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'APPETITE' AND THE RELATIONSHIPS BETWEEN EXPENDITURE AND INTAKE OF CALORIES IN MAN

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'Appetite' is a word which may vary considerably in its meaning with the context and the user. In this present paper the term refers simply to the natural desire for food. This desire, at least in human beings, is primarily directed towards replacing the energy which is continually being expended; the most important factor, commonly, is therefore the calorie value of the food eaten. This is not to say that other factors are unimportant. Eating by man is complicated by social customs, meal patterns, and so on. In special circumstances a craving for carbohydrate, protein or fat, or a mineral or vitamin may become evident, and it is at least theoretically possible that they may constantly exert some control over the type of diet eaten. Nevertheless, some balance between the energy value of the food eaten and the energy dissipated clearly exists. And the existence of a balance postulates the existence of some form of control.

The nature of the control which balances the intake of calories against expenditure of energy has provoked much speculation and experimentation, particularly within the past decade or so. The theories which have been proposed to explain the control of the stimuli to eat have concomitantly tended to become more refined; the range extends from the apparently old-fashioned and relatively crude idea that the mechanism involves contractions of the stomach to the more complex theories that changes in the heat balance of the body or changes in the concentration of various metabolites in the blood are the effective stimuli (e.g. Carlson, 1916; Brobeck, 1947; Kennedy, 1952–53; Mayer, 1955*b*). Whatever the mechanism, the end result is obvious. In the words of Janowitz & Grossman (1949–50) 'ingestion of food leads to inhibition of the appetitive behaviour and is accompanied by a loss of the desire to eat,... and (only) under pathological conditions (is) this association between the hunger state and desire for food...disturbed in the direction of excessive, defective or perverted tendencies'. In other words, in *physiological* conditions, where there should be no tendency to excessive or defective eating, one might expect the regulation between expenditure and intake to be a finely adjusted

mechanism and, equally, the individual to be in weight balance. The calorie value of the food eaten would, therefore, equal the calories of energy expended, with perhaps a small lapse of time in the equation of these two quantities. However, in the ordinary life of man, the regulatory mechanisms often do not appear to be particularly well adjusted. A very large number of people are frequently not in weight balance or are not regulated at their ideal weight. The commonest form of maladjustment of this regulation manifests itself in the condition of obesity which, although most prevalent in societies enjoying a high level of material prosperity, may be found in almost any region where food is not universally in short supply. Apart from the obvious maladjustment of obesity, many people who remain for long periods of time at approximately their ideal weight are probably subjectively aware that their intake of calories may vary quite markedly on separate days with little apparent relation to changes in their energy expenditure.

Only recently has there become available sufficient information to put this subjective impression to test by objective study of actual intake and expenditure of energy. Durnin (1957) briefly reported such a study. The present paper describes in detail, and discusses the implications of, an analysis which has been done on published day-to-day calorie intakes and expenditures of several groups of people living under varying circumstances.

METHODS

The daily individual intakes and expenditures of calories have been compared in six groups of people of different ages and of both sexes, who expended widely dissimilar total amounts of energy. The first group of twelve young women had a mean energy expenditure of about 2200 kcal/day (Durnin, Blake & Brockway, 1957). The second group contained twelve middle-aged housewives with a mean energy output of 2100 kcal/day (Durnin *et al.* 1957). The third group of ten male office clerks expended about 2800 kcal/day (Garry, Passmore, Warnock & Durnin, 1955). The fourth group of four male students had an expenditure of about 3200 kcal/day (Durnin & Brockway, 1959). The fifth was a group of twelve military cadets whose expenditure averaged 3400 kcal/day (Edholm, Fletcher, Widdowson & McCance, 1955), and the sixth group consisted of nineteen coal-face miners, whose average expenditure was about 3700 kcal/day (Garry *et al.* 1955). The range of these values thus encompasses the energy expenditures of the great majority of adults in this country.

Each of the sixty-nine individuals had been studied for 1 week so that there were seven consecutive daily determinations, on each subject, of both energy expenditure and calorie intake. The methods used to obtain these results were, in all cases, identical. The food intake was measured by the individual inventory method and the expenditure of energy by indirect calorimetry. Details are given in the respective publications.

The relationship between the day-to-day intake and expenditure of calories has now been analysed statistically for each individual within these groups. This has been done by obtaining the correlation coefficient (r) of the two variables and determining its significance and also by finding whether there was a significant difference between the intake (x) and expenditure (y) of calories. If the intake and expenditure of energy were perfectly adjusted

then there would be a highly significant positive correlation between the two and, since they would be equal in amount (i.e. $x-y = 0$), there would be no significant difference between them. These statistical calculations have been made (1) by comparing the expenditure and intake of calories on the same day. Since it is quite possible that there may be a delay in the adjustment of intake to expenditure (Mayer, 1955*a*, *b*) and since it has been suggested that this delayed adjustment possibly occurs 1 or 2 days after the actual expenditure (e.g. Edholm *et al.* 1955), the results have been analysed (2) by comparing food intake with the energy expenditure of the previous day and again (3) with the energy expenditure of 2 days previously.

RESULTS

The correlation coefficient (r) is given in Table 1 for the ten individual subjects in the six groups, where the relationship between intake and expenditure of calories reached significance when these two variables were

TABLE 1. The correlation coefficients (r) of intake and expenditure of calories for all of the individual subjects where this reached a statistically significant level. This occurred in ten cases out of the sixty-nine subjects. Intake related to expenditure of the same day

Group	Code no. of subject	r	Significance level (%)
Young women	7	+0·818	5
Housewives	2	+0·928	1
	3	−0·850	5
	11	−0·799	5
Clerks	None	—	—
Students	2	−0·875	1
Cadets	1	−0·823	5
	6	+0·889	1
Miners	4	+0·771	5
	7	+0·839	5
	16	+0·867	5

compared for the same day. Only one of the young women, one middle-aged housewife, one cadet and three of the miners showed a significant positive correlation; in addition, two housewives, one student and one cadet had significant negative correlations of the variables. Therefore, out of the sixty-nine individual subjects, fifty-nine show no significant correlation whatever between the energy expended on any one day and the intake of calories on the same day. When the intake of calories is compared with the energy expenditure of the previous day, the number of individuals showing a significant correlation between these variables becomes reduced to 3 or 4; there is no vestige of evidence from these results that adjustment of intake to expenditure is postponed by 1 day. Intake of calories and the expenditure 2 days previously shows a similar low correlation.

The differences between the mean daily intakes ($\bar{x}$) and expenditures ($\bar{y}$)

of calories over the 7 consecutive days are presented in Table 2 in the case of those subjects where these differences are statistically significant. Some of these differences were positively significant—the intake exceeded the expenditure; negative significance signifies the reverse condition. The degree of significance is not always directly related to the amount of the difference between $\bar{x}$ and $\bar{y}$; this is explained by the fact that $\bar{x}$ might vary between 2000 and 4000 kcal and also that there might be a greater or less extent of variability in this difference—e.g. the difference of -293 kcal in student No. 4 is significant, although a difference of $+500$ kcal in one of the clerks was not statistically significant.

TABLE 2. The difference between the mean daily intake ($\bar{x}$) of calories and the expenditure ($\bar{y}$) in the individual subjects, where this was statistically significant

Group	Code no. of subject	$\bar{x}-\bar{y}$ (kcal)	Significance level (%)
Young women	4	−837	1
	9	−424	1
	12	+488	1
Housewives	8	−391	5
	10	−316	5
	12	+225	5
Clerks	3	+508	1
	4	+538	5
	5	+582	1
Students	1	−601	5
	4	−293	5
Cadets	6	+600	1
	10	+568	5
Miners	4	+992	1
	5	−610	5
	9	+883	5
	11	+870	5
	13	+962	1
	15	+991	5
	17	+484	5

DISCUSSION

A quick and even balance between intake and expenditure of energy would give a markedly positive correlation between the two and ($\bar{x}-\bar{y}$) would be non-significant. The results, summarized in Table 3, show this to be true in only four out of the sixty-nine subjects, one young woman, one middle-aged housewife and two miners. Two typical examples of this type of correlation (Type III) are shown in Fig. 1. It is obvious that the two variables do not need to follow each other identically to be significantly correlated; it is not an artificial concept. Nevertheless, it seems remarkable that such a small proportion of the total numbers of subjects (6 %) should fit into this ideal pattern.

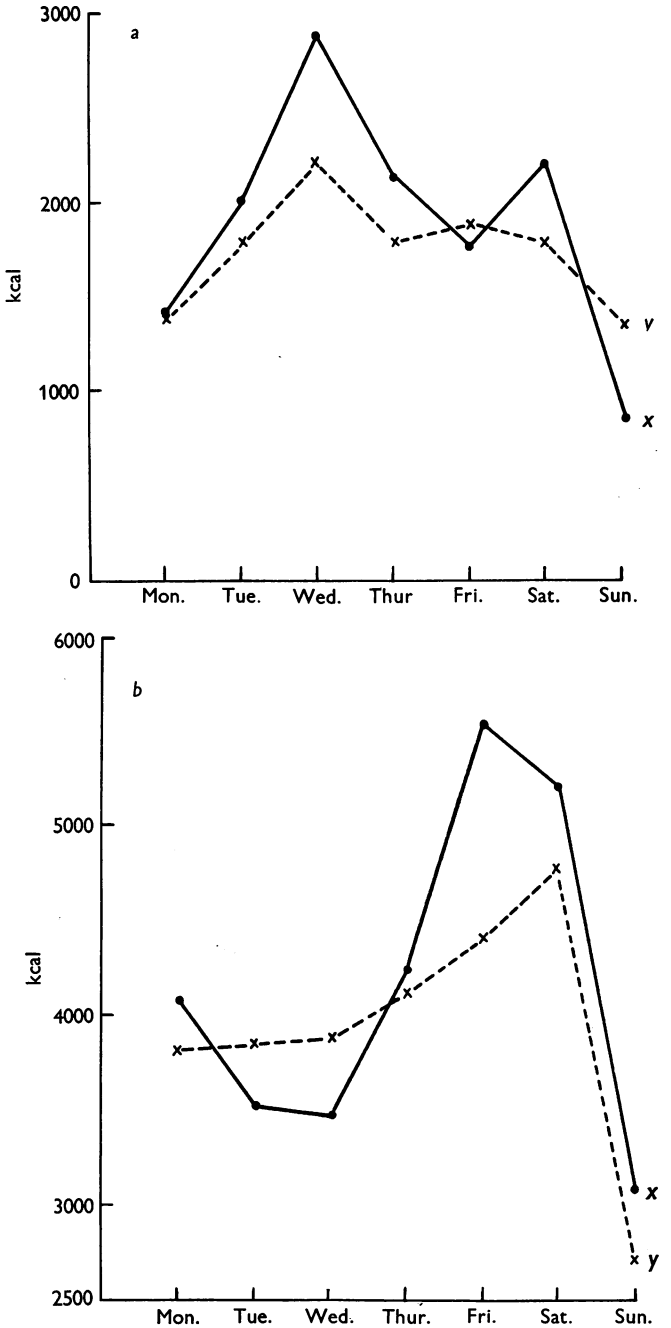

Fig. 1. Two examples showing a positive and significant correlation between daily intake (x) and expenditure (y) of calories where the mean values did not differ significantly ($\bar{x}-\bar{y}$ non-significant (n.s.)). *a*, Housewife 2: $r = +0{\cdot}928$; $\bar{x} = 1915$ kcal; $\bar{y} = 1764$ kcal. *b*, Miner 7: $r = +0{\cdot}839$; $\bar{x} = 4163$ kcal; $\bar{y} = 3940$ kcal.

On the other hand, forty-one individuals (i.e. 59 %) appear to have no significant daily correlation between their energy expenditure and food intake, although, since intake and expenditure do not differ significantly in their mean values over the week, presumably there is some form of regulation acting which prevents upset of calorie balance. Figure 2 shows two examples of this type (Type I).

TABLE 3. The differing forms of correlation* of intake and expenditure of calories shown by the individuals in each group of subjects

Correlation type	Groups: Young women	House-wives	Clerks	Students	Cadets	Miners
I	8	6	7	1	9	10
II	3	3	3	2	1	6
III	1	1	.	.	.	2
IV	.	2	.	1	1	.
V	.	.	.	.	1	1
Total	12	12	10	4	12	19

Grand total: 69 subjects

Type	r	$\bar{x}-\bar{y}$	n	% of total
I	n.s.	n.s.	41	59
II	n.s.	s.	18	26
III	+s.	n.s.	4	6
IV	−s.	n.s.	4	6
V	+s.	s.	2	3

* s. = significant; n.s. = non-significant; +s. = positively significant; −s. = negatively significant.

Figure 3 gives two examples of the eighteen individuals (26 %) classified as Type II, where there is no significant correlation between daily calorie expenditure and intake but where the mean values of the two series of measurements differ significantly. This difference shows an insufficiency of calorie intake in seven individuals and an excess in the other eleven, so that presumably if this were a process continuing over a sufficiently long period, these individuals would lose or gain weight, respectively. An analysis of the separate subjects in this category is not very rewarding. Three of the four women with a calorie intake less than output were plump in physique and might possibly have been deliberately restricting their food intake. The other woman and all the men, with one exception (miner 17), were normal in build, neither thin nor fat, and were eating their normal diet. If the individuals were obese, then this might satisfactorily explain either a positive or a negative difference between $\bar{x}$ and $\bar{y}$—they might still be gaining weight or they might be trying to lose weight. Where there is no evidence of other than a healthy distribution of body tissue, theorizing about the significant difference between $\bar{x}$ and $\bar{y}$ is difficult.

Four individuals (Fig. 4) have a significant *negative* correlation between

intake of energy and output; again, however, as with the four subjects in Type III, with no difference between the mean values for the two measures, (Type IV). It is theoretically possible that an individual might have fluctuations in daily energy expenditure of such an order that, on the days

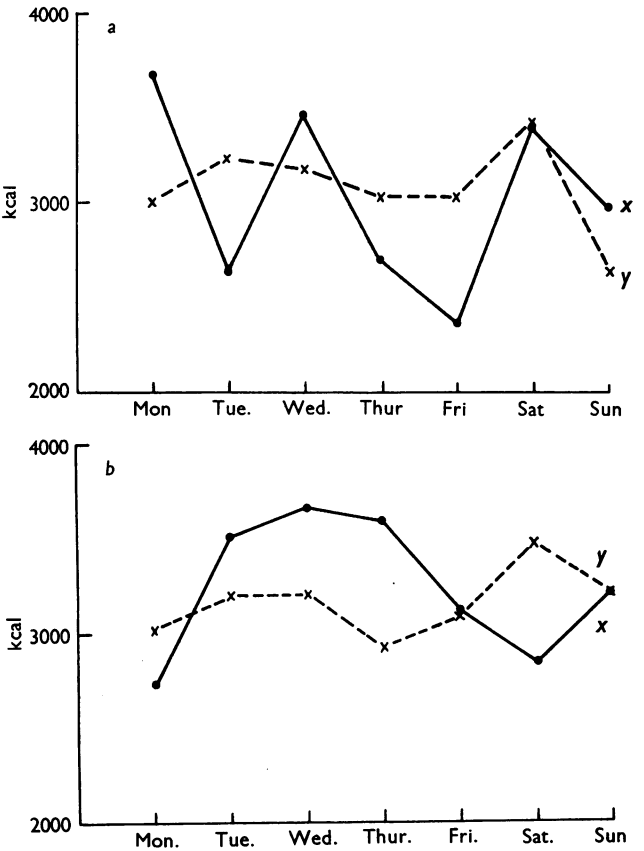

Fig. 2. Two examples where individuals showed no significant correlation between daily intake (x) and expenditure (y) of calories and where ($\bar{x}-\bar{y}$) was non-significant. *a* Cadet 8: $r = +0{\cdot}196$; $\bar{x} = 3034$ kcal; $\bar{y} = 3080$ kcal. *b* Clerk 8: $r = -0{\cdot}274$; $\bar{x} = 3248$ kcal; $\bar{y} = 3168$ kcal.

when this was at a high level, there might be insufficient time or inclination to eat enough, and the deficit might be made up on a subsequent day. This would result in a form of graph such as that seen in Fig. 4, but the explanation is not valid in any of the four cases here. If there is a satisfactory interpretation it is difficult to imagine one agreeing with present physiological explanations of appetite control.

Only two individuals fall into Type V, where there is a high positive correlation between intake and expenditure but a significant excess of

intake over output (Fig. 5). This would suggest a control of appetite regulated consistently but at the wrong level. A mechanism such as this would explain those cases of obesity which develop over a period and then eventually become stable.

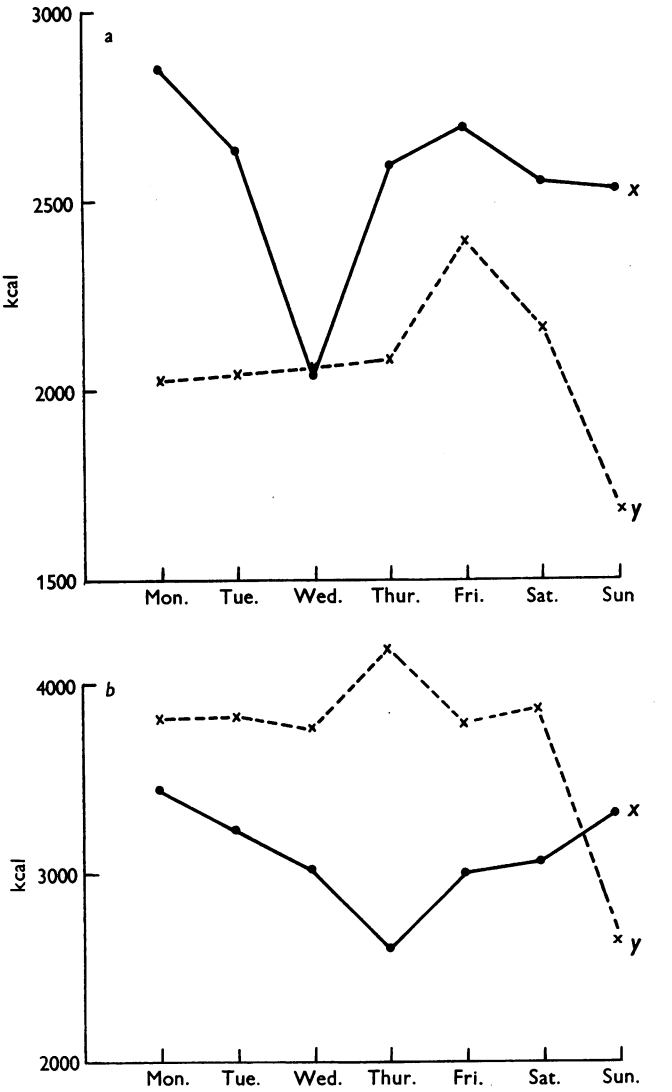

Fig. 3. Two examples showing no significant correlation between daily intake (x) and expenditure (y) of calories but where ($\bar{x}-\bar{y}$) was significant. In (a), there was an excess of intake over expenditure and in (b) a deficiency. *a* Young woman: $r = +0{\cdot}156$; $\bar{x} = 2555$ kcal; $\bar{y} = 2067$ kcal; $\bar{x}-\bar{y}$ significant, $P < 0{\cdot}01$. *b* Miner 5: $r = -0{\cdot}535$; $\bar{x} = 3089$ kcal; $\bar{y} = 3699$ kcal; $\bar{x}-\bar{y}$ significant, $P < 0{\cdot}05$.

The findings analysed above, if they represent in a reasonably accurate way the normal relationship between expenditure and replacement of calories in human beings, make total acceptance of any of the current explanations of appetite control unsatisfactory. That the results are not totally unrepresentative is demonstrated by some other relevant publications; for example, the results of Booyens & McCance (1957) show similar trends, even in the case of such a well-regulated subject as R.A.McC.

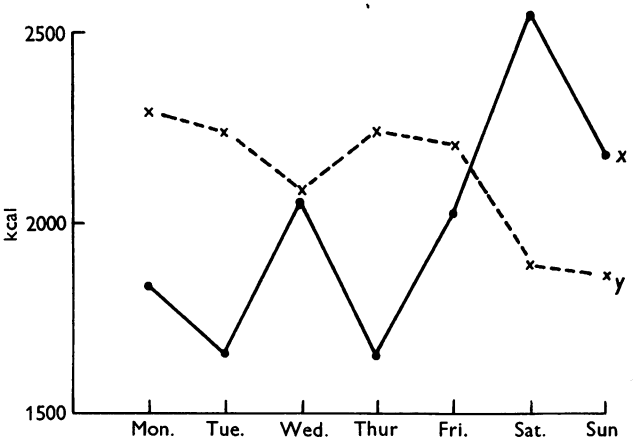

Fig. 4. An illustration of a *negative* and significant correlation between intake (x) and expenditure (y) of calories where ($\bar{x}-\bar{y}$) was non-significant (n.s.). Housewife 3: $r = -0{\cdot}850$; $\bar{x} = 1999$ kcal; $\bar{y} = 2120$ kcal.

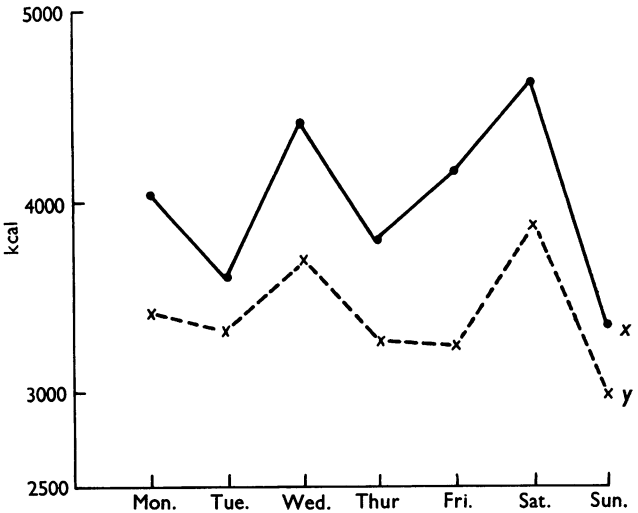

Fig. 5. An individual subject where intake (x) of calories was significantly and positively correlated with expenditure (y) but where the mean values differed significantly. Cadet 6: $r = +0{\cdot}889$; $\bar{x} = 3992$ kcal; $\bar{y} = 3396$ kcal; ($\bar{x}-\bar{y}$) significant, $P < 0{\cdot}01$.

The values analysed in this paper bear little relation to the much more uniform distribution found in studies on lower mammals (e.g. Gasnier & Mayer, 1939). Figure 6 shows the scatter of the results (for the young women and the housewives) where intake on the abscissa is plotted against expenditure as the ordinate. The other groups show a similar scatter. And the relationship cannot be elucidated by postulating a delay in adjustment, as did Edholm *et al.* (1955). In fact, their results, when analysed in the above manner, show no grounds for inferring delay in operation of control.

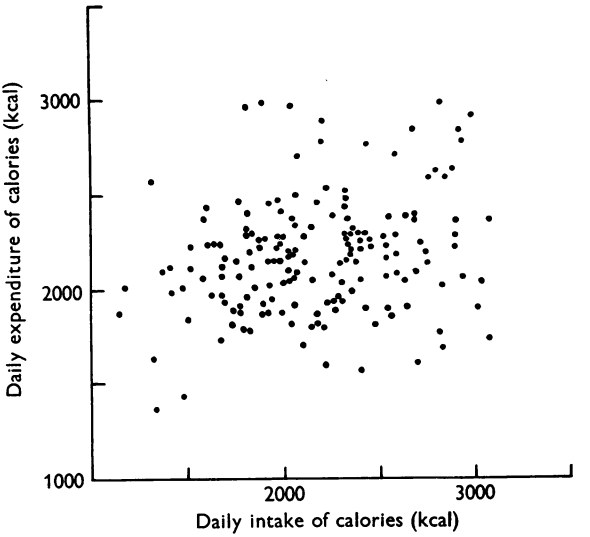

Fig. 6. Scatter of daily intake of calories plotted against expenditure (same day) for 7 consecutive days in 24 young and middle-aged women.

Both the subjective and the objective evidence analysed here lead to the conclusion that the mechanism whereby our appetite is satisfied is by no means nicely adjusted to expenditure of energy. The high incidence of obesity when there are no restraints on the availability of food would alone suggest a control relatively insensitive to precise regulation of calorie balance, as also would the low correlation of intake and expenditure shown in the above analysis. In contrast, there is clearly some functioning control since a long-term approximate calorie balance is generally attained in man.

It may be inferred, then, that perhaps a double mechanism controls appetite, (1) a gross, short-term regulation and (2) a long-term one, operating with a delay of days, weeks or occasionally months. The usually dominant control, the short-term control, may be a simple physical mechanism, such as the state of distension or motility of the stomach or

possibly also of the duodenum and proximal jejunum. A control such as this would satisfactorily interpret the large variability shown in the intake of calories by an individual, since the same bulk of food may have a very different calorie content. The temporary efficacy of high-bulk, low-calorie diets in the treatment of obesity would also be explained. Studies on babies described by Yorston & Hytten (1957) give added support for such a theory. They found that a certain number of babies fed on breast milk cried soon after a feed although there were no indications of underfeeding; the signs were similar to those of other similarly fed babies suffering from underfeeding. When these first mentioned babies were fed with similar quantities of reconstituted dried milk, the 'hunger' crying stopped. When returned again to breast milk of the same amount crying recommenced. Radiological investigation showed that the stomach and duodenum emptied much more rapidly with the breast-milk feed than with dried milk. The physical state of the stomach would here seem to be the determining factor; babies, also, are free from most of the other psychological factors which affect eating in adults.

The factors determining the satisfaction of 'appetite' would thus usually seem to be, in man, much cruder in action than those proposed by workers who have experimented mainly with lower mammals. The existence of a finely triggered control mechanism, which is clearly ineffectual in adapting immediate intake of food to balance expenditure of energy, is physiologically unacceptable. The presence of any fine control therefore becomes suspect as a means of attaining day-to-day balance. Yet it is possible that one may exist for the purpose of regulating intake after short periods (e.g. a day or part of a day) of strenuous physical exercise, where large debts of calories may require to be repaid. However, almost certainly, there must be another, long-term control exerted over appetite and some metabolic, possibly lipostatic, factor must act as a further, superadded influence.

SUMMARY

1. Relationships between the intake and expenditure of calories in man have been determined. Measurements, previously published, of the daily intake and expenditure of energy during a period of 7 consecutive days by each of sixty-nine individual subjects have been analysed statistically. The subjects were adults of both sexes, with a range in age from young to elderly and in mean daily energy expenditure from 2000 to 4000 kcal.

2. In each individual the correlation coefficient (r) was determined for (1) intake of calories and the expenditure of the same day. Since there may be a delay in the adjustment of intake to expenditure, r has also been calculated where the intake has been related to the energy expenditure (2)

of the previous day and again (3) with the energy expenditure of 2 days previously. The significance or otherwise of the difference between the mean daily calorie intake ($\bar{x}$) and expenditure ($\bar{y}$) (over 7 days) has also been analysed.

3. A quick and even balance between intake and expenditure would give a markedly positive correlation between the two (r positive and significant) and $\bar{x}$ minus $\bar{y}$ would be non-significant. This was the case in four out of the sixty-nine subjects. In forty-one subjects (59 %) r was not significant and ($\bar{x}-\bar{y}$) was also not significant; that is, intake and expenditure were balanced over the 7 days, although there was no significant correlation between the two from day to day. Eighteen individuals (26 %), showed r to be non-significant but there was a significant difference between mean intake and expenditure of calories (seven subjects had an insufficient intake of calories and eleven an excess). A significant *negative* correlation for r was present in four individuals, where $\bar{x}-\bar{y}$ was not significant. Two subjects had a significant and positive r, but a significant excess of intake over output of calories.

4. These results make it unlikely that most of the current theories on the control of 'appetite' can be directly applied to man; the factors regulating this control from day to day would seem to be much more gross in action.

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