Letters to the Editors

Comparing energy expenditure between groups of people with different body masses

The relationship between obesity and energy intake appears to be complex. At two extremes of a continuum are people who are able to eat large amounts of food without showing any weight gain ('large eaters'), and people on very low energy intakes who show a tendency for weight gain due to increased fat deposition ('small eaters') (Clark *et al.* 1992).

Clark *et al.* (1994) provide a very interesting study on energy intake and expenditure in people belonging to the two aforementioned groups. An interesting question that arises from the study is whether greater energy expenditure, due to either greater activity and/or a higher basal metabolic rate (BMR) should offset the high food intake of 'large-eaters', and conversely whether lower BMR/reduced activity should lead to very low metabolic energy demands in 'small eaters'.

In the study they measure total energy expenditure (TEE) over a 28 d period in six 'small-eaters' and six 'large-eaters' using the doubly-labelled water method (Lifson & McClintock, 1966). If we assume that TEE for women of similar weights is an approximately normally-distributed variable with the same variance for 'small-' and 'large-eaters', then the two-sample (pooled standard deviation) t test that Clark *et al.* (1994) have computed provides some evidence that the higher mean TEE in the 'small-eater' group reflects a true difference between the two putative metabolic groups (t_{10} = 2·26, $P = 0{\cdot}047$). This result appears to be the opposite to that expected.

The biological significance of this finding becomes questionable if we examine the body masses of the subjects used in the study. TEE depends on body mass (M), and mean mass differs between the two subject groups. Ideally we would wish to make a comparison between people of the same mass. Samples of people of different body masses are likely to have different mean energy expenditures, irrespective of whether they are 'small-' or 'large-eaters'. It is clearly not realistic to recruit volunteers of identical body masses. However, if we can estimate the functional relationship between body mass and energy expenditure, we can allow for differences in body mass between groups when we carry out the statistical analysis of the data.

A method that can often be applied to physiological variables which covary with body size is analysis of covariance (ANCOVA). Here I outline the principles of analysing data on energy expenditure (and other physiological variables) using ANCOVA, and re-analyse the Clark *et al.* (1994) data on TEE in 'small-' and 'large-eaters'.

Sample sizes were small in the Clark *et al.* study, so we cannot assess whether the functional relationship between TEE (MJ/d) and M (kg); the average of the initial and final body masses is linear or not. The relationship between body mass and energy expenditure is thought to be allometric (Reiss, 1989). Hence, a common practice is to transform logarithmically both variables. In this case we assume that the functional relationship between the two variables is:

$$\mathrm{TEE} = \alpha \mathrm{M}^{\beta},$$

where α and β are constants.

If we take the logarithms of both sides of the above equation, we obtain a simple linear regression equation:

$$\log \mathrm{TEE} = \log \alpha + \beta \log \mathrm{M},$$

where $\log \alpha$ is the parametric intercept and β is the parametric gradient.

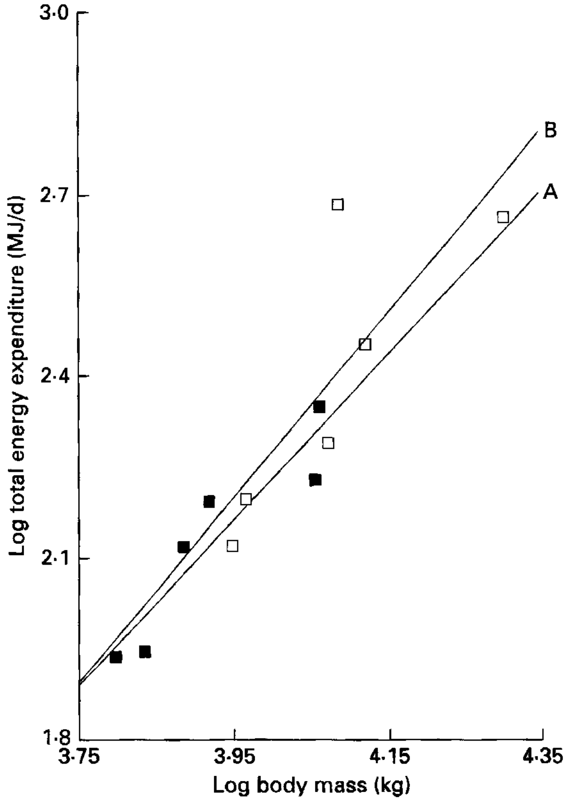

Figure 1. Simple linear regression lines for 'large-eaters' (■) (line A, $\log TEE_I = -3{\cdot}16 + 1{\cdot}35 \log M_I$) and 'small-eaters' (□) (line B, $\log TEE_S = -3{\cdot}75 + 1{\cdot}50 \log M_S$). The regression slope is significantly different from zero for the 'large-eaters' ($F_{1,4} = 25{\cdot}49$, $P = 0{\cdot}007$). The regression slope does not differ from zero for the 'small-eaters' at the 5% significance level ($F_{1,4} = 7{\cdot}59$, $P = 0{\cdot}051$); however, this might be expected, even for very strong functional relationships, when sample sizes are small.

If the following reasonable assumptions hold: (1) common β for both 'small-eaters' and 'large-eaters' (supported by similarity of sample estimates of β, see below), (2) log TEE is a normally-distributed variable for people of the same group with the same body size, (3) log TEE has common variance within groups for different body masses, and (4) log TEE has common variance between groups (for a given body mass), then we can make a robust, body size-independent comparison between the two groups based on the principles of simple linear regression and analysis of variance.

Consider the two simple linear regressions between the logarithmic transforms of the data (see Fig. 1). Both provide sample estimates of β ('large-eaters', $b = 1{\cdot}35$, 'small-eaters', $b = 1{\cdot}50$), and so we can combine them and (hopefully) obtain a better estimate of β ('average', or pooled within-group, $b = 1{\cdot}44$).

Once our pooled estimate of β has been calculated we can use it to adjust individual observations by 'moving' the observations up or down the estimated gradient to the overall mean of log M for the subjects used in the study (the back-transform of the overall mean was 54·88 kg). In other words, we adjust TEE to simulate an experiment in which all the subjects were of 54·88 kg. We are then in a position to test the null hypothesis of equality of 'size-adjusted means' between the groups, which we can do using an analysis of variance procedure on the size-adjusted observations.

When we do this we find that there is no evidence for a difference in energy expenditure between 'small-eaters' and 'large-eaters' ($F_{1,9} = 0{\cdot}29$, $P = 0{\cdot}603$). The back-transformed adjusted means are 9·41 MJ/d for the large eaters and 9·83 MJ/d for the smaller eaters, a much smaller difference than that computed between the unadjusted means (8·49 and 11·27 MJ/d, respectively). The magnitude of the difference between the unadjusted sample means observed by Clark *et al.* (1994) is largely attributable to the differences in body size between the subjects in the different groups. Hence, the conclusion for the study is that there is no evidence differences in energy expenditure between 'small-eaters' and 'large-eaters', when the effects of size have been removed from the analysis.

The method described (ANCOVA) could be used to analyse other size-dependent variables presented in the Clark *et al.* (1994) study (e.g. energy intake). However, it should be noted that ANCOVA is not the perfect solution to the problem, even when all the major assumptions outlined above are reasonable. The accuracy of the estimated functional relationship depends on a further assumption that there is no error term associated with the covariate. This is clearly not the case for $\log M$ (however, note that deviations from this assumption should not affect the analyses greatly, particularly when the correlation between the two variables is high). Despite this, ANCOVA provides a generally robust method for testing for size-independent differences between populations, and for this reason it is widely used in several areas of biology (e.g. see Packard & Boardman, 1988).

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Energy expenditure in 'large-' and 'small-eaters'

We thank Dr Brown for his interest in our research on different aspects of energy metabolism in self-perceived, 'large-eating' (those people who appear to eat to excess yet stay slim) and 'small-eating' (those people who appear to restrict food intake in order to stay within the normal weight range) humans (Clark *et al.* 1992, 1993, 1994). This research was initiated in an attempt to determine whether there are 'metabolically efficient' ('small-eating') and 'metabolically inefficient' ('large-eating') humans in the free-living population (Clark *et al.* 1992, 1993).

As rates of energy intake (approximately 12 MJ/d *v.* approximately 5·5 MJ/d) and energy expenditure (approximately 9 MJ/d and approximately 12 MJ/d for the 'large-' and 'small-eaters', respectively) determined from self-reporting, weighed food and activity diaries (Clark *et al.* 1992) were obviously not sustainable without appreciable weight changes, we used the doubly-labelled water ($^2H_2{}^{18}O$) technique (Schoeller *et al.* 1986) to determine the long-term rates of energy expenditure and energy intake in selected, 'large-' (*n* 6) and 'small-eating' (*n* 6) women (Clark *et al.* 1994). These studies demonstrated that the $^2H_2{}^{18}O$-assessed rates of energy expenditure for the 'large-' (approximately 8·5 MJ/d) and 'small-eaters' (approximately 11·5 MJ/d) were in close agreement with those obtained using the 5 d activity diaries: they also showed that the rates of energy intake derived from the $^2H_2{}^{18}O$-determined rates of energy expenditure and corrected for changes in body composition were approximately 11 MJ/d for the 'small-eaters' and approximately 8·5 MJ/d for the 'large-eaters' (Clark *et al.* 1994). As these intakes bore no resemblance to the results obtained with the self-reporting, weighed food diaries, we not only confirmed the unreliability of energy intakes determined using self-reporting, weighed food diaries in some food (weight)-conscious people but also challenged the existence of normal-weight, 'metabolically efficient' ('small-eating') females in the community (Clark *et al.* 1994). The fact that the self-perceived, 'small-eaters' had similar or greater energy intakes and similar or greater energy expenditures than the self-perceived, 'large-eaters' (Clark *et al.* 1994) is sufficient information to reject the hypothesis that 'small-eaters' are able to support the same or a higher energy expenditure on a lower energy intake. For this reason, Dr Brown's detailed reanalysis of some of the energy metabolism data obtained with the self-perceived 'large-' and 'small-eating' subjects is not central to the aim of our study and does not weaken our conclusions (Clark *et al.* 1994).

Total energy expenditure (TEE) is composed of three main components, basal metabolic rate (BMR), thermic effect of activity (TEA) and thermic effect of food (TEF), which normally comprise 60–75, 15–30 and approximately 10% of daily energy expenditure respectively (Poehlman & Horton, 1990). While BMR is most strongly related to fat-free mass (Ravussin & Bogardus, 1989), energy expenditure during weight-bearing activity is more generally related to body mass. Thus Dr Brown's analysis with body mass as covariate would, as he suggested in the second paragraph of his letter, have been more usefully applied to the TEA rather than the TEE measurements.

We would like to point out that we are familiar with analysis of covariance and have analysed the BMR data from our initial experiments with the self-perceived, 'large-' and 'small-eating' males and females (Clark *et al.* 1992, 1993) in this manner (Clark *et al.* 1993, 1995).

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