body plus load) | (14) $\left(\frac{15}{7 x 6}\right)$ Working-Kilo-calories per hori-zontal metre-Kilogram (Load only) | (15) (10 - 4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| .90 | 7.49 | 3.52 | .098 | 0.74 | .0031 | 6.20 |
| .81 | 7.36 | 3.45 | .096 | 0.73 | .0030 | 6.07 |
| .91 | 6.93 | 3.20 | .089 | 0.75 | .0103 | 5.64 |
| .87 | 6.97 | 3.23 | .090 | 0.71 | .0052 | 5.68 |
| .79 | 7.01 | 3.25 | .090 | 0.71 | .0052 | 5.72 |
| .83 | 8.34 | 4.01 | .115 | 0.88 | .0064 | 7.05 |
| .82 | 7.85 | 3.73 | .104 | 0.82 | .0060 | 6.56 |
| .87 | 7.15 | 3.33 | .093 | 0.73 | .0053 | 5.86 |
| .96 | 7.70 | 3.64 | .101 | 0.75 | .0039 | 6.41 |
| .92 | 7.90 | 3.76 | .104 | 0.72 | .0030 | 6.61 |
| .81 | 8.33 | 4.00 | .111 | 0.77 | .0024 | 7.04 |
| .72 | 10.34 | 5.14 | .143 | 0.85 | .0062 | 9.05 |
| .81 | 11.49 | 5.79 | .161 | 0.95 | .0070 | 10.20 |
| .98 | 12.15 | 6.17 | .172 | 0.95 | .0050 | 10.86 |
| .77 | 13.13 | 6.73 | .187 | 0.95 | .0129 | 11.84 |
| .79 | 12.53 | 7.85 | .219 | 1.11 | .0151 | 13.82 |
| .92 | 12.91 | 6.39 | .178 | 0.84 | .0062 | 11.24 |
| .86 | 13.01 | 6.66 | .185 | 0.88 | .0064 | 11.72 |
| .81 | 12.62 | 6.44 | .179 | 0.85 | .0062 | 11.33 |
| .96 | 13.87 | 7.15 | .199 | 0.88 | .0046 | 12.58 |
| nk | 2.76 | 0.96 | .0268 | 0.35 | .00124 | 1.78 |
| " | 2.26 | 0.69 | .019 | 0.31 | .0026 | 1.28 |
| " | 4.43 | 1.86 | .052 | 0.45 | .0016 | 3.45 |
| " | 3.73 | 1.48 | .041 | 0.44 | .0037 | 2.75 |
| " | 7.28 | 3.39 | .095 | 0.62 | .0022 | 6.30 |
| " | 5.68 | 2.59 | .071 | 0.57 | .0047 | 4.69 |
| " | 1.47 | 0.168 | .005 | .074 | .00056 | 0.28 |
| " | 3.60 | 1.44 | .040 | .34 | .0011 | 2.41 |
| " | 2.59 | 0.78 | .022 | .23 | .0018 | 1.30 |
| " | 4.58 | 2.03 | .056 | .45 | .0034 | 3.39 |
| nk | nk | 2.50 | .065 | .531 | .00204 | 4.42 |
| " | " | 2.36 | 0.062 | .484 | .00169 | 4.18 |
| " | " | 2.67 | 0.070 | .513 | .00155 | 4.720 |
| nk | " | 4.46 | 0.117 | .791 | .00305 | 7.89 |
| " | " | 4.42 | 0.116 | .756 | .00265 | 7.82 |
| " | " | 4.65 | 0.122 | .746 | .00225 | 8.233 |
| " | " | 1.48 | 0.039 | .262 | .00152 | 2.616 |
| " | " | 1.51 | 0.039 | .258 | .00135 | 2.666 |
| " | " | 1.76 | 0.046 | .282 | .00128 | 3:118 |

Appx. A

| eference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface area Square Metres | (4) Resting metabolism Kilo-calories /min | (5) Conditions | (6) Rate of walking Metres /min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| athcart t al 923 | Campbell | 67.4 | 168 | 1.77 | nk | Marching level floor lab | 54.9 | 23.59 | AM |
| | | " | " | " | " | " | " | 26.96 | " |
| | | " | " | " | " | " | " | 33.3 | " |
| | | " | " | " | " | " | 91.7 | 17.31 | " |
| | | " | " | " | " | " | " | 20.67 | " |
| | | " | " | " | " | " | " | 24.09 | " |
| | | " | " | " | " | " | " | 27.45 | " |
| | | " | " | " | " | " | " | 30.86 | " |
| | | " | " | " | " | " | " | 34.25 | " |
| | | " | " | " | " | " | " | 38.64 | " |
| | | " | " | " | " | " | " | 41.03 | " |
| | | " | " | " | " | " | " | 44.41 | " |
| " | " | 67.4 | 168 | 1.77 | nk | After marching at least one hour | 91.7 | 17.31 | AM |
| | | " | " | " | " | " | " | 20.67 | " |
| | | " | " | " | " | " | " | 24.09 | " |
| | | " | " | " | " | " | " | 27.45 | " |
| | | " | " | " | " | " | " | 30.86 | " |
| | | " | " | " | " | " | " | 34.25 | " |
| | | " | " | " | " | " | " | 38.64 | " |
| | | " | " | " | " | " | " | 41.03 | " |
| | | " | " | " | " | " | " | 44.41 | " |
| " | Richardson | 70.3 | 174.5 | 1.85 | nk | Marching level floor lab | 91.6 | 17.81 | AM |
| | | " | " | " | " | " | " | 21.35 | " |
| | | " | " | " | " | " | " | 24.88 | " |
| | | " | " | " | " | " | " | 27.9 | " |
| | | " | " | " | " | " | " | 32.0 | " |
| | | " | " | " | " | " | " | 34.7 | " |
| | | " | " | " | " | " | " | 39.0 | " |
| | | " | " | " | " | " | " | 42.0 | " |
| | | " | " | " | " | " | " | 46.0 | " |
| | | " | " | " | " | " | " | 17.4 | " |
| | | " | " | " | " | " | " | 20.9 | " |
| | | " | " | " | " | " | " | 24.9 | " |
| | | " | " | " | " | " | " | 28.4 | " |
| | | " | " | " | " | " | " | 31.95 | " |
| | | " | " | " | " | " | " | 35.45 | " |
| | | " | " | " | " | " | " | 39.00 | " |
| | | " | " | " | " | " | " | 42.5 | " |
| | | " | " | " | " | " | 91.4 | 24.9 | " |
| | | " | " | " | " | " | " | 27.9 | " |
| | | " | " | " | " | " | " | 31.9 | " |
| | | " | " | " | " | " | 109.7 | 24.9 | " |
| | | " | " | " | " | " | " | 27.9 | " |
| | | " | " | " | " | " | " | 31.9 | " |
| | | " | " | " | " | " | 73.15 | 24.9 | " |

nk = not known

| (9) R.Q. | (10) Rate of total energy expenditure Kilo-calories /min | (11) (15 ÷ 3) Working Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7)\times 6}\right)$ Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | (14) $\left(\frac{15}{7 \times 6}\right)$ Working-Kilo-calories per horizontal metre-Kilogram (Load only) | (15) (10 – 4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| nk | nk | 0.93 | 0.024 | .165 | .00127 | 1.648 |
| " | " | 1.18 | 0.031 | .201 | .00141 | 2.088 |
| " | " | 1.34 | 0.035 | .215 | .00130 | 2.370 |
| " | " | 2.68 | .0705 | .61 | .0030 | 4.75 |
| " | " | 2.67 | .0702 | .59 | .0025 | 4.73 |
| " | " | 2.54 | .0667 | .54 | .0020 | 4.49 |
| " | " | 2.92 | .0765 | .59 | .0020 | 5.16 |
| " | " | 2.98 | .0784 | .59 | .0019 | 5.28 |
| " | " | 3.24 | .0852 | .62 | .0018 | 5.74 |
| " | " | 3.16 | .0831 | .576 | .0016 | 5.60 |
| " | " | 3.45 | .0907 | .614 | .0016 | 6.11 |
| " | " | 4.00 | .1048 | .690 | .0017 | 7.07 |
| nk | nk | 2.44 | .0640 | .557 | .0027 | 4.32 |
| " | " | 2.53 | .0664 | .554 | .0024 | 4.47 |
| " | " | 2.62 | .0689 | .553 | .0021 | 4.64 |
| " | " | 2.48 | .0650 | .504 | .0017 | 4.38 |
| " | " | 2 69 | .0706 | .528 | .0017 | 4.76 |
| " | " | 2.96 | .0075 | .561 | .0017 | 5.23 |
| " | " | 3.22 | .0844 | .585 | .0016 | 5.69 |
| " | " | 3.49 | .0917 | .621 | .0016 | 6.18 |
| " | " | | | | | |
| nk | nk | 2.05 | 0.054 | 0.47 | .00233 | 3.80 |
| " | " | 2.23 | 0.059 | 0.49 | .00211 | 4.12 |
| " | " | 2.28 | 0.060 | 0.48 | .00185 | 4.22 |
| " | " | 2.36 | 0.062 | 0.49 | .00171 | 4.37 |
| " | " | 2.57 | 0.068 | 0.51 | .00162 | 4.76 |
| " | " | 2.77 | 0.073 | 0.53 | .00161 | 5.13 |
| " | " | 2.73 | 0.072 | 0.51 | .00141 | 5.05 |
| " | " | 2.99 | 0.079 | 0.54 | .00144 | 5.53 |
| " | " | 3.32 | 0.088 | 0.58 | .00146 | 6.15 |
| " | " | 2.48 | 0.065 | 0.57 | .00288 | 4.59 |
| " | " | 2.30 | 0.061 | 0.51 | .00223 | 4.26 |
| " | " | 2.46 | 0.047 | 0.52 | .00200 | 4.55 |
| " | " | 2.43 | 0.064 | 0.50 | .00173 | 4.49 |
| " | " | 2.89 | 0.076 | 0.57 | .00183 | 5.36 |
| " | " | 2.90 | 0.076 | 0.56 | .00165 | 5.37 |
| " | " | 3.18 | 0.084 | 0.59 | .00165 | 5.89 |
| " | " | 3.07 | 0.082 | 0.50 | .00146 | 5.68 |
| " | " | 2.59 | 0.068 | 0.55 | .00211 | 4.80 |
| " | " | 2.50 | 0.066 | 0.52 | .00181 | 4.62 |
| " | " | 2.81 | 0.074 | 0.56 | .00178 | 5.19 |
| " | " | 4.19 | 0.110 | 0.74 | .00284 | 7.75 |
| " | " | 4.35 | 0.115 | 0.75 | .00263 | 8.05 |
| " | " | 4.32 | 0.114 | 0.71 | .00228 | 7.99 |
| " | " | 1.54 | 0.040 | 0.41 | .00156 | 2.84 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Square metres | (4) Resting metabolism Kilo calories/min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Cathcart et al 1923 | Richardson | 70.3 | 174.5 | 1.85 | nk | Level floor lab | 73.15 | 27.9 | AM |
| | | " | " | " | " | " | " | 31.9 | " |
| | | " | " | " | " | | 54.9 | 24.9 | " |
| | | " | " | " | " | | " | 27.9 | " |
| | | " | " | " | " | | " | 31.9 | " |
| Daniels et al 1953 | E | 67.7 | 172. | 1.80 | 1,20* | Horizontal Tread mill lab. | 93.87 | ZERO | nk " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.69 | " |
| | | " | " | " | " | " | " | 34.50 | " |
| " | F | 68.2 | 174 | 1.82 | 1.21* | " | 93.87 | ZERO | " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.69 | " |
| | | " | " | " | " | " | " | 34.50 | " |
| " | A | 65.5 | 167 | 1.72 | 1.15* | Horizontal Treadmill lab. | 93.87 | ZERO | " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.69 | " |
| | | " | " | " | " | " | " | 34.50 | " |
| " | B | 76.4 | 167 | 1.86 | 1.21* | Horizontal Treadmill lab | 93.87 | ZERO | " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.69 | " |
| | | " | " | " | " | " | " | 34.50 | " |
| " | C | 90.0 | 179 | 2.11 | 1.41* | Horizontal Treadmill lab. | 93.87 | ZERO | " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.09 | " |
| | | " | " | " | " | " | " | 34.50 | " |
| " | D | 66.3 | 168 | 1.75 | 1.16* | Horizontal Treadmill lab. | 93.87 | ZERO | " |
| | | " | " | " | " | " | " | 14.07 | " |
| | | " | " | " | " | " | " | 20.88 | " |
| | | " | " | " | " | " | " | 27.69 | " |
| | | " | " | " | " | " | " | 34.50 | " |

* Calculated from SA assuming normal BMR.

| (9)<br><br>R.Q. | (10)<br><br>Rate of total energy expenditure<br>Kilo-calories /min | (11)<br>(15 ÷ 3)<br>Working-Kilo-calories per square metre per minute | (12)<br>(15 ÷ 1)<br>Working-Kilo-calories per Kilogram of body weight | (13)<br>$\left(\frac{15}{(1+7)x6}\right)$<br>Working-gram-calories per horizon-tal metre-Kilogram (Total weight of body plus load) | (14)<br>$\left(\frac{15}{7 \times 6}\right)$<br>Working-Kilo-calories per horizontal metre-Kilogram (Load only) | (15)<br>(10 - 4)<br>Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| nk | nk | 1.49 | 0.039 | 0.38 | .00134 | 2.75 |
| " | " | 1.77 | 0.047 | 0.44 | .00141 | 3.28 |
| " | " | 1.06 | 0.028 | 0.38 | .00144 | 1.97 |
| " | " | 1.25 | 0.033 | 0.43 | .00151 | 2.32 |
| " | " | 1.29 | 0.034 | 0.42 | .00135 | 2.38 |
| .080✓ | 4.61 | 0.78 | .021 | .222 | 00 | 3.41 |
| " | 5.16 | 2.20 | .059 | 0.51 | .00300 | 3.96 |
| " | 5.23 | 2.23 | .060 | 0.48 | .00206 | 4.03 |
| " | 5.96 | 2.64 | .070 | 0.53 | .00183 | 4.76 |
| " | 7.24 | 3.35 | .089 | 0.63 | .00186 | 6.04 |
| " | 4.60 | 1.86 | .050 | 0.53 | 00 | 3.39 |
| " | 5.36 | 2.28 | .061 | 0.54 | .00314 | 4.15 |
| " | 5.79 | 2.52 | .075 | 0.55 | .00234 | 4.58 |
| " | 6.10 | 2.69 | .072 | 0.545 | .00276 | 4.89 |
| " | 6.87 | 3.11 | .083 | 0.59 | .00175 | 5.66 |
| .080✓ | 4.87 | 2.163 | .057 | 0.58 | 00 | 3.72 |
| " | 4.91 | 2.19 | .057 | 0.50 | .0028 | 3.76 |
| " | 5.86 | 2.74 | .072 | 0.58 | .0024 | 4.71 |
| " | 6.67 | 3.21 | .084 | 0.63 | .0021 | 5.52 |
| " | 7.04 | 3.43 | .090 | 0.63 | .0018 | 5.89 |
| " | 5.62 | 2.37 | .058 | 0.61 | 00 | 4.41 |
| " | 5.86 | 3.50 | .061 | 0.55 | .0035 | 4.65 |
| " | 6.60 | 2.90 | .071 | 0.59 | .0028 | 5.39 |
| " | 6.68 | 2.94 | .072 | 0.56 | .0021 | 5.47 |
| " | 8.09 | 3.70 | .090 | 0.66 | .0021 | 6.88 |
| " | 5.76 | 2.06 | .048 | 0.52 | 00 | 4.35 |
| " | 6.17 | 2.26 | .053 | 0.49 | .0036 | 4.76 |
| " | 7.33 | 2.81 | .066 | 0.57 | .0030 | 5.92 |
| " | 7.78 | 3.02 | .071 | 0.58 | .0025 | 6.37 |
| " | 8.49 | 3.36 | .079 | 0.61 | .0022 | 7.08 |
| " | 4.77 | 2.06 | .055 | 0.58 | 00 | 3.61 |
| " | 5.15 | 2.28 | .060 | 0.53 | .0030 | 3.99 |
| " | 5.43 | 2.44 | .064 | 0.52 | .0022 | 4.27 |
| " | 5.81 | 2.66 | .070 | 0.53 | .0018 | 4.65 |
| " | 6.87 | 3.26 | .086 | 0.60 | .0018 | 5.71 |
| Assumed to be 0.80 | | | | | | |

Appx.A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Square metres | (4) Resting metabolism Kilo-calories/min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Daniels et al 1953 | M.o. | 63 | 168 | 1.70 | 1.16 | Road level | 93.87 | 20.9 | nk |
| | | " | " | " | " | Treadmill horizontal | 93.87 | 20.9 | " |
| " | C.a. | 80 | 178 | 1.92 | 1.31 | Road | 93.87 | 20.9 | nk |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | M.i. | 67 | 170 | 1.78 | 1.22 | Road | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | H.d. | 62 | 170 | 1.68 | 1.15 | Road | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | H.c. | 75 | 169 | 1.86 | 1.27 | Road | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | S.m. | 72 | 172 | 1.85 | 1.26 | Road | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | M.y. | 51 | 167 | 1.54 | 1.00 | Road | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | B.r. | 61 | 170 | 1.70 | 1.16 | Road level | " | " | " |
| " | | " | " | " | " | Tr. Mill | " | " | " |
| " | W.e | 72.2 | 180 | 1.91 | $1.31^x$ | Treadmill horizontal lab | 67.06 | 11.35 | " |
| " | | " | " | " | " | " | | | |
| " | | " | " | " | " | " | 93.87 | " | " |
| " | | " | " | " | " | " | 134.11 | " | " |
| " | P.a. | 70.8 | 176 | 1.86 | $1.27^x$ | " | 67.06 | 18.16 | |
| " | | " | " | " | " | " | 67.06 | 11.35 | " |
| " | | " | " | " | " | " | 93.87 | " | " |
| " | | " | " | " | " | " | 134.11 | " | " |
| " | R.a. | 73.1 | 180 | 1.92 | $1.31^x$ | " | 67.06 | 18.16 | " |
| " | | " | " | " | " | " | 67.06 | 11.35 | " |
| " | | " | " | " | " | " | 93.87 | " | " |
| " | | " | " | " | " | " | 134.11 | " | " |
| " | P.e. | 69.5 | 172 | 1.81 | $1.23^x$ | " | 67.06 | 18.16 | " |
| " | | " | " | " | " | " | 67.06 | 11.35 | " |
| " | | " | " | " | " | " | 93.87 | " | " |
| " | | " | " | " | " | " | 134.11 | " | " |
| | | | | | | | 67.06 | 18.16 | " |

nk = not known
x = Estimated from S.A., assuming normal B.M.R.
* = Assumed

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 3) | (15 ÷ 1) | $\left(\frac{15}{(1+7)x6}\right)$ | $\left(\frac{15}{7 \times 6}\right)$ | (10 - 4) |
| R.Q. | Rate of total energy expenditure Kilo-calories /min | Working-Kilo-calories per square metre per minute | Working-Kilo-calories per Kilogram of body weight | Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | Working-Kilo-calories per horizontal metre-Kilogram (Load only) | Working-Kilo-calories expended per minute |
| 0.80* | 6.55 | 3.17 | .086 | 0.68 | .0027 | 5.39 |
| | 5.89 | 2.78 | .075 | 0.60 | .0024 | 4.73 |
| " | 7.19 | 3.06 | .074 | 0.62 | .0030 | 5.88 |
| " | 7.02 | 2.97 | .071 | 0.60 | .0029 | 5.71 |
| " | 6.75 | 3.11 | .083 | 0.67 | .0028 | 5.53 |
| " | 6.11 | 2.74 | .073 | 0.59 | .0025 | 4.89 |
| " | 6.84 | 3.39 | .092 | 0.73 | .0029 | 5.69 |
| " | 5.60 | 2.65 | .072 | 0.57 | .0023 | 4.45 |
| " | 7.31 | 3.25 | .081 | 0.67 | .0031 | 6.04 |
| " | 6.95 | 3.05 | .076 | 0.63 | .0029 | 5.68 |
| " | 6.55 | 2.85 | .073 | 0.61 | .0027 | 5.29 |
| " | 6.48 | 2.82 | .073 | 0.60 | .0027 | 5.22 |
| " | 5.95 | 3.21 | .097 | 0.73 | .0025 | 4.95 |
| " | 5.82 | 3.13 | .095 | 0.72 | .0025 | 4.82 |
| " | 7.65 | 3.82 | .106 | 0.84 | .0033 | 6.49 |
| " | 6.57 | 3.18 | .089 | 0.70 | .0028 | 5.41 |
| .80* | 4.361 | 1.597 | .0423 | 0.54 | .0040 | 3.051 |
| " | 5.921 | 2.414 | .0639 | 0.59 | .0043 | 4.611 |
| " | 12.13 | 5.66 | .1499 | 0.97 | .0071 | 10.82 |
| " | 4.201 | 1.51 | .0400 | 0.48 | .0024 | 2.891 |
| " | 4.618 | 1.30 | .0473 | 0.61 | .0044 | 3.348 |
| " | 6.107 | 2.60 | .0683 | 0.63 | .0045 | 4.837 |
| " | 11.19 | 5.33 | .1401 | 0.90 | .0065 | 9.920 |
| " | 4.72 | 1.85 | .0487 | 0.58 | .0028 | 3.450 |
| " | 4.97 | 1.91 | .0501 | 0.65 | .0048 | 3.66 |
| " | 6.528 | 2.72 | .0714 | 0.66 | .0049 | 5.218 |
| " | 12.58 | 5.87 | .1542 | 0.99 | .0074 | 11.27 |
| " | 5.05 | 1.95 | .0512 | 0.61 | .0031 | 3.74 |
| " | 5.07 | 2.12 | .0553 | 0.71 | .0051 | 3.84 |
| " | 6.52 | 2.92 | .0761 | 0.70 | .0050 | 5.29 |
| " | 14.18 | 7.15 | .1863 | 1.19 | .0085 | 12.95 |
| " | 5.068 | 2.12 | .0552 | 0.65 | .0032 | 3.838 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height cm | (3) Surface area Square metres | (4) Resting Metabolism Kilocalories/min | (5) Conditions | (6) Rate of Walking Metres/min | (7) Load Kgm | (8) Post absorptive (PA) or After meal (AM) | |
|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] & | Herr [illegible] | 6[illegible] | nk | nk | nk | level | 62.7 | 8.8 | | |
| Schumberg | " | " | " | " | " | road | 75.2 | 11.0 | | |
| | " | " | " | " | " | " | 81.5 | 12.3 | | |
| 190[illegible] | " | " | " | " | " | " | 75.4 | 12.3 | | |
| | " | " | " | " | " | " | 68.1 | 16.0 | | |
| | " | " | " | " | " | " | 76.9 | 16.0 | | |
| | " | " | " | " | " | " | 69.7 | 28.2 | | |
| | " | " | " | " | " | " | 76.8 | 28.2 | | |
| | " | " | " | " | " | " | 70.4 | 27.0 | | |
| | " | " | " | " | " | " | 74.3 | 27.0 | | |
| | " | " | " | " | " | " | 75.2 | 5.2 | | |
| | " | " | " | " | " | " | 89.1 | 4.9 | | |
| | " | " | " | " | " | " | 78.1 | 30.8 | | |
| | " | " | " | " | " | " | 75.2 | 30.8 | | |
| | Herr B | 68 | nk | nk | nk | Level | 53.6 | 13.2 | | |
| | " | " | " | " | " | road | 87.7 | 13.2 | | |
| | " | " | " | " | " | " | 74.9 | 14.4 | | |
| | " | " | " | " | " | " | 80.0 | 14.4 | | |
| | " | " | " | " | " | " | 72.7 | 28.03 | | |
| | " | " | " | " | " | " | [illegible].6 | 28.03 | | |
| | " | " | " | " | " | " | 58.2 | 3.85 | | |
| | " | " | " | " | " | " | 76.4 | 3.85 | | |
| | " | " | " | " | " | " | 82.4 | 3.85 | | |
| | " | " | " | " | " | " | 76.9 | 13.2 | | |
| | " | " | " | " | " | " | 93.3 | 13.2 | | |
| | " | " | " | " | " | " | 77.9 | 11.9 | | |
| | " | " | " | " | " | " | 8[illegible].7 | 11.9 | | |
| | " | " | " | " | " | " | 68.6 | 26.4 | | |
| | " | " | " | " | " | " | 73.7 | 26.4 | | |

| (9)<br><br>R.Q. | (10)<br><br>Rate of total energy expenditure<br><br>Kilocalories/min. | (11)<br>(15 ÷ 3)<br>Working-Kilo-calories per square metre per minute | (12)<br>(15 ÷ 1)<br>Working-Kilo-calories per Kilogram of body weight | (13)<br>$\left(\frac{15}{(1+7)x6}\right)$<br>Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | (14)<br>$\left(\frac{15}{7 \times 6}\right)$<br>Working-Kilo-caloris per horizontal metre-Kilogram (Load only) | (15)<br>(10 - 4)<br>Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| 0.719 | nk | nk | .047 | 0.658 | .00536 | 2.96 |
| 0.778 | " | " | .0604 | 0.683 | .0046 | 3.30 |
| 0.744 | " | " | .0676 | 0.694 | .00425 | 4.26 |
| 0.801 | " | " | .0644 | 0.669 | .0041 | 3.80 |
| 0.776 | " | " | .0557 | 0.580 | .00322 | 3.51 |
| 0.773 | " | " | .0643 | 0.592 | .0033 | 4.05 |
| 0.850 | " | " | .0564 | 0.553 | .00182 | 3.55 |
| 0.834 | " | " | .0693 | 0.623 | .00263 | 4.37 |
| 0.799 | " | " | .0549 | 0.546 | .00182 | 3.46 |
| 0.744 | " | " | .0591 | 0.556 | .00186 | 3.72 |
| 0.887 | " | " | .0452 | 0.555 | .00731 | 2.85 |
| 0.807 | " | " | .0599 | 0.623 | .00864 | 3.77 |
| 0.703 | " | " | .0630 | 0.542 | .00165 | 3.97 |
| 0.712 | " | " | .0581 | 0.519 | .00158 | 3.66 |
| | | | | | | |
| 0.761 | " | " | .0372 | 0.582 | .00358 | 2.53 |
| 0.782 | " | " | .0693 | 0.662 | .00407 | 4.71 |
| 0.833 | " | " | .044 | 0.485 | .00278 | 2.99 |
| 0.759 | " | " | .0514 | 0.529 | .00303 | 3.49 |
| 0.859 | " | " | .0589 | 0.575 | .00196 | 4.00 |
| 0.866 | " | " | .0616 | 0.569 | .00195 | 4.19 |
| 0.809 | " | " | .031 | 0.504 | .00942 | 2.11 |
| 0.792 | " | " | .0399 | 0.494 | .00922 | 2.71 |
| 0.729 | " | " | .0453 | 0.521 | .00972 | 3.08 |
| 0.835 | " | " | .065 | 0.707 | .00436 | 4.42 |
| 0.885 | " | " | .0819 | 0.734 | .00452 | 5.57 |
| 0.726 | " | " | .0665 | 0.726 | .00488 | 4.52 |
| 0.697 | " | " | .0765 | 0.796 | .00536 | 5.20 |
| 0.762 | " | " | .0596 | 0.627 | .00224 | 4.06 |
| 0.797 | " | " | .0618 | 0.603 | .00216 | 4.20 |

Appx. A

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|---|
| Reference | Subject | Weight | Height | Surface Area | Resting Metabolism | Conditions | Rate of walking | Load | Post-absorptive (PA) or After meal (AM) |
| | | Kgm | Cm | Square metres | Kilo-calories /min | | Metres /min | Kgm | |
| **Durig 1911** | **Durig in Vienna** | 62.6 | nk | nk | nk | level track | 126 | 13.5 | nk |
| | | " | " | " | " | " | 116.6 | " | " |
| | | " | " | " | " | " | 141.8 | " | " |
| | " | " | " | " | " | " | 152.5 | " | " |
| | " | " | " | " | " | " | 102.3 | " | " |
| | " | " | " | " | " | " | 102.1 | " | " |
| | " | " | " | " | " | " | 83.8 | " | " |
| | " | " | " | " | " | " | 72.3 | " | " |
| **Durig 1911** | **Reichel in Vienna** | 84.3 | nk | nk | nk | level track | 100.8 | 16.0 | nk |
| | | " | " | " | " | " | 96.4 | " | " |
| | | " | " | " | " | " | 94.8 | " | " |
| | " | " | " | " | " | " | 95.2 | " | " |
| | " | " | " | " | " | " | 95.2 | " | " |
| | " | " | " | " | " | " | 75.9 | " | " |
| | " | " | " | " | " | " | 59.3 | " | " |
| **Durig** | **Kolmer in Vienna** | 81.2 | nk | nk | nk | level track | 100.9 | 13.0 | nk |
| | | " | " | " | " | " | 105.2 | " | " |
| | | " | " | " | " | " | 100.0 | " | " |
| | " | " | " | " | " | " | 100.4 | " | " |
| | " | " | " | " | " | " | 69.2 | " | " |
| | " | " | " | " | " | " | 62.4 | " | " |
| | " | " | " | " | " | " | 67.0 | " | " |
| | " | " | " | " | " | " | 66.4 | " | " |
| | " | " | " | " | " | " | 49.2 | " | " |
| **Durig 1911** | **Rainer in Vienna** | 62.4 | nk | nk | nk | level track | 91.3 | 13.0 | nk |
| | | " | " | " | " | " | 88.8 | " | " |
| | | " | " | " | " | " | 90.4 | " | " |
| | " | " | " | " | " | " | 88.8 | " | " |
| | " | " | " | " | " | " | 115.8 | " | " |
| | " | " | " | " | " | " | 76.9 | " | " |
| | " | " | " | " | " | " | 47.2 | " | " |
| | " | " | " | " | " | " | 129.5 | " | " |

| (9) R.Q. | (10) Rate of total energy expenditure Kilo-calories /min | (11) (14 ÷ 3) Working-Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working-Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7)\times 6}\right)$ Working-gram-calories per horizontal metre-kilogram (total weight of body plus load) | (14) $\left(\frac{15}{7 \times 6}\right)$ Working-Kilo-calories per horizontal metre-kilogram (load only) | (15) (10-4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| 0.920 | nk | nk | .1125 | 0.735 | .00414 | 7.05 |
| 0.877 | " | " | .0889 | 0.628 | .00355 | 5.57 |
| 0.874 | " | " | .1472 | 0.854 | .00482 | 9.21 |
| 0.851 | " | " | .1891 | 1.023 | .00598 | 11.87 |
| 0.804 | " | " | .0676 | 0.543 | .00306 | 4.23 |
| 0.743 | " | " | .0693 | 0.559 | .00315 | 4.34 |
| 0.759 | " | " | .0527 | 0.517 | .00292 | 3.30 |
| 0.758 | " | " | .0471 | 0.536 | .00302 | 2.95 |
| | | | | | | |
| 0.893 | nk | nk | .066 | 0.550 | .00345 | 5.56 |
| 0.860 | " | " | .0669 | 0.583 | .00366 | 5.64 |
| 0.867 | " | " | .0625 | 0.554 | .00347 | 5.27 |
| 0.857 | " | " | .063 | 0.556 | .00349 | 5.31 |
| 0.858 | " | " | .0645 | 0.570 | .00357 | 5.44 |
| 0.844 | " | " | .046 | 0.510 | .0032 | 3.88 |
| 0.855 | " | " | .0363 | 0.514 | .00323 | 3.06 |
| | | | | | | |
| 0.784 | nk | nk | .0744 | 0.635 | .0046 | 6.03 |
| 0.873 | " | " | .1131 | 0.642 | .00672 | 9.19 |
| 0.891 | " | " | .0765 | 0.659 | .00478 | 6.21 |
| 0.874 | " | " | .0763 | 0.654 | .00474 | 6.19 |
| 0.763 | " | " | .043 | 0.535 | .00388 | 3.49 |
| 0.751 | " | " | .0407 | 0.561 | .00407 | 3.30 |
| 0.725 | " | " | .0435 | 0.560 | .00406 | 3.53 |
| 0.818 | " | " | .0456 | 0.591 | .00429 | 3.70 |
| 0.776 | " | " | .0309 | 0.542 | .00393 | 2.51 |
| | | | | | | |
| 0.816 | nk | nk | .0638 | 0.578 | .00335 | 3.98 |
| 0.857 | " | " | .0613 | 0.571 | .00331 | 3.82 |
| 0.829 | " | " | .0638 | 0.564 | .00339 | 3.98 |
| 0.820 | " | " | .0609 | 0.567 | .00329 | 3.80 |
| 0.793 | " | " | .1080 | 0.772 | .00448 | 6.74 |
| 0.724 | " | " | .0556 | 0.533 | .00348 | 3.47 |
| 0.806 | " | " | .0306 | 0.538 | .00311 | 1.91 |
| 0.866 | " | " | .1491 | 0.954 | .00554 | 9.31 |

Appx.A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Square metres | (4) Resting Metabolism Kilo-calories/min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Level treadmill | | | |
| Benedict | 1 | 72.3 | 180 | | 1.22 | 8.12.13 | 79.7 | zero | P.A. |
| and | (A.J.O.) | 72.1 | " | | " | 15.12.13 | 74.2 | " | " |
| Murschhauser | " | " | " | | " | | 75.6 | " | " |
| 1915 | " | " | " | | " | | 76.3 | " | " |
| | " | " | " | | " | | 76.3 | " | " |
| | " | 72.5 | " | | " | 16.12.13 | 75.1 | " | " |
| | " | " | " | | " | | 76.7 | " | " |
| | " | " | " | | " | | 77.6 | " | " |
| | " | 72.82 | " | | " | 17.12.13 | 75.0 | " | " |
| | " | " | " | | " | | 76.4 | " | " |
| | " | " | " | | " | | 78.1 | " | " |
| | " | " | " | | " | | 78.6 | " | " |
| | " | 74.76 | " | | " | 18.12.13 | 75.3 | " | " |
| | " | " | " | | " | | 76.4 | " | " |
| | " | " | " | | " | | 76.7 | " | " |
| | " | " | " | | " | | 76.9 | " | " |
| | " | 74.17 | " | | " | 19.12.13 | 76.1 | " | " |
| | " | " | " | | " | | 77.9 | " | " |
| | " | " | " | | " | | 78.3 | " | " |
| | " | " | " | | " | | 78.7 | " | " |
| | " | 74.31 | " | | " | 20.12.13 | 76.2 | " | " |
| | " | " | " | | " | | 77.7 | " | " |
| | " | " | " | | " | | 78.6 | " | " |
| | " | " | " | | " | | 78.9 | " | " |
| | " | 73.77 | " | | " | 22.12.13 | 76.3 | " | " |
| | " | " | " | | " | | 65.9 | " | " |
| | " | " | " | | " | | 77.4 | " | " |
| | " | " | " | | " | | 67.5 | " | " |
| | " | 73.75 | " | | " | 23.12.13 | 75.9 | " | " |
| | " | " | " | | " | | 66.4 | " | " |
| | " | " | " | | " | | 76.9 | " | " |
| | " | " | " | | " | | 66.4 | " | " |
| | " | 72.96 | " | | " | 27.12.13 | 78.4 | " | " |
| | " | " | " | | " | | 65.2 | " | " |
| | " | " | " | | " | | 78.6 | " | " |
| | " | " | " | | " | | 65.1 | " | " |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15÷3) | (15÷1) | ($\frac{15}{(1+7) \times 6}$) | ($\frac{15}{7 \times 6}$) | (10-4) |
| R.Q. | Rate of total energy expenditure Kilo-calories/min | Working-Kilo-calories per square metre per minute | Working-Kilo-calories per Kilogram of body weight | Working-gram-calories per horizontal metre-Kilogram (total weight of body plus load) | Working-Kilo-calories per horizontal metre-Kilogram (load only) | Working-Kilo-calories expended per minute |
| 0.78 | 4.39 | nk | .0438 | 0.550 | ∞ | 3.17 |
| 0.82 | 4.73 | " | .0487 | 0.657 | " | 3.51 |
| 0.85 | 4.33 | " | .0431 | 0.571 | " | 3.11 |
| 0.84 | 4.24 | " | .0418 | 0.549 | " | 3.02 |
| 0.84 | 4.20 | " | .0413 | 0.542 | " | 2.98 |
| 0.86 | 4.30 | " | .0425 | 0.566 | " | 3.08 |
| 0.88 | 4.18 | " | .0408 | 0.532 | " | 2.96 |
| 0.91 | 3.91 | " | .0371 | 0.477 | " | 2.69 |
| 0.84 | 3.99 | " | .038 | 0.507 | " | 2.77 |
| 0.83 | 4.12 | " | .0399 | 0.522 | " | 2.90 |
| 0.81 | 4.20 | " | .0408 | 0.525 | " | 2.98 |
| 0.79 | 4.33 | " | .0427 | 0.544 | " | 3.11 |
| 0.89 | 3.98 | " | .0370 | 0.490 | " | 2.76 |
| 0.89 | 4.09 | " | .0384 | 0.503 | " | 2.87 |
| 0.84 | 4.19 | " | .0398 | 0.518 | " | 2.97 |
| 0.85 | 4.22 | " | .0402 | 0.522 | " | 3.00 |
| 0.91 | 4.29 | " | .0414 | 0.543 | " | 3.07 |
| 0.90 | 4.23 | " | .0406 | 0.521 | " | 3.01 |
| 0.87 | 4.26 | " | .041 | 0.525 | " | 3.04 |
| 0.87 | 4.26 | " | .041 | 0.521 | " | 3.04 |
| 0.84 | 4.00 | " | .0374 | 0.491 | " | 2.78 |
| 0.83 | 4.28 | " | .0412 | 0.530 | " | 3.06 |
| 0.79 | 4.43 | " | .0432 | 0.550 | " | 3.21 |
| 0.80 | 4.48 | " | .0438 | 0.556 | " | 3.26 |
| 0.82 | 4.21 | " | .0406 | 0.531 | " | 2.99 |
| 0.77 | 3.76 | " | .0345 | 0.523 | " | 2.54 |
| 0.71 | 4.23 | " | .0408 | 0.527 | " | 3.01 |
| 0.76 | 3.74 | " | .0342 | 0.506 | " | 2.52 |
| 0.83 | 4.03 | " | .0381 | 0.502 | " | 2.81 |
| 0.80 | 3.55 | " | .0316 | 0.476 | " | 2.33 |
| 0.80 | 4.14 | " | .0396 | 0.514 | " | 2.92 |
| 0.79 | 3.66 | " | .0331 | 0.498 | " | 2.44 |
| 0.81 | 4.07 | " | .0391 | 0.498 | " | 2.35 |
| 0.78 | 3.46 | " | .0307 | 0.471 | " | 2.24 |
| 0.78 | 4.07 | " | .0392 | 0.497 | " | 2.85 |
| 0.76 | 3.48 | " | .031 | 0.476 | " | 2.26 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilo-calories/min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After Meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | level treadmill | | | |
| Benedict | 2 | 68.3 | 177 | | 1.11 | 24.3.14 | 60.6 | zero | P.A. |
| and | (H.A.M.) | unclothed | " | | " | 25.3.14 | 60.6 | " | " |
| Murschhauser | " | | " | | " | 26.3.14 | 62.7 | " | " |
| 1915 | " | 72 clothed | " | | " | 27.3.14 | 57.6 | " | " |
| | " | | " | | " | 31.3.14 | 57.2 | " | " |
| | " | " | " | | " | 1.4.14 | 59.3 | " | " |
| | " | " | " | | " | 3.4.14 | 76.2 | " | " |
| | " | " | " | | " | 6.4.14 | 57.8 | " | " |
| | " | " | " | | " | " | 56.8 | " | " |
| | " | " | " | | " | " | 56.0 | " | " |
| | " | " | " | | " | 7.4.14 | 59.6 | " | " |
| | " | " | " | | " | " | 58.2 | " | " |
| | " | " | " | | " | 8.4.14 | 76.1 | " | " |
| | " | " | " | | " | " | 77.6 | " | " |
| | " | " | " | | " | " | 78.3 | " | " |
| | " | " | " | | " | 9.4.14 | 59.3 | " | " |
| | " | " | " | | " | " | 58.8 | " | " |
| | " | " | " | | " | " | 59.0 | " | " |
| | " | " | " | | " | 10.4.14 | 77.3 | " | " |
| | " | " | " | | " | " | 78.9 | " | " |
| | " | " | " | | " | 14.4.14 | 61.7 | " | " |
| | " | " | " | | " | " | 62.1 | " | " |
| | " | " | " | | " | " | 62.4 | " | " |
| | " | 71.5 | " | | " | 15.4.14 | 77.2 | " | " |
| | " | " | " | | " | " | 79.4 | " | " |
| | " | " | " | | " | " | 80.2 | " | " |
| | " | " | " | | " | 16.4.14 | 61.9 | " | " |
| | " | " | " | | " | " | 62.3 | " | " |
| | " | " | " | | " | " | 61.8 | " | " |
| | " | " | " | | " | 17.4.14 | 76.6 | " | " |
| | " | " | " | | " | " | 78.1 | " | " |
| | " | " | " | | " | " | 79.3 | " | " |
| | " | 70.5 | " | | " | 21.4.14 | 60.8 | " | " |
| | " | " | " | | " | 22.4.14 | 76.8 | " | " |
| | " | " | " | | " | " | 78.6 | " | " |
| | " | " | " | | " | " | 79.2 | " | " |
| | " | " | " | | " | 23.4.14 | 61.1 | " | " |
| | " | " | " | | " | 24.4.14 | 76.4 | " | " |
| | " | " | " | | " | " | 78.4 | " | " |
| | " | 69.9 | " | | " | 25.4.14 | 63.0 | " | " |
| | " | " | " | | " | " | 64.0 | " | " |
| | " | 70.5 | " | | " | 27.4.14 | 73.5 | " | " |
| | " | " | " | | " | " | 78.1 | " | " |
| | " | " | " | | " | 28.4.14 | 78.2 | " | " |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 3) | (15 ÷ 1) | $(\frac{15}{(1+7)x6})$ | $(\frac{15}{7 \times 6})$ | (10–4) |
| R.Q. | Rate of total energy expenditure kilo-calories/min | Working-kilocalories per square metre per minute | Working-kilocalories per kilogram of body weight | Working-gram-calories per horizontal metre-kilogram (total weight of body plus load) | Working-Kilocalories per horizontal metre-kilogram (load only) | Working-kilocalories expended per minute |
| 0.81 | 3.74 | n.k. | .0385 | 0.603 | [illegible] | 2.63 |
| 0.80 | 3.40 | " | .0335 | 0.525 | " | 2.29 |
| 0.86 | 3.42 | " | .0338 | 0.512 | " | 2.31 |
| 0.83 | 3.15 | " | .0298 | 0.492 | " | 2.04 |
| 0.85 | 3.27 | " | .0316 | 0.525 | " | 2.16 |
| 0.81 | 3.36 | " | .0329 | 0.527 | " | 2.25 |
| 0.85 | 4.39 | " | .048 | 0.598 | " | 3.28 |
| 0.86 | 3.32 | " | .0324 | 0.531 | " | 2.21 |
| 0.85 | 3.25 | " | .0313 | 0.523 | " | 2.14 |
| 0.84 | 3.20 | " | .0306 | 0.518 | " | 2.09 |
| 0.83 | 3.53 | " | .0354 | 0.564 | " | 2.42 |
| 0.82 | 3.19 | " | .0304 | 0.496 | " | 2.08 |
| 0.82 | 4.45 | " | .0439 | 0.610 | " | 3.34 |
| 0.80 | 3.97 | " | .0419 | 0.512 | " | 2.86 |
| 0.82 | 3.89 | " | .0407 | 0.493 | " | 2.78 |
| 0.84 | 3.40 | " | .0335 | 0.536 | " | 2.29 |
| 0.82 | 3.20 | " | .0306 | 0.494 | " | 2.09 |
| 0.81 | 3.36 | " | .033 | 0.530 | " | 2.25 |
| 0.98 | 4.09 | " | .0437 | 0.535 | " | 2.98 |
| 0.85 | 4.09 | " | .0437 | 0.525 | " | 2.98 |
| 0.91 | 3.43 | " | .034 | 0.523 | " | 2.32 |
| 0.90 | 3.28 | " | .0318 | 0.486 | " | 2.17 |
| 0.84 | 3.26 | " | .0314 | 0.479 | " | 2.15 |
| 0.88 | 4.58 | " | .0364 | 0.629 | " | 2.47 |
| 0.84 | 4.02 | " | .0429 | 0.513 | " | 2.91 |
| 0.82 | 4.04 | " | .0432 | 0.511 | " | 2.93 |
| 0.88 | 3.16 | " | .0302 | 0.463 | " | 2.05 |
| 0.81 | 3.22 | " | .0311 | 0.474 | " | 2.11 |
| 0.84 | 3.21 | " | .031 | 0.475 | " | 2.10 |
| 0.86 | 4.36 | " | .0332 | 0.593 | " | 2.25 |
| 0.82 | 3.94 | " | .0418 | 0.507 | " | 2.83 |
| 0.80 | 4.14 | " | .0447 | 0.534 | " | 3.03 |
| 0.88 | 3.13 | " | .0302 | 0.471 | " | 2.02 |
| 0.85 | 3.91 | " | .0419 | 0.517 | " | 2.80 |
| 0.79 | 3.97 | " | .0428 | 0.516 | " | 2.86 |
| 0.79 | 3.94 | " | .0424 | 0.507 | " | 2.83 |
| 0.83 | 3.27 | " | .0323 | 0.501 | " | 2.16 |
| 0.80 | 3.79 | " | .0401 | 0.498 | " | 2.68 |
| 0.77 | 3.94 | " | .0428 | 0.512 | " | 2.83 |
| 0.82 | 3.21 | " | .0318 | 0.477 | " | 2.10 |
| 0.76 | 3.30 | " | .0331 | 0.489 | " | 2.19 |
| 0.89 | 3.77 | " | .0398 | 0.513 | " | 2.66 |
| 0.83 | 3.97 | " | .0428 | 0.519 | " | 2.86 |
| 0.86 | 4.04 | " | .0439 | 0.531 | " | 2.93 |

Appx. A

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|---|
| Reference | Subject | Weight | Height | Surface Area | Resting metabolism | Conditions | Rate of walking | Load | Post-absorptive (PA) or After meal (AM) |
| | | Kgm | Cm | Square metres | Kilo-calories /min | | Metres /min | Kgm | |
| Benedict | 2 | 70.5 | 177 | | 1.11 | 23.4.14 | 79.8 | zero | PA |
| and | (M.A.M.) | " | " | | " | level | 80.0 | " | " |
| Mursch- | " | " | " | | " | treadmill | 80.7 | " | " |
| hauser | " | " | " | | " | " | 80.4 | " | " |
| 1915 | " | " | " | | " | " | 80.2 | " | " |
| | " | " | " | | " | " | 80.2 | " | " |
| | " | " | " | | " | " | 80.4 | " | " |
| | " | 71.5 | " | | " | 13.5.14 | 82.6 | " | " |
| | " | " | " | | " | " | 89.7 | " | " |
| | " | " | " | | " | " | 80.1 | " | " |
| | " | " | " | | " | " | 76.6 | " | " |
| | " | " | " | | " | " | 93.3 | " | " |
| | " | " | " | | " | " | 91.9 | " | " |
| | " | 71.7 | " | | " | 4.5.14 | 114.5 | " | " |
| | " | " | " | | " | " | 109.1 | " | " |
| | " | " | " | | " | " | 102.2 | " | " |
| | " | " | " | | " | 5.5.14 | 106.0 | " | " |
| | " | " | " | | " | " | 102.6 | " | " |
| | " | " | " | | " | " | 103.6 | " | " |
| | " | " | " | | " | 6.5.14 | 140.7 | " | " |
| | " | " | " | | " | " | 139.6 | " | " |
| | " | " | " | | " | " | 142.9 | " | " |
| | " | 72.3 | " | | " | 10.5.14 | 145.5 | " | " |
| | " | " | " | | " | " | 146.8 | " | " |
| | " | " | " | | " | " | 146.6 | " | " |
| | " | 71.5 | " | | " | 14.5.14 | 146.4 | " | " |
| Smith | 1 | 69.7 | 180 | | 1.22 | 29.11.13 | 75.1 | zero | PA |
| 1922 | (A.J.O.) | (unclothed) | " | | " | 1.12.13 | 76.0 | " | " |
| | " | 72.5 | " | | " | | 76.6 | " | " |
| | " | (clothed) | " | | " | 2.12.13 | 76.2 | " | " |
| | " | 73.2 | " | | " | | 76.8 | " | " |
| | " | 72.8 | " | | " | 3.12.13 | 76.5 | " | " |
| | " | " | " | | " | | 77.2 | " | " |
| | " | " | " | | " | | 77.5 | " | " |
| | " | 73.1 | " | | " | 4.12.13 | 77.7 | " | " |
| | " | " | " | | " | | 77.7 | " | " |
| | " | " | " | | " | | 78.2 | " | " |
| | " | 72.5 | " | | " | 5.12.13 | 75.7 | " | " |
| | " | " | " | | " | | 79.2 | " | " |
| | " | " | " | | " | | 79.0 | " | " |
| | " | 72.3 | " | | " | 8.12.13 | 76.5 | " | " |
| | " | " | " | | " | | 78.6 | " | " |
| | " | " | " | | " | | 79.3 | " | " |

| (9) R.Q. | (10) Rate of total energy expenditure Kilo-calories /min | (11) (15 ÷ 3) Working-Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working-Kilo-calories per Kilogram of body weight | (13) $(\frac{15}{(1+7)x6})$ Working-gram-calories per horizontal metre-Kilogram (total weight of body plus load) | (14) $(\frac{15}{7 \times 6})$ Working-Kilo-calories per horizontal metre-kilogram (load only) | (15) (10-4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| 0.85 | 3.99 | nk | .0431 | 0.512 | ∞ | 2.88 |
| 0.80 | 4.06 | " | .0442 | 0.523 | " | 2.95 |
| 0.80 | 4.12 | " | .0451 | 0.529 | " | 3.01 |
| 0.77 | 4.40 | " | .0493 | 0.580 | " | 3.29 |
| 0.77 | 4.07 | " | .0443 | 0.524 | " | 2.96 |
| 0.79 | 4.14 | " | .0454 | 0.536 | " | 3.03 |
| 0.77 | 4.09 | " | .0446 | 0.526 | " | 2.98 |
| 0.84 | 4.13 | " | .0445 | 0.511 | " | 3.02 |
| 0.78 | 4.50 | " | .0500 | 0.529 | " | 3.39 |
| 0.77 | 3.94 | " | .0417 | 0.494 | " | 2.83 |
| 0.76 | 3.75 | " | .0389 | 0.482 | " | 2.64 |
| 0.74 | 4.72 | " | .0532 | 0.541 | " | 3.61 |
| 0.77 | 4.67 | " | .0525 | 0.542 | " | 3.56 |
| 0.86 | 6.71 | " | .0824 | 0.682 | " | 5.60 |
| 0.90 | 5.79 | " | .069 | 0.698 | " | 4.68 |
| 0.84 | 5.42 | " | .0635 | 0.589 | " | 4.31 |
| 0.90 | 5.54 | " | .0651 | 0.583 | " | 4.43 |
| 0.83 | 5.33 | " | .0621 | 0.574 | " | 4.22 |
| 0.79 | 5.51 | " | .0647 | 0.592 | " | 4.40 |
| 0.92 | 10.23 | " | .1341 | 0.904 | " | 9.12 |
| 0.87 | 10.38 | " | .1362 | 0.926 | " | 9.27 |
| 0.79 | 10.91 | " | .144 | 0.956 | " | 9.80 |
| 0.90 | 10.99 | " | .1452 | 0.939 | " | 9.88 |
| 0.88 | 11.68 | " | .1552 | 0.996 | " | 10.57 |
| 0.90 | 11.00 | " | .1453 | 0.933 | " | 9.89 |
| 0.90 | 11.23 | " | .1489 | 0.967 | " | 10.12 |
| 1.02 | 4.41 | nk | .0458 | 0.586 | " | 3.19 |
| 0.81 | 4.10 | " | .0414 | 0.523 | " | 2.88 |
| 0.81 | 4.35 | " | .0449 | 0.564 | " | 3.13 |
| 0.74 | 4.03 | " | .0404 | 0.509 | " | 2.81 |
| 0.82 | 4.10 | " | .0409 | 0.512 | " | 2.88 |
| 0.81 | 4.07 | " | .0407 | 0.512 | " | 2.85 |
| 0.83 | 4.07 | " | .0407 | 0.507 | " | 2.85 |
| 0.80 | 4.19 | " | .0425 | 0.526 | " | 2.97 |
| 0.79 | 4.19 | " | .0425 | 0.523 | " | 2.97 |
| 0.79 | 4.22 | " | .0427 | 0.528 | " | 3.00 |
| 0.82 | 4.14 | " | .0416 | 0.511 | " | 2.92 |
| 0.78 | 4.43 | " | .046 | 0.585 | " | 3.21 |
| 0.85 | 4.50 | " | .0471 | 0.579 | " | 3.28 |
| 0.77 | 4.68 | " | .0496 | 0.604 | " | 3.46 |
| 0.84 | 4.02 | " | .0403 | 0.506 | " | 2.80 |
| 0.82 | 4.29 | " | .0442 | 0.540 | " | 3.07 |
| 0.81 | 4.27 | " | .0439 | 0.532 | " | 3.05 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilocalories/ min | (5) Conditions | (6) Rate of Walking Metres/ min | (7) Load Kgm | (8) Post absorbtive (PA) or After meal(AM) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | level treadmill | | | |
| Smith 1922 | E.D.B. | 57.0 | 173 | 1.68 | 1.12** | 9.10.15 | 57.8 | Zero | PA |
| | " | " | " | " | " | " | 56.4 | " | " |
| | " | " | " | " | " | 11.10.15 | 56.3 | " | " |
| | " | " | " | " | " | | 53.7 | " | " |
| | " | " | " | " | " | 13.10.15 | 55.8 | " | " |
| | " | " | " | " | " | 14.10.15 | 55.3 | " | " |
| | " | " | " | " | " | | 54.2 | " | " |
| | " | " | " | " | " | | 54.1 | " | " |
| | " | " | " | " | " | 15.10.15 | 55.4 | " | " |
| | " | " | " | " | " | | 54.3 | " | " |
| | " | " | " | " | " | | 53.6 | " | " |
| | " | " | " | " | " | 16.10.15 | 65.2 | " | " |
| | " | " | " | " | " | | 64.9 | " | " |
| | " | " | " | " | " | | 65.0 | " | " |
| | " | " | " | " | " | | 64.9 | " | " |
| | " | " | " | " | " | 18.10.15 | 63.4 | " | " |
| | " | " | " | " | " | | 64.5 | " | " |
| | " | " | " | " | " | | 64.4 | " | " |
| | " | " | " | " | " | | 64.8 | " | " |
| | " | " | " | " | " | 19.10.15 | 64.6 | " | " |
| | " | " | " | " | " | | 64.1 | " | " |
| | " | " | " | " | " | | 63.9 | " | " |
| | " | " | " | " | " | | 64.5 | " | " |
| | " | " | " | " | " | 20.10.15 | 64.6 | " | " |
| | " | " | " | " | " | | 64.4 | " | " |
| | " | " | " | " | " | | 64.7 | " | " |
| | " | " | " | " | " | | 64.5 | " | " |
| | " | " | " | " | " | | 64.7 | " | " |
| | " | " | " | " | " | 21.10.15 | 63.8 | " | " |
| | " | " | " | " | " | | 63.6 | " | " |
| | " | " | " | " | " | | 63.7 | " | " |
| | " | " | " | " | " | | 63.8 | " | " |
| | " | " | " | " | " | | 64.3 | " | " |
| | " | " | " | " | " | 22.10.15 | 71.6 | " | " |
| | " | " | " | " | " | | 72.0 | " | " |
| | " | " | " | " | " | | 72.6 | " | " |
| | " | " | " | " | " | | 72.4 | " | " |
| | " | " | " | " | " | 23.10.15 | 71.6 | " | " |
| | " | " | " | " | " | | 72.4 | " | " |
| | " | " | " | " | " | | 72.2 | " | " |
| | " | " | " | " | " | | 72.6 | " | " |
| | " | " | " | " | " | 25.10.15 | 72.5 | " | " |
| | " | " | " | " | " | | 72.9 | " | " |
| | " | " | " | " | " | | 73.0 | " | " |
| | " | " | " | " | " | | 73.7 | " | " |
| | " | " | " | " | " | | 73.7 | " | " |
| | " | " | " | " | " | 26.10.15 | 72.5 | " | " |
| | " | " | " | " | " | | 72.2 | " | " |
| | " | " | " | " | " | | 73.5 | " | " |
| | " | " | " | " | " | | 72.9 | " | " |
| | " | " | " | " | " | | 73.2 | " | " |
| | " | " | " | " | " | 27.10.15 | 76.6 | " | " |
| | " | " | " | " | " | | 77.0 | " | " |
| | " | " | " | " | " | | 77.3 | " | " |
| | " | " | " | " | " | | 78.3 | " | " |
| | " | " | " | " | " | | 78.5 | " | " |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 3) | (15 ÷ 1) | ($\frac{15}{(1+7)x6}$) | ($\frac{15}{7 x 6}$) | (10 - 4) |
| R.Q. | Rate of total energy expenditure Kilocalories/min | Working-Kilo-calories per square metre per minute | Working-Kilo-calories per Kilogram of body weight | Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | Working-Kilo-calories per horizontal metre-Kilogram (Load only) | Working-Kilo-calories expended per minute |
| | | | | | ∞ | |
| 0.75 | 3.36 | 1.335 | .0393 | 0.681 | " | 2.24 |
| 0.78 | 3.15 | 1.21 | .0356 | 0.682 | " | 2.03 |
| 0.88 | 2.99 | 1.113 | .0328 | 0.583 | " | 1.87 |
| 0.77 | 2.98 | 1.108 | .0327 | 0.608 | " | 1.86 |
| 0.80 | 2.93 | 1.079 | .0318 | 0.569 | " | 1.81 |
| 0.79 | 2.80 | 1.0 | .0295 | 0.533 | " | 1.68 |
| 0.76 | 2.85 | 1.03 | .0304 | 0.560 | " | 1.73 |
| 0.76 | 2.91 | 1.068 | .0314 | 0.581 | " | 1.79 |
| 0.82 | 2.77 | 0.984 | .029 | 0.522 | " | 1.65 |
| 0.77 | 2.83 | 1.018 | .030 | 0.553 | " | 1.71 |
| 0.77 | 2.90 | 1.06 | .0312 | 0.584 | " | 1.78 |
| 0.90 | 2.95 | 1.09 | .0321 | 0.492 | " | 1.83 |
| 0.86 | 3.01 | 1.125 | .0332 | 0.511 | " | 1.89 |
| 0.81 | 3.05 | 1.149 | .0338 | 0.522 | " | 1.93 |
| 0.83 | 3.02 | 1.131 | .0333 | 0.514 | " | 1.90 |
| 0.91 | 2.87 | 1.041 | .0307 | 0.485 | " | 1.75 |
| 0.87 | 3.01 | 1.125 | .0332 | 0.514 | " | 1.89 |
| 0.89 | 2.95 | 1.09 | .0321 | 0.499 | " | 1.83 |
| 0.88 | 3.01 | 1.125 | .0332 | 0.512 | " | 1.89 |
| 0.88 | 2.90 | 1.06 | .0312 | 0.484 | " | 1.78 |
| 0.78 | 3.14 | 1.201 | .0354 | 0.553 | " | 2.02 |
| 0.81 | 2.97 | 1.101 | .0325 | 0.508 | " | 1.85 |
| 0.77 | 3.19 | 1.231 | .0363 | 0.564 | " | 2.07 |
| 0.89 | 3.00 | 1.121 | .033 | 0.511 | " | 1.88 |
| 0.83 | 3.13 | 1.198 | .0353 | 0.548 | " | 2.01 |
| 0.83 | 3.12 | 1.191 | .0351 | 0.542 | " | 2.00 |
| 0.81 | 3.10 | 1.18 | .0348 | 0.540 | " | 1.98 |
| 0.83 | 3.11 | 1.185 | .035 | 0.541 | " | 1.99 |
| 0.90 | 2.97 | 1.101 | .0324 | 0.508 | " | 1.85 |
| 0.82 | 3.07 | 1.161 | .0342 | 0.539 | " | 1.95 |
| 0.84 | 3.08 | 1.166 | .0344 | 0.540 | " | 1.96 |
| 0.82 | 3.11 | 1.185 | .0349 | 0.547 | " | 1.99 |
| 0.81 | 3.07 | 1.161 | .0342 | 0.533 | " | 1.95 |
| 0.85 | 3.12 | 1.191 | .0351 | 0.490 | " | 2.00 |
| 0.84 | 3.17 | 1.22 | .036 | 0.500 | " | 2.05 |
| 0.81 | 3.20 | 1.239 | .0365 | 0.502 | " | 2.08 |
| 0.82 | 3.22 | 1.25 | .0368 | 0.508 | " | 2.10 |
| 0.84 | 3.23 | 1.255 | .037 | 0.517 | " | 2.11 |
| 0.82 | 3.25 | 1.269 | .0374 | 0.516 | " | 2.13 |
| 0.82 | 3.19 | 1.232 | .0363 | 0.504 | " | 2.07 |
| 0.81 | 3.25 | 1.27 | .0374 | 0.514 | " | 2.13 |
| 0.88 | 3.12 | 1.191 | .0351 | 0.484 | " | 2.00 |
| 0.83 | 3.22 | 1.25 | .0368 | 0.506 | " | 2.10 |
| 0.81 | 3.22 | 1.25 | .0368 | 0.503 | " | 2.10 |
| 0.81 | 3.24 | 1.262 | .0372 | 0.505 | " | 2.12 |
| 0.81 | 3.27 | 1.28 | .0378 | 0.512 | " | 2.15 |
| 0.79 | 3.15 | 1.21 | .0356 | 0.492 | " | 2.03 |
| 0.76 | 3.19 | 1.231 | .0363 | 0.504 | " | 2.07 |
| 0.78 | 3.25 | 1.27 | .0374 | 0.508 | " | 2.13 |
| 0.78 | 3.19 | 1.232 | .0363 | 0.499 | " | 2.07 |
| 0.77 | 3.23 | 1.256 | .037 | 0.506 | " | 2.11 |
| 0.84 | 3.22 | 1.25 | .0368 | 0.481 | " | 2.10 |
| 0.81 | 3.27 | 1.28 | .0377 | 0.490 | " | 2.15 |
| 0.80 | 3.30 | 1.298 | .0382 | 0.494 | " | 2.18 |
| 0.80 | 3.38 | 1.345 | .0397 | 0.507 | " | 2.26 |
| 0.79 | 3.40 | 1.359 | .04 | 0.510 | " | 2.28 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilocalories/min | (5) Conditions | (6) Rate of Walking Metres/min | (7) Load Kgm | (8) Post-absorptive(PA) or After meal(AM) |
|---|---|---|---|---|---|---|---|---|---|
| Smith 1922 | E.D.B. | 57.0 | 173 | 1.68 | 1.12* | level treadmill 29.10.15 | 77.1 | zero | P.A. |
| | " | " | " | " | " | | 78.1 | " | " |
| | " | " | " | " | " | | 78.3 | " | " |
| | " | " | " | " | " | | 78.5 | " | " |
| | " | " | " | " | " | 30.10.15 | 45.2 | " | " |
| | " | " | " | " | " | | 43.5 | " | " |
| | " | " | " | " | " | | 43.1 | " | " |
| | " | " | " | " | " | 1.11.15 | 44.9 | " | " |
| | " | " | " | " | " | | 44.5 | " | " |
| | " | " | " | " | " | | 43.5 | " | " |
| | " | " | " | " | " | 2.11.15 | 43.9 | " | " |
| | " | " | " | " | " | | 43.4 | " | " |
| | " | " | " | " | " | | 42.3 | " | " |
| | " | " | " | " | " | 3.11.15 | 45.4 | " | " |
| | " | " | " | " | " | | 44.7 | " | " |
| | " | " | " | " | " | | 43.4 | " | " |
| | " | " | " | " | " | 4.11.15 | 53.5 | " | " |
| | " | " | " | " | " | | 53.2 | " | " |
| | " | " | " | " | " | | 53.9 | " | " |
| | " | " | " | " | " | 5.11.15 | 46.9 | " | " |
| | " | " | " | " | " | | 46.2 | " | " |
| | " | " | " | " | " | | 45.6 | " | " |
| | " | " | " | " | " | 6.11.15 | 46.8 | " | " |
| | " | " | " | " | " | | 45.8 | " | " |
| | " | " | " | " | " | | 45.0 | " | " |
| | " | " | " | " | " | 8.11.15 | 55.2 | " | " |
| | " | " | " | " | " | | 56.1 | " | " |
| | " | " | " | " | " | | 57.0 | " | " |
| | " | " | " | " | " | 9.11.15 | 54.9 | " | " |
| | " | " | " | " | " | | 54.5 | " | " |
| | " | " | " | " | " | | 54.6 | " | " |
| | " | " | " | " | " | 10.11.15 | 48.4 | " | " |
| | " | " | " | " | " | | 47.8 | " | " |
| | " | " | " | " | " | | 47.1 | " | " |
| | " | " | " | " | " | 11.11.15 | 67.1 | " | " |
| | " | " | " | " | " | | 68.2 | " | " |
| | " | " | " | " | " | | 68.4 | " | " |
| | " | " | " | " | " | 12.11.15 | 66.0 | " | " |
| | " | " | " | " | " | | 67.7 | " | " |
| | " | " | " | " | " | | 67.6 | " | " |
| | " | " | " | " | " | 13.11.15 | 76.1 | " | " |
| | " | " | " | " | " | | 76.9 | " | " |
| | " | " | " | " | " | | 77.0 | " | " |
| | " | " | " | " | " | 15.11.15 | 76.3 | " | " |
| | " | " | " | " | " | | 77.1 | " | " |
| | " | " | " | " | " | | 77.5 | " | " |
| | " | " | " | " | " | 16.11.15 | 76.4 | " | " |
| | " | " | " | " | " | | 77.0 | " | " |
| | " | " | " | " | " | | 77.4 | " | " |
| | " | " | " | " | " | 17.11.15 | 46.2 | " | " |
| | " | " | " | " | " | | 45.4 | " | " |
| | " | " | " | " | " | | 45.6 | " | " |
| | " | " | " | " | " | 18.11.15 | 55.7 | " | " |
| | " | " | " | " | " | | 54.9 | " | " |
| | " | " | " | " | " | | 54.6 | " | " |

| (9)<br>R.Q. | (10)<br>Rate of total energy expenditure<br>Kilocalories/min | (11)<br>(15 ÷ 3)<br>Working-Kilocalories per square metre per minute | (12)<br>(15 ÷ 1)<br>Working-Kilocalories per Kilogram of body weight | (13)<br>( 15 / (1+7) x6 )<br>Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | (14)<br>( 15 / 7 x 6 )<br>Working-Kilocalories per horizontal metre-Kilogram (load only) | (15)<br>(10 - 4)<br>Working-Kilocalories expended per minute |
|---|---|---|---|---|---|---|
| 0.86 | 3.36 | 1.335 | .0393 | 0.510 | " | 2.24 |
| 0.83 | 3.33 | 1.315 | .0388 | 0.497 | " | 2.21 |
| 0.82 | 3.40 | 1.358 | .04 | 0.511 | " | 2.28 |
| 0.83 | 3.50 | 1.417 | .0418 | 0.532 | " | 2.38 |
| 0.86 | 2.42 | 0.774 | .0228 | 0.504 | " | 1.30 |
| 0.88 | 2.32 | .714 | .0211 | 0.484 | " | 1.20 |
| 0.83 | 2.34 | .726 | .0212 | 0.496 | " | 1.22 |
| 0.92 | 2.33 | .72 | .0212 | 0.473 | " | 1.21 |
| 0.87 | 2.31 | .709 | .0209 | 0.469 | " | 1.19 |
| 0.85 | 2.32 | .715 | .021 | 0.484 | " | 1.20 |
| 0.89 | 2.31 | .709 | .0209 | 0.476 | " | 1.19 |
| 0.85 | 2.35 | .732 | .0216 | 0.498 | " | 1.23 |
| 0.85 | 2.30 | .703 | .0207 | 0.490 | " | 1.18 |
| 0.90 | 2.27 | .685 | .0202 | 0.444 | " | 1.15 |
| 0.85 | 2.28 | .69 | .0204 | 0.455 | " | 1.16 |
| 0.89 | 2.23 | .66 | .0195 | 0.449 | " | 1.11 |
| 0.87 | 2.43 | .78 | .023 | 0.430 | " | 1.31 |
| 0.86 | 2.45 | .791 | .0234 | 0.439 | " | 1.33 |
| 0.83 | 2.54 | .845 | .0249 | 0.463 | " | 1.42 |
| 0.89 | 2.32 | .714 | .0211 | 0.449 | " | 1.20 |
| 0.84 | 2.32 | .714 | .0211 | 0.456 | " | 1.20 |
| 0.83 | 2.32 | .714 | .0211 | 0.462 | " | 1.20 |
| 0.89 | 2.24 | .666 | .0197 | 0.449 | " | 1.12 |
| 0.89 | 2.25 | .673 | .0198 | 0.433 | " | 1.13 |
| 0.87 | 2.26 | .678 | .020 | 0.445 | " | 1.14 |
| 0.95 | 2.54 | .845 | .0249 | 0.451 | " | 1.42 |
| 0.92 | 2.59 | .875 | .0258 | 0.459 | " | 1.47 |
| 0.90 | 2.59 | .875 | .0258 | 0.452 | " | 1.47 |
| 0.95 | 2.42 | .774 | .0228 | 0.415 | " | 1.30 |
| 0.86 | 2.41 | .768 | .0226 | 0.415 | " | 1.29 |
| 0.91 | 2.46 | .797 | .0235 | 0.431 | " | 1.34 |
| 0.91 | 2.27 | .684 | .0202 | 0.417 | " | 1.15 |
| 0.86 | 2.32 | .714 | .0211 | 0.441 | " | 1.20 |
| 0.85 | 2.38 | .75 | .0221 | 0.470 | " | 1.26 |
| 0.84 | 2.78 | .988 | .0292 | 0.435 | " | 1.66 |
| 0.86 | 2.96 | 1.082 | .0322 | 0.473 | " | 1.84 |
| 0.85 | 2.93 | 1.078 | .0318 | 0.464 | " | 1.81 |
| 0.92 | 2.84 | 1.024 | .0312 | 0.457 | " | 1.72 |
| 0.88 | 2.91 | 1.065 | .0214 | 0.464 | " | 1.79 |
| 0.90 | 2.92 | 1.071 | .0316 | 0.468 | " | 1.80 |
| 0.96 | 3.04 | 1.142 | .0337 | 0.442 | " | 1.92 |
| 0.89 | 3.23 | 1.225 | .037 | 0.482 | " | 2.11 |
| 0.88 | 3.11 | 1.185 | .0349 | 0.453 | " | 1.99 |
| 0.96 | 3.15 | 1.209 | .0356 | 0.467 | " | 2.03 |
| 0.92 | 3.21 | 1.244 | .0367 | 0.476 | " | 2.09 |
| 0.90 | 3.18 | 1.255 | .0362 | 0.466 | " | 2.06 |
| 0.86 | 3.19 | 1.231 | .0364 | 0.476 | " | 2.07 |
| 0.82 | 3.17 | 1.22 | .036 | 0.467 | " | 2.05 |
| 0.81 | 3.17 | 1.22 | .036 | 0.465 | " | 2.05 |
| 0.86 | 2.29 | .687 | .0205 | 0.445 | " | 1.17 |
| 0.84 | 2.28 | .69 | .0204 | 0.448 | " | 1.16 |
| 0.85 | 2.30 | .703 | .0207 | 0.454 | " | 1.18 |
| 0.84 | 2.46 | .799 | .0235 | 0.423 | " | 1.34 |
| 0.85 | 2.39 | .755 | .0223 | 0.406 | " | 1.27 |
| 0.83 | 2.47 | .804 | .0237 | 0.434 | " | 1.35 |
| 0.83 | 2.50 | [illegible] | [illegible] | [illegible] | " | [illegible] |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting metabolism kilo-calories /min. | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Smith | E.D.B. | 57.0 | 173 | 1.68 | 1.12* | Level treadmill 28.10.15 | 77.1 | zero | PA |
| 1922 | " | " | " | " | " | | 77.8 | " | " |
| | " | " | " | " | " | | 77.8 | " | " |
| | " | " | " | " | " | | 78.1 | " | " |
| | " | " | " | " | " | | 78.2 | " | " |
| | " | " | " | " | " | 19.11.15 | 76.5 | " | " |
| | " | " | " | " | " | | 77.7 | " | " |
| | " | " | " | " | " | | 77.9 | " | " |
| | " | " | " | " | " | | 78.4 | " | " |
| | " | " | " | " | " | | 78.9 | " | " |
| | " | " | " | " | " | 22.11.15 | 48.0 | " | " |
| | " | " | " | " | " | | 47.3 | " | " |
| | " | " | " | " | " | | 46.8 | " | " |
| | " | " | " | " | " | 23.11.15 | 55.5 | " | " |
| | " | " | " | " | " | | 53.9 | " | " |
| | " | " | " | " | " | | 54.9 | " | " |
| | " | " | " | " | " | 24.11.15 | 57.7 | " | " |
| | " | " | " | " | " | | 57.6 | " | " |
| | " | " | " | " | " | | 57.1 | " | " |
| | " | " | " | " | " | 26.11.15 | 65.3 | " | " |
| | " | " | " | " | " | | 66.2 | " | " |
| | " | " | " | " | " | | 66.2 | " | " |
| | " | " | " | " | " | 1.12.15 | 74.9 | " | " |
| | " | " | " | " | " | | 76.4 | " | " |
| | " | " | " | " | " | | 77.3 | " | " |
| | " | " | " | " | " | 2.12.15 | 71.3 | " | " |
| | " | " | " | " | " | | 71.8 | " | " |
| | " | " | " | " | " | | 71.8 | " | " |
| | " | " | " | " | " | 3.12.15 | 70.5 | " | " |
| | " | " | " | " | " | | 71.2 | " | " |
| | " | " | " | " | " | | 72.1 | " | " |
| | " | " | " | " | " | 6.12.15 | 45.2 | " | " |
| | " | " | " | " | " | | 45.1 | " | " |
| | " | " | " | " | " | | 44.7 | " | " |
| | " | " | " | " | " | 7.12.15 | 43.8 | " | " |
| | " | " | " | " | " | | 43.1 | " | " |
| | " | " | " | " | " | | 50.6 | " | " |
| | " | " | " | " | " | 13.12.15 | 66.8 | " | " |
| | " | " | " | " | " | | 66.6 | " | " |
| | " | " | " | " | " | | 66.7 | " | " |
| | " | " | " | " | " | 31. 1.16 | 62.0 | " | " |
| | " | " | " | " | " | | 63.5 | " | " |
| | " | " | " | " | " | | 63.4 | " | " |
| | " | " | " | " | " | | 63.9 | " | " |
| | " | " | " | " | " | 1. 2.16 | 62.9 | " | " |
| | " | " | " | " | " | | 63.2 | " | " |
| | " | " | " | " | " | | 64.3 | " | " |
| | " | " | " | " | " | | 63.9 | " | " |
| | " | " | " | " | " | 20. 3.16 | 59.5 | " | " |
| | " | " | " | " | " | | 60.7 | " | " |
| | " | " | " | " | " | 22. 3.16 | 74.8 | " | " |
| | " | " | " | " | " | | 76.9 | " | " |
| | " | " | " | " | " | 29. 3.16 | 57.6 | " | " |
| | " | " | " | " | " | | 55.5 | " | " |
| | " | " | " | " | " | 30. 3.16 | 68.5 | " | " |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 3) | (15 ÷ 1) | $\left(\frac{15}{(1+7)x6}\right)$ | $\left(\frac{15}{7 \times 6}\right)$ | (10 – 4) |
| R.Q. | Rate of total energy expenditure kilo-calories/ min. | Working-kilo-calories per square metre per minute | Working-kilo-calories per kilogram of body weight | Working-gram-calories per horizontal metre-kilo-gram (total weight of body plus load) | Working-kilo-calories per horizontal metre-kilogram (load only) | Working-kilo-calories expended per minute |
| 0.91 | 3.23 | 1.257 | .037 | 0.481 | ∞ | 2.11 |
| 0.89 | 3.28 | 1.285 | .0379 | 0.487 | " | 2.16 |
| 0.83 | 3.33 | 1.33 | .0388 | 0.498 | " | 2.21 |
| 0.83 | 3.36 | 1.37 | .0393 | 0.503 | " | 2.24 |
| 0.83 | 3.30 | 1.3 | .0382 | 0.489 | " | 2.18 |
| 0.85 | 3.06 | 1.155 | .034 | 0.445 | " | 1.94 |
| 0.82 | 3.24 | 1.26 | .0372 | 0.478 | " | 2.12 |
| 0.80 | 3.19 | 1.23 | .0363 | 0.466 | " | 2.07 |
| 0.80 | 3.22 | 1.25 | .0368 | 0.470 | " | 2.10 |
| 0.81 | 3.25 | 1.269 | .0374 | 0.474 | " | 2.13 |
| 0.87 | 2.37 | .745 | .0219 | 0.456 | " | 1.25 |
| 0.86 | 2.37 | .745 | .0219 | 0.464 | " | 1.25 |
| 0.85 | 2.32 | .714 | .0211 | 0.449 | " | 1.20 |
| 0.90 | 2.42 | .774 | .0228 | 0.411 | " | 1.30 |
| 0.88 | 2.41 | .768 | .0226 | 0.420 | " | 1.29 |
| 0.89 | 2.43 | .78 | .023 | 0.418 | " | 1.31 |
| 0.94 | 2.44 | .785 | .0232 | 0.401 | " | 1.32 |
| 0.89 | 2.46 | .788 | .0235 | 0.408 | " | 1.34 |
| 0.89 | 2.47 | .804 | .0237 | 0.415 | " | 1.35 |
| 0.95 | 2.72 | .952 | .0281 | 0.430 | " | 1.60 |
| 0.94 | 2.78 | .989 | .0291 | 0.440 | " | 1.66 |
| 0.91 | 2.78 | .989 | .0291 | 0.440 | " | 1.66 |
| 0.96 | 3.13 | 1.196 | .0352 | 0.471 | " | 2.01 |
| 0.91 | 3.24 | 1.26 | .0372 | 0.487 | " | 2.12 |
| 0.89 | 3.18 | 1.227 | .0362 | 0.467 | " | 2.06 |
| 0.95 | 2.89 | 1.053 | .0310 | 0.436 | " | 1.77 |
| 0.90 | 2.93 | 1.078 | .0317 | 0.407 | " | 1.81 |
| 0.89 | 2.87 | 1.042 | .0307 | 0.428 | " | 1.75 |
| 0.92 | 2.95 | 1.09 | .0321 | 0.455 | " | 1.83 |
| 0.88 | 2.96 | 1.095 | .0323 | 0.453 | " | 1.84 |
| 0.86 | 2.97 | 1.101 | .0325 | 0.450 | " | 1.85 |
| 0.91 | 2.17 | .565 | .0167 | 0.369 | " | 0.95 |
| 0.85 | 2.19 | .577 | .017 | 0.377 | " | 0.97 |
| 0.87 | 2.16 | .56 | .0165 | 0.368 | " | 0.94 |
| 0.91 | 2.24 | .667 | .0197 | 0.450 | " | 1.12 |
| 0.92 | 2.20 | .643 | .0189 | 0.439 | " | 1.08 |
| 0.88 | 2.37 | .744 | .0219 | 0.434 | " | 1.25 |
| 0.86 | 2.63 | .899 | .0265 | 0.396 | " | 1.51 |
| 0.82 | 2.81 | 1.008 | .0296 | 0.445 | " | 1.69 |
| 0.82 | 2.68 | .928 | .0274 | 0.410 | " | 1.56 |
| 0.84 | 3.20 | 1.24 | .0365 | 0.589 | " | 2.08 |
| 0.79 | 3.22 | 1.25 | .0368 | 0.580 | " | 2.10 |
| 0.78 | 3.29 | 1.292 | .0381 | 0.601 | " | 2.17 |
| 0.79 | 3.22 | 1.25 | .0368 | 0.577 | " | 2.10 |
| 0.88 | 3.19 | 1.232 | .0363 | 0.578 | " | 2.07 |
| 0.81 | 3.09 | 1.171 | .0346 | 0.547 | " | 1.97 |
| 0.80 | 2.95 | 1.09 | .0321 | 0.500 | " | 1.83 |
| 0.81 | 3.11 | 1.185 | .0349 | 0.546 | " | 1.99 |
| 0.85 | 2.94 | 1.082 | .032 | 0.537 | " | 1.82 |
| 0.88 | 2.85 | 1.03 | .0304 | 0.500 | " | 1.73 |
| 0.82 | 3.32 | 1.31 | .0386 | 0.516 | " | 2.20 |
| 0.83 | 3.40 | 1.36 | .04 | 0.528 | " | 2.28 |
| 0.7[illegible] | 2.89 | 1.053 | .031 | 0.539 | " | 1.77 |

Appx.A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilo-calories/min | (5) Conditions | (6) Rate of walking Metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After Meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Smith 1922 | E.D.B | 57.0 | 173 | 1.68 | 1.12* | level treadmill 4.12.15 | 47.5 | zero | P.A. |
| | " | " | " | " | " | | 46.6 | " | " |
| | " | " | " | " | " | | 45.9 | " | " |
| | " | " | " | " | " | 31.3.15 | 55.2 | " | " |
| | " | " | " | " | " | | 52.9 | " | " |
| | " | " | " | " | " | 1.4.15 | 53.4 | " | " |
| | " | " | " | " | " | | 51.7 | " | " |
| | " | " | " | " | " | | 50.4 | " | " |
| | " | " | " | " | " | 3.4.15 | 35.1 | " | " |
| | " | " | " | " | " | | 35.7 | " | " |
| | " | " | " | " | " | | 36.7 | " | " |
| | " | " | " | " | " | 4.4.15 | 35.9 | " | " |
| | " | " | " | " | " | | 37.0 | " | " |
| | " | " | " | " | " | | 37.0 | " | " |
| | " | " | " | " | " | 5.4.15 | 77.4 | " | " |
| | " | " | " | " | " | | 76.5 | " | " |
| | " | " | " | " | " | | 79.3 | " | " |
| | " | " | " | " | " | 10.4.15 | 78.7 | " | " |
| | " | " | " | " | " | | 77.1 | " | " |
| | " | " | " | " | " | 11.4.15 | 95.9 | " | " |
| | " | " | " | " | " | | 92.0 | " | " |
| | " | " | " | " | " | | 89.0 | " | " |
| | " | " | " | " | " | 12.4.15 | 89.2 | " | " |
| | " | " | " | " | " | | 89.0 | " | " |
| | " | " | " | " | " | | 86.6 | " | " |
| | " | " | " | " | " | 13.4.15 | 99.7 | " | " |
| | " | " | " | " | " | | 97.7 | " | " |
| | " | " | " | " | " | | 94.9 | " | " |
| Smith 1922 | J.H.G. | 68.0 | 185 | 1.89 | 1.26* | level treadmill 18.1.16 | 55.3 | zero | P.A. |
| | " | " | " | " | " | | 55.2 | " | " |
| | " | " | " | " | " | | 54.5 | " | " |
| | " | " | " | " | " | 19.1.16 | 55.3 | " | " |
| | " | " | " | " | " | | 55.1 | " | " |
| | " | " | " | " | " | | 53.8 | " | " |
| | " | " | " | " | " | 20.1.16 | 55.9 | " | " |
| | " | " | " | " | " | | 55.6 | " | " |
| | " | " | " | " | " | | 53.5 | " | " |
| Smith 1922 | E.L.F. | 70.4 | 171 | 1.82 | 1.21* | level treadmill 21.1.16 | 52.5 | zero | P.A. |
| | " | " | " | " | " | | 52.3 | " | " |
| | " | " | " | " | " | | 52.5 | " | " |
| | " | " | " | " | " | 22.1.16 | 53.6 | " | " |
| | " | " | " | " | " | | 52.5 | " | " |
| | " | " | " | " | " | | 52.3 | " | " |
| | " | " | " | " | " | 24.1.16 | 49.6 | " | " |
| | " | " | " | " | " | | 49.2 | " | " |
| | " | " | " | " | " | | 48.4 | " | " |

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15 ÷ 3) | (15 ÷ 1) | $\left(\frac{15}{(1+7.)x6}\right)$ | $\left(\frac{15}{7 \times 6}\right)$ | (10-4) |
| R.Q. | Rate of total energy expenditure kilo-calories/min | Working-kilocalories per square metre per minute | Working-kilocalories per kilogram of body weight | Working-gram-calories per horizontal metre-kilogram (total weight of body plus load) | Working-Kilo calories per horizontal metre-kilogram (load only) | Working-kilocalories expended per minute |
| 0.93 | 2.23 | .655 | .0195 | 0.409 | [illegible] | 1.11 |
| 0.88 | 2.20 | .644 | .0189 | 0.406 | " | 1.08 |
| 0.86 | 2.24 | .666 | .0211 | 0.427 | " | 1.12 |
| 0.95 | 2.69 | .935 | .0276 | 0.498 | " | 1.57 |
| 0.92 | 2.73 | .958 | .0282 | 0.535 | " | 1.61 |
| 0.86 | 2.67 | .923 | .0272 | 0.510 | " | 1.55 |
| 0.83 | 2.61 | .886 | .0262 | 0.505 | " | 1.49 |
| 0.83 | 2.59 | .875 | .0258 | 0.512 | " | 1.47 |
| 0.90 | 2.18 | .63 | .0186 | 0.530 | " | 1.06 |
| 0.87 | 2.27 | .685 | .0202 | 0.566 | " | 1.15 |
| 0.84 | 2.24 | .666 | .0195 | 0.536 | " | 1.12 |
| 0.83 | 2.30 | .702 | .027 | 0.576 | " | 1.18 |
| 0.83 | 2.25 | .672 | .0198 | 0.456 | " | 1.13 |
| 0.78 | 2.33 | .72 | .0212 | 0.573 | " | 1.21 |
| 0.82 | 3.53 | 1.435 | .0423 | 0.546 | " | 2.41 |
| 0.82 | 3.42 | 1.369 | .0404 | 0.527 | " | 2.30 |
| 0.83 | 3.51 | 1.423 | .042 | 0.529 | " | 2.39 |
| 0.94 | 3.59 | 1.47 | .0433 | 0.551 | " | 2.47 |
| 0.91 | 3.56 | 1.451 | .0428 | 0.556 | " | 2.44 |
| 0.87 | 4.47 | 1.991 | .0588 | 0.613 | " | 3.35 |
| 0.88 | 4.14 | 1.798 | .053 | 0.576 | " | 3.02 |
| 0.84 | 4.10 | 1.775 | .0523 | 0.587 | " | 2.98 |
| 0.81 | 4.34 | 1.94 | .0565 | 0.635 | " | 3.22 |
| 0.81 | 4.18 | 1.84 | .0537 | 0.603 | " | 3.06 |
| 0.81 | 4.04 | 1.738 | .0512 | 0.591 | " | 2.92 |
| 0.88 | 4.55 | 2.04 | .0602 | 0.603 | " | 3.43 |
| 0.86 | 4.59 | 2.065 | .061 | 0.623 | " | 3.47 |
| 0.87 | 4.29 | 1.88 | .0556 | 0.586 | " | 3.17 |
| 0.78 | 3.55 | 1.22 | .0336 | 0.609 | " | 2.29 |
| 0.77 | 3.45 | 1.16 | .0322 | 0.584 | " | 2.19 |
| 0.76 | 3.39 | 1.15 | .0313 | 0.574 | " | 2.13 |
| 0.81 | 3.31 | 1.085 | .0302 | 0.545 | " | 2.05 |
| 0.75 | 3.42 | 1.143 | .0318 | 0.576 | " | 2.16 |
| 0.75 | 3.31 | 1.085 | .0302 | 0.560 | " | 2.05 |
| 0.84 | 3.33 | 1.095 | .0304 | 0.545 | " | 2.07 |
| 0.78 | 3.33 | 1.095 | .0304 | 0.548 | " | 2.07 |
| 0.81 | 3.26 | 1.06 | .0294 | 0.549 | " | 2.00 |
| 0.80 | 3.85 | 1.45 | .0375 | 0.713 | " | 2.64 |
| 0.77 | 3.39 | 1.188 | .031 | 0.592 | " | 2.18 |
| 0.76 | 3.40 | 1.198 | .0312 | 0.592 | " | 2.19 |
| 0.90 | 3.39 | 1.188 | .631 | 0.578 | " | 2.18 |
| 0.83 | 3.40 | 1.198 | .0312 | 0.592 | " | 2.19 |
| 0.86 | 3.33 | 1.165 | .0302 | 0.576 | " | 2.12 |
| 0.81 | 3.28 | 1.14 | .0294 | 0.593 | " | 2.07 |
| 0.80 | 3.24 | 1.115 | .0288 | 0.537 | " | 2.03 |
| 0.81 | 3.21 | 1.1 | .0284 | 0.586 | " | 2.00 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square Metres | (4) Resting Metabolism Kilo-calories /min | (5) Conditions | (6) Rate of walking Metres /min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Smith 1922 | A.J.O. | 69.5 | 180 | 1.88 | 1.25* | level treadmill 15.2.15 | 63.1 | zero | PA |
| | " | " | " | " | " | 24.2.15 | 63.1 | " | " |
| | " | " | " | " | " | " | 63.8 | " | " |
| | " | | | | | 2.3.15 | 63.8 | " | " |
| | | | | | | " | 60.7 | " | " |
| | | | | | | " | 63.6 | " | " |
| Smith 1922 | H.R.R. | 70.0 | 185 | 1.93 | 1.29* | level treadmill 20.3.15 | 67.7 | zero | PA |
| | " | " | " | " | " | " | 64.5 | " | " |
| | " | " | " | " | " | 27.3.15 | 65.8 | " | " |
| | " | " | " | " | " | " | 67.2 | " | " |
| | " | " | " | " | " | " | 67.5 | " | " |
| | " | " | " | " | " | 3.4.15 | 60.9 | " | " |
| | " | " | " | " | " | " | 60.5 | " | " |
| | " | " | " | " | " | " | 60.0 | " | " |
| | " | " | " | " | " | 10.4.15 | 60.1 | " | " |
| | " | " | " | " | " | 17.4.15 | 60.0 | " | " |
| | " | " | " | " | " | " | 59.9 | " | " |
| | " | " | " | " | " | 24.4.15 | 61.8 | " | " |
| | " | " | " | " | " | " | 60.2 | " | " |
| | " | " | " | " | " | " | 60.6 | " | " |
| | " | " | " | " | " | " | 60.1 | " | " |
| Smith 1922 | T.H.H. | 54.5 | 171 | 1.63 | 1.09* | level treadmill 25.2.15 | 63.4 | zero | PA |
| | " | " | " | " | " | " | 63.7 | " | " |
| | " | " | " | " | " | " | 63.7 | " | " |
| | " | " | " | " | " | 19.3.15 | 65.7 | " | " |
| | " | " | " | " | " | " | 66.7 | " | " |
| | " | " | " | " | " | " | 67.1 | " | " |
| | " | " | " | " | " | " | 67.8 | " | " |
| | " | " | " | " | " | 22.3.15 | 67.5 | " | " |
| | " | " | " | " | " | " | 67.5 | " | " |
| | " | " | " | " | " | 24.3.15 | 67.4 | " | " |
| | " | " | " | " | " | " | 68.1 | " | " |
| | " | " | " | " | " | " | 67.3 | " | " |
| | " | " | " | " | " | 26.3.15 | 65.9 | " | " |
| | " | " | " | " | " | " | 67.6 | " | " |
| | " | " | " | " | " | " | 68.2 | " | " |
| | " | " | " | " | " | 30.3.15 | 62.4 | " | " |
| | " | " | " | " | " | " | 62.7 | " | " |
| | " | " | " | " | " | " | 63.2 | " | " |
| | " | " | " | " | " | 5.4.15 | 62.4 | " | " |
| | " | " | " | " | " | " | 63.2 | " | " |

* Estimated from Surface Area assuming Basal Metabolic Rate of 40 calories/square metre/hour

| (9) R.Q. | (10) Rate of total energy expenditure Kilo-calories /min | (11) (15 ÷ 3) Working-Kilo-calories per square metre per minute | (12) (15 ÷ 1) Working-Kilo-calories per Kilogram of body weight | (13) $\left(\frac{15}{(1+7)x6}\right)$ Working-gram-calories per horizontal metre-Kilogram (total weight of body plus load) | (14) $\left(\frac{15}{7 \times 6}\right)$ Working-Kilo calories per horizontal metre-Kilogram (load only) | (15) (10-4) Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| 0.87 | 3.28 | 1.08 | .0292 | 0.463 | .0 | 2.03 |
| 0.83 | 3.67 | 1.288 | .0348 | 0.552 | " | 2.42 |
| 0.83 | 3.63 | 1.267 | .0342 | 0.537 | " | 2.38 |
| 0.87 | 3.58 | 1.24 | .0336 | 0.526 | " | 2.33 |
| 0.84 | 3.37 | 1.128 | .0305 | 0.502 | " | 2.12 |
| 0.90 | 3.27 | 1.075 | .0291 | 0.457 | " | 2.02 |
| | | | | | | |
| 0.80 | 4.88 | 1.86 | .0513 | 0.757 | | 3.59 |
| 0.79 | 4.48 | 1.655 | .0453 | 0.707 | " | 3.19 |
| 0.85 | 4.32 | 1.57 | .0433 | 0.657 | " | 3.03 |
| 0.81 | 4.31 | 1.565 | .0431 | 0.643 | " | 3.02 |
| 0.80 | 4.36 | 1.592 | .044 | 0.650 | " | 3.07 |
| 0.83 | 4.05 | 1.43 | .0394 | 0.633 | " | 2.76 |
| 0.81 | 4.10 | 1.456 | .0401 | 0.664 | " | 2.81 |
| 0.81 | 4.12 | 1.468 | .0404 | 0.674 | " | 2.83 |
| 0.81 | 4.27 | 1.545 | .0426 | 0.708 | " | 2.98 |
| 0.83 | 3.87 | 1.34 | .0369 | 0.614 | " | 2.58 |
| 0.83 | 3.87 | 1.34 | .0369 | 0.615 | " | 2.58 |
| 0.80 | 3.87 | 1.34 | .0369 | 0.596 | " | 2.58 |
| 0.81 | 3.76 | 1.28 | .0353 | 0.587 | " | 2.47 |
| 0.79 | 3.76 | 1.28 | .0353 | 0.582 | " | 2.47 |
| 0.80 | 3.82 | 1.312 | .0361 | 0.601 | " | 2.53 |
| | | | | | | |
| 0.83 | 3.02 | 1.185 | .0354 | 0.559 | " | 1.93 |
| 0.91 | 2.98 | 1.16 | .0347 | 0.545 | " | 1.89 |
| 0.90 | 2.99 | 1.167 | .0349 | 0.548 | " | 1.90 |
| 0.84 | 3.44 | 1.442 | .0431 | 0.656 | " | 2.35 |
| 0.80 | 3.43 | 1.437 | .0429 | 0.645 | " | 2.34 |
| 0.77 | 3.49 | 1.473 | .0441 | 0.656 | " | 2.40 |
| 0.79 | 3.41 | 1.425 | .0426 | 0.629 | " | 2.32 |
| 0.81 | 3.47 | 1.461 | .0436 | 0.647 | " | 2.38 |
| 0.82 | 3.30 | 1.356 | .0405 | 0.601 | " | 2.21 |
| 0.86 | 3.34 | 1.38 | .0413 | 0.613 | " | 2.25 |
| 0.77 | 3.22 | 1.308 | .0391 | 0.574 | " | 2.13 |
| 0.88 | 3.19 | 1.289 | .0385 | 0.569 | " | 2.10 |
| 0.92 | 3.32 | 1.37 | .0409 | 0.621 | " | 2.23 |
| 0.73 | 3.18 | 1.282 | .0384 | 0.568 | " | 2.09 |
| 0.86 | 3.15 | 1.264 | .0378 | 0.554 | " | 2.06 |
| 0.89 | 3.35 | 1.388 | .0414 | 0.665 | " | 2.26 |
| 0.86 | 3.39 | 1.412 | .0422 | 0.673 | " | 2.30 |
| 0.83 | 3.27 | 1.338 | .04 | 0.634 | " | 2.18 |
| 0.86 | 3.36 | 1.394 | .0417 | 0.668 | " | 2.27 |
| 0.82 | 3.42 | 1.43 | .0428 | 0.677 | " | 2.33 |

Appx. A

| Reference | Subject | (1) Weight Kgm | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilocalories/min | (5) Conditions | (6) Rate of Walking Metres/min | (7) Load Kgm | (8) Post absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | level treadmill | | | |
| Smith | W.K. | 49.2 | 162 | 1.51 | 1.01* | 18.2.15 | 65.6 | zero | P.A. |
| 1922 | " | " | " | " | " | " | 66.9 | " | " |
| | " | " | " | " | " | " | 66.3 | " | " |
| | " | " | " | " | " | 26.2.15 | 64.4 | " | " |
| | " | " | " | " | " | 4.3.15 | 64.0 | " | " |
| | " | " | " | " | " | " | 62.9 | " | " |
| | " | " | " | " | " | " | 66.0 | " | " |
| | " | " | " | " | " | 5.3.15 | 65.3 | " | " |
| | " | " | " | " | " | " | 65.9 | " | " |
| | " | " | " | " | " | " | 66.2 | " | " |
| | " | " | " | " | " | 8.3.15 | 65.4 | " | " |
| | " | " | " | " | " | " | 66.6 | " | " |
| | " | " | " | " | " | " | 66.6 | " | " |
| | " | " | " | " | " | 9.3.15 | 66.0 | " | " |
| | " | " | " | " | " | " | 62.5 | " | " |
| | " | " | " | " | " | " | 62.2 | " | " |
| | " | " | " | " | " | " | 53.6 | " | " |
| | " | " | " | " | " | 12.3.15 | 60.9 | " | " |
| | " | " | " | " | " | " | 58.5 | " | " |
| | " | " | " | " | " | " | 63.2 | " | " |
| | " | " | " | " | " | 13.3.15 | 65.1 | " | " |
| | " | " | " | " | " | " | 64.7 | " | " |
| | " | " | " | " | " | " | 59.4 | " | " |
| | " | " | " | " | " | " | 59.1 | " | " |
| | " | " | " | " | " | 16.3.15 | 59.2 | " | " |
| | " | " | " | " | " | " | 62.3 | " | " |
| | " | " | " | " | " | " | 60.9 | " | " |
| | " | " | " | " | " | " | 60.6 | " | " |
| | " | " | " | " | " | 17.3.15 | 67.3 | " | " |
| | " | " | " | " | " | " | 67.4 | " | " |
| | " | " | " | " | " | " | 67.8 | " | " |
| | " | " | " | " | " | " | 67.5 | " | " |
| | " | " | " | " | " | 18.3.15 | 62.5 | " | " |
| | " | " | " | " | " | " | 58.4 | " | " |
| | " | " | " | " | " | " | 60.8 | " | " |
| | " | " | " | " | " | " | 58.8 | " | " |
| | " | " | " | " | " | 23.3.15 | 64.3 | " | " |
| | " | " | " | " | " | " | 66.4 | " | " |
| | " | " | " | " | " | " | 66.5 | " | " |
| | " | " | " | " | " | 25.3.15 | 67.3 | " | " |
| | " | " | " | " | " | " | 67.5 | " | " |
| | " | " | " | " | " | " | 67.0 | " | " |
| | " | " | " | " | " | 29.3.15 | 63.3 | " | " |
| | " | " | " | " | " | " | 60.8 | " | " |
| | " | " | " | " | " | " | 62.8 | " | " |
| | " | " | " | " | " | 31.3.15 | 64.8 | " | " |
| | " | " | " | " | " | " | 65.8 | " | " |
| | " | " | " | " | " | " | 64.8 | " | " |
| | " | " | " | " | " | " | 64.9 | " | " |
| | " | " | " | " | " | 23.6.15 | 58.2 | " | " |
| | " | " | " | " | " | " | 57.1 | " | " |
| | " | " | " | " | " | " | 56.0 | " | " |

*Estimated from Surface Area assuming Basal Metabolic Rate for 40 Calories/Square metres/hour

| (9)<br><br>R.Q. | (10)<br><br>Rate of total energy expenditure<br><br>Kilocalories/min | (11)<br>(15 ÷ 3)<br>Working-Kilo-calories per square metre per minute | (12)<br>(15 ÷ 1)<br>Working-Kilo-calories per Kilogram of body weight | (13)<br>$\left(\frac{15}{(1+7)\times 6}\right)$<br>Working-gram-calories per horizontal metre-Kilogram (Total weight of body plus load) | (14)<br>$\left(\frac{15}{7 \times 6}\right)$<br>Working-Kilo-caloris per horizontal metre-Kilogram (Load only) | (15)<br>(10 - 4)<br>Working-Kilo-calories expended per minute |
|---|---|---|---|---|---|---|
| | | | | | ∞ | |
| 0.69 | 2.95 | 1.285 | .0394 | 0.6006 | " | 1.94 |
| 0.77 | 2.68 | 1.107 | .0338 | 0.508 | " | 1.67 |
| - | - | - | - | - | " | - |
| 0.82 | 2.55 | 1.02 | .0313 | 0.486 | " | 1.54 |
| 1.05 | 3.06 | 1.359 | .0417 | 0.651 | " | 2.05 |
| 0.90 | 2.98 | 1.306 | .0401 | 0.638 | " | 1.97 |
| 0.90 | 3.08 | 1.371 | .0421 | 0.637 | " | 2.07 |
| 0.90 | 2.93 | 1.271 | .039 | 0.598 | " | 1.92 |
| 0.87 | 2.84 | 1.212 | .0372 | 0.565 | " | 1.83 |
| 0.85 | 2.88 | 1.239 | .038 | 0.574 | " | 1.87 |
| 0.83 | 2.99 | 1.31 | .0403 | 0.607 | " | 1.98 |
| 0.85 | 2.87 | 1.231 | .0378 | 0.570 | " | 1.86 |
| 0.84 | 2.83 | 1.206 | .037 | 0.555 | " | 1.82 |
| 0.87 | 3.01 | 1.325 | .0406 | 0.615 | " | 2.00 |
| 0.80 | 2.65 | 1.088 | .0334 | 0.534 | " | 1.64 |
| 0.81 | 2.57 | 1.033 | .0317 | 0.510 | " | 1.56 |
| 0.82 | 2.47 | .966 | .0297 | 0.507 | " | 1.46 |
| 0.76 | 2.82 | 1.199 | .0368 | 0.603 | " | 1.81 |
| 0.84 | 2.48 | .974 | .0299 | 0.510 | " | 1.47 |
| 0.87 | 2.76 | 1.16 | .0356 | 0.522 | " | 1.75 |
| 0.80 | 2.87 | 1.232 | .0378 | 0.512 | " | 1.86 |
| 0.78 | 2.78 | 1.172 | .036 | 0.557 | " | 1.77 |
| 0.72 | 2.85 | 1.219 | .0374 | 0.630 | " | 1.84 |
| 0.83 | 2.63 | 1.074 | .033 | 0.557 | " | 1.62 |
| 0.83 | 3.70 | 1.12 | .0344 | 0.581 | " | 1.69 |
| 0.83 | 2.64 | 1.08 | .0332 | 0.533 | " | 1.63 |
| 0.73 | 2.86 | 1.225 | .0376 | 0.617 | " | 1.85 |
| 0.78 | 2.69 | 1.112 | .0342 | 0.564 | " | 1.68 |
| 0.85 | 2.99 | 1.311 | .0403 | 0.598 | " | 1.98 |
| 0.89 | 2.77 | 1.168 | .0358 | 0.530 | " | 1.76 |
| 0.85 | 2.78 | 1.172 | .036 | 0.532 | " | 1.77 |
| 0.87 | 2.76 | 1.159 | .0356 | 0.527 | " | 1.75 |
| 0.87 | 2.78 | 1.172 | .036 | 0.577 | " | 1.77 |
| 0.83 | 2.60 | 1.053 | .0323 | 0.554 | " | 1.59 |
| 0.84 | 2.58 | 1.04 | .0319 | 0.525 | " | 1.57 |
| 0.82 | 2.54 | 1.015 | .0311 | 0.529 | " | 1.53 |
| 0.67 | 2.82 | 1.199 | .0368 | 0.573 | " | 1.81 |
| 0.77 | 2.77 | 1.165 | .0358 | 0.545 | " | 1.76 |
| 0.76 | 2.70 | 1.12 | .0344 | 0.517 | " | 1.69 |
| 0.80 | 3.00 | 1.319 | .0405 | 0.601 | " | 1.99 |
| 0.83 | 2.79 | 1.18 | .0362 | 0.536 | " | 1.78 |
| 0.80 | 2.72 | 1.131 | .0348 | 0.518 | " | 1.71 |
| 0.79 | 2.58 | 1.04 | .0319 | 0.505 | " | 1.57 |
| 0.75 | 2.55 | 1.02 | .0313 | 0.515 | " | 1.54 |
| 0.77 | 2.54 | 1.014 | .0311 | 0.495 | " | 1.53 |
| 0.86 | 2.58 | 1.04 | .0319 | 0.492 | " | 1.57 |
| 0.84 | 2.59 | 1.48 | .0321 | 0.488 | " | 1.58 |
| 0.84 | 2.55 | 1.02 | .0313 | 0.483 | " | 1.54 |
| 0.83 | 2.50 | .986 | .0303 | 0.467 | " | 1.49 |
| 0.87 | 2.31 | .861 | .0264 | 0.455 | " | 1.30 |
| 0.82 | 2.28 | .841 | .0258 | 0.452 | " | 1.27 |
| 0.84 | 2.21 | .794 | .0244 | 0.436 | " | 1.20 |

Appx. A

| Reference | Subject | (1) Weight Kgm. | (2) Height Cm | (3) Surface Area Square metres | (4) Resting Metabolism Kilo-calories/min | (5) Conditions | (6) Rate of walking metres/min | (7) Load Kgm | (8) Post-absorptive (PA) or After meal (AM) |
|---|---|---|---|---|---|---|---|---|---|
| Smith 1922. | H.M.S. | 60.4 | 180 | 1.78 | 1.19* | level treadmill 25.1.16 | 44.6 | zero | P.A. |
| | " | " | " | " | " | | 42.2 | " | " |
| | " | " | " | " | " | | 41.6 | " | " |
| | " | " | " | " | " | 26.1.16 | 53.5 | " | " |
| | " | " | " | " | " | | 52.7 | " | " |
| | " | " | " | " | " | | 52.3 | " | " |

* Estimated from Surface Area assuming Basal Metabolic Rate of 40 Calories/square metre/Hour.

| (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|
| | | (15÷3) | (15÷1) | $\left(\frac{15}{(1+7)x6}\right)$ | $\left(\frac{15}{7x6}\right)$ | (10-4) |
| R.Q. | Rate of Total energy expenditure Kilo-calories/min | Working-Kilo-calories per square metre per minute | Working-Kilo-calories per Kilo-gram of body weight | Working-gram-calories per horizontal metre-Kilo-gram (total weight of body plus load) | Working-Kilo-calories per horizontal metre-Kilo-gram (load only) | Working-Kilo-calories expended per minute |
| 0.76 | 2.97 | 1.0 | .0294 | 0.662 | ∞ | 1.78 |
| 0.77 | 2.78 | 0.902 | .0263 | 0.623 | " | 1.59 |
| 0.72 | 2.79 | 0.906 | .0265 | 0.637 | " | 1.60 |
| 0.79 | 3.18 | 1.119 | .0329 | 0.616 | " | 1.99 |
| 0.77 | 3.07 | 1.057 | .0312 | 0.591 | " | 1.88 |
| 0.74 | 3.04 | 1.04 | .0306 | 0.585 | " | 1.85 |

## Appendix B

### Statistical Analysis of Experimental Data

B.1. This appendix presents the statistical analysis of the experimental data tabulated in Appendix A.

B.2. Definitions

wC = Energy expended in 'working kilo calories' per minute.

W = Weight of man in kilos.

L = Load carried in kilos.

V = Rate of walking in metres per minute.

Z = Random term measuring the variation in the data ascribable to random causes.

N = Total number of observations.

B.3. Data

The data (listed in Appendix A) have been extracted from a number of different sources which are described in the main body of this report. A total of 817 observations was obtained and in each case the values of wC, W, L and V were available.

B.4. Object

All observational data are subject to variation which may be due to a number of causes or factors. Of these, those that can be identified may be called assignable causes, whilst those that cannot may be called chance or random causes. The assignable causes of these data are W, L and V, and it is the object of analysis to:-

(a) determine a mathematical law that adequately describes the relationship between wC and W, L and V,

(b) establish how much of the overall variation of wC can be attributed to W, L and V,

(c) estimate the accuracy that can be expected in using this law to predict wC from given values of W, L and V.

B.5. The General Mathematical Law

As there is no analytical technique which can be applied to the data to produce a general form of the required relationship, a suitable model must be postulated. In general the choice of such a model is essentially arbitrary and in these instances it is necessary to appeal to other evidence, such as past results involving the same elements, or certain a priori information, to indicate a likely fundamental form. In this case previous authors have discovered that for given values of W and V the relationship between wC and W is linear. Furthermore, from the evidence of the data (see Figs. 1 to 3) it seems reasonable to infer that, if the other two independent variates remain constant, the relationship between wC and L may also be adequately represented by a linear law. In order to postulate a suitable law for the relationship between wC and V, consideration was given to the experimental results. These are illustrated in Figs. B1 and B2. In Fig. B1 the results are divided into 4 groups defined by the following values of L:-

| | |
|---|---|
| 0.0 | Kilogram |
| 0.01 to 15.0 | " |
| 15.01 to 30.0 | " |
| greater than 30.0 | " |

In each group the value of wC is plotted against the value of V. For convenience the values of V are themselves grouped, the following 12 sub-groups of V being taken as 35.01-45, 45.01-55 ......., 135.01-145, 145.01-155, so that the actual values plotted are the 12 values of $\bar{V}$ and $\overline{wC}$, where $\bar{V}$ is the mean value of V in a sub-group and $\overline{wC}$ is the mean value of wC in the same sub-group. In these curves no specific allowance is made for variation of W. Examination of the results, however, shows that the average values of W for these sub-groups are very nearly the same. Thus the curves effectively give the relationship between wC and V for each group of L, virtually independent of W.

Fig. B2 is similar to Fig. B1, except that for each grouping of L the 12 values of log $\overline{wC}$ are plotted against $\bar{V}$. From this latter it is seen that

(a) for each of the 4 groups of data a straight line gives a good fit

and (b) the 4 straight lines so fitted are approximately parallel.

It is therefore reasonable to suggest that for constant W, the relationship between wC and V is of the form

$$\log wC = A + KV \qquad (1)$$

where A is independent of the value of V.

This suggests for the complete relation between wC and the independent variates a form

$$wC = f(W, L)e^{KV} \qquad (2)$$

Incorporating the indicated form of f(W, L) we have

$$wC = (a_1 + a_2W + a_3W^2 + a_4L + a_5L^2)e^{KV} \qquad (3)$$

The quadratic terms that are included in this model are intended to provide a basis for assessing the adequacy of the linear terms in describing the relationship between wC and W and L.

## B.6. Estimation of Parameters

If the least squares technique is applied to estimating the unknown parameters in equation (3), 6 simultaneous equations result. However, as these equations are non-linear, their solution would require excessive computation. It is therefore required to find some method that simplifies the problem. Such a method is indicated by the fact that if the parameter, K, can be estimated by other methods yielding a value of $\hat{K}$, then a statistical model of the following form may be set up to describe the data:-

$$y = wCe^{-\hat{K}V} = a_1 + a_2W + a_3W^2 + a_4L + a_5L^2 + Z \quad (4)$$

The five unknown parameters in this model may then be simply estimated by solving the 5 simultaneous equations resulting from the application of the least squares principle.

## B.7. Estimation of K

It has already been noted that the 4 straight lines fitted to the points obtained by plotting log $\overline{WC}$ against V for 4 different load ranges are approximately parallel (see para. B5 and Fig. B2). Now it follows from equation (1) that the slope of each line may be taken as an estimate of K. Hence, by taking an average of the four slopes, suitably weighted to account for the different numbers of observations associated with each point on each line, an estimate of K based on all the data is obtained. The estimate, $\hat{K}$, derived by this method is

$$\hat{K} = 0.019625$$

As the data are grouped to produce the points of Fig. B2, $\hat{K}$ is not necessarily the best estimate of K that can be obtained. It is, however, probably as accurate as any other estimate not based on the solution of a set of non-linear equations.

## B.8. Estimation of $a_1$, $a_2$, $a_3$, $a_4$ and $a_5$

Minimization of

$$\sum_{i=1}^{N} (y_i - a_1 - a_2W_i - a_3W_i^2 - a_4L_i - a_5L_i^2)^2$$

with respect to $a_1$, $a_2$, $a_3$, $a_4$ and $a_5$ yields the estimates

$$\hat{a}_1 = -0.031215$$

$$\hat{a}_2 = 0.011795$$

$$\hat{a}_3 = -0.000029$$

$$\hat{a}_4 = 0.008449$$

$$\hat{a}_5 = 0.000001$$

The significance of each of the $\hat{a}_i$'s can then be determined by referring the value $\frac{\hat{a}_i}{\sqrt{V\hat{a}_i}}$ to tables of the t-statistic with 817-5 = 812 degrees of freedom,

where $V\hat{a}_i$ denotes the (standard error)$^2$ of the estimate $\hat{a}_i$. The results of this test are summarized in Table 1 below.

Table 1

| i | $\hat{a}_i$ | $V\hat{a}_i$ | $t_{812}$ | Level of Significance |
|---|---|---|---|---|
| 2 | 0.011795 | $4.08302\times10^{-5}$ | 1.85 | .08 |
| 3 | -0.000029 | $2.49247\times10^{-9}$ | 0.58 | - |
| 4 | 0.008449 | $1.34618\times10^{-6}$ | 7.28 | .001 |
| 5 | 0.000001 | $1.30614\times10^{-8}$ | - | - |

It follows from this table that y is probably unrelated to $W^2$ and $L^2$ and may accordingly be omitted from equation (4).

B.9. Modified Mathematical Law

From the previous section it is deduced that the statistical model

$$y = wCe^{-\hat{K}V} = b_1 + b_2W + b_3L + Z$$

adequately describes the data. As before, the parameters $b_1$, $b_2$ and $b_3$ are estimated by using the least squares technique, yielding the estimates:-

$$\hat{b}_1 = .083156$$
$$\hat{b}_2 = .0081433$$
$$\hat{b}_3 = .0084894$$
$$V_{\hat{b}_1} = 1.2579 \times 10^{-3}$$
$$V_{\hat{b}_2} = 3.1459 \times 10^{-7}$$
$$V_{\hat{b}_3} = 1.7002 \times 10^{-7}$$
$$C_{\hat{b}_1\hat{b}_2} = -1.9631 \times 10^{-5}$$
$$C_{\hat{b}_1\hat{b}_3} = 2.2155 \times 10^{-6}$$
$$C_{\hat{b}_2\hat{b}_3} = -5.7402 \times 10^{-8}$$
$$\hat{\sigma}^2 = .017336$$

where $\hat{\sigma}^2$ is the least squares estimate of the variance of y, $C_{\hat{b}_i\hat{b}_j}$ denotes the covariance of the two estimates $\hat{b}_i$ and $\hat{b}_j$ and, as before, $V_{\hat{b}_i}$ denotes the (Standard error)$^2$ of the estimate $\hat{b}_i$.

It may be shown that by fitting equation (5) to the data .5062 of the overall variation of y is extracted which is considered to be a satisfactory figure for data of this type. The final regression equation is therefore

$$\hat{wC} = (.083156 + .0081433W + .0084894L)e^{.019625V} \qquad (6)$$

which may be approximately re-written as

$$\hat{wC} = .0083(10 + W + L)e^{V/50} \qquad (7)$$

B.10. Accuracy of Prediction

Having determined an equation that fits the data fairly well it is now required to estimate the accuracy that can be expected in using this equation to predict wC from given values of W, L and V. It is important to note that the error attendant to the estimation of K by .019625 is incorporated in the random term, Z, of equation (5) and is therefore taken into account. It may be shown that $V_{\hat{wC}}$, the variance of the predicted wC may be estimated by

$$V_{\hat{wC}} = (V_{\hat{b}_1} + W^2V_{\hat{b}_2} + L^2V_{\hat{b}_3} + 2WC_{\hat{b}_1\hat{b}_2} + 2LC_{\hat{b}_1\hat{b}_3} + 2WLC_{\hat{b}_2\hat{b}_3} + \hat{\sigma}^2)e^{2\hat{K}V} \qquad (8)$$

The values to be substituted into this equation appropriate to these data are quoted in the previous paragraph. By making the assumption of normality an approximate confidence interval can be constructed for the predicted wC.

As an example, suppose it is required to predict wC from the following values of W, L and V:-

W = 70 Kgm

L = 21 Kgm

V = 80 metres per minute

Substituting into equation (6) we have for the estimate of wC

$$\hat{wC} = (.083156 + .0081433 \times 70 + .0084894 \times 31)e^{.019625 \times 80} = 4.00$$

Substituting into equation (7) the variance of $\hat{wC}$ is given by

$$V_{\hat{wC}} = ( 1.2579\times10^{-3} + 4,900 \times 3.1459\times10^{-7} + 441 \times 1.7002 \times 10^{-7}$$
$$- 140\times1.9631\times10^{-5} + 42\times2.2155\times10^{-6} - 2940\times5.7402\times10^{-8}$$
$$+ .017336 )e^{160\times.019625} = .402$$

Assuming that the distribution of $\hat{wC}$ is normal it may be deduced that the 90% confidence interval associated with wC is approximately $[4.00-1.645\sqrt{.402}, 4.00 + 1.645\sqrt{.402}] = [2.96, 5.04]$. It is evident that in this case the only term that makes any material contribution to $V_{\hat{wC}}$ is $\hat{\sigma}^2$. Other examples have been evaluated with the same result. It is therefore considered that for reasonable values of W and L, $V_{\hat{wC}}$ may be approximately estimated by

$$V_{\hat{wC}} \simeq .017336e^{.03925V} \simeq .017e^{V/25}$$

B.11. <u>Conclusion</u>

It is suggested that the mathematical law

$$\hat{wC} = .0083(10 + W + L)e^{V/50}$$

adequately describes the relationship between wC and W, L and V, and that the variance of the error associated with the prediction of wC from given values of W, L and V may be approximately expressed as

$$V_{\hat{wC}} = .017e^{V/25}$$

FIG. B.I.

The relationship between energy expenditure and rate of walking for four different load ranges.

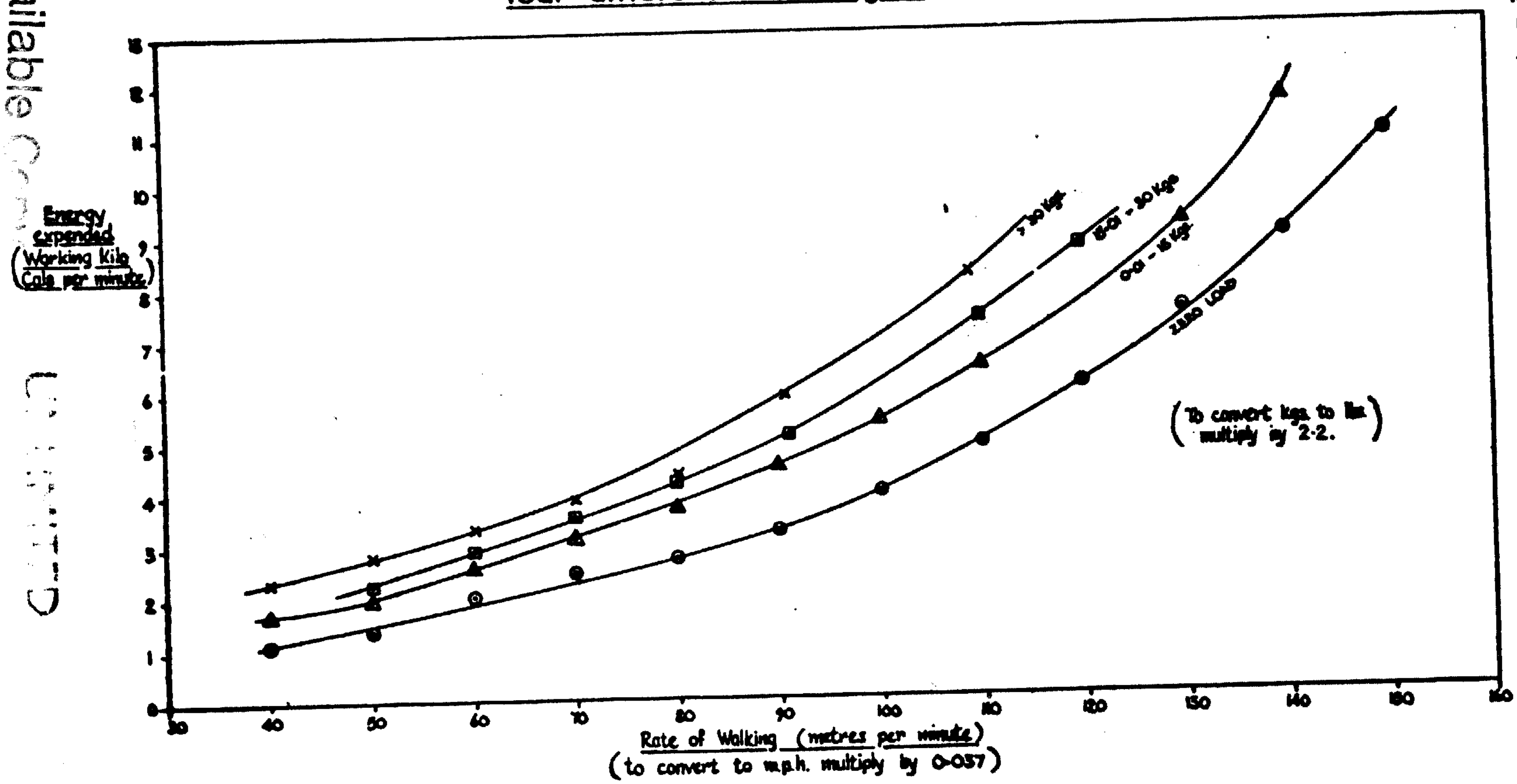


FIG. B2

The relationship between log (energy expended) and rate of walking for four different load ranges.