

The efficiency of food utilization, digestibility of foodstuffs and energy expenditure of mice selected for large or small body size

By RUTH E. FOWLER

Institute of Animal Genetics, University of Edinburgh

(Received 15 July 1961)

Many patterns of growth are controlled by genes, and selection for heritable differences between animals in body size has resulted in divergent strains of both domestic livestock (e.g. Dickerson & Grimes, 1947) and laboratory animals (e.g. in the mouse: Goodale, 1938; MacArthur, 1944; Falconer, 1953). The changes in body size are often substantial and must be due to alterations in the basic physiology of the animals. In the present work, a study has been made of the physiology of two lines of mice in which selection for large or small body size respectively had been practised for a number of generations. The characters chosen for study were the efficiency of food utilization, digestibility of foodstuffs, total energy expenditure and body activity.

Studies on the growth and reproductive physiology of these selected lines have been reported previously. Growth in the large line was largely due to an increase in protein and associated water up to 40 days of age, and to fat deposition thereafter (Fowler, 1958). In the small line, the deposition of protein and fat was much lower at all ages. Some infertility occurred in both lines, though through different causes (Fowler & Edwards, 1960). Sterility in pair matings of the large line was due to low libido in the males, whereas insufficient secretion of pituitary gonadotrophins appeared to be fairly general in females of the small line.

MATERIAL

The mice used in the present study came from strain *N* which had been selected by Falconer for large (*NL*) and small (*NS*) body size at 6 weeks of age. Details of the foundation population and method of selection have been described by Falconer (1953). An unselected control line (*NC*) was constructed at a later date than the selected lines, but was derived from the same original cross (Falconer 1953). Selection had been practised for many generations at the time the present work was undertaken. During the course of selection the generation interval in the small line had increased because mice of this line were slow to reach sexual maturity. Comparisons between mice of the large and small lines were therefore necessarily limited to the generations available during the course of the investigation. The mice used came from the following generations: *NL*, 25-30; *NC*, 11-12; *NS*, 21-26.

METHODS

Efficiency of food utilization

Two criteria were used to measure the efficiency of utilization of ingested food. First, *gross efficiency* was estimated by the increase in weight per unit time per unit of food consumed. Secondly, an alternative measure of efficiency in terms of energy units, *total energetic efficiency* (Brody, 1945), was used. This measurement takes into account the composition of the weight-gains, the energy increase in the carcass being calculated as a fraction of the total energy consumed. The composition of the carcasses of *NL* and *NS* mice has been analysed previously (Fowler, 1958). The mice were fed on a standard cubed diet containing 74% cereals, 11% fish and meat meal, 13% dried milk and whey in addition to small amounts of yeast, molasses, cod-liver oil and salt. The food was analysed for ash, fat, water and nitrogen; the protein content of the food was then estimated by multiplying the nitrogen content by 6.25, and the carbohydrate content was obtained by subtraction. The calorific value of the food (dry weight) and of the carcasses were calculated from their respective compositions using the conversion factors 4.10, 9.45, and 5.65 Calories per gram, which are the average heats of oxidation obtained by the combustion of carbohydrate, fat and protein respectively in a bomb calorimeter (Widdowson, 1955).

In a first series of experiments, measurements of food intake and weight of animals were obtained concurrently at weekly intervals from 3 to 12 weeks of age. A total of fifteen *NL*, eighteen *NC*, and twenty-six *NS* males, and nineteen *NL*, twenty-four *NC*, and seventeen *NS* females were used in these experiments, two or three mice being housed per cage and fed *ad libitum* on stock cube diet from normal food hoppers. Mean values for food intake (after excluding the food spilt) and body weight were calculated for each line. In a second series of experiments, a more detailed study was made when differences in growth-rates between the selected lines were at a maximum, i.e. from 3 to 6 weeks of age. Measurements were made at 2-day intervals on twenty-eight *NL*, twenty-two *NC*, and twenty *NS* male mice which were housed singly on wood-wool bedding.

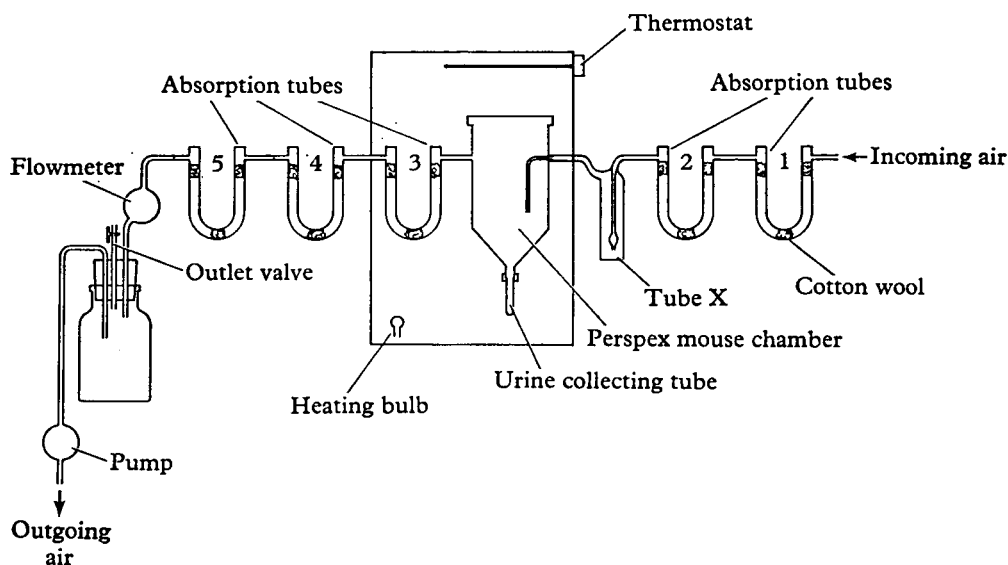
Digestibility of foodstuffs, respiratory quotients, nitrogen balances and energy expenditure

The total food consumption, the excreta, and the carbon dioxide and oxygen exchange were measured over periods of approximately 24 hours under conditions as near normal as possible. Measurements were made on eleven *NL*, sixteen *NS* and five *NC* mice at various ages. These measurements included a series of determinations on two *NL* males at various ages between 22 and 73 days, and on two *NS* males between 22 and 40 days. Energy expenditure was also determined in five *NL* mice prior to weaning. The duration of the measurement of gaseous exchange was necessarily limited to 2 hours in these pre-weaning mice.

The metabolism apparatus used was of the open-train type of Haldane (1892), considerably modified by the use of many features used in the closed-circuit apparatus of Dewar & Newton (1948*a*). A plan of the apparatus is given in

Text-fig. 1. The mouse was housed in an airtight perspex chamber fitted with a grid to collect faeces and spilled food, a urine collecting tube, a food-box designed to minimize spilling, and a drinking-water bulb. The temperature of the chamber was thermostatically controlled at 25° C.

Carbon dioxide in the dried emergent air was collected in soda-asbestos tubes and estimated from the weight change of tubes 4 and 5 (Text-fig. 1). Oxygen



Text-fig. 1. A plan of the open-circuit apparatus used to measure the carbon dioxide and oxygen exchange and water balance of the mouse over a 24-hour period. Air is drawn through the apparatus by the water filter-pump at a rate of about 350 ml./min.

Tubes 1 and 2, containing anhydrous magnesium perchlorate and soda asbestos respectively, remove water and CO_2 from incoming air.

Tube X contains water to moisten incoming air; is weighed before and after each run.

Tube 3 contains anhydrous magnesium perchlorate to collect evaporated water from the chamber; is weighed before and after each run.

Tubes 4 and 5 contain soda asbestos and some anhydrous magnesium perchlorate to collect CO_2 in air from chamber; is weighed before and after each run.

was determined from the net gain in weight of the complete chamber and distal absorption tubes. *Respiratory quotients* and *energy expenditure* (metabolic rate) were calculated as described by Dewar & Newton (1948a).

The faeces were weighed and analysed as described for food. Faecal protein was determined concurrently with each 24-hour experiment; faecal fat and ash were determined from an analysis of faeces collected from a group of mice of the same line fed on the diet. The composition of faeces may vary between different mice,

though Dewar & Newton (1948*a*) have estimated that the error due to grouping the faeces would be small. After each 24-hour experiment, the floor and grid were washed and the washings added to the urine which was then filtered. The nitrogen of the urine was determined by the micro-kjeldahl method. The residue containing the food spilled was weighed after drying. *Nitrogen balances* were obtained directly by subtracting the nitrogen loss in the urine from the digestible nitrogen of the food.

The *total digestibility* of the foodstuffs was estimated as the percentage absorbed (i.e. eaten less that in the faeces). The digestibility of each constituent of the food, i.e. fat, protein and carbohydrate, was also determined. The *calorific digestibility* was estimated from the calorific value of the ingested food and excreta.

Activity

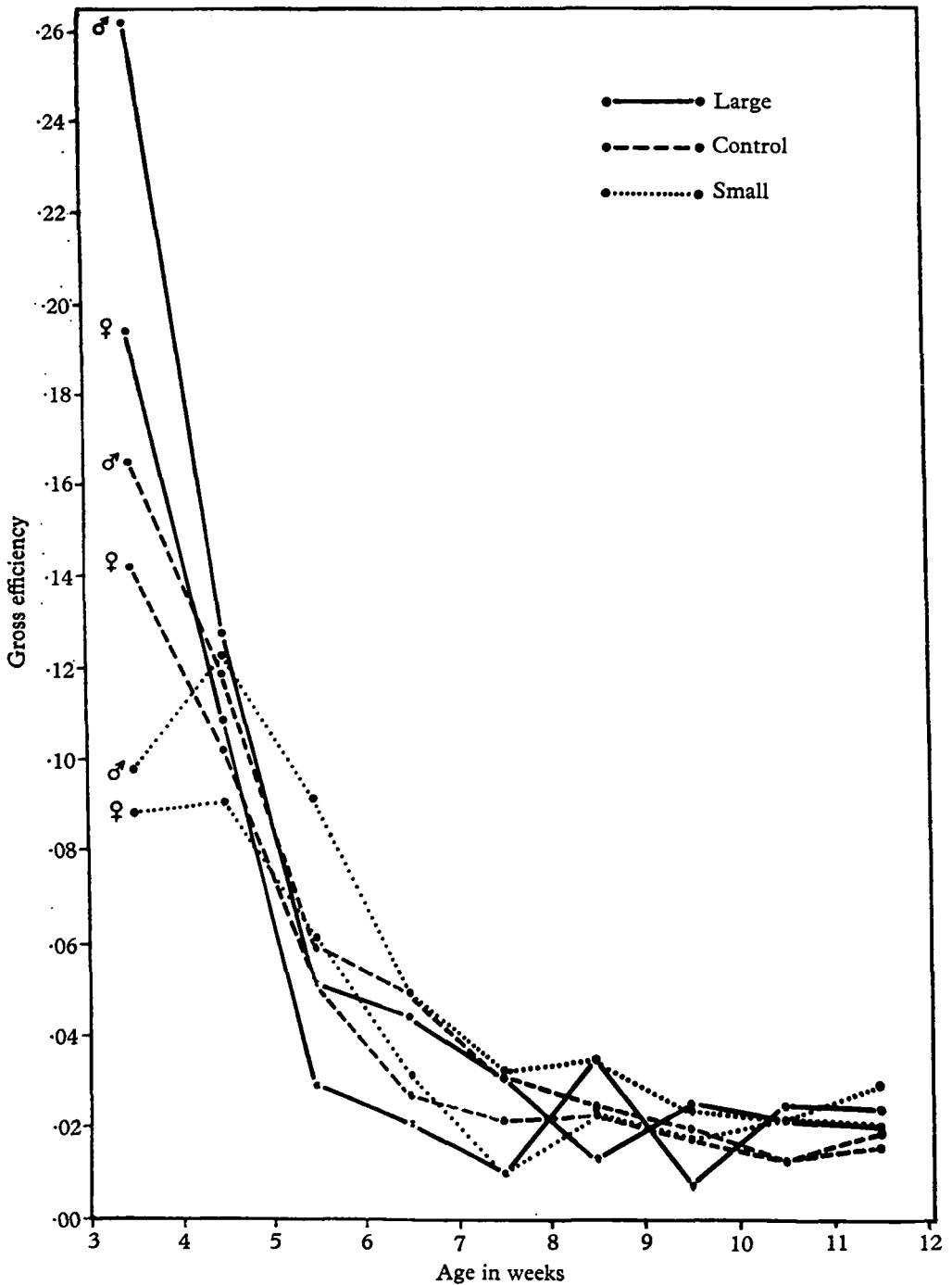
The activity of eleven *NL* mice and seventeen *NS* mice was measured using a simple form of activity cage in which movements of the mouse from one end of the cage to the other were recorded on a revolving drum. The activity of each mouse was measured for approximately 18–24 hours (one recording) in order to reduce errors in the measurements due to their diurnal rhythm of activity. Activity was studied during the period when differences in growth-rate were maximum, i.e. between 3 and 6 weeks of age. The measurements included a series on two of the *NL* and three of the *NS* mice which were recorded on several different days between 22 and 46 days of age.

RESULTS

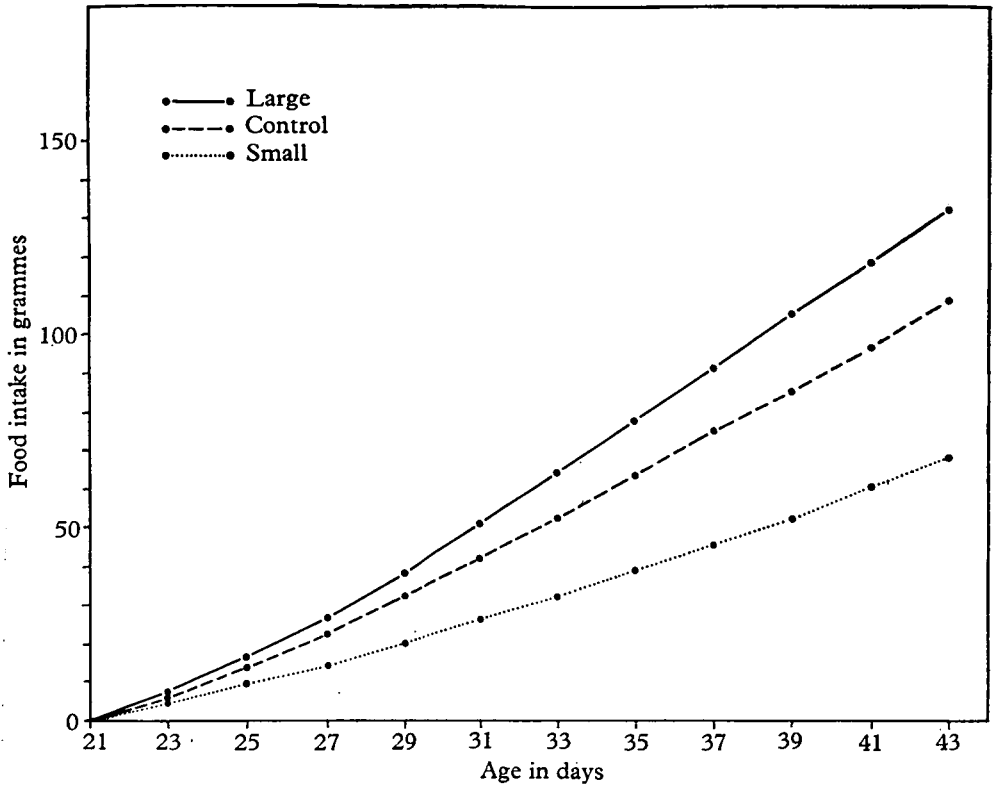
(a) *Efficiency of food utilization*

Mean values of gross efficiency for large, control and small lines are plotted in Text-fig. 2. During the period of most rapid growth, i.e. between 3 and 5 weeks of age, gross efficiency was highest in *NL* mice, intermediate in *NC*, and lowest in *NS*. In *NL* and *NC* mice it decreased markedly from weaning to 6 weeks of age, but showed very little change after this age. In the small line, gross efficiency remained constant or actually increased in males up to 5 weeks of age and declined thereafter. Gross efficiency was generally higher in males than in females.

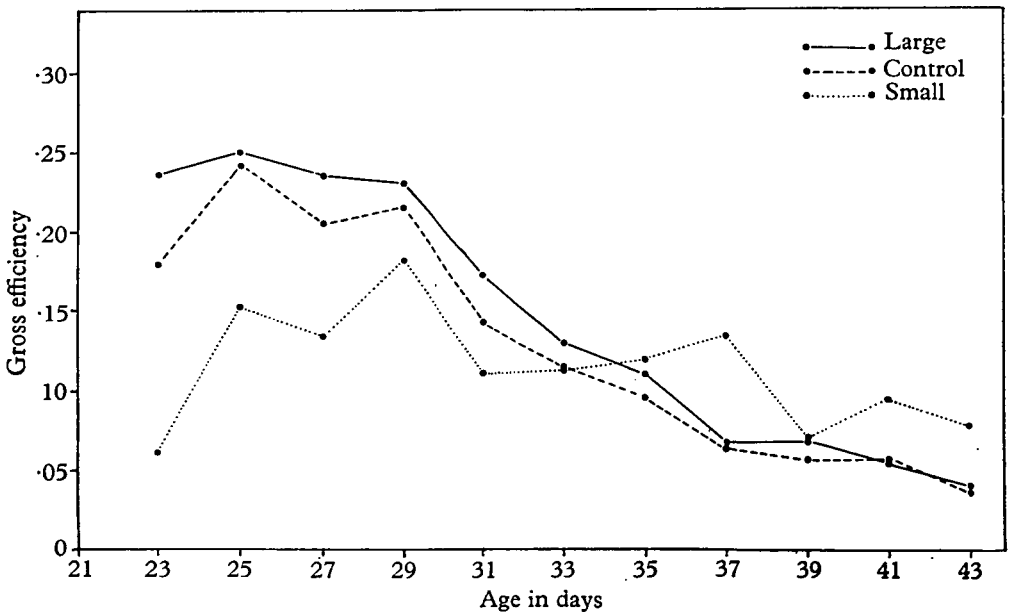
Mean values for the more detailed examination of food intake and gross efficiency in males between 21 and 43 days of age are plotted in Text-figs. 3 and 4. Food intake was highest in the large line, intermediate in the controls and lowest in the small line (Text-fig. 3). Gross efficiency increased from 23 to 25 days of age in all lines but most markedly in the small line. The low levels immediately post-weaning may be partially due to the change-over to a solid diet in mice which were still suckling at 3 weeks of age, or to other effects of weaning, e.g. the relatively greater heat loss in small than in large mice. Gross efficiency was again highest in the large line, intermediate in controls, and lowest in the small line until approximately 31 days of age (Text-fig. 4). The percentage composition of the food (dry weight) was found to be: ash 8.24%, protein 20.95%, fat 4.98% and carbohydrate 65.83%, its gross calorific value being 4.35 Calories per gram.



Text-fig. 2. Mean values of gross efficiency in large, control and small lines calculated for weekly intervals from 3 to 12 weeks of age.

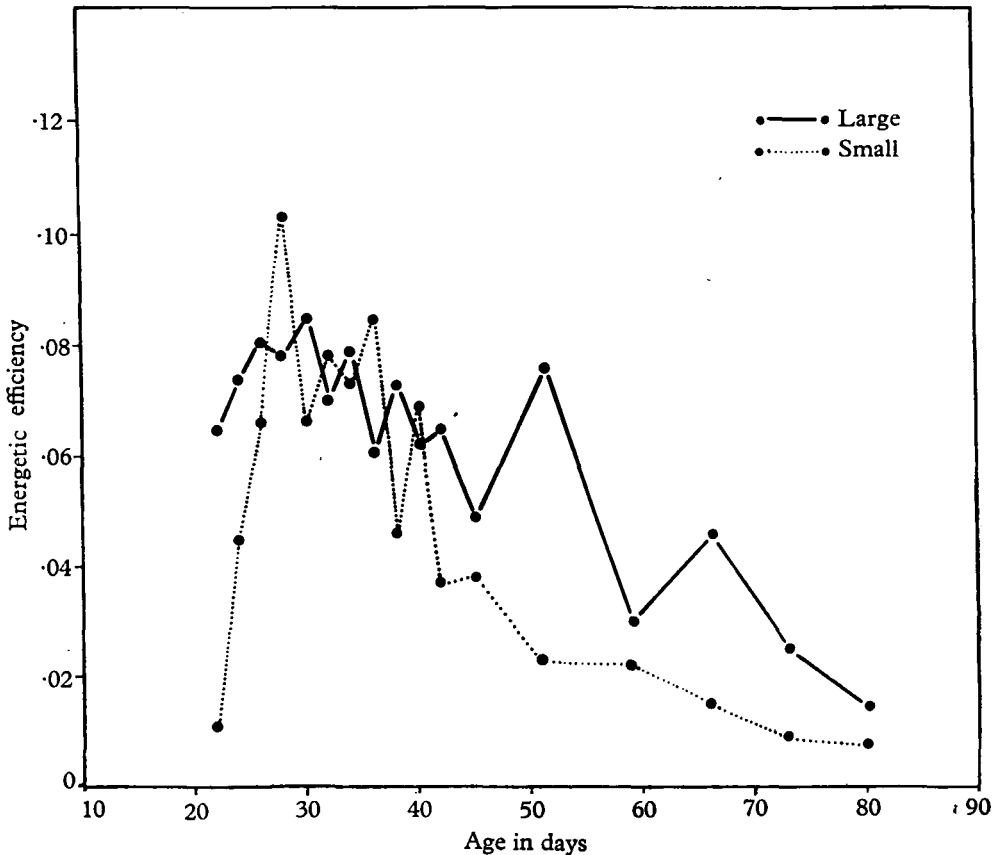


Text-fig. 3. Cumulative food intake of males in large, control and small lines from 21 to 43 days of age.



Text-fig. 4. Gross efficiency of males of large, control and small lines calculated for each 2-day interval from 21 to 43 days of age.

Estimates of total energetic efficiency at 2-day intervals from 21 to 43 days and at weekly intervals between 6 and 12 weeks are shown in Text-fig. 5. Total



Text-fig. 5. Estimates of the energetic efficiency of males of large and small lines calculated for each 2-day interval between 21 and 43 days of age and for weekly intervals from 42 to 84 days of age.

energetic efficiency was higher in the large line until about 4 weeks of age, similar in both lines between 4 and 6 weeks of age, and higher in the large line from 6 to 12 weeks of age.

(b) Digestibility of foodstuffs

The composition of the faeces of *NL* and *NS* mice was unaffected by age, hence the mean percentage of faecal protein, fat and ash was calculated as shown in Table 1. The percentage of faecal protein was significantly higher for mice of the small line ($F_{53}^1 = 22.5, P < 0.01$). The percentage of faecal fat was higher and the percentage of carbohydrate lower in the small than the large line, although these differences were not significant. Despite these differences in the faecal composition, the mean calorific value of the faeces was similar in the two lines.

Table 1. *The composition of the faeces of NL and NS mice, expressed as a percentage of the dry weight*

Line	% Ash	% Fat	% Protein	% Carbo- hydrate	Calorific value of faeces
NL	16.25 ± 0.72	2.39 ± 0.27	23.57 ± 0.56	57.79	3.93
NS	16.56 ± 0.36	3.43 ± 0.58	27.98 ± 0.75	53.03	4.08

No significant correlation between body weight and total digestibility, calorific digestibility or the digestibility of the constituent foodstuffs was found in either line. Mean values were therefore calculated and are shown in Table 2. Despite large differences in food intake, total and calorific digestibilities were similar in

Table 2. *The digestibility of foodstuffs in NL and NS mice*

Line	No. of determinations	Total digestibility	Calorific digestibility	Digestibility of		
				Protein	Fat	Carbohydrate
NL	21	62.82 ± 0.83	66.97 ± 0.58	58.09 ± 1.40	82.42	67.47
NS	26	64.42 ± 1.46	67.63 ± 1.23	53.31 ± 1.60	76.09	72.05

both lines. Nevertheless, a greater proportion of protein was absorbed by *NL* mice ($F_{46}^1 = 4.61$, $P < 0.05$). *NL* mice also had a higher digestibility of fat and a lower digestibility of carbohydrate, though significance tests were not carried out on these data which were obtained from groups of several animals.

(c) *Respiratory quotients and nitrogen balances*

The R.Q.s, although variable, were similar in both selected lines (e.g. see Tables 3 and 4); all exceeded 0.8, approximately half exceeded 0.9, and a few animals of each line had an R.Q. exceeding 1. The higher R.Q.s were frequently associated with positive weight increases in both *NL* and *NS* mice.

Nitrogen balances were generally positive in *NL* mice during the period of most rapid growth, i.e. 3–5 weeks of age, and reduced or negative after this age. Examples are given in Table 3. In the small line during the growing period, nitrogen retention was much lower corresponding with the smaller weight increments (e.g. see Table 4).

(d) *Energy expenditure*

Results of the experiments on energy expenditure are given in Text-figs. 6–9, details on the series of recordings on the two *NL* and two *NS* males being given in Tables 3 and 4. The total energy expenditure per day was considerably higher in the large than in the small line at comparable ages (Text-fig. 6; Tables 4 and 5). The relation between energy expenditure and body weight in both lines is shown in Text-fig. 7. Variability was higher in the small than the large line, but when animals of the same weight were compared, the energy expenditure of *NL* mice

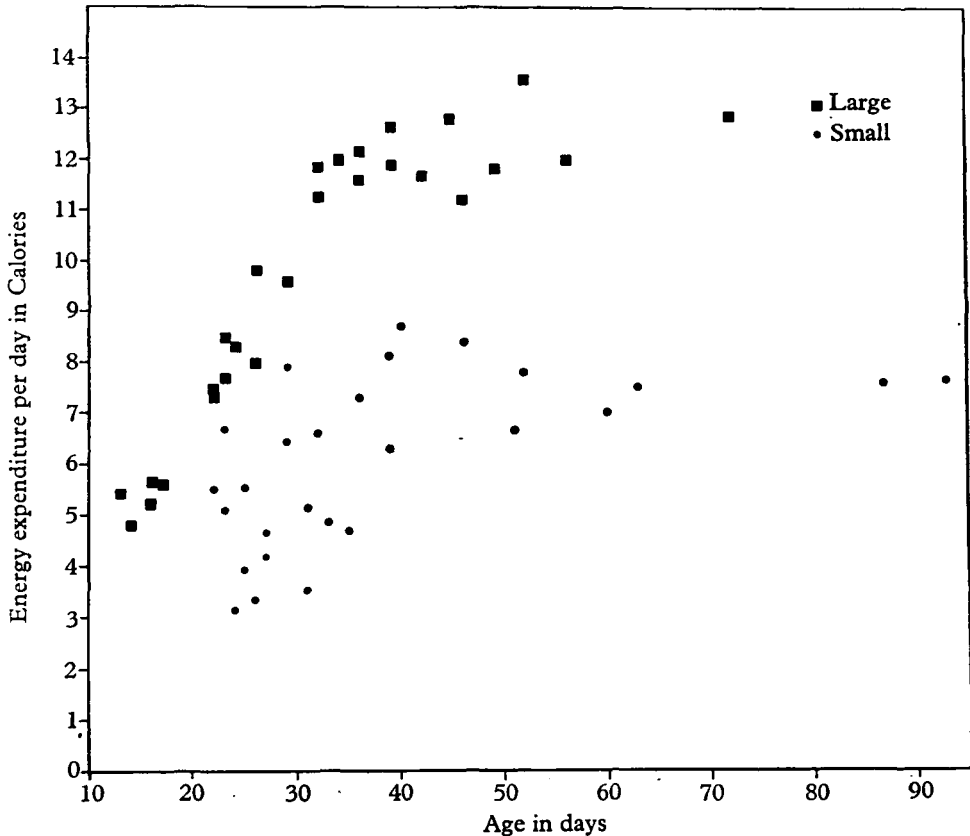
Table 3. Energy expenditure and nitrogen balances of two male mice of the large line from 22 to 73 days of age

		Age in days														
Mouse		22-23	24-25	26-27	29-30	32-33	34-35	36-37	39-40	42-43	45-46	46-47	52-53	56-57	72-73	
Mean weight during experimental period (g.)	a		14.52	17.88	21.56	22.93	24.52	26.67	27.92	28.97	28.20	29.82	31.80	32.16	33.58	
	b	13.20	14.85	17.04												
Change in weight during experimental period (g.)	a		+1.25	+0.95	+0.34			-0.04	-0.89		-0.52					-1.28
	b	+0.54	+2.25	+0.98	-1.45	-0.04	+0.72	+0.75	-0.18			+0.47	-0.62	-0.83		
Respiratory quotient	a		0.99	0.97	1.00		1.00	0.94		0.98						
	b	0.89	0.93	0.87	0.92	0.90	0.90	0.92	0.86		0.89	0.87	0.83	0.95		
Energy expenditure (Cals.)	a		7.55	8.47	9.86	11.95	12.05	11.60	12.65	11.70	12.80	11.20	13.61	12.00	12.90	
	b	7.55	8.47	9.86	11.95	12.05	11.60	12.65	11.70							
Nitrogen balance (mg.)	a		+21	+26	+11		+26	+14		+1						-4
	b	-19	+48	+23	-1	+16	+22	+28	+2	+2	+1	+2	-15	-38		

Table 4. *Energy expenditure and nitrogen balances of two male mice of the small line from 22 to 40 days of age*

		Age in days											
Mouse		22-23	23-24	25-26	27-28	29-30	31-32	32-33	33-34	35-36	36-37	39-40	
Mean weight during experimental period (g.)	a	7.42	6.49	8.66	7.53	10.40	9.38	11.83	9.93	12.70	10.27	13.35	
	b												
Change in weight during experimental period (g.)	a	+1.21		+0.72	+0.20	+0.52	+0.36	+0.58	+0.25	+0.01		-0.80	
	b		-0.15	+0.14	+0.20	+0.12	+0.36				-1.05		
Respiratory quotient	a	0.99	0.88	1.01	0.95	0.94	0.94	1.01	0.94	0.86	0.83	1.02	
	b												
Energy expenditure (Cals.)	a	5.50	6.70	5.57	4.64	6.44	5.15	6.60	4.85	7.30	4.71	6.36	
	b												
per day	a	0.74	1.03	0.64	0.62	0.62	0.55	0.55	0.49	0.58	0.46	0.48	
	b												
per day per g.	a	1.27	1.71	1.15	1.04	1.17	1.00	1.09	0.93	1.27	0.86	0.96	
	b												
Nitrogen balance (mg.)	a	+8	+8	+15	+11	+12	-7	-5	-3	+11	-26	-24	
	b												

was similar to that of *NS* mice. Weight losses during the experimental period can lower energy expenditure (Dewar & Newton, 1948*a*), but the conclusion was unaffected if animals with excessive weight loss (greater than 3%) were excluded. When energy expenditure per unit weight was plotted against age, it was found to decrease in both selected lines though values were higher in the small line (Text-fig. 8). Values for mice of the control line are shown in the same figure for comparison.

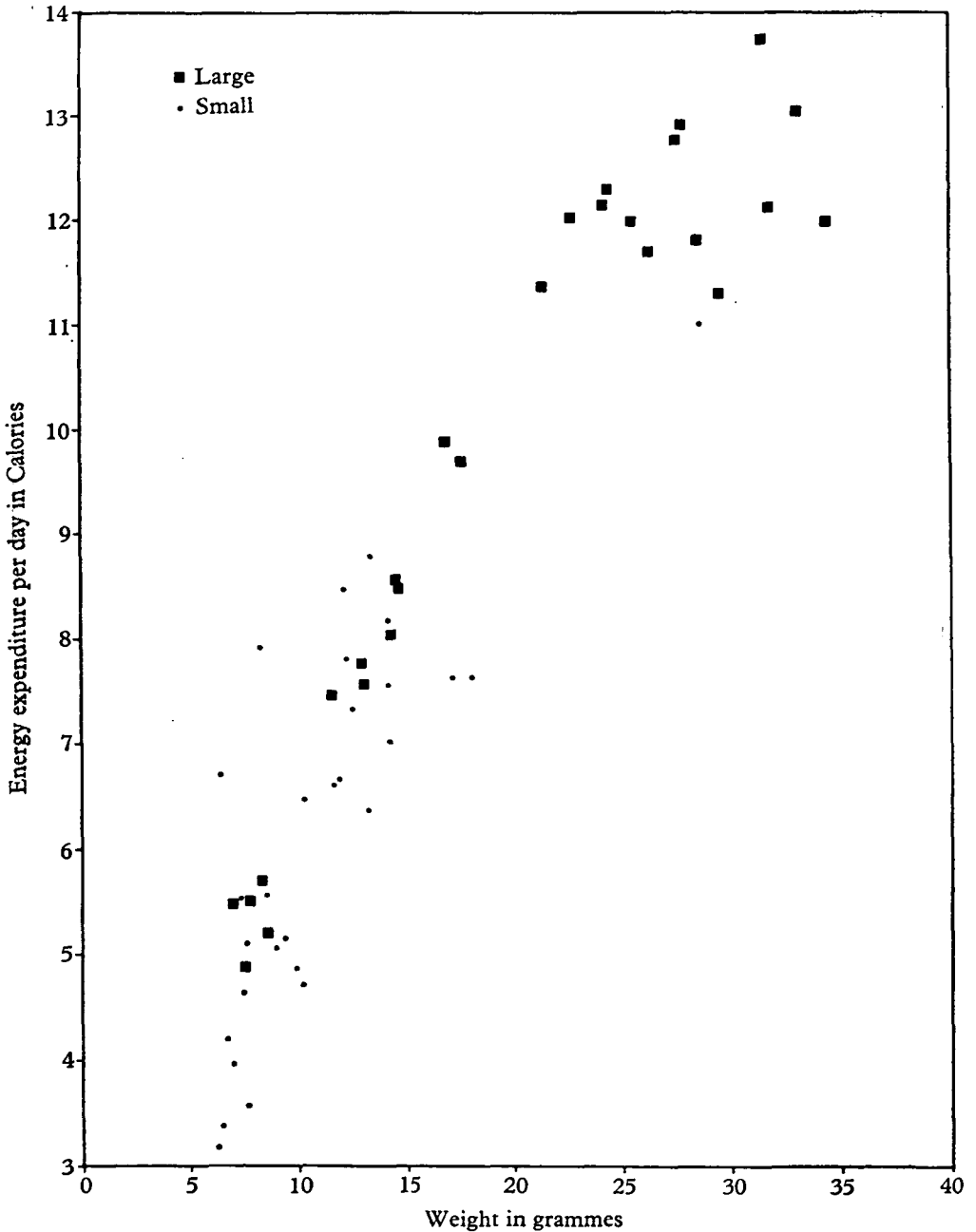


Text-fig. 6. The relation between energy expenditure per day and age in large and small lines.

Brody (1945) has shown that the energy expenditure of adult animals is nearly proportional to $W^{0.73}$. In *NL* mice energy expenditure per $W^{0.73}$ was relatively constant during the period of most rapid growth (7–25 grams) but decreased as weight increments became progressively less (Text-fig. 9, Table 4). Values for growing animals were therefore higher than those of adult mice of the same line. Values for *NS* mice were extremely variable but generally lower than those for *NL* mice (Text-fig. 9, Table 5); with two exceptions the values appeared to be related to the weight change during the experiment, being lower in mice with weight losses than in those with weight gains.

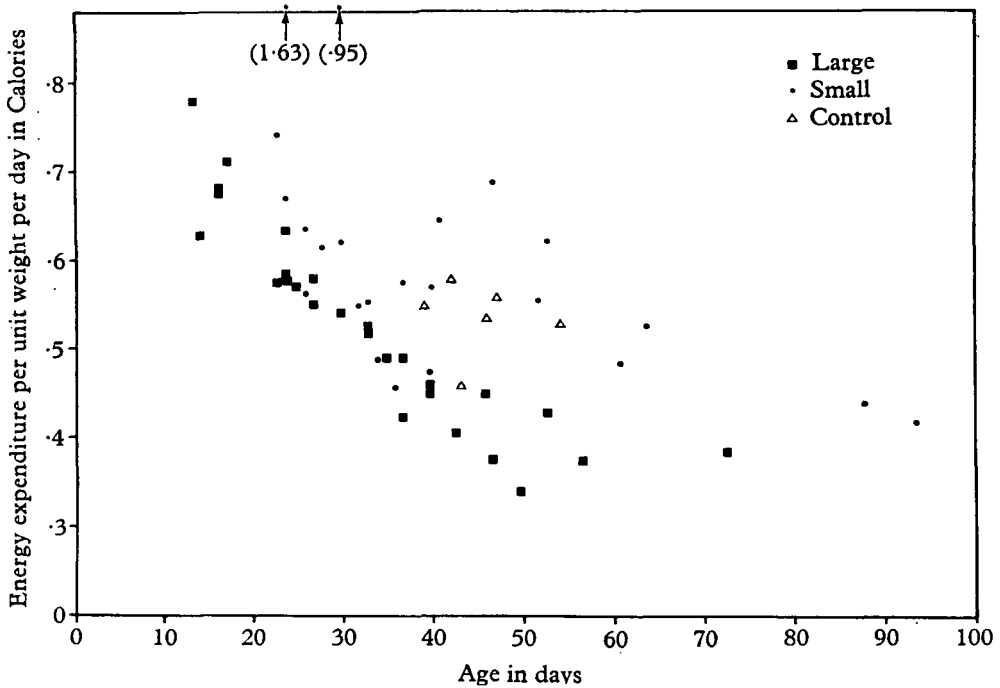
(e) Activity

Results were expressed in units of activity per day, a unit of activity being defined as the movement of the mouse from one end of the cage to the other. In order to determine the error in counting a recording, the total number of activity



units of eighteen separate recordings were counted on four different days. From the variation in counts of each recording, the coefficient of variation could be calculated. The mean coefficient of variation was 4.73%.

Data on the activity of *NL* and *NS* mice is given in Text-fig. 10. Variation in activity was considerable in both selected lines. Post-weaning activity was especially high in *NL* mice; this may be due to a weaning effect associated with loss of litter-mates. Nevertheless, the growth-rate of the large line, which is extremely rapid at weaning, appeared to be unaffected by the high levels of activity. After 23 days there appeared to be an overall increase in the activity of



Text-fig. 8. The relation between energy expenditure per unit weight per day and age in large, control and small lines.

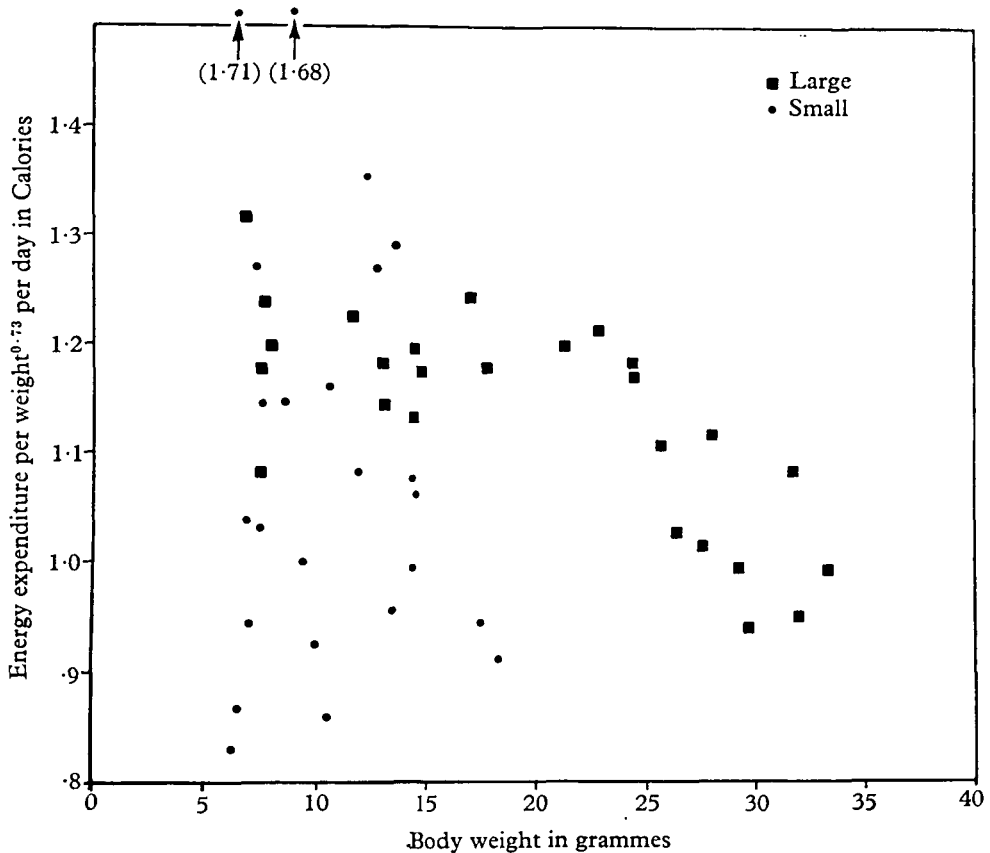
NL mice with advancing age, though the high level of activity of three *NL* males aged 6 weeks or more may have been associated with the onset of sexual maturity. In the small line, activity levels were generally lower than in the large line, and were more constant in the small line at all ages (Text-fig. 10).

DISCUSSION

Several physiological mechanisms have been affected during the course of selection for large or small body size. Mice of the large line consume more food and utilize it more efficiently during the period of most rapid growth than do mice of the small line. The efficiency with which food is utilized is thus evidently gene controlled and capable of modification by selection, changes in efficiency and

appetite being positively correlated with changes in growth-rate. A similar association has been found when selecting for efficiency of food utilization in rats (Morris *et al.*, 1933; Palmer *et al.*, 1946) and for rate and economy of gain in pigs (e.g. Dickerson, 1947; Dickerson & Grimes, 1947).

The greater efficiency of large mice up to approximately 5 weeks of age indicates that the energy required for maintenance was low per unit food consumed when the growth rate was high. With increasing size and decreasing growth-rate, gross

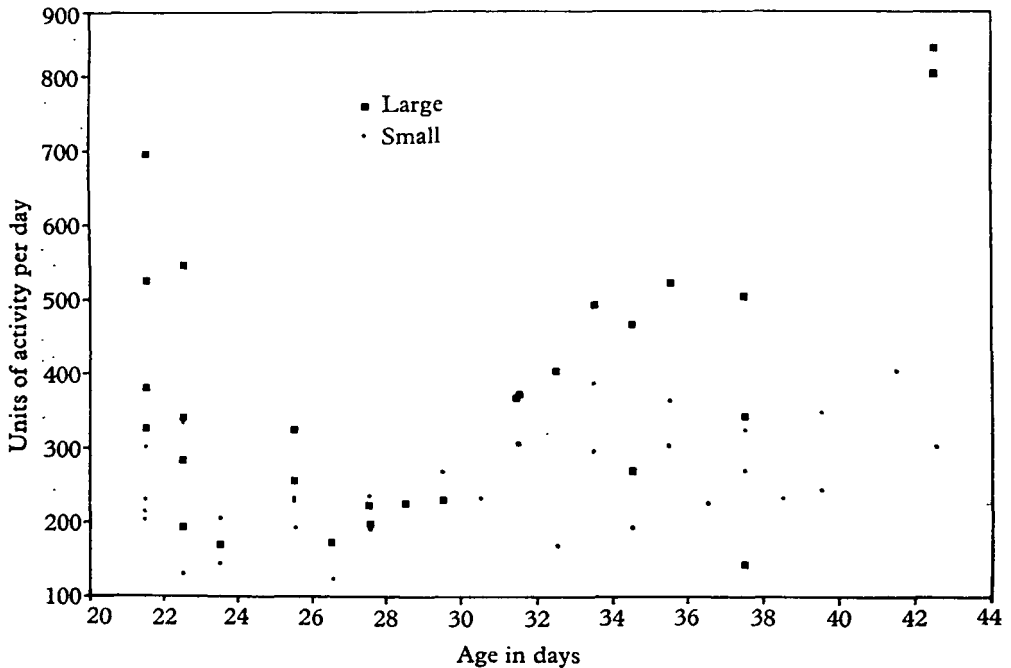


Text-fig. 9. The relation between energy expenditure per $W^{0.73}$ per day and body weight in large and small lines.

efficiency would be expected to decline, for maintenance costs will increase in comparison with the weight gained in unit time. Moreover, from 35 days of age the composition of the weight gained in the large line changes from mainly protein and associated water to largely fat tissue (Fowler, 1958), and gross efficiency does not measure such qualitative differences in weight gain. Gross efficiency stresses increments due to protein and associated water rather than those associated with fat deposition; for body protein is highly correlated with body water, an increase of 1 gram of protein being associated with 3-4 grams body water. In contrast,

energetic efficiency stresses weight increments due to fat deposition, each component of the weight gained being multiplied by its calorific value (i.e. fat \times 9.45, protein \times 5.65). Hence energetic efficiency was generally higher in the large than in the small line up to 4 weeks of age, i.e. when the growth-rate was high, and after 6 weeks of age, when fat was being deposited at an increased rate.

The increased efficiency of food utilization of mice selected for large size was not associated with a greater proportion of the ingested food being absorbed from the gut. Nevertheless, they absorbed a greater proportion of protein (5%) than did mice selected for small size. The maximum increase in weight of the small mice



Text-fig. 10. The activity of mice of the large and small lines between 21 and 43 days of age.

which would result from a 5% increase in digestibility of protein has been calculated assuming that all the increased protein would be utilized for growth purposes. The calculated increase in weight (3.1 grams) was insufficient to account for the large weight difference between the two lines. The main difference between the two lines thus lay in the amount of food consumed.

Respiratory quotients were similar in the two lines although the adult mice of each line generally had a lower R.Q. than the younger mice. Food intake in growing animals will far exceed maintenance requirements. Dewar & Newton (1948*b*) have shown that if this occurs the R.Q. increases in proportion to the food intake. Either carbohydrate is preferred as a source of energy and fat is stored, or the same proportions are burnt and the excess carbohydrate converted to fat and stored along with the corresponding excess of ingested fat.

The energy expenditure of *NL* mice was greater than that of *NS* mice at all ages. This is to be expected since increased size is associated with increased maintenance costs. But when animals of the same weight were compared, energy expenditure of *NL* mice was similar to that of *NS* mice. The greater growth-rate of large mice may have caused an increase in their energy metabolism since energy metabolism and growth-rate are known to be positively correlated (Brody, 1945). A positive correlation between energy metabolism and growth rate was also found in the present work when metabolism was expressed per $W^{0.73}$.

Values were thus high in the large line during the period of most rapid growth, whereas in the small line they were generally lower and usually correlated with the weight change during the experimental period. When energy expenditure per unit body weight was expressed against age, however, values for *NS* mice were higher than those of *NL* mice. But this measurement is not a true indication of a higher level of energy expenditure in *NS* mice. The *NL* mice must have weighed the same as *NS* mice at an earlier age, and, as shown above, energy expenditure of large mice was similar to that of small mice of the same body weight. The higher energy expenditure per unit body weight with increasing age in small mice must be due to the greater heat loss from the relatively larger surface of smaller animals rather than to an increase in energy metabolism. In contrast with this observation, Palmer *et al.* (1946) found that a strain of rats selected for low efficiency of gain had significantly higher energy requirements per unit of body weight than a strain selected for high efficiency of gain, even when animals of the same weight were compared.

While activity need be neither a direct cause nor in any way related to the size of the animal, changes in body size are sometimes associated with changes in activity levels. For example, in hereditary obese mice activity is reduced almost to nil (Mayer, 1955). But there was no evidence in the present experiments that activity levels determined or restricted the rate of growth in either line. Indeed, activity levels of *NS* mice were usually lower than those of *NL* mice, which indicates that small size was not a result of excessive energy costs due to increased activity. Furthermore, it seems probable that under normal conditions any temporary increase in activity, such as that found in *NL* mice immediately after weaning, is generally offset by an increase in food intake so that the growth-rate is unaffected.

The reduced growth-rate of small mice is obviously not due to an increase in energy costs such as that associated with excessive activity or hyper-thyroidism. Confirmatory evidence of this comes from histological studies of the thyroids of *NL* and *NS* mice. Hypertrophy of the epithelial cells and loss of colloid were not evident in the thyroid of *NS* mice; their thyroid appeared to be normal in all respects and very similar to those of *NL* mice. In addition, studies on the uptake of I^{131} into the thyroids of *NL* and *NS* mice have shown that uptake was higher in *NL* mice (Edwards, unpublished).

Neither was small body size associated with a depressed metabolic rate, a low body temperature, and a decreased activity as in pituitary dwarfs (Benedict &

Lee, 1936; Schonholtz & Osborn, 1949). *NS* mice are phenotypically unlike pituitary dwarfs and their metabolic rate was not depressed. Moreover, acidophilic cells of the anterior pituitary are largely absent in pituitary dwarfs (e.g. Elftman & Wegelius, 1959) but plentiful in *NS* mice. Nevertheless, in comparison with *NL* mice, *NS* mice were evidently deficient in pituitary growth hormone or some other fundamental growth stimulus as judged by the lower nitrogen balances.

Growth will only occur if total energy intake exceeds energy output. But as far as is known, intake is a factor determining growth only when too little food is eaten. Though little is known of the mechanisms regulating food intake, obesity has been shown to be associated with an increased appetite in Yellow mice (Dickerson & Gowen, 1947) and in mice with 'hypothalamic obesity' (Mayer, 1955). In the present study, inherent differences in growth-rate between the selected lines could not be attributed to basic changes in energy metabolism increasing or reducing the amount of food available for growth purposes.

SUMMARY

The efficiency of food utilization, the digestibility of foodstuffs, energy metabolism, and body activity have been studied in three lines of mice, one selected for large, another for small body size, and a third, control, line.

The gross efficiency of food utilization was highest in the large line, intermediate in the control line and lowest in the small line between 21 and approximately 35 days of age. During this period, gross efficiency declined in the large and control lines with increasing size and decreasing growth-rate, presumably due to an increase in maintenance costs in comparison with the weight gained. In the small line, the efficiency of food utilization increased up to 35 days of age but declined thereafter. The energetic efficiency (measured in Calories) was higher in the large than in the small line up to 4 weeks of age, i.e. when the growth-rate was high, and after 6 weeks of age, when fat was being deposited at an increased rate.

The increased efficiency of large mice was not entirely associated with a greater proportion of the ingested food being absorbed from the gut. Large mice absorbed a greater proportion of protein, though the difference was not sufficient to account for the large weight difference between the large and small lines.

The energy expenditure of mice of the large line was greater than that of the small line at all ages and similar for the same body weights. The reduced growth-rate of small mice was not due to abnormally high or low energy costs. There was no evidence that body activity determined or restricted the rate of growth in either line.

Mice selected for small size were phenotypically unlike pituitary dwarf mice, although the low nitrogen retention during the growing-period indicated a deficiency of some growth stimulus.

I should like to thank Dr A. D. Dewar both for the use of his apparatus and for his help and advice during this work. I should also like to thank Dr R. G. Edwards and Dr D. Naismith for their helpful criticisms in the preparation of this manuscript.

REFERENCES

- BENEDICT, F. G. & LEE, R. C. (1936). La production de chaleur de la souris. Etude de plusieurs races de souris. *Ann. Physiol. Physicochim. biol.* **12**, 983-1064.
- BRODY, S. (1945). *Bioenergetics and Growth*. New York: Reinhold Publishing Corporation.
- DEWAR, A. D. & NEWTON, W. H. (1948a). The determination of total metabolism in the mouse. *Brit. J. Nutrit.* **2**, 123-141.
- DEWAR, A. D. & NEWTON, W. H. (1948b). The relationship between food intake and respiratory quotient in mice. *Brit. J. Nutrit.* **2**, 142-145.
- DICKERSON, G. E. (1947). Composition of hog carcasses as influenced by heritable differences in rate and economy of gain. *Res. Bull. Ia agric. Exp. Sta.* no. 354, 489-524 (B).
- DICKERSON, G. E. & GRIMES, J. C. (1947). Effectiveness of selection for efficiency of gain in Duroc swine. *J. Anim. Sci.* **6**, 265-287.
- DICKERSON, G. E. & GOWEN, J. W. (1947). Hereditary obesity and efficiency of food utilisation in mice. *Science*, **105**, 496-498.
- ELFTMAN, H. & WEGELIUS, O. (1959). Anterior pituitary cytology of the dwarf mouse. *Anat. Rec.* **135**, 43-47.
- FALCONER, D. S. (1953). Selection for large and small size in mice. *J. Genet.* **51**, 470-501.
- FOWLER, R. E. (1958). The growth and carcass composition of strains of mice selected for large and small body size. *J. agric. Sci.* **51**, 137-148.
- FOWLER, R. E. & EDWARDS, R. G. (1960). The fertility of mice selected for large or small body size. *Genet. Res., Camb.*, **1**, 393-407.
- GOODALE, H. D. (1938). A study of the inheritance of body weight in the albino mouse by selection. *J. Hered.* **29**, 101-112.
- HALDANE, J. (1892). A new form of apparatus for measuring the respiratory exchange of animals. *J. Physiol.* **13**, 419-430.
- MACARTHUR, J. N. (1944). Genetics of body size and related characters. I. Selecting small and large races of the laboratory mouse. *Amer. Nat.* **78**, 142-157.
- MAYER, J. (1955). Mechanism of regulation of food intake and multiple etiology of obesity. *Voeding*, **16**, 62-88.
- MORRIS, H. P., PALMER, L. S. & KENNEDY, C. (1933). An experimental study of inheritance as a factor influencing food utilisation in the rat. *Tech. Bull. Minn. Agric. Exp. Sta.* no. 92, 56 pp.
- PALMER, L. S., KENNEDY, C., CALVERLEY, C. E., LOHN, C. & WESWIG, P. H. (1946). Genetic differences in the biochemistry and physiology influencing food utilization for growth in rats. *Tech. Bull. Minn. agric. Exp. Sta.* no. 176, 54 pp.
- SCHONHOLZ, D. H. & OSBORN, C. M. (1949). Temperature studies in dwarf mice. *Anat. Rec.* **105**, 605 (Abstr.).
- WIDDOWSON, E. M. (1955). Assessment of energy value of human foods. *Proc. Nutr. Soc.* **14**, 142-154.