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Selection for fertility in mice using different methods of litter size manipulation

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Summary. A short-term selection experiment for increasing the first-day litter size (LS 1) and 28-day litter weight (LW28) was conducted with three populations of mice over 8 generations. Different methods of litter size manipulation were used for the populations – in S the litter size was standardized to 8 (4 ♂♂, 4 ♀♀) on the first day, in LA it was adjusted to the average size of all litters born on the same day and NL had the natural litter size. To eliminate temporary environmental effects, a control population was kept in each case. The selection results per generation were, for LS 1 b=0.30 (S, NL) and 0.20 (LA), and for LW28 b=5.62 g (S), 5.26 g (NL), and 4.32 g (LA). The heritability obtained was between 0.18 and 0.13 for LS 1 and from 0.42 to 0.12 for LW28. The populations differed in the correlated responses for body weight parameters (litter weight gain). The implantation rate increased in populations S and NL (b=0.19, 0.37), but not in population LA. Postnatal mortality went down (b=–0.07) and the dam's milk production rose (b=1.11 g) only in population LA. The estimated partial regression coefficient linking body weight at mating (BWM) for the dam and the daughter's litter size showed an effect on the litter size.

Key words: Mice – Selection experiments – Maternal effects litter size manipulation – Fertility

Introduction

Litter size standardization/balancing in multiparous animals is essential both from a genetic and practical point of view. Standardization eliminates postnatal maternal influences and thus reduces the negative relations between directly genetic and maternal-genetic effects. These negative genetic relations lead to reduced genetic variance and detract from the success of selecting for fertility in the first few generations (van der Steen 1983). This has led a number of works proposing the following as a result of direct and simulated selection experiments (Eisen et al. 1970; van der Steen 1983; Schüler 1985): (1) elimination/reduction of maternal effects; (2) use of combined selection criteria; (3) selection over several generations (long-term selection).

Litter size balancing is used in all breeding and production establishments with the principal aim of making the best possible use of housing/suckling capacity, of evening out individual body weights and the effects from gilts and sows, etc.

It was with these genetic and practical aspects in mind that an experiment was set up with laboratory mice to establish the effect that can be expected from different methods of litter size control on the direct and indirect success of selecting animals for fertility.

Materials and methods

The animals for selection came from an outbreeding line (Fzt: DU) of laboratory mice kept in a semi-barrier environment. Selection itself extended over eight generations, and the index used combined litter size on the first day of life of the first litter (LS 1) and the weight of the litter on the 28th day (LW28). The selection intensity was 40% and 2–3 animals of each sex were selected at random for the next generation from the litters giving the highest indices. Mating of full sibs and half sibs was prevented. Table 1 shows the scope of the experiment and the environmental conditions for the individual populations.

The following data were collected for all populations in a particular generation. Litter traits: size and weight on 1st, 10th and 21st day of life (LS 1, 10, 21; LW 1, 10, 21), losses before weaning (L 1–21), litter-weight on the 28th day (LW28, g), implantation rate (IR); body weight: litter weight after 42 and 63 days (LW42, 63, g), milk yield (g), weight gain (WG n_1-n_2, g), body weight at mating (63 days) (BWM, g).

All averages of data obtained for the populations used in the selection experiment were corrected by calculating differences between them and the averages found for the control populations, and testing took place within and between populations ($\alpha=0.05$). The direct and indirect results of selection were expressed as coefficients of heritability and as linear regression coefficients for population averages related to generation numbers (Schüler and Herrendörfer 1984). For these parameters we obtained 95% confidence intervals. For daughter-dam pairs we estimated partial linear regression coefficients for litter size and body weight.

Results

Direct selection results

Table 2 and Figs. 1 and 2 illustrate direct results as reflected in the selection index and its elements. Selection was successful in all three types of environment provided for litters. The elements which make up the selection index reacted differently compared to the populations used for selection. The best litter size increase was obtained under conditions of standardization, whereas litter size balancing was most successful in raising LW28, as can be seen from the figures.

Table 1. Experimental population

Population	n^a	Litter size manipulation
S (K)	50	control, litter size standardization[b]
S	80	selection, litter size standardization[b]
NS (K)	50	control, natural litter size
NS	80	selection, natural litter size
WA (K)	50	control, litter size balancing[c]
WA	80	selection, litter size balancing[c]

[a] No. of animal pairs
[b] Standardization to 8 (4 ♂♂, 4♀♀) on the first day
[c] Litter size was adjusted to the average size of all litters born on the same day

Correlated selection results

These differed due to different environmental conditions, as far as weight gain and fertility were concerned. The regression coefficients for growth/weight gain in the entire litter shown in Table 3 indicate a sig-

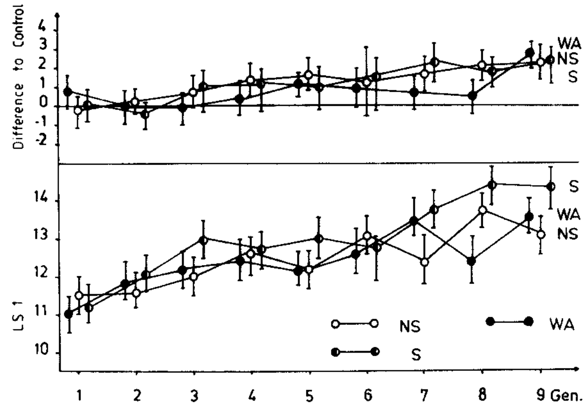

Fig. 1. Generation means with 95% confidence limits and difference of means to control populations in the parameter litter size of the index (LS 1)

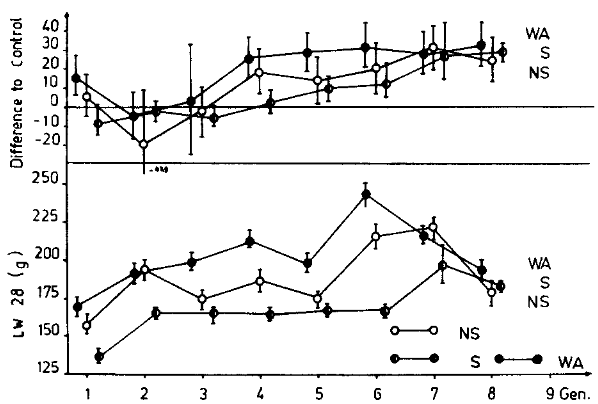

Fig. 2. Generation means with 95% confidence limits and difference of means to control population in the parameter litter weight of the index (LW28)

Table 2. Direct response to selection

Parameter	Population	ΔG^a	$b_{Gen}{}^b$	$h^{2\,c}$
Selection-index	S	73.71	19.4 (−3.5; 42.3)	0.62 (0.05; 1.18)
	NS	140.03	21.8 (−0.9; 44.5)	0.21 (−0.16; 0.59)
	WA	59.68	2.1 (−6.1; 10.3)	0.18 (−0.09; 0.45)
LS 1	S	3.10	0.30 (0.17; 0.43)	0.18 (0.08; 0.28)
	NS	1.64	0.30 (0.21; 0.39)	0.14 (0.05; 0.24)
	WA	2.62	0.20 (−0.01; 0.41)	0.13 (0.03; 0.22)
LW 28 (g)	S	44.33	5.62 (4.00; 7.25)	0.42 (0.01; 0.82)
	NS	20.90	5.26 (1.19; 9.34)	0.11 (−0.27; 0.48)
	WA	24.19	4.32 (0.69; 7.96)	0.12 (−0.32; 0.57)

[a] $\Delta G = \bar{x}_{9th\ Gen} - \bar{x}_{1st\ Gen}$
[b] Linear regression coefficient (b) of correlated generation means on the generation number with confidence interval
[c] Heritability – linear regression coefficient of the cumulative selection difference on the selection response with confidence interval

Table 3. Correlated response to selection in the parameters weight gain of the litter (g). Linear regression coefficients with 95% confidence limits

Parameter	Population		
	S	NS	WA
WG 0–10	1.18 (0.60; 1.77)	−0.32 (−0.94; 0.29)	0.85 (−0.01; 1.72)
WG 10–21	1.85 (1.29; 2.41)	0.96 (0.12; 1.80)	1.02 (−0.64; 2.68)
WG 21–28	1.99 (0.37; 3.41)	4.43 (1.51; 7.35)	2.66 (−0.23; 5.55)
WG 28–42	−1.52 (−4.08; 1.07)	2.69 (−1.38; 6.77)	3.93 (0.47; 7.39)
WG 42–63	−1.08 (−4.39; 2.24)	−2.18 (−7.47; 3.18)	−1.05 (−6.14; 4.04)
WG 0–28	5.57 (3.98; 7.17)	5.08 (1.58; 8.58)	2.50 (0.47; 4.54)
WG 21–24	0.65 (−2.26; 3.57)	7.32 (3.56; 11.10)	5.13 (1.32; 8.95)
milk yield (g)	−0.14 (−0.73; 0.40)	−0.14 (−0.73; 0.46)	1.11 (0.43; 1.80)

Table 4. Correlated response to selection in the parameters of fertility. Linear regression coefficients with 95% confidence limits

Parameter	Population		
	S	NS	WA
LS 10	–	0.18 (0.04; 0.32)	0.21 (0.04; 0.38)
LS 21	–	0.15 (0.02; 0.27)	0.22 (0.06; 0.38)
L 1–21	–	0.14 (0.03; 0.26)	−0.07 (−0.28; 0.14)
IR	0.19 (0.02; 0.35)	0.37 (0.23; 0.51)	0.12 (−0.12; 0.37)

nificant increase up to the age of 28 days under conditions of standardization and with natural litter size. Litter size balancing produced correlated selection results, especially after weaning. With litter size balancing alone, the selection strategy significantly raised the milk yields of the dams, by 1.11 g per generation. The milk yield was calculated in terms of weight gain using the litter size and weight at birth and at the age of 10 days. This is possible because the entire weight gain of the progeny is produced by the dam's milk yield up to that time. Selection had no effect on the weight gain between the 42nd and 63rd day.

Table 4 shows that the correlated selection results for litter size were higher with litter size balancing. At the same time, losses before weaning did not increase compared to natural litter sizes. Another element, the implantation rate, also illustrates that litter size balancing gave different correlated selection results.

Dam-daughter relations

For successive generations we determined the litter size and body weight data for mating dams and daughters. From these data partial linear regression coefficients were estimated to compare the performance of daughters and dams. The estimates obtained from the populations involved in selection ($n = 720$ dam-daughter pairs) show an effect as a result of selection. Pairs of 350 values were obtained for the control populations. The estimates contained in Table 5 illustrate the effect of selection and litter size control, with the regression coefficients indicating the amount of change in y if x_1 increases by one unit and x_2 is kept constant.

Discussion

With litter size standardization, the direct result of selection was significant growth rates of 0.3 animals at birth and a litter weight increase of 5.6 g per generation, equal to a heritability of 0.65 for the index, 0.18 for LS and 0.42 for LW28. With natural litter sizes and litter size balancing, significant heritability coefficients were estimated only for LS. The absolute selection results (ΔG) across all generations for LW28 are between 21 g and 24 g for natural and balanced litter sizes, compared with 44 g under conditions of standardization.

For LS both the heritability coefficients and the growth rates (b_{Gen}) achieved across the generations are in agreement with the results reported in other work (Hörstgen 1978; Eisen 1978; Durrant et al. 1980; Joakimsen and Baker 1977; Schüler 1976, 1985). On litter weight as a selection criterion, little is said in the literature. Thus Dalton and Bywater (1963) selected for litter weight on the 25th day and achieved an estimated heritability of 0.06 across 14 generations. Due to the small population size, however, these results are affected by inbreeding and drift. Baharin and Beilharz (1976) selected for WM42 in mice over 8 and 15 generations, but the estimated results from their experiment also suffer as a result of inbreeding and drift as only 10 pairs per generation were used. Eisen et al. (1970) have reported success in family selection for litter weight on the 12th day, achieving 0.11 ± 0.02 heritability, or an increase of 0.25 ± 0.04 g per generation. In the experiment, litter size was standardized to 6 animals on the 5th day (4 ♀♀, 2 ♂♂) and positive correlated selection results were obtained for BW42, BW56 and WG12–42.

Table 5. Partial linear regression coefficients between mother (m) and daughter (d). LS_m, BWM_m – parameters of the mother; LS_d, BWM_d – parameters of the daughter

Parameters			Selection populations			Control population		
Y	X_1	(X_2)	S	NS	WA	S (K)	NS (K)	WA (K)
LS_d	LS_m	BWM_d	0.08	0.02	0.07	0.04	0.10	0.14[a]
LS_d	BWM_d	LS_m	0.24[a]	0.23[a]	0.24[a]	0.23[a]	0.24[a]	0.14[a]
LS_d	LS_m	BWM_m	0.09	-0.05	0.10	0.07	0.06	0.15[a]
LS_d	BWM_m	LS_m	0.12[a]	0.18[a]	0.12[a]	0.00	0.001	0.01
BWM_d	BWM_m	LS_m	0.37[a]	0.58[a]	0.27[a]	0.30[a]	0.22[a]	0.38[a]
BWM_d	LS_m	BWM_m	0.09	-0.18[a]	0.13[a]	0.04	-0.34[a]	-0.002

[a] Significant regression

There was also a slightly positive partial correlation of 0.19 between LS on the one hand, and BW12 and BW56 (b = 0.69) on the other. In a previous selection experiment, the effects obtained had been characterized by different degrees of correlation for weight gain and reproductive fitness.

From the breeder's viewpoint, selection involving litter size balancing leads to a combined criterion of fitness (litter size and litter weight), which in turn gives the best direct and correlated selection results. The superiority of this selection strategy is based largely on the positive effect it has on postnatal losses and the dam's milk yield alike. Similar advantages have been reported by Seyer and Ritter (1982) for swine using as a selection criterion the litter weight on the 95th day of life. In multiparous species such as swine and mice, litter size manipulation in the form of standardization and balancing reduces or eliminates postnatal maternal effects. This is a major element in successful short-time selection for reproductive fitness. Litter size manipulation and selection have both changed the phenotypic relations between the dam and the daughter's litter size (LS_d) and body weight at the time of mating (BWM_d).

Partial standardized regression coefficients for mouse litter size standardization were calculated as early as 1955 (Falconer) and 1970 (Eisen). Both standardization to 8 animals on the first day, and litter size balancing to the average on the day of birth, reinforced the relation between the litter sizes (LS) of dam and daughter and reduced the negative relations between the dam's litter size and the daughter's body weight to zero. There was no effect on the relation between the daughter's litter size and the dam's body weight at the time of mating. Selection in the presence of these different litter sizes had an effect on all phenotypic relations in comparison with the controls, and the relations between the dam's and daughter's litter sizes, in particular, were reinforced. With litter size manipulation, a positive relation emerged between the body weight of the daughter and the litter size of the dam. There was also a positive relation between the daughter's litter size and the dam's body weight. This means that the selection favoured dams with large litters and a good rearing performance expressed in terms of weight gain. At the same time, these dams showed high body weight themselves when mated.

References

Baharin K, Beilharz RG (1978) Effects of selection for high litter weight on reproductive performance in mice. Pertanika 1:97–104

Dalton DC, Bywater TL (1963) The effect of selection for litter size and litter weight at weaning in mice maintained on two diets. Anim Prod 5:317–326

Durrant BS, Eisen EJ, Ulberg LC (1980) Ovulation rate, embryo survival and ovarian sensitivity to gonadotrophins in mice selected for litter size and body weight. J Reprod Fertil 59:329–339

Eisen EJ (1970) Maternal effects on litter size in mice. Can J Genet Cytol 12:209–216

Eisen EJ (1978) Realized selection response for body weight and litter size in mice. 14 Int Congr Genet Moscow. Contributed Paper Sessions Abstr Part 1, P 507

Eisen EJ, Legates JE, Robinson OW (1970) Selection for 12-day litter weight in mice. Genetics 64:511–532

Falconer DS (1955) Patterns of response in selection experiments with mice. Cold Spring Harbor Symp Quant Biol 20:178–196

Hörstgen G (1978) Modellversuch mit Mäusen zur genetischen Differenzierung von Zuchtlinien durch Selektion für quantitative Merkmale. Diss Georg-August Universität Göttingen

Joakimsen O, Baker RL (1977) Selection for litter size in mice. Acta Agric Scand 27:301–318

Schüler L (1985) Die Selektion auf Komponenten der Fruchtbarkeit unter den Bedingungen der Zyklussynchronisation bei der Labormaus. 1. Mitt. Die Ergebnisse der Selektion und der gestagenen Synchronisation. Arch Tierz 19:235–242

Schüler L (1985) Selection for fertility in mice – the selection plateau and how to overcome it. Theor Appl Genet 70:72–79

Schüler L, Herrendörfer G (1984) Schätzung genetischer Parameter. In: Genetische Probleme in der Tierzucht, Heft 2. Schriftenreihe des Forschungszentrums für Tierproduktion, Dummerstorf-Rostock

Seyer D, Ritter E (1982) Die Selektionswürdigkeit der 95-Tage-Wurfmasse beim Schwein. Arch Tierz 25:407–412

Van der Steen HAM (1983) Maternal and genetic influences on production and reproduction traits in pigs. Diss, Agricultural University Wageningen (The Netherlands)