

## Genetic and phenotypic relationships between ovulation rate and body weight in the mouse

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### SUMMARY

The genetic and phenotypic regressions and correlations between ovulation rate and body weight were examined in a random bred strain (Q) of laboratory mice during the course of three experiments. These experiments were (1) a sib analysis; (2) selection for natural and induced primiparous ovulation rate; and (3) replicated selection for 6-week weight. The following results were obtained:

(a) The genetic correlations between body weight and natural and induced ovulation rate were positive, and approximately equal to 0.4 and 0.6 respectively.

(b) The genetic regressions of natural and of induced ovulation rate on body weight were approximately 0.4 and 0.9 eggs per gram respectively.

(c) The genetic regressions of body weight on natural and on induced ovulation rate were approximately 0.5 and 0.25 g per egg respectively.

(d) The phenotypic correlation between natural ovulation rate and body weight was approximately 0.4 and the corresponding regression of ovulation rate on body weight approximately 0.4 eggs per gram.

(e) The phenotypic correlation between induced ovulation rate and body weight declined from 0.4 at 6 weeks of age to zero at the time of scoring, the corresponding regressions of ovulation rate on body weight declining from 0.1 eggs per gram to zero.

It was concluded that natural ovulation rate itself, and both its components (FSH activity and ovarian sensitivity) are positively genetically correlated with body weight. Furthermore, the observation that large mice shed at least as many eggs as small ones in response to the same dose of PMS showed that the response was more closely related to the absolute dose than to the resultant concentration.

### 1. INTRODUCTION

The complex relationships between body weight, litter size and fitness in the mouse have been the subject of many discussions. Both body weight and litter size can be readily changed by selection, reported first by Goodale (1938) and Falconer (1960*a*) respectively, and additive genetic variation in these two traits has invariably been found in outbred populations of mice. In addition to demonstrating the presence of genetic variation, the results of selection experiments

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have also indicated that the two traits are not under independent genetic control, but have led to conflicting conclusions about the nature of the relationship between them. On the one hand, selection for body weight has always led to changes in litter size in the same direction as that of selection, but on the other, when the change in body weight was examined following selection for litter size (Falconer, 1960*a*), it was found that body weight had increased following selection for both high and low litter size. However, when litter size is considered in terms of its components—ovulation rate and embryonic mortality—a much clearer picture emerges. Whenever body weight has been changed by selection, either directly or as a correlated response, ovulation rate has been found to change in the same direction. This relationship was first reported many years ago (MacArthur, 1944) but the magnitude of the correlation has not been estimated.

The first object of the work described here was to estimate the magnitude of the genetic correlation between ovulation rate and body weight in an outbred strain of mice. This was done in two ways, by estimating the components of variance and covariance in a half-sib analysis, and by examining the changes in body weight following two-way selection for ovulation rate and vice versa.

Ovulation rate can not only be considered as a component of litter size, but may also be considered in terms of its own components—the activity of circulating follicle-stimulating hormone (FSH), and the sensitivity of the ovary to this hormone. When the correlated changes in ovulation rate have been analysed in terms of these components, it has been found that when the change has followed selection for body weight, most of the change in ovulation rate has been due to changes in FSH activity (Fowler & Edwards, 1960; Edwards, 1962), whereas changes in ovulation rate following selection for litter size were mainly due to ovarian sensitivity (McLaren, 1962)—even though these changes were also accompanied by changes in body weight. The second object of the present study was to compare the genetic correlation between ovulation rate and body weight with that between ovarian sensitivity and body weight. Ovarian sensitivity was measured as the number of eggs shed in response to exogenous gonadotrophins (the induced ovulation rate); and the genetic correlation between body weight and ovarian sensitivity was estimated by recording the changes in body weight following two way selection for induced ovulation rate.

The phenotypic correlation between body weight and ovulation rate was also examined in the mice used for the half-sib analysis and at different stages during the selection programmes.

## 2. MATERIALS AND METHODS

This investigation was made possible by the use of mice from experiments which were primarily designed for other purposes. These were: (1) a study of growth (Monteiro & Falconer, 1966); (2) a study of ovulation rate (Land & Falconer, 1969); and (3) a further study of growth (Falconer, unpublished). The first incorporated a sib analysis, the second two way selection for both natural and

induced ovulation rate, and the third replicated two way selection for body weight. These experiments are described in more detail below.

The stock of mice used for all experiments was the genetically heterogeneous Q-strain, the background of which is described by Land & Falconer (1969).

#### *Experiment 1. Sib analysis*

Seventy-one males were each mated to three females, providing groups of full and half-sib offspring. Females from each group were obtained and their natural ovulation rate scored when they were between 6 and 8 weeks of age (Land & Falconer, 1969). All females were weighed at 6 weeks of age, and on the day that their ovulation rate was scored.

The components of variance of ovulation rate and body weight and the covariance between them were calculated, and the results are given in Table 1.

#### *Experiment 2. Selection for ovulation rate*

Four selected lines were established, and maintained together with an unselected control line (Land & Falconer, 1969). Each line was maintained by eight pair matings with minimal inbreeding. Natural ovulation rate was scored as the

Table 1. *Components of variance of ovulation rate and body weight at 6 weeks of age and at the time of scoring, and the covariance between ovulation rate and the two body weights*

Source	d.f.	Composition*	Component of variance			Covariance between ovulation rate and body weight at	
			Ovulation rate	Body weight		6 weeks	Scoring
				6 weeks	Scoring	6 weeks	Scoring
Between sires	70	$\frac{1}{4}A$	0.305	0.302	0.482	0.138	0.127
Between dams							
within sires	119	$\frac{1}{4}A + \frac{1}{4}D + Ec$	1.219	3.410	3.704	1.582	1.587
Within dam							
progenies	368	$\frac{1}{2}D + \frac{3}{4}D + Ew$	3.901	2.325	2.947	0.949	1.144
Total			5.425	6.003	7.113	—	—

\* A = additive genetic; Ew = environmental within full-sib families; Ec = environmental common to full-sibs; D = dominance.

Variance and covariance due to epistatic interactions is assumed to be negligible.

number of eggs shed at natural oestrus. Induced ovulation rate was scored as the number of eggs shed in response to treatment with 4 i.u. pregnant mares' serum (PMS) at 17.00 h on the day after weaning, followed by 3 i.u. human chorionic gonadotrophin (HCG) at 12.00 h 2 days later. The hormones used to induce ovulation were 'Gestyl' (Organon Ltd.) PMS and 'Pregnyl' (Organon Ltd.) HCG. The ovulation rate was scored after the females had had their first litter of young weaned from them. The ovulation rate is therefore that of primiparous females, and

in this respect differed from the ovulation rate scored in the sib analysis which was that of virgin, or nulliparous, females.

The mean ovulation rate and body weight of each line was estimated each generation as the mean of family means. The body weight of each female was recorded at 3 and 6 weeks of age, and at the time of scoring; these are presented graphically in Fig. 1. It can be seen that there is very little difference between the mean 3-week weights of any of the lines. Differences can, however, be seen between the mean weights of the 5 lines at 6 weeks of age and at the time of scoring, the differences at 6 weeks being in the same direction but smaller than those at the

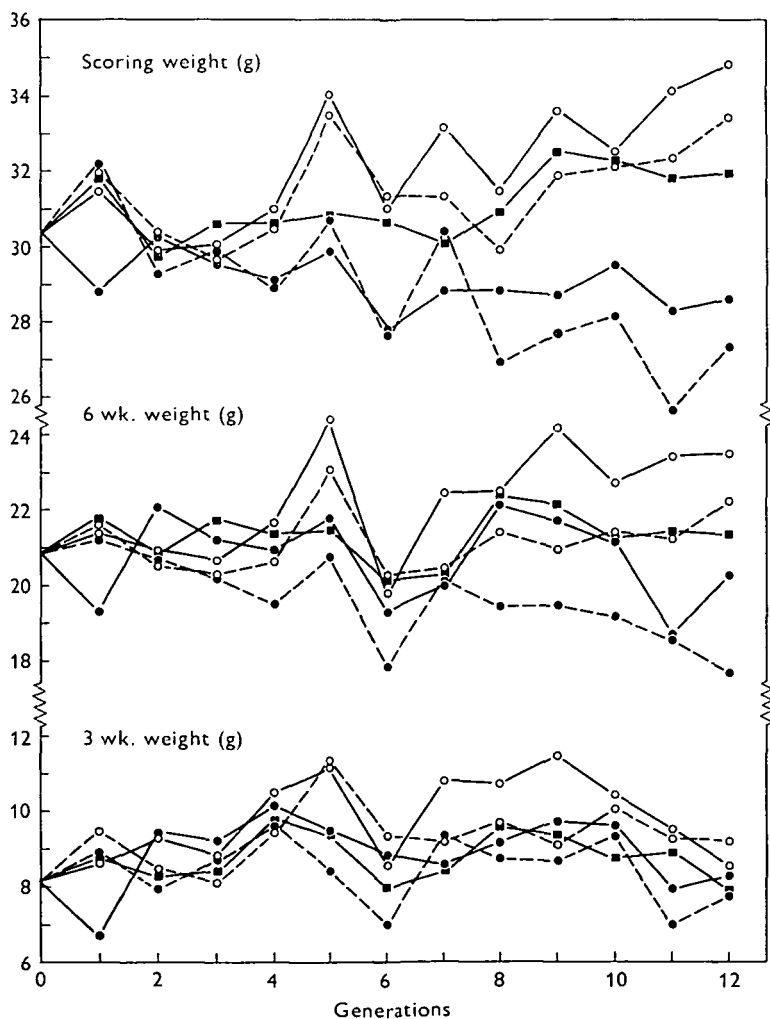


Fig. 1. The body weight of each of the four selected lines and the control line in each generation of selection at 3 and 6 weeks of age and at the time of scoring. The lines selected for natural ovulation rate are represented by solid lines (—) and induced ovulation by broken lines (---). High line means are represented by open circles (O), low line means by solid circle (●). The control line is represented by a solid line and solid squares (■—■).

time of scoring. The divergence in body weight at 6 weeks of age and at the time of scoring between the high and low natural and the high and low induced lines are illustrated in Fig. 2, together with the divergence in ovulation rate. The correlated response of 6-week and scoring weight after twelve generations of selection were estimated from the regression of the response on the selection differential in eggs to be 2.79 and 5.39 g respectively for the natural lines, and 2.90 and 5.20 g respectively for the induced lines.

The results of this experiment which are relevant to the calculation of the genetic and phenotypic relationships between body weight and ovulation rate are summarized in Table 2.

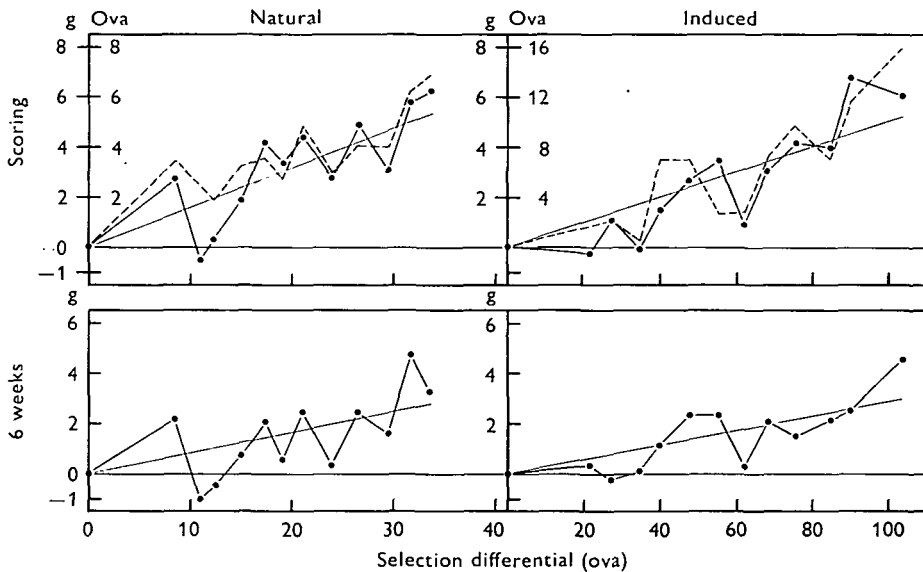


Fig. 2. The divergence in body weight (●—●) at 6 weeks of age and at the time of scoring between the lines selected for high and low natural ovulation rate and high and low induced ovulation rate; plotted against the cumulative selection differential in eggs. The regressions of the divergence in body weight on cumulative selection differential (—) and the actual divergences in eggs ( - - ) are also given.

### Experiment 3. Selection for body weight

A replicated body weight selection experiment was started by Professor D. S. Falconer in 1963. Selection was applied to body weight at 6 weeks of age, the heaviest individuals were selected in the large lines, the lightest in the small lines. Each pair of lines, together with their control was replicated six times, making 18 lines in all. Selection was carried out within families and each line was maintained by eight matings in each generation, with minimal inbreeding. This experiment is still in progress, and the parameters of body weight quoted in this paper are the results of intermediate calculations generously provided by Professor Falconer.

Table 2. *Summary of the results of selection for natural and induced primiparous ovulation rate*

Parameter	Estimate	Source
Response to selection for natural primiparous ovulation rate	6.89 eggs	2
Response to selection for induced primiparous ovulation rate	15.89 eggs	2
Correlated response of 6-week weight to selection for natural primiparous ovulation rate	2.79 g	1
Correlated response of 6-week weight to selection for induced primiparous ovulation rate	2.90 g	1
Correlated response of scoring weight to selection for natural primiparous ovulation rate	5.39 g	1
Correlated response of scoring weight to selection for induced primiparous ovulation rate	5.20 g	1
Intensity of selection for natural primiparous ovulation rate ( <i>i</i> ) cumulated over all generations	13.38 $\sigma$	2
Intensity of selection for induced primiparous ovulation rate ( <i>i</i> ) cumulated over all generations	12.58 ( <i>i</i> )	2
Square root of within-family heritability of natural primiparous ovulation rate ( <i>h</i> )	0.424	2
Square root of within family heritability of induced primiparous ovulation rate ( <i>h</i> )	0.332	2
Within-family phenotypic variance of bodyweight at the time of scoring	6.841 g <sup>2</sup>	1
Within-family additive genetic variance of natural primiparous ovulation rate	1.134 eggs <sup>2</sup>	2
Within-family additive genetic variance of induced primiparous ovulation rate	7.001 eggs <sup>2</sup>	2

1, data given in the present paper; 2, Land & Falconer (1969).

The ovulation rates of females discarded from all 18 lines were scored after five generations of selection. The animals from the selection lines were of course selected from the total number of available animals on the basis of their phenotypic body weight. The mean ovulation rate for each line was therefore corrected to that which it would have been if all individuals had been scored. This was done as follows: the regression of ovulation rate on body weight was first calculated for each line; analysis of covariance indicated that the regression coefficients did not differ significantly within the control or small lines, but that significant differences were present between the six large lines ( $P < 0.05$ ). The individual regression coefficients were therefore used to correct the ovulation rates of the large lines, the mean for all lines being the mean of corrected means. In the control and small lines the best estimate of the regression coefficient within each set of lines was used to correct the mean of uncorrected means.

Variation between replicates has been ignored for the purpose of the genetic analyses, and the direct and correlated responses were assessed in terms of the divergence between the means of the high and low lines. Each line was given equal weighting. The mean ovulation rate, 6-week weight before and after selection and the regression of body weight on 6-week weight in each of the lines are given

in Table 3, together with the corrected ovulation rates. The divergence of body weight was 6.0 g and the corrected divergence of ovulation rate 2.9 eggs.

In addition to the results given above, the square root of the within family heritability of 6-week weight and the within family additive genetic standard deviation of 6-week weight were also needed. These were calculated to be 0.602 and 1.163 g respectively.

The genetic correlations and regressions presented in the next section were calculated from the results of these experiments by the methods described by Falconer (1960*b*).

Table 3. *The mean body weights and ovulation rates of the body weight selection lines after selection from generation 5 together with the body weights before selection, the regressions of ovulation rate on body weight, and the corrected ovulation rates. The means are expressed as the mean of line means, and the regression coefficients were computed from the pooled sums of squares and cross-products*

Lines	Body weight before selection (g)	Body weight after selection (g)	Ovulation rate after selection (eggs)	Regression of ovulation rate on body weight	Corrected ovulation rate (eggs)
Large	24.3	23.8	14.8	0.34*	14.9
Control	20.8	20.5	13.2	0.39	13.3
Small	18.3	18.7	12.2	0.43	12.0

\* The differences between individual regressions were statistically significant ( $P < 0.05$ ).

### 3. RESULTS

#### (1) *The genetic correlation between body weight and ovulation rate*

All individuals were killed at the time of scoring, and consequently although the body weight of an individual could be recorded several times during its life, the ovulation rate of that individual could only be recorded once. It is therefore possible to examine the relationship between ovulation rate and body weight at various times up to and including the time of scoring.

The genetic correlation between the natural ovulation rate of nulliparous females at 8 weeks of age and their body weight at the time of scoring could only be calculated from the sib analysis (Expt 1), and was found to be  $0.33 \pm 0.58$ . The correlation between the same ovulation rate and body weight at 6 weeks of age can, however, be calculated from both Expt 1 and the body weight selection experiment (Expt 3). These experiments give estimates of  $0.45 \pm 0.59$  and 0.87 respectively. Unfortunately it is not possible to calculate the standard error of the realized genetic correlation, and hence there is no logical way of pooling these estimates.

In addition to the results obtained directly from the ovulation rate selection experiment (Expt 2) summarized in Table 2, the genetic correlation between primiparous ovulation rate and body weight at the time of scoring is also dependent upon the heritability of body weight at the time of scoring, which has not

been estimated. Monteiro & Falconer (1966), however, observed that there is little variation in the heritability of body weight between 6 and 8 weeks of age, and consequently the heritability of primiparous scoring weight has been assumed to be the same as that of 6-week weight. The genetic correlations between natural primiparous ovulation rate and body weight at the time of scoring and at 6 weeks of age were calculated and found to be 0.60 and 0.42 respectively. These estimates suggest that the genetic correlation between body weight and ovulation rate may decline either with parity, or with age at the time of scoring. In general, however, it is possible to conclude from this section that the genetic correlation between body weight and natural ovulation rate is positive, and is probably greater than 0.4.

The correlation between ovulation rate and body weight within full sib families was calculated from the sib analysis to be 0.86 and 0.85 at 6 weeks and at the time of scoring, compared to 0.45 and 0.33 for the estimates of the additive genetic correlations. The higher estimates within full sib families could be due to non-additive genetic causes, but are much more likely to be due to the effect of the common environment within full sib families (i.e. maternal effects).

The genetic correlations between induced primiparous ovulation rate and body weight were calculated to be 0.78 and 0.58 at the time of scoring and 6 weeks of age respectively. The genetic correlation between body weight and ovarian sensitivity may therefore be concluded to be positive, and of a similar order of magnitude to that between body weight and ovulation rate itself.

### (2) *The genetic regression of ovulation rate on body weight*

Just as it is possible to calculate the genetic correlation between body weight and ovulation rate from the results of these experiments it is also possible to calculate the genetic change in ovulation rate which would be expected to follow, or which has followed, a unit genetic change in body weight, that is the genetic regression of ovulation rate on body weight.

The genetic regression of natural nulliparous ovulation rate on body weight at 6 weeks of age and at the time of scoring was calculated from the genetic correlation multiplied by the ratio of the additive genetic standard deviations (i.e.  $r_{Ao,w} \times \sigma_{Ao}/\sigma_{Aw}$ ). The regression was estimated from the results of Expt 1 to be 0.45 eggs per gram at 6 weeks of age, and 0.26 eggs per gram at the time of scoring.

The realized genetic regression of natural nulliparous ovulation rate of 6-week weight was calculated from Expt 3 to be 0.48 eggs per gram, which is very close to that predicted above.

Similar parameters were estimated from Expt 2 for natural and induced primiparous ovulation rate. The genetic regressions of primiparous natural ovulation rate on body weight at 6 weeks of age and at the time of scoring were estimated to be 0.34 and 0.35 eggs per gram respectively. Likewise, the genetic regressions of primiparous induced ovulation rate on body weight at 6 weeks of age and at the time of scoring were estimated to be 0.93 and 0.91 eggs per gram respectively.



(3) *The genetic regression of body weight on ovulation rate*

The genetic regression of body weight on ovulation rate is an estimate of the genetic change in body weight which would be expected from a unit genetic change in ovulation rate. As in the case of the previous two parameters its magnitude is dependent upon the additive genetic variances of each of the two characters and the genetic covariance between them.

Expt 1 yielded estimates of 0.45 and 0.42 g per egg for the regression of body weight at 6 weeks and at the time of scoring on natural nulliparous ovulation rate. The corresponding estimate from the body weight selection experiment for 6-week weight was 0.53 g per egg. Again, the agreement between these two experiments is very close.

The genetic regression of body weight on primiparous ovulation rate was obtained from Expt 2, by multiplying the regression of ovulation rate on body weight by the ratio of the additive variances ( $b_{\Delta w.o} = b_{\Delta o.w} \times \sigma_{\Delta w}^2 / \sigma_{\Delta o}^2$ ). The regressions of body weight at 6 weeks of age and at the time of scoring on natural primiparous ovulation rate were 0.40 and 0.78 g per egg respectively, which are of the same order of magnitude as those for nulliparous ovulation rate. The corresponding regressions for induced primiparous ovulation rate were 0.18 and 0.33 respectively, the low values being a reflexion of the high variation in induced ovulation rate.

(4) *The phenotypic relationships between body weight and ovulation rate*

The phenotypic correlations between natural nulliparous ovulation rate and body weight at 6 weeks of age and at the time of scoring were both estimated from Expt 1 to be 0.46. The regression of ovulation rate on body weight at 6 weeks of age and at the time of scoring being 0.44 and 0.40 eggs per gram respectively.

Table 4. *The phenotypic correlation ( $r$ ) between body weight at 6 weeks of age and at the time of scoring and natural and induced primiparous ovulation rate, together with the regressions of ovulation rate on body weight ( $b$ )*

Primiparous ovulation rate	Body weight			
	6 weeks		Scoring	
	$r$	$b$	$r$	$b$
Natural	0.33	0.41	0.41	0.39
Induced	0.11	0.38	0.00	0.00

All relationships greater than zero are significantly different from zero ( $P < 0.05$ ).

The corresponding parameters were calculated from Expt 2 and are summarized in Table 4. The regression of the number of eggs shed at natural oestrus on body weight is 0.4 eggs per gram, which is similar to that for nulliparous females. In addition, the correlation between body weight and natural primiparous ovulation

rate (0.3 to 0.4) is similar to that for nulliparous females. The correlations between primiparous induced ovulation rate and body weight and the regressions of induced ovulation rate on body weight are lower than their natural counterpart. However, there is no indication of a negative relationship between ovarian sensitivity and body weight, showing that it is the absolute dose of PMS which determines the response, not the concentration.

The above estimates of the relationships between body weight and primiparous ovulation rate are the pooled estimates over the course of selection, but the data were also examined for possible changes in these relationships during the course of selection. The differences between each parameter in the high and the low lines were regressed on the generation number (the regressions being constrained to pass through zero). In this way, consistent changes could be differentiated from random fluctuations. None of the regressions so calculated were significantly different from zero, nor was there any indication of a uniform change in these parameters during the course of selection. It is therefore reasonable to assume that the changes in gene frequency during selection have not affected the phenotypic relationships between body weight and ovulation rate.

The phenotypic regressions of ovulation rate and body weight in the body weight selection lines have already been used to correct the mean ovulation rates of the lines to that which they would have been before selection. In general the relationships are positive and confirm the data presented earlier in the section, in addition, however, they also indicate that the phenotypic relationships differ between the lines. Part of the differences between the regression coefficients are related to differences in body weight. This was demonstrated by regressing the regression coefficient of ovulation rate on body weight within a line on the mean body weight of that line. These regressions were  $-0.15$ ,  $-0.20$  and  $-0.08$  in the large, control and small lines respectively. Although each of these individual regressions and the pooled estimate are not significantly different from zero ( $P > 0.05$ ), the large, control, small and pooled regressions remove 66.3, 49.5, 6.9 and 43.3% of the total variation in the regression coefficients of ovulation rate on body weight in each of the four groups respectively.

#### 4. DISCUSSION

All the analyses presented show that there is a positive genetic relationship between body weight and ovulation rate in the mouse; and between body weight and ovarian sensitivity—as measured by the response to PMS. Furthermore, the change in the body weight of the lines selected for natural ovulation rate (5.3 g) is greater than would have been expected if the correlation between body weight and ovulation rate was only mediated via ovarian sensitivity (1.5 g). Both components of ovulation rate (FSH activity and ovarian sensitivity) must therefore be genetically correlated with body weight. This demonstration of the correlation between body weight and the two components of ovulation rate is compatible with the changes in FSH activity following selection for body weight (Fowler & Edwards,

1960; Edwards, 1962), and the changes in ovarian sensitivity and body weight following selection for litter size (McLaren, 1962).

The analyses of the phenotypic relationships between body weight and ovulation rate all indicate that the regression of natural ovulation rate on body weight at the time of scoring is about 0.4 eggs per gram, and that the regression of induced ovulation rate on body weight at the time of scoring is zero. The later result is of particular interest as it shows that larger females shed a similar number of eggs to their smaller counterparts in response to a lower concentration of exogenous gonadotrophin. This result confirms the decision to select for ovarian sensitivity on the basis of the response to a standard dose of PMS. If the response to a standard concentration had been chosen—as has been done by most workers in the field—the dose of PMS and the body weight of the recipient would have been fully confounded, and the response would have been biased in favour of large animals. In this situation it would have been impossible to separate the effects of body weight and dose of PMS on the number of eggs shed. The estimate of 0.4 for the phenotypic regression of natural ovulation rate on body weight is similar to one of the estimates of Fowler & Edwards (1960), i.e. 0.49, but higher than the estimates from the other four lines they examined, none of which were significantly different from zero. One possible reason for this discrepancy is that in the present study the range in age of females at the time of scoring was rarely more than 2 weeks whereas in the earlier work, age at scoring varied between 6 and 25 weeks of age.

The genetic regression of ovulation rate on body weight calculated from the body weight selection experiment is similar to those predicted from the sib analysis and the ovulation rate selection experiment. After five generations of selection however the phenotypic regression is declining in the lines with higher body weights. It is possible therefore that some of the alleles which produce a positive phenotypic correlation between these two traits may be becoming fixed in the larger lines.

The consistency of the results of this and earlier studies leads to the conclusion that in the mouse, natural selection has failed to fix some genes which affect body weight and ovulation rate in the same direction.

One reason for the maintenance of this segregation can be deduced from the results of earlier experiments. Selection for both high and low litter size (Falconer, 1960*a*) led to increases in body weight, ovulation rate and embryonic mortality; two way selection for body weight led to changes in ovulation rate and embryonic mortality in the same direction as selection (Fowler & Edwards, 1962); and selection for natural ovulation rate (Land & Falconer, 1969) led to changes in body weight without any changes in litter size, changes in embryonic mortality compensating for the differences. In each case the three traits, body weight, ovulation rate and embryonic mortality were all positively genetically correlated in the mouse populations concerned. It is possible therefore that the segregation of the alleles affecting body weight and ovulation rate is maintained in the populations through the pleiotropic deleterious effects of these alleles on embryonic mortality, and that the intermediate optima for body weight and ovulation rate are arte-

facts resulting from the antagonistic action of natural selection on the traits themselves or those genetically correlated with them. This system may be regarded as an example of the maintenance of genetic variation in a population by the counteracting forces of natural selection on different end-products of gene action.

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#### REFERENCES

- EDWARDS, R. G. (1962). The size and endocrine activity of the pituitary in mice selected for large or small body size. *Genet. Res.* **3**, 428–443.
- FALCONER, D. S. (1960*a*). The genetics of litter size in mice. *J. Cell. Comp. Physiol.* **56**, (suppl. 1), 153–167.
- FALCONER, D. S. (1960*b*). *Introduction to Quantitative Genetics*. Edinburgh: Oliver and Boyd.
- FOWLER, R. E. & EDWARDS, R. G. (1960). The fertility of mice selected for large or small body size. *Genet. Res.* **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.
- LAND, R. B. & FALCONER, D. S. (1969). Genetic studies of ovulation rate in the mouse. *Genet. Res.* **13**, 25–46.
- MACARTHUR, J. W. (1944). Genetics of body size and related characters. II. Satellite characters associated with body size in mice. *Am. Nat.* **78**, 224–237.
- MCLAREN, A. (1962). The relation between natural fecundity and response to follicle-stimulating hormone. *J. Endocrin.* **25**, 137–144.
- MONTEIRO, L. S. & FALCONER, D. S. (1966). Compensatory growth and sexual maturity in mice. *Anim. Prod.* **8**, 179–192.