Metabolic studies on large and small eaters

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Why do some people eat more than others? Two men may weigh the same and have a similar work output, yet one may eat twice as much as the other. This situation is strangely unbiological, for efficiently adapted organisms might all be expected to show maximum economy in the use of food. A tendency to fuel wastage may not be without risk: Keen & Rose (1958) found that men with ischaemic heart disease and intermittent claudication ate 25% more than randomly selected controls.

The problem of variation in food intake has been studied by others, notably by Booyens & McCance (1957). These workers found wide variations in the energy utilization of their subjects, both basally and during activity. They had, however, purposely selected for detailed study a heterogeneous group of subjects with atypical metabolism.

In the present study we selected from a more homogeneous population two groups of subjects similar in weight but differing in calorie intake, and then tried to account for the disposal of the surplus intake by the larger eaters. A brief outline of the work has been published already (Rose & Williams, 1959).

METHODS

Forty male medical students provided detailed records of their diets for a week. The dietary questionnaires were those described by Keen & Rose (1958), who had shown them to be a satisfactory means for comparing the calorie intakes of groups of subjects. On the basis of these dietary records five pairs of subjects were selected so that the members of each pair were similar in body-weight but different in calorie intake. Two young doctors, one a large and the other a small eater, were also included. The participants were weighed at the beginning and at the end of the week, and again some weeks later when their metabolism was studied. The weights of all subjects varied little over the whole period.

The food eaten by the subjects was not weighed, but the dietary assessment was accurate enough for the recognition of two groups with widely differing calorie intakes.

After a light supper and an overnight fast the subject came to the laboratory at 9 a.m. and then lay at complete rest in a comfortably warm bed for 30 min. Oral temperature, pulse rate and blood pressure were recorded; and then, after a trial run, oxygen consumption over the next 8 min was measured with a Benedict–Roth

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spirometer and kymograph (Benedict, 1918). This was not, of course, a measurement of metabolic rate under true basal conditions. But all subjects were treated alike and, in any event, the difference was probably small. Booyens & McCance (1957) adopted a similar approach.

The subject next stood up, unsupported but 'at ease'. After 5 min for equilibration, the oxygen uptake was measured for the next 8 min. Similar equilibration and measurement were repeated with the subject sitting.

The next procedure was designed to assess muscular efficiency in performing a measured amount of work under standardized conditions. A bicycle ergometer or treadmill was considered unsuitable because of the amount of extraneous effort that might go into movement and posture maintenance of the upper part of the body. Instead the subject was instructed to lie as relaxed as possible on a couch. The weight of his legs was borne by a sling which passed under his ankles. A cord attached to his feet ran through a pulley behind the head of the couch where it was attached to a weight of 21 lb (9·55 kg). When the subject drew up his legs the weight came to rest on a shelf; the cord length was adjusted so that full extension of the legs raised the weight 15 in. (38 cm) above the shelf. The cycle of raising and lowering the weight by extending and flexing the legs was completed nineteen times/min, the rate being governed by a metronome. A period of 5 min was allowed for equilibration, and oxygen uptake was then measured for 6 min.

The next series of manoeuvres involved the use of a light-weight Douglas bag (Douglas, 1911) made of polyvinyl chloride. Sampling and volume measurement were undertaken immediately after each collection. Samples were analysed in duplicate in a Haldane apparatus (Haldane, 1892). Volumes were measured with a wet-gas meter.

The first manoeuvre consisted of a form of standardized walking and climbing. Steps were used of the type described by Master & Oppenheimer (1929); the height of the bottom step was 23 cm, and of the top step 15·5 cm. The subject mounted the steps on one side, descended on the other, and then returned alongside the steps to his starting point; a metronome fixed the rate at 88 steps/min. A period of 5 min was allowed for equilibration, and expired air was then collected for a further 6 min.

For the last two activities the subject was instructed to proceed at his own 'normal' pace; he was not aware that his speed was being measured. First he walked up and down a 50 yd (45·7 m) stretch of corridor, with 5 min for equilibration followed by the collection of expired air while he walked the next 500 yd (457 m). The last activity consisted of climbing and then descending stairs (total vertical height 7·4 m), followed by 20 sec of rest. Three circuits were completed for equilibration, followed by three more for measurement.

After these labours the subject was rewarded with a standard breakfast of cornflakes, milk, sugar, coffee, two boiled eggs, toast, butter and marmalade, which provided some 810 kcal, 103 g carbohydrate, 26 g protein and 33 g fat. For the rest of the experiment he remained comfortably seated. Oxygen uptake was recorded on a spirometer for 8 min in every half hour. Oral temperature and pulse rate were also recorded at the same intervals. These measurements were usually continued for 4 h from the end of the meal; occasionally they were ended earlier, when the rate of oxygen uptake had already fallen to the fasting base-line for sitting.

Some difficulty arises in an investigation of this type in deciding the units in which to express the results: the choice may greatly affect interpretation. Booyens & McCance (1957) comment that one of their subjects was able to cycle with greater economy as compared with another, the results being expressed as kcal/m^2 h. But one subject was ectomorphic and the other endomorphic, and if the results are recalculated as kcal/kg km, the more economical subject becomes the more costly. It is not easy to say which statement is the more meaningful, and we have therefore expressed our results simply as rates of oxygen uptake.

RESULTS

The results are given in Table 1.

Calorie intake and body-weight. The group of large eaters had a nominal calorie intake almost double that of the small eaters: even though the absolute figures may not be accurate, it is clear that the two groups differed widely in energy intake. Subject L. 1 in particular was a quite unusually large eater; his diet included large amounts of fried potatoes, cheese (up to ½ lb at a session), bananas (sometimes seven at a time) and chocolate (½ lb each day). He seemed to be in good health.

The mean body-weight of the large eaters was 5·5 kg less than that of the small eaters, chiefly because of the poor matching of the first and fourth pairs. It was preferred that the discrepancy should be this way round, so that it would be certain that any greater oxygen cost among the large eaters was not due to greater body-weight. But the discrepancy may have masked small differences between the groups.

Energy expenditure at rest. There was a wide scatter between individuals in the various values for oxygen consumption. The mean 'basal' oxygen consumption was identical in the two groups; the small eaters, being on average larger men, had lower uptakes in relation to their surface areas. The increments due to standing and sitting were generally small, and differed little between the two groups. One subject (S. 3) used less oxygen standing or sitting than lying; the result was the same when he was re-tested on another day. Booyens & McCance (1957) noted similar anomalies.

Energy expenditure during activity. It was hoped that the weight-raising exercise would give some indication of the constitutional efficiency of the body under standardized conditions. But this hope may not have been fully realized, for repeated testing with one subject showed that experience could improve efficiency. There was much variation between subjects, but on average the two groups behaved similarly.

The step test, involving walking and climbing at a standard rate, also gave similar values for oxygen cost (over the standing rate) in the two groups. If an allowance is made for the greater body-weight of the small eaters, the difference still fails to achieve significance at the 5% level.

The remaining two exercises were carried out free-style, the subject being advised to choose his own 'natural' pace. Here, in terms of oxygen consumption per min, the small eaters appeared to score a small success. It disappears, however, when oxygen consumption is related not to time taken but to distance covered.

Table 1. *Information about, and results of tests with, large (L) and small (S) eaters*

					Basal state					Standing		Sitting		Weight raising		Steps, standard	Walking, 'free-style'			Stairs, 'free-style'		Specific dynamic action of standard meal			
Subject	Age (years)	Height (cm)	Weight (kg)	Diet (kcal/day)	Blood pressure (mm Hg)	Oral temperature (° F)	Heart rate (beats/min)	Oxygen uptake (ml/min)	Energy expenditure (kcal/m² h)	Oxygen uptake (ml/min)	Rise in heart rate over basal (beats/min)	Oxygen uptake (ml/min)	Rise in heart rate over basal (beats/min)	Oxygen uptake (ml/min)	Rise in heart rate over basal (beats/min)	Oxygen uptake (ml/min)	Rate (miles/h)	Oxygen uptake (ml/min)	Cost over standing (ml oxygen/m)	Time per circuit (sec)	Oxygen uptake (ml/min)	Total oxygen cost (l.) over 4 h period	Maximum rise in heart rate (beats/min)	Maximum temperature rise (° F)	Estimated mean energy cost of day's activity (kcal)
L. 1	24	177	74·5	7400	140/95	97·4	54	311	46·0	340	22	340	0	498	18	1020	3·38	980	5·9	93	1630	—	—	—	630
L. 2	23	179	97·5	3000	135/85	98·2	70	332	44·5	358	23	343	5	459	11	1750	2·81	1500	12·4	58	2830	3·7	28	0·8	890
L. 3	21	187	79	4800	110/70	97·9	57	295	41·7	296	25	293	4	384	19	1200	3·22	960	6·4	70	2100	12·7	23	−0·1	450
L. 4	22	185	70	4850	110/70	98·2	64	282	42·5	313	0	298	−4	397	14	1240	3·65	1530	10·4	47	1930	6·5	28	0·2	770
L. 5	22	184	68·5	4200	115/80	97·0	68	338	52·1	338	12	327	−4	446	16	1140	3·36	1190	7·9	58	1700	8·3	26	0·8	600
L. 6	31	179	65	3500	110/75	98·0	67	269	42·8	329	15	330	9	477	15	1490	3·70	1680	11·3	55	2420	7·0	31	0·7	790
Mean	23·8	181·8	75·7	4625	120/79	97·78	63	304	44·9	329	16	322	2	443	15·5	1307	3·35	1307	9·0	63	2102	7·6	27	0·48	690
S. 1	28	183	85·5	2650	115/75	97·0	56	308	43·0	312	17	318	9	506	16	1310	2·70	980	7·8	81	1690	—	—	—	410
S. 2	23	185	97	1600	115/75	97·1	59	322	42·2	352	18	337	9	377	13	1580	3·06	1370	10·4	73	2620	5·3	21	0·7	640
S. 3	23	174	84	2000	120/75	98·0	38	354	51·6	332	8	312	4	497	22	1360	2·78	1290	10·8	69	2050	7·3	6	0·0	715
S. 4	31	184	82	2940	105/70	97·9	51	275	38·9	320	7	311	0	462	11	1175	3·04	1180	8·8	67	1970	8·3	19	0·3	385
S. 5	21	172	70	2700	120/65	97·7	58	300	47·5	352	18	320	3	541	11	1490	2·92	1150	8·6	60	1890	6·4	7	0·3	730
S. 6	23	182	69·5	2400	120/85	97·9	57	266	40·6	325	12	280	1	342	5	1210	3·03	1465	11·7	69	1800	9·8	25	0·1	670
Mean	24·8	180·0	81·3	2380	116/74	97·60	53	304	43·97	332	13	313	4	454	13	1354	2·92	1238	9·7	70	2003	7·4	16	0·28	590

Note was taken of the walking rates which the subjects chose during this test. To our surprise they proved to be the criterion by which the two groups could be most clearly distinguished. The mean rate of the large eaters was 3·35 miles/h (5·39 km/h), as compared with 2·92 miles/h (4·69 km/h) for the small eaters. The standard error of the difference is 0·103 miles/h, and the likelihood of the observed difference arising by chance is less than 1 % ($n = 11$). The ranges covered by the two groups showed no overlap at all, with the exception of one large eater (subject L.2) whose rate of 2·81 miles/h was well within the small eaters' range. This subject's calorie intake was the lowest in his group, in which he had only been included because of the difficulty of finding any large man with a large appetite.

The final exercise consisted of going up and down stairs, the subject again being told to go at his natural speed. The small eaters once more tended to be slower movers. They accomplished their work at an oxygen cost (over their standing rates) of 6 % less than the large eaters, despite their greater body-weight.

One subject (L.6), whose stair-climbing was more costly in relation to his body-weight than that of all the others, was re-tested at a variety of rates. At 97 sec/circuit, his oxygen cost was only 1280 ml/circuit, as compared with 2090 ml at his natural rate of 55 sec/circuit; intermediate rates gave intermediate values.

Specific dynamic action of a standard meal. Spirometric measurements after the standard meal usually showed two peaks of oxygen uptake, occurring at 5–30 and 90–120 min respectively after the end of the meal. By the end of the period of observation (4 h) the oxygen uptake was usually back to the same level as for sitting in the fasting state. The specific dynamic action of the meal was calculated from the area of the oxygen-uptake curve above the base-line level for sitting. Variation between individuals proved to be wide, the extremes being 3·7 and 12·7 l. oxygen. These results are broadly similar to those obtained by Lauter (1926) and by Glickman, Mitchell, Lambert & Keeton (1948). The group means for large and small eaters were identical.

Body temperature, blood pressure and heart rate. In addition to these estimates of energy expenditure we also noted oral temperature (basally and after the meal), basal blood pressure, and heart rate (basally, and during those exercises in which the spirometer was used, and after the meal). The large eaters showed consistently higher values; for basal heart rate and for rise of heart rate after food the differences were statistically significant ($P < 0·01$). In none of these instances was there any significant correlation with body-weight, although a small correlation was found for the postprandial rises of heart rate and temperature ($r = +0·452$ and $+0·415$ respectively, $P > 0·1$).

Amount of normal physical activity. The study was concerned primarily with laboratory measurements; but a rough estimate of the subjects' activities was made by recording the type and duration of active hobbies in the week during which diet was recorded, and also by arranging for each man to wear a pedometer for 1 week (except when he was pursuing an active sport). The 'mileage' recorded by the instrument, even though corrected for pace length, cannot be taken as an accurate measure of the distance covered. It gives a measure rather of 'movement units'.

The values given in Table 1 for the cost (kcal) of activity are the sum of two components. The first is the estimated daily cost of walking the distance recorded by the pedometer, after the cost of sitting for the same period has been deducted: the mean value was 590 kcal/day for the large eaters and 540 kcal/day for the small eaters. The second is the estimated cost of other activities (such as cycling, football, running, swimming), the values of Passmore & Durnin (1955) being used: the mean value was 100 kcal/day for the large eaters and 50 kcal/day for the small eaters. The totals give a mean calorie cost for all activities of 690 kcal/day for the large eaters and 590 for the small eaters. These values, although only approximate, suggest that the amount of activity did not account for much of the difference between the two groups.

DISCUSSION

Widdowson (1936) and Widdowson & McCance (1936) found that the calorie intake of an apparently healthy group of adults ranged from 1772 to 4955 kcal daily for men, and from 1453 to 3110 for women. In her studies of children's diets Widdowson (1947) found an even more remarkable degree of variation, to the extent that one boy of 16 was found to subsist on less food than a child aged 1 year. The dietary records of our students have also shown evidence of wide variation, even within this fairly homogeneous group.

The first question that arises is whether the large eaters are really absorbing all that they consume. Passmore, Meiklejohn, Dewar & Thow (1955) found evidence from faecal analyses that when the diet of three healthy young men was increased from 2300 to 4000 kcal/day, over 90% of the excess food was absorbed. Lewis & Masterton (1958) obtained similar results with intakes of 4800 kcal/day. Masterton, Lewis & Widdowson (1957), Passmore, Thomson & Warnock (1952) and Edholm, Fletcher, Widdowson & McCance (1955) all found that in individuals whose body-weight is constant there is a close correspondence between calorie intake and expenditure. This finding again suggests that in healthy persons the absorption of food is more or less complete. The problem is thus to find out how the large eaters utilize their extra energy.

In general terms it may be supposed that variations in calorie intake could be due to three possible factors. (1) Variation in bodily constitution. Two men of the same weight might walk at the same rate and in similar style and yet use different amounts of energy owing to differences in the efficiency of muscular contraction. Constitutional differences might also be expressed as variations in basal metabolic rate or in the specific dynamic action of food. Such constitutional differences might be inborn; or they might have been conditioned by environmental factors, such as physical activity or the quantity of food eaten. (2) Variation in amount of activity. (3) Variation in manner of activity. The energy cost of walking a given distance may depend on the rate of movement, the amount of unnecessary movement, and so on. We have found, for example, that a man standing up may increase his oxygen uptake by 80% merely by fidgeting; there may be a further rise of 20% if he also tenses himself.

We aimed to study the existence of any relevant constitutional differences by the measurement of basal oxygen uptakes, oxygen costs of standardized activities and specific dynamic action, together with body temperature, heart rate and blood pressure. By drawing comparisons between groups rather than between individuals we sought to uncover factors of general importance. We attempted only an approximate assessment of the amount of activity which the subjects undertook. Manner of activity is hard to assess, and doubtless laboratory conditions tend to impose an unwonted uniformity on the subjects. The only objective measurements were the rates at which subjects walked or went upstairs, and comparison of the behaviour of the two groups at standardized and free activities.

Our measurements of oxygen uptake under various conditions have shown, in common with those of other workers (e.g. Edholm *et al.* 1955; Booyens & McCance, 1957), a wide variation between individuals. Such differences must clearly affect the subject's calorie needs. Yet in practice it seemed that among this particular group of young men there was no systematic trend: those who were economical in one respect were more costly in others.

Like Booyens & McCance (1957) we found big differences in basal oxygen consumption. The difference between the highest and the lowest was 88 ml/min, which would account for a difference of about 600 kcal daily between the diets of the two men. However, both were in the group of small eaters, and the one with the higher basal oxygen uptake appeared to be eating 400 kcal/day less than the other. Booyens & McCance described one subject ('R.M.') in whom low basal oxygen requirements were reflected in an all-round tendency to fuel economy; but in our series we did not meet this situation.

The weight-raising exercise revealed even greater variations between subjects, with oxygen costs ranging from 55 ml/min in the smallest eater up to 241 ml/min, again in a small eater.

In the free-style walking exercise there was a strikingly consistent tendency for the large eaters to walk faster. Identical instructions had been given to all subjects, and the fact that their rate was to be measured had not been mentioned. The difference therefore appears to be genuine.

The two groups differed not only in calorie intake but also (to a lesser extent) in body-weight. Between weight and walking rate there was a significant negative correlation ($r = -0.637$, $n = 11$, $P < 0.02$). There was also some, not significant, negative correlation between weight and calorie intake ($r = -0.402$, $P > 0.1$). In order to assess the independent importance of calorie intake and body-weight in the determination of walking rate, the partial correlation coefficients have been calculated (although the number of observations was rather small). For calorie intake *v.* walking rate (weight constant), $r = +0.483$. For body-weight *v.* walking rate (calories constant), $r = -0.541$. Both these correlations fall a little below the 5% level of significance ($n = 9$). But there is at least suggestive evidence that calorie intake has its own independent relation with walking rate.

When walking rates are compared with oxygen costs per metre walked there is no evidence of any correlation. This finding accords with the results of Passmore & Durnin (1955), which showed that within the whole range of normal walking rates (4–7 km/h) a man's speed is unlikely to affect the amount of energy he expends in covering a given distance. (It does of course affect the amount of time left to him in which to use up energy in other pursuits.)

From this we conclude that the difference in walking rates of the large and small eaters had no direct bearing on their calorie needs during walking itself. It may, nevertheless, have an indirect bearing on their general restlessness and the briskness of their approach to other tasks. Noltie (1956) has stressed the high metabolic cost of the first few moments of activity, during which the release of energy occurs anaerobically. He quotes the work of Christensen & Högberg (1950) who found that the oxygen uptake of a subject working at a constant rate (20 km/h) on a treadmill was doubled during the first 15 sec of activity as compared with the rate during the subsequent steady state. The pattern of daily activity of our subjects consisted mainly of repeated brief periods of movement. If the large eaters compressed more into the first moments of each period, it might account for an appreciable waste of energy. Similarly their faster walking rates may have been an index of a general restlessness which was temporarily suppressed during the artificial conditions of laboratory observation.

The increase in oxygen uptake after a mixed meal is known to vary widely between individuals (Lauter, 1926; Glickman *et al.* 1948; Buskirk, Iampietro & Welch, 1957). Buskirk *et al.* found that a meal sometimes doubled an individual's resting oxygen uptake. An estimate of the specific dynamic action of a mixed meal was therefore included in our study. The results gave no indication of any association between customary calorie intake and the specific dynamic action of the standard meal. The mean for all subjects was 7·5 l. oxygen, equivalent to about 4% of the ingested calories. When this figure is applied to the estimated mean daily calorie intakes of the two groups, it appears that specific dynamic action averaged about 100 kcal for each small eater, and about double that for each large eater.

SUMMARY

1. From a group of forty young men six pairs were selected, the members of each pair differing as widely as possible in calorie intake but as little as possible in body-weight. Oxygen uptakes of these subjects were measured basally and during a variety of standard and free-style exercises, and also after a standard meal.

2. In each instance the two groups gave very similar results, and it was concluded that the differences in their calorie intakes were not due primarily to any constitutional differences in energy requirements.

3. The large eaters had natural rates of walking consistently faster than those of the small eaters. Possibly this is an index of a general restlessness and pace of activity which may be related to their large food intake.

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REFERENCES

Benedict, F. G. (1918). *Boston med. surg. J.* **178**, 667.
Booyens, J. & McCance, R. A. (1957). *Lancet*, **272**, 225.
Buskirk, E. R., Iampietro, P. F. & Welch, B. E. (1957). *Metabolism*, **6**, 144.
Christensen, E. H. & Högberg, P. (1950). *Arbeitsphysiologie*, **14**, 249.
Douglas, C. G. (1911). *J. Physiol.* **42**, xvii.
Edholm, O. G., Fletcher, J. G., Widdowson, E. M. & McCance, R. A. (1955). *Brit. J. Nutr.* **9**, 286.
Glickman, N., Mitchell, H. H., Lambert, E. H. & Keeton, R. W. (1948). *J. Nutr.* **36**, 41.
Haldane, J. S. (1892). *J. Physiol.* **13**, 419.
Keen, H. & Rose, G. A. (1958). *Brit. med. J.* i, 1508.
Lauter, S. (1926). *Dtsch. Arch. klin. Med.* **150**, 315.
Lewis, H. E. & Masterton, J. P. (1958). *Proc. Nutr. Soc.* **17**, 170.
Master, A. M. & Oppenheimer, E. T. (1929). *Amer. J. med. Sci.* **177**, 223.
Masterton, J. P., Lewis, H. E. & Widdowson, E. M. (1957). *Brit. J. Nutr.* **11**, 346.
Noltie, H. R. (1956). *Proc. Nutr. Soc.* **15**, 93.
Passmore, R. & Durnin, J. V. G. A. (1955). *Physiol. Rev.* **35**, 801.
Passmore, R., Meiklejohn, A. P., Dewar, A. D. & Thow, R. K. (1955). *Brit. J. Nutr.* **9**, 20.
Passmore, R., Thomson, J. G. & Warnock, G. M. (1952). *Brit. J. Nutr.* **6**, 253.
Rose, G. A. & Williams, R. T. (1959). *Proc. Nutr. Soc.* **18**, xxix.
Widdowson, E. M. (1936). *J. Hyg., Camb.*, **36**, 269.
Widdowson, E. M. (1947). *Spec. Rep. Ser. med. Res. Coun. no.* 257.
Widdowson, E. M. & McCance, R. A. (1936). *J. Hyg., Camb.*, **36**, 293.

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