The Inheritance of Jumping Activity in Reciprocal Cross of Two Subspecies of Mice

E. Kurnianto[1], **A. Shinjo*** **and D. Suga**
Faculty of Agriculture, University of the Ryukyus, 1 Senbaru, Nishihara-cho, Okinawa 903-0213, Japan

---

ABSTRACT : The objective of this study was to describe the nature of the inheritance of jumping as a behavioral trait and to analyze quantitatively the jumping height as a measure of vigor in two subspecies of mice. Two subspecies of mice, Yonakuni wild mouse (Y) and CF$_{\#1}$ laboratory mouse (C), were used as the parental types. Reciprocal mating between these two subspecies was made to produce subsequently the first and second generations. The first generation was F$_1$ (YC) resulting from Y male×C female, and F$_1$' (CY) from C male×Y female. The second generation F$_2$ (YCYC) was from mating F$_1$×F$_1$ and F$_2$' (CYCY) from F$_1$'×F$_1$'. Individuals were treated with a set of direct current shock apparatus at six weeks of age to evoke jumping. The results showed that the ratio between jumping and non jumping mice (J: NJ) for C was 0%:100% (0:1), which means that all C did not jump throughout the experiment, whereas Y was 68%:32% (2:1); and the F$_1$ and F$_2$ showed 65%:35% (2:1) and 51%:49% (1:1), respectively. All F$_1$' and F$_2$' individuals jumped as indicated by the ratio 100%:0% (1:0) for both these two genetic groups. Of the jumped mice, average height of the first three jumping observed for pooled sexes in Y, F$_1$, F$_2$, F$_1$', and F$_2$' were 19.3 cm, 19.3 cm, 18.0 cm, 19.9 cm and 16.4 cm, respectively. The distribution of jumping height showed a tendency to be a normal distribution. The jumping activity and jumping height may be affected by some major genes and polygenes, respectively. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 6 : 733-738*)

Key Words : Jumping Inheritance, Reciprocal Cross, Subspecies of Mice

---

INTRODUCTION

Many studies of crossing effects have been conducted on productive and reproductive traits, like body weight and litter size (McGloughlin, 1978; Nagai et al., 1980) because of its economic importance in animal production. However, report of behavioral traits is relatively lacking.

Wild mice are selected for wildness by natural selection and selected for tameness by artificial selection of the domestication process (Dawson, 1932). If wildness or tameness is inherited, then there would be a tendency to be homozygous for genes for a condition of wildness or tameness. Experimental work that dealt with wildness or tameness has been reported on mice which focused on behavioral description of differences in performance between wild and domesticated mice (Price, 1972; Smith, 1972).

The process of domestication can produce population of mice with certain behavioral attributes such as jumping, wheel activity, underwater escape, grooming etc. By using diallel cross technique, Smith and Connor (1974) reported that the behavioral traits exhibited many instances of additive variance, especially among open field behavior, while exhibiting relatively few instances of dominant variance and heterosis. Jumping was the only open-field behavior not demonstrating significant additivity.

The objective of this study was to analyze the inheritance of jumping as a behavioral trait and of jumping height as a measure of vigor in two subspecies of mice; that is, wild and laboratory mice, with quite distinctive in genotype and body weight. Jumping height was chosen because it can easily be measured quantitatively.

MATERIALS AND METHODS

Animals

Yonakuni wild mouse (Y) and CF$_{\#1}$ laboratory mouse (C) were used as the experimental materials. The performance of these two subspecies, mating system and rearing condition were identical to those described in the earlier papers (Kurnianto et al., 1997; Kurnianto et al., 1998). In this study, parental type Y and C were reciprocally crossed to produce the first and the second generations. The first generation was F$_1$ (YC) and F$_1$' (CY) resulting from Y male×C female and C male×Y female, respectively. While the second generation was F$_2$ (YCYC) resulting from *inter se* crossed of YC male×YC female and F$_2$' (CYCY) from CY male×CY female. A total of 255 mice tested: 60 C, 22 Y, 88 F$_1$, 39 F$_2$, 30 F$_1$' and 16 F$_2$'. Body weight and jumping height were measured individually at six weeks of age.

Apparatus

A set of apparatus used for measuring jumping

---

* Address reprint request to A. Shinjo. Tel/Fax: +81-98-895-8756, E-mail: ashinjo@agr.u-ryukyu.ac.jp.

[1] Permanent address: Faculty of Animal Sciences, Diponegoro University, Semarang, Central Java, Indonesia.

Received May 20, 1999; Accepted September 8, 1999

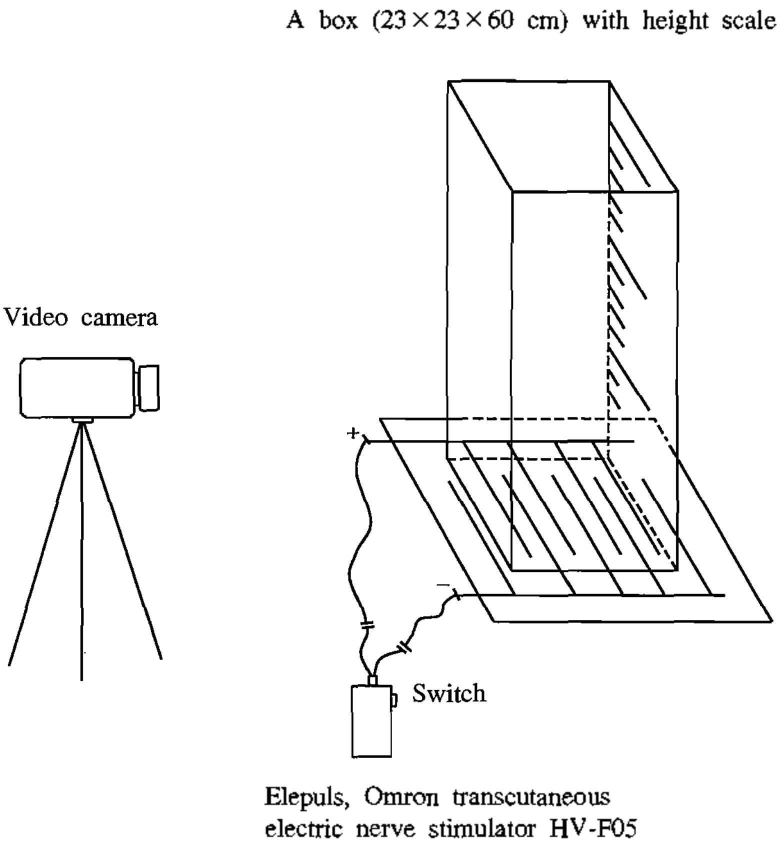

Figure 1. A set of apparatus used to measure jumping activity

height is presented in figure 1. A wood box with fiberglass at the front side (23 cm long, 23 cm wide and 60 cm high), provided with height scale, was made to place individual mouse for measuring its jumping height. The bottom part of the box (floor) was constructed of hard rubber, and the shock circuit was completed through the grid floor. Shock was delivered to the grid floor by the direct current of shock source (Elepuls, Omron Transcutaneous Electric Nerve Stimulator HV-F05 with 9 voltage). When the Elepuls switched on, the current go to the positive and negative poles and this then cause mouse shock. Because of the shocking, the mouse will jump up and the jumping height was recorded by the video camera. Within 15 second the frequency of jumping and jumping height were measured.

Statistical analysis

Data of jumping heights within genetic group-sex subclass were analyzed by GLM (SAS, 1990; Shinjo, 1994). Six genetic groups involved were two parental types C and Y, two reciprocal first generation (F_1 and F_1') and two reciprocal second generation (F_2 and F_2'). Qualitative aspect of jumping activity was tested by x^2 method. Quantitative aspect of jumping height among genetic groups were compared by use of Duncan's multiple range test, and comparison between sexes within each genetic groups of the parental type, the first generation and the second generation were examined by t-test.

RESULTS

The ratio of jumping and non jumping mice for pooled sexes for parental types, reciprocal F_1 and F_2 are presented in table 1. It can be seen that the ratio for C was 0%:100% (0:1), which means all C did not show response to shocking, just walked around on the space of the box used. Meanwhile, Y demonstrated 68%:32% (2:1). The offspring F_1, F_2, F_1' and F_2' demonstrated 65%:35% (2:1), 51%:49% (1:1), 100%:0% (1:0) and 100%:0% (1:0), respectively. The x^2 test was performed on the jumping activity on the basis of the ratio between jumping and non jumping mice. This revealed the jumping activity differences due to shock to be non significant.

From mice that showed jumping, their jumping heights were analyzed. Tables 2 to 4 show jumping height measured during 15 second for male, female and pooled sexes. As can be seen from the three

Table 1. The ratio of jumping (J) and non jumping (NJ) for pooled sexes at the parental types, first and second generations

Genetic group		Number of mice		Percentage ratio between J and NJ
		J	NJ	
C		0	60	0:100 (0:1)
Y		15	7	68: 32 (2:1)[a]
F_1	(Y♂×C♀; YC)	57	31	65: 35 (2:1)[b]
F_2	(YC♂×YC♀; YCYC)	20	19	51: 49 (1:1)[c]
F_1'	(C♂×Y♀; CY)	30	0	100: 0 (1:0)
F_2'	(CY♂×CY♀; CYCY)	16	0	100: 0 (1:0)

x^2 tests: [a] 0.022 (0.75<p<0.90); [b] 0.147 (0.50<p<0.75); [c] 0.026 (0.75<p<0.90).

tables, frequency of the jumping ranged from 4.3～5.9 times. No significant differences were found in the average jumping height between sexes within genetic group, except for F_2 at the first jumping in which males were significantly higher than females ($p<0.01$). There was tendency of similarity in jumping height among seven times of successive observations within genetic group. Following this result, only the first three jumping heights were chosen for further analysis. Moreover, it can also be seen that the number of mice, which jumped at successive jumping activity, decreased especially after the third jumping. This was possible due to an adaptation to the shock treatment, so that some of the mice did not jump anymore.

The distribution with regard to their response to

Table 2. Jumping height of the parental types

Genetic group	i^{th} jumping							Aver.[1]	Freq.[2]
	1	2	3	4	5	6	7		
CF$_{\#1}$ laboratory mouse (C)									
	0	0	0	0	0	0	0	0	0
Yonakuni wild mouse (Y)									
Male	17.9±3.0 (15)	19.7±2.6 (15)	20.1±3.0 (14)	19.6±3.2 (10)	17.7±3.1 (6)	20.3±4.0 (3)	17.0±0.0 (1)	19.4±1.5 (15)	4.3
Female	16.5 ± 3.0^{i} (15)	20.8 ± 3.1^{h} (15)	20.6 ± 3.3^{h} (14)	21.2 ± 2.1^{h} (12)	20.5 ± 4.2^{h} (8)	19.3 ± 3.4^{hi} (6)	18.7 ± 4.7^{hi} (3)	19.6±1.5 (15)	4.8
Pooled sexes	17.2 ± 3.0^{i} (30)	20.3 ± 2.8^{h} (30)	20.4 ± 5.1^{h} (28)	20.5 ± 2.7^{h} (22)	19.3 ± 3.9^{hi} (14)	19.7 ± 3.4^{hi} (9)	18.2 ± 3.9^{hi} (4)	19.4±1.7 (30)	4.6

[1] Aver represents average jumping height from all jumping (Mean±SD, in cm).

[2] Freq represents frequency of jumping weighed within 15 second.

[h,i] Different superscripts at the same raw indicate differences in jumping height among i^{th} jumping ($p<0.05$).

Jumping height between sexes are non significant ($p>0.05$); Number in the parenthesis represents the number of mice.

Table 3. Jumping height of the F_1 (YC) and F_2 (YCYC) mice

Genetic group	i^{th} jumping							Aver.[1]	Freq.[2]
	1	2	3	4	5	6	7		
F_1									
Male	17.9±3.0 (24)	20.3±2.8 (23)	20.1±2.3 (19)	19.6±3.7 (17)	19.4±3.5 (13)	17.9±2.8 (8)	18.8±2.9 (4)	19.3±2.0 (24)	4.5
Female	17.5 ± 3.6^{i} (33)	20.5 ± 3.7^{hi} (33)	20.0 ± 3.6^{hi} (30)	19.4 ± 4.1^{hi} (19)	20.7 ± 4.7^{hi} (22)	21.8 ± 6.3^{h} (12)	21.5 ± 5.7^{hi} (8)	19.5±3.1 (33)	5.1
Pooled sexes	17.7 ± 3.4^{i} (57)	20.4 ± 3.3^{h} (56)	20.0 ± 3.1^{h} (49)	19.5 ± 3.9^{hi} (46)	20.2 ± 4.3^{h} (35)	20.2 ± 5.4^{h} (20)	20.6 ± 4.9^{h} (12)	19.4±2.7 (57)	4.8
F_2									
Male	18.4 ± 3.4^{a} (12)	19.4±4.1 (11)	20.5±4.0 (10)	20.2±4.8 (10)	21.4±4.6 (7)	21.6±6.1 (7)	21.3±6.1 (7)	19.9±3.6 (12)	5.3
Female	13.6 ± 4.6^{b} (8)	17.3±2.6 (8)	18.1±5.9 (7)	17.1±4.8 (7)	18.7±3.3 (7)	19.0±4.7 (6)	19.3±3.4 (4)	17.0±3.1 (8)	5.9
Pooled sexes	16.5 ± 4.5^{i} (20)	18.5 ± 3.6^{hi} (19)	19.5 ± 4.8^{hi} (17)	18.9 ± 4.9^{hi} (17)	20.1 ± 4.1^{hi} (14)	20.4 ± 5.5^{h} (11)	20.5 ± 5.2^{h} (11)	18.8±3.7 (20)	5.6

[1] Aver. represents average jumping height from all jumping (Mean±SD, in cm).

[2] Freq. represents frequency of jumping weighed within 15 second.

[a,h] Different superscripts at the same column indicate difference in jumping height at the first jumping between sexes ($p<0.01$).

[h,i] Different superscripts at the same raw indicate differences in jumping height among i^{th} jumping ($p<0.05$).

Jumping height between two genetic groups from pooled sexes are non significant ($p>0.05$).

Number in the parenthesis represents the number of mice.

Table 4. Jumping height of the F_2 (CY) and F_2' (CYCY) mice

Genetic group	i^{th} jumping							Aver.[1]	Freq.[2]
	1	2	3	4	5	6	7		
F_1'									
Male	18.1±5.4	21.1±3.7	19.9±5.3	20.5±4.0	19.8±4.9	19.8±5.3	21.5±0.7	19.4±3.8	4.6
	(15)	(15)	(13)	(11)	(9)	(4)	(2)	(15)	
Female	17.9±3.2^{i}	20.7±3.6^{hi}	21.8±3.4^{hi}	21.3±2.6^{hi}	21.1±4.3^{hi}	23.8±1.5^{h}	20.0±1.4^{hi}	20.7±1.7	4.8
	(15)	(15)	(15)	(13)	(9)	(5)	(2)	(15)	
Pooled sexes	18.0±4.3^{i}	20.9±3.6^{hi}	20.9±4.4^{hi}	20.9±3.3^{hi}	20.4±4.5^{hi}	22.0±4.0^{h}	20.8±1.3^{hi}	20.1±2.9	4.7
	(30)	(28)	(28)	(24)	(18)	(9)	(4)	(30)	
F_2'									
Male	15.4±2.3	16.6±2.2	17.7±2.7	16.5±2.3	17.2±3.8	17.3±2.5	18.3±0.5	16.7±1.5	5.9
	(7)	(7)	(7)	(6)	(6)	(4)	(4)	(7)	
Female	15.3±3.4^{i}	16.8±2.9^{hi}	16.8±3.5^{hi}	17.2±1.8^{hi}	16.6±1.9^{hi}	17.0±2.5^{hi}	19.3±2.6^{h}	16.8±1.9	5.9
	(9)	(9)	(9)	(8)	(8)	(6)	(4)	(9)	
Pooled sexes	15.4±2.9^{i}	16.9±2.5^{hi}	17.2±3.1^{hi}	16.9±1.9^{hi}	16.9±2.8^{hi}	17.1±2.4^{hi}	18.8±1.8^{h}	16.8±1.7	5.9
	(16)	(16)	(16)	(14)	(14)	(10)	(8)	(16)	

[1] Aver. represents average jumping height from all jumping (Mean±SD, in cm).

[2] Freq. represents frequency of jumping weighed within 15 second.

[h,i] Different superscripts at the same raw indicate differences in jumping height among i^{th} jumping ($p<0.05$).

Jumping height between two genetic groups from pooled sexes are non significant ($p>0.05$).

Number in the parenthesis represents the number of mice.

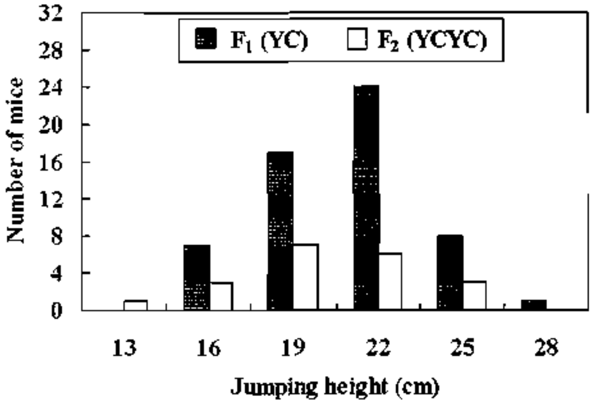

Figure 2. Distribution of F_1 (YC) and F_2 (YCYC) in the average height of the first three jumping

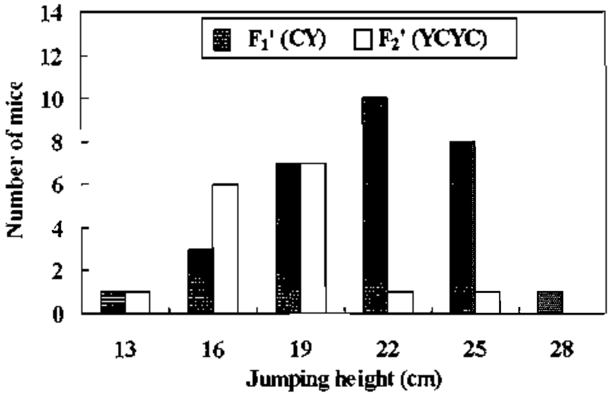

Figure 3. Distribution of F_1' (CY) and F_2' (CYCY) in the average height of the first three jumping

Table 5. The relationships between body weight and average height of the first three jumping at the first and second generations

Genetic group	N[#]	Body weight (g)	Average height of first three jumping (cm)	Co-efficient of co-rrelation (r)[$]
F_1				
Male	24	23.3±3.4	19.3±2.2	0.340
Female	33	18.4±2.2	19.2±3.2	0.133
Pooled sexes	57	20.5±3.7	19.3±2.8^{hi}	0.166
F_2				
Male	12	20.8±2.6	19.2±2.9	0.126
Female	8	15.7±3.0	16.3±3.3	0.174
Pooled sexes	20	18.8±3.7	18.0±3.3^{i}	0.398
F_1'				
Male	15	23.1±3.9	19.6±3.9	0.008
Female	15	17.1±2.5	20.1±2.5	0.564
Pooled sexes	30	20.1±4.5	19.9±3.3^{h}	0.062
F_2'				
Male	7	19.1±1.8	16.6±1.7	0.354
Female	9	17.4±1.8	16.3±2.7	0.170
Pooled sexes	16	18.1±2.0	16.4±2.2^{j}	0.229

[#] The number of mice used.

[$] Coefficient of correlation between body weight and average height of the first three jumping.

[h,i,j] Different superscripts at the same column indicate differences in average height of the first three jumping of pooled sexes among genetic group ($p<0.05$).

the shock on the jumping height were made for illustrating the proportion of individual jumping heights at different scale of height. Figures 2 and 3 present the distribution of F_1, F_2, F_1' and F_2' for the average height of the first three jumping that was made in 3-cm class intervals. From these figures, the distribution tended to show a normal distribution. Most of the mice in F_1, F_2, F_1' and F_2' demonstrated jumping height around 22 cm, 19 cm, 22 cm and 19 cm, respectively.

The relationship between body weight and average height of the first three jumping at the first and second generations is summarized in table 5. All coefficient values were small (0.008～0.398), indicating no closeness of relationship between these two traits. It is possible that many different genes responsible for quantitative inheritance affect body weight and jumping height separately.

DISCUSSION

From the two parental types used, the wild mouse proved to be more aggressive than the laboratory mouse by because about two-thirds of those mice jumped when treated with shock tool, while the laboratory mice did not show jump. This is probably due to the past domestication process with culling the jumping gene. The responses of the laboratory mouse to the shock treatment was typically explained as walking around which often involved leaping about the walls of the test box. The response of the wild mouse observed in this study indicated the existence of genes that play in role of jumping activity as a behavioral trait of mouse. However, the type of gene action in this case is still unclear yet as shown in table 1, that no definite specification was observed in ratio of jumping and non jumping both at the first generation and the second generation. The inheritance of jumping activity may be controlled by some major genes. Evidence for the coexistence of some major loci and polygenic effects has been found (Hoeschele, 1988; Falconer and Mackay, 1989). Some examples are the muscle hypertrophy in cattle and pig, the recessive dwarf gene in beef cattle and the rapid postweaning growth in mice.

Obviously, genes are deeply involved in the development of behavior, but the problem of how genes exert their control on behavior remains largely unexplored (Alcock, 1979). Oliverio et al. (1972) conducted an experiment to assess the mode of inheritance of avoidance, maze learning and wheel-running activity in three strains of inbred SEC/re, DA/J and C57BL/6J.

Falconer and Mackay (1996) stated that characters directly related to fitness have been under strong selection pressure with reducing in additive genetic variance. Smith and Connor (1974) used the diallel technique to analyze polygenetically inherited behavioral traits and reported that jumping was one of the behavior traits that did not demonstrate significant additivity.

No significant differences were found in average of the first three jumping height between sexes within genetic group both in the first and second generations, and no differences that could be considered significant was observed among genetic groups. On the whole, the results indicated that the mean jumping height at crossbred offspring resulting from these two subspecies were uniform. Furthermore, distribution of the number of mice to jumping height within genetic group tended to show normal distribution.

As pointed out by Lasley (1978) in some polygenic traits non additive and additive genes may both affect the same trait. If a trait is low to medium in its degree of heritability and shows improvement when crossbreeding is practiced, this indicates it is probably affected by both non additive and additive genes. Following the result of jumping ratio and shape of distribution in this study, we assume that jumping activity is affected by some major genes, whereas jumping height itself is by polygenes. For proving this assumption in detail we are still conducting another experiment.

In conclusion, the Yonakuni wild mice were more vigor than $CF_{\#1}$ laboratory mice, while the vigor of the crossbred offspring from these two subspecies were uniform as indicated by the uniformity of the average height of the first three jumping.

ACKNOWLEDGMENTS

The authors wish to thank Ms. Nobumi Yamada for her assistance in recording data. The authors also gratefully acknowledge the kind assistance Mr. Buah J. Nelson for correcting the English usage.

REFERENCES

Alcock, J. 1979. Animal Behavior, An Evolutionary Approach. Second Edition, Sinaurer Associates, Sunderland, Massachusetts.

Dawson, W. M. 1932. Inheritance of wildness and tameness in mice. Genetics. 17:296-326.

Falconer, D. S and T. F. C. Mackay. 1996. Introduction to Quantitative Genetics (4th Ed.). Longman, NY, USA.

Hoeschele, I. 1988. Genetic evaluation with data presenting evidence of mixed major gene and polygenic inheritance. Theor. Appl. Genet. 76:81-92.

Kurnianto, E., A. Shinjo and D. Suga. 1997. Comparison of the three growth curve model for describing the growth patterns in wild and laboratory mice. J. Vet. Epidemiol. 1:49-55.

Kurnianto, E., A. Shinjo and D. Suga. 1998. Analysis of growth in intersubspecific crossing of mice using Gompertz model. Asian-Aus. J. Anim. Sci. 11:84-88.

Lasley, J. F. 1978. Genetics of Livestock Improvement. Third Edition, Prentice-Hall of India.

McGloughlin, P. 1980. The relationship between heterozygosity and heterosis in reproductive traits in mice. Anim. Prod. 30:69-77.

Nagai. J., D. L. Harris and A. J. McAllister. 1980. Growth, feed efficiency and lifetime performance of cross between lines selected for nursing ability and/or adult weight in mice. Theor. Appl. Genetic. 58:59-69.

Oliverio, A., C. Castellano and P. Messeri. 1972. Genetic analysis of avoidance, maze, and wheel-running behaviors in the mouse. Journal of Comparative and Physiological Psychology. 79:459-473.

Price, E. O. 1972. Domestication and early experience effects on escape conditioning in the Norway rat. Journal of Comparative and Physiological Psychology. 79:51-55.

SAS. SAS/STAT User's Guide, Volume 2, Version 6, Fourth Edition. 1990. SAS Institute Inc., SAS Campus Drive, Cary, NC 27513, USA.

Shinjo, A. 1994. Introduction to Statistics by PC SAS (in Japanese). Tokai University Press, Japan.

Smith, R. H. 1972. Wildness and domestication in *Mus musculus*: A. Behavioral analysis. Journal of Comparative and Physiological Psychology. 79:22-29.

Smith, R. H. and J. L. Connor. 1974. The inheritance of behavioral wildness in house mice (*Mus musculus L.*). Animal Learning & Behavior. 2:249-258.