already been determined and to much higher accuracy than would be possible with a spacecraft, because the very precise angle observations of Venus over many decades can be utilized in the computation.

The Goldstone radar achieved its superior performance principally because it contained a supersensitive receiving system—as opposed to transmitting with extremely high power, for example. For this reason the receiving portion of the radar is presently capable of detecting a 50-milliwatt transmitter located on the surface of Venus at a distance of 30 million miles while radiating its power omnidirectionally. By comparison, the transmitters on the first Explorer satellite had outputs of 10 and 100 milliwatts, and the transmitter on the first lunar probe, Pioneer IV, had an output of 250 milliwatts. This capability will undoubtedly influence the choice of missions for future planetary spacecraft and may be expected to accelerate the landing of a capsule on the surface of Venus to measure temperature, pressure, wind velocity, and other scientific data in preparation for the first manned exploration to the planets.

Until this year the science of radar astronomy had been restricted to gathering and analyzing data principally about the Moon and the Sun. This science has now received new impetus with the gathering of hundreds of hours of data about Venus. The fact that Venus is now within radar range will encourage scientists to search for still more sophisticated techniques to map the surface features of Venus, to determine whether its surface is liquid or solid, and to discover the presence or verify the absence of an ionosphere, a magnetic field, or other phenomena of scientific interest on Venus.

But probably one of the most significant results of this experiment is that we now know how to specify and design a planetary radar observatory which is capable of almost continuous surveillance of our planetary neighbors, Venus, Mars, Mercury, and Jupiter. Prior to this year this information was not known with any degree of certainty. And because the precision range and velocity data of a radar complement the precise angle data obtained from optical devices, we believe that the combination of data obtained by radar and optics will permit the future computation of planetary ephemerides to much greater precision than heretofore believed possible. Such precision will undoubtedly reveal many minor perturbations in the orbits of the major planets, which could make it possible to discover new minor planets and natural satellites of our solar system.

Note

1. The Jet Propulsion Laboratory is operated by California Institute of Technology for the National Aeronautics and Space Administration. The Goldstone tracking and communications station is part of NASA's Deep Space Instrumentation Facility.

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Correlation between Mean Litter Size and Mean Life Span among 12 Inbred Strains of Mice

Abstract. In 12 inbred strains of mice there was no general correlation between litter size and parental life span within strains, although a significant between-strain correlation of +0.69 was found between mean life span of the dams and the mean size of their litters. When data for AKR/J mice, which characteristically die early from leukemia, were excluded, the correlation was increased to +0.90 for the remaining 11 strains. These findings indicate that the correlation is of genetic origin—that is, that genes affecting a dam's life span also affect the size of her litters.

Life span and litter size in mice are components of fitness, both affected by genetic constitution and environment. The present study was undertaken as part of a search for correlates of life span. It is an attempt to determine whether the environmental factors in this laboratory which influence litter size also influence parental life span and whether litter size and parental life span are genetically correlated.

Breeding records and life span data for 12 inbred strains of mice were made available to us through the kindness of Elizabeth S. Russell. These animals were bred and maintained in the pedigreed expansion stocks of the Jackson Memorial Laboratory. All strains had been inbred by brother-sister matings for many generations in this laboratory. Under the system used in the pedigreed expansion stocks, complete breeding records for each mating were maintained. When the breeders reached the age of 11 mo, they were retired and in many cases were set aside in groups of two to five to live out their lives. The pairs usually continued to be caged together until one of the pair died. If the survivor was the male, he was recaged with a surviving female from another pair. In some instances surviving females would be caged together, but in no instance were males caged together because of the fighting habits of males of many strains. The cages were checked once a week for dead animals, and the date of death was recorded. In some cases moribund animals were killed to obtain fresh histological material for determination of disease incidence by strain.

Breeding performance and life span data were tabulated for 1717 mated pairs of mice which had had at least five litters. It is known that litter size generally increases with parity, reaches a maximum, and then declines (*1*). If data from all mice had been included, the resulting mean would have been more heavily weighted by the smaller early litters, and mean litter size would have been partially a function of mean reproductive life. Therefore, only data from pairs having five or more litters were included, and the average litter size per dam was calculated from her first five litters. Life span data were computed for the breeding pairs whose litters were used to compute mean litter size. This procedure tended to result in stratification of the sample in favor of good breeders and longer lived animals, since any

Table 1. Within-strain correlations and strain parameters for the variables, litter size (*x* in mice), dam life span (*y* in days), and sire life span (*z* in days).

Strain	N	Within-strain correlations			Strain statistics (means ± standard error)		
		r_{xy}	r_{xz}	r_{yz}	$\bar{x}$	$\bar{y}$	$\bar{z}$
C57BR/cdJ	135	−0.15	−0.17*	+0.24†	6.34 ± 0.10	551.2 ± 10.6	483.3 ± 10.7
C57BL/6J	377	−0.02	−0.01	+0.14†	5.91 ± 0.06	600.4 ± 7.5	533.3 ± 0.8
129/J	51	+0.25	+0.24	+0.13	5.78 ± 0.15	543.6 ± 16.0	577.8 ± 17.1
RF/J	31	+0.27	−0.18	+0.34	5.48 ± 0.70	513.6 ± 62.8	578.2 ± 64.4
C57L/J	82	+0.06	−0.23*	+0.25*	5.39 ± 0.12	548.4 ± 13.0	538.0 ± 15.6
C3HeB/FeJ	143	−0.19*	+0.01	+0.16	5.37 ± 0.09	543.6 ± 10.8	549.5 ± 10.6
BALB/cJ	164	−0.05	−0.03	+0.25	5.20 ± 0.09	506.8 ± 8.8	494.4 ± 11.0
AKR/J	79	+0.07	+0.16	−0.05	5.20 ± 0.09	319.8 ± 8.6	291.1 ± 6.5
A/J	177	+0.04	+0.08	+0.26‡	4.97 ± 0.07	441.5 ± 7.5	488.0 ± 9.5
DBA/2J	82	+0.06	+0.01	+0.21	4.74 ± 0.10	458.6 ± 11.4	419.7 ± 11.8
DBA/1J	226	+0.02	+0.03	+0.11	4.42 ± 0.06	431.6 ± 5.6	453.1 ± 9.7
A/HeJ	170	+0.07	+0.05	+0.21†	3.91 ± 0.06	395.0 ± 6.5	461.2 ± 9.2
Total	1717	0.00	0.00	+0.18‡			

* $p < .05$ (all two-tail tests). † $p < .01$. ‡ $p < .001$.

Table 2. Between-strain correlations for the variables, litter size (x in mice), dam life span (y in days), and sire life span (z in days).

N	$r_{\bar{x}\bar{y}}$	$r_{\bar{x}\bar{z}}$	$r_{\bar{y}\bar{z}}$
		All strains	
12	+0.69*	+0.37	+0.76†
		All strains except AKR/J	
11	+0.90‡	+0.58	+0.67*

* $p < .05$ (all two-tail tests). † $p < .01$. ‡ $p < .001$.

pairs in which one partner did not survive long enough to produce five litters were rejected. Because early deaths include the majority of deaths from infectious diseases, the net effect was to favor selection of mice dying primarily from degenerative diseases of aged mice. A comparison of our life span data with that tabulated by Russell for the entire group from which these mice are but a sample indicated that our life span values were greater for all strains, but that the order of longevity by strains was not altered.

Coefficients of correlation between the three variables (x, mean litter size of dam; y, life span of dam; z, life span of sire) were calculated both within and between the 12 strains (Tables 1 and 2). Three of the 24 within-strain correlations between litter size and life span of dam or sire (r_{xy} and r_{xz}) were significant at the 5-percent level. There was no evidence from a homogeneity test that the within-strain correlations were not drawn from the same population of correlations, so it was proper to calculate total within-strain correlations (*2*). Both the r_{xy} total and the r_{xz} total were zero. (A correlation of +.040 with an N of 1717 would be necessary for significance at the 5-percent level, one-tail test.) Thus, the three significant correlations do not indicate a general within-strain correlation and are probably due to sampling variation. A lack of correlation within strains indicates that for good breeders (i) there is no evidence of an environmental correlation between litter size and parental life span and (ii) if there is any genetic heterogeneity remaining within strains, there is no genetic correlation between these variables. The existence or nonexistence of an environmental correlation between the variables is of course dependent upon the particular environment in which the mice are raised. The mice in these laboratories are raised under uniform conditions in so far as possible. An environmental correlation would be expected between the variables if such factors as food, cleanliness, temperature, and so forth, varied extensively within the animal quarters. Also there is a possibility that a within-strain correlation between these variables may exist for dams who have less than five litters.

The significant positive correlation between dam and sire life spans within strains suggests that cage environmental factors are contributing significantly to the determination of life span. Since the dam and sire were in all cases litter mates, they shared a maternal and cage environment throughout their lives. Therefore, this relationship is not unexpected. No attempt has been made to estimate which aspects of the maternal or cage effects may be most important in producing the correlation.

Between-strain coefficients of correlation between the three variables were also calculated (Table 2). A significant correlation of +0.69 was found between strain mean litter size and strain dam life span. A graphical plot of the data (Fig. 1) reveals that the only strain deviating seriously from a linear relationship between these variables is AKR/J. This deviation is not unexpected because 80 percent of the deaths in this strain are due to leukemia where a virus-inciting agent has been strongly implicated (*3*). Therefore, the primary cause of death may be an environmental agent rather than a constitutional degenerative disease (*4*). When the data for strain AKR/J are excluded from the computation, the between-strain correlation between mean dam life span and mean litter size was +0.90. It is interesting that this correlation exists in spite of the tendency for some strain specific pathologies among aged mice (*5*). There is no reason to suspect that environmental differences between strains is contributing to the correlation; during the duration of their lives the mice had been moved about the laboratory quarters. In addition, at any one time, the strains were dispersed over shelves and in varying degrees in a vertical direction.

There exist some genetic relationships among these strains (*6*), and thus the actual degrees of freedom are not as high as $N - 2$. There are three groups which contain strains that are related as sublines from an inbred line: (i) DBA/1J and DBA/2J, (ii) C57BR/cdJ and C57L/J, and (iii) A/J and A/HeJ. The separations of these sublines occurred many generations ago, and there is much evidence of genetic differences between the strains within the groups. However, if the strains within the groups are lumped in order to approach greater genetic independence between strains, the $r_{\bar{x}\bar{y}}$ becomes +0.94, $N = 8$, $p < .001$; and $r_{\bar{x}\bar{z}}$ becomes +0.69, $N = 8$, and $p < .05$ (AKR/J excluded).

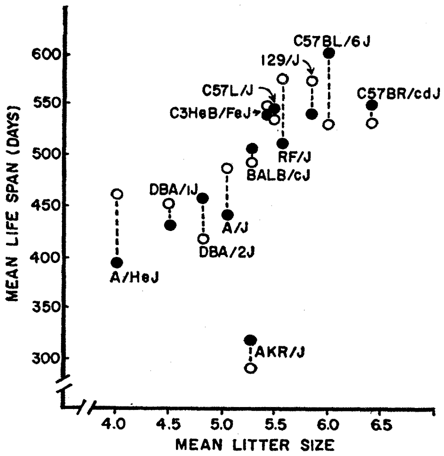

Fig. 1. Litter size and life span for 12 inbred strains of mice. A solid circle represents mean dam life span; a clear circle represents mean sire life span.

The correlation between strain mean litter size and strain sire life span was positive but not significant ($r_{\bar{x}\bar{z}}$ all strains = +0.37, $p \cong 0.20$; $r_{\bar{x}\bar{z}}$ all strains but AKR/J = +0.58, $p \cong 0.05$). These correlations of strain mean litter size and strain sire life span are not significantly different from the correlations of strain mean litter size and strain dam life span (*2*).

The between-strain correlation of sire and dam life spans ($r_{\bar{y}\bar{z}}$) are considerably larger than the within-strain correlation (total r_{yz}), indicating that a major part of the correlation is due to a genetic correlation between the variables (*7*).

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References and Notes

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7. This investigation was supported by research grants H-4083, RG-7249 and C-1074 from the National Institutes of Health and by Atomic Energy Commission contracts AT(30-1)2313 and AT(30-1)1979.

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