irradiated on the first day of pregnancy. It was demonstrated that 150R wholebody irradiation was no more deleterious than irradiation of the pregnant abdominal reproductive organs in rats. Therefore, it was concluded that there is no maternal effect due to irradiation of maternal structures other than abdominal reproductive organs at this stage of gestation and dose of irradiation. If a maternal effect exists it may be due to oviduct irradiation or it may be present with higher doses of irradiation. 2. One hundred fifty Roentgens irradiation on the first day of gestation in the rat did not increase the incidence of exencephaly or gross congenital malformations and did not result in fetal growth retardation. These facts and their significance, reported previously reinforce the discrepancy in the incidence and type of malformations induced in the mouse and rat following irradiation on the first day of gestation. 3. Although irradiation of the mouse during the preimplantation period produces a phenomenon referred to as whole-litter resorptions, this does not occur in the rat. Thus, the exencephally reported by Rugh and the whole-litter resorptions reported by Russell and Brent are produced by irradiating the preimplanted mouse embryo, but do not occur following irradiation of the preimplanted rat embryo. These variations in species response must be explained before attempting to apply any of these data to the human.

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Synodic Monthly Modulation of the Diurnal Rhythm of Hamsters.* (32187)

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Biological rhythms and clocks appear to be very widespread, if not of universal occurrence, in animals, plants, and microorganisms, and probably most physiological processes reflect to some degree their presence. This indicates a very ancient origin, long prior to when living creatures left their ancestral marine habitat. A great deal of evidence has established the existence of a fundamental sol-lunar timing system for rhythmic physiological variations in marine organisms, adjusting the

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latter's activities simultaneously to the solar day and ocean tides. Investigations of freshwater and land organisms have, however, been chiefly directed toward a solar-day rhythmic component. The now well-known, persistent diurnal physiological patterns appear to play important roles in adjusting the organisms to their rhythmic physical and biological environments. No useful role of a lunar periodic component is ordinarily obvious for the nonmarine species. Exceptions might include such special cases as regulation of activity and feeding schedules of birds and mammals that forage in intertidal regions, regulation of reproductive activity of animals with near-monthly or near-semimonthly cycles, or remotely, adaptively adjusting amount of activity to brightness of natural nighttime illumination.

Nevertheless, the question of the existence of a lunar periodic component in such an organism as a hamster is of substantial interest for several reasons both theoretical and practical. These include further understanding of the fundamental nature of the mechanism underlying biological rhythms and clocks and an increase in our ability to predict and explain some of the biological variability with time which superficially seems random.

Some previous quantitative studies of rats (1,2), mice(3), and hamsters(4) have provided evidence that all 3 possess, in addition to a diurnally rhythmic or circadian component, a lunar-day (24.8-hour) one. The study to be reported here provides further, and a different form of, evidence for the existence of a lunar component in hamsters corroborating earlier conclusions and, therefore, gives reason to postulate that a fundamental sol-lunar timing system for rhythms is a more general attribute of animals and plants than has been presumed previously.

Methods and materials. A running wheel actograph was placed in a nearly light-proof compartment, 48″ × 25″ × 16″, located in a dimly illuminated (<1 f.c.) room. The cubicle contained a 6-watt incandescent lamp programmed to provide illumination (intensity differing greatly over the running wheel assemblage) from 6 a.m. to 6 p.m. and none the remainder of the day. The turns of the running wheel were registered on an Esterline-Angus operations recorder. Over the course of 2 years beginning June, 1964, 4 male hamsters, seriatim, occupied this actograph keeping it in continuous operation except for November and December, 1964, ten days in July, 1965, and 7 days in February, 1966. At the ends of these intervals a different hamster replaced the preceding one. Food and water were always available in excess and were replenished at intervals of 4 to 8 days.

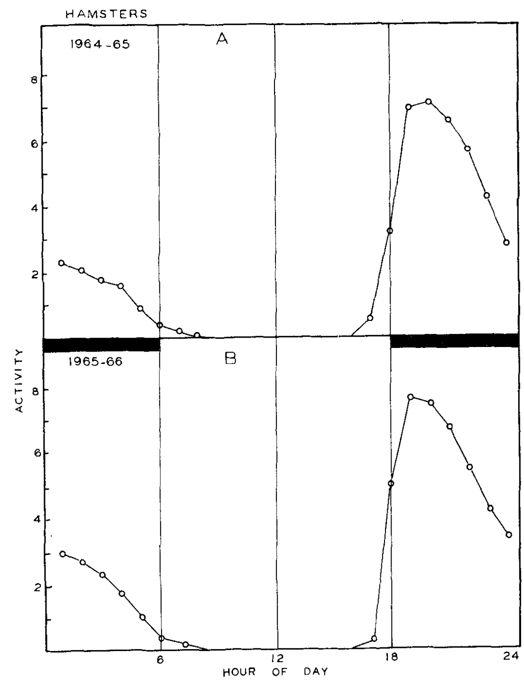

FIG. 1. Mean diurnal pattern of activity of hamsters during each of 2 years of study. Shaded horizontal bar indicates hours of darkness. Activity expressed in tenths of hours running in wheel.

Results. The amount of running-wheel activity of the hamsters was estimated to the nearest tenth of each hour. The mean activity for each hour of the light-programmed day is depicted in Fig. 1 for each of the 2 years. The value at each hour on the abscissa indicates the activity during the hour terminating at that time. The animals' activity was clearly synchronized with the lighting schedule, with activity trailing off nearly to zero before light onset, and commencing just prior to, thereby appearing to anticipate, the initiation of the next dark period. It is evi-

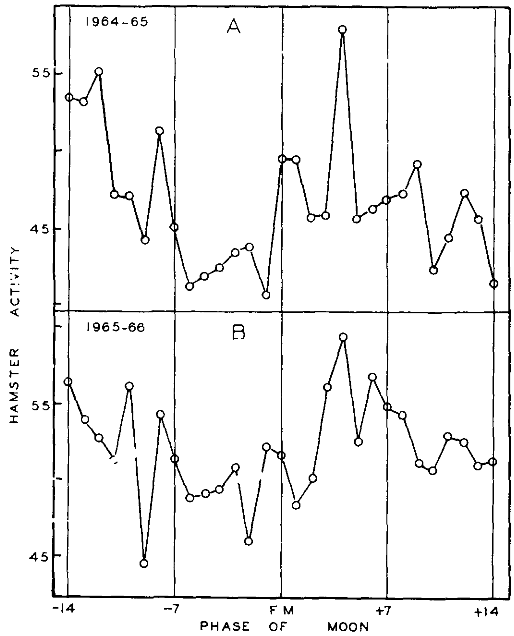

FIG. 2. Relation of total daily amount of running in tenths of hours to day of month for the hamsters for each of the 2 years of study. FM indicates day of full moon.

dent that for all 4 hamsters over the 2 years the bulk of the activity occurred between 5 p.m. and 11 p.m.

The data derivation and reduction leading to Fig. 1 was intentionally completed without any awareness or information on the part of the technicians working with the project as to the concurrent lunar relationships of the hourly values in order to protect against any unconscious bias.

It is obvious that if there existed a lunar-day periodism in activity, this would move across the solar-daily cycle at the mean rate of about 50 minutes a day, rhythmically reinforcing the solar-day maximum with a mean synodic monthly (29.53-day) period. Indeed, work with fiddler crabs has indicated a lunar-day variational component to persist accurately and without diminution even over extended periods of 24-hour light-dark cycles (5,6).

When the mean daily hamster activity (contributed almost wholly during the dark period, and especially the 6-hour period of relatively high activity) was computed for each day of synodic month for the 2 years separately, the results illustrated in Fig. 2A and 2B were obtained. The unit of the year was selected in order to eliminate any influence of an annual modulation in the sol-lunar rhythmic complex which might exist. An annual modulation in a persistent lunar rhythm has been reported for a behavioral parameter in fresh-water planarians (7,8) and an annual modulation in a persistent solar-day component has been described for metabolism in potatoes (9).

A remarkable similarity is seen for the patterns of the monthly modulation of the mean daily activity for the 2 years. The maximum value in the cycle for the first year is about 40% higher than the minimum, and for the second year, about 36%. The maximum value occurred the same lunar monthly day for the 2 years. Even for such relatively smoothed monthly variations as might be derived from 3-day moving means, the monthly variations for the 2 years would also possess not only closely similar and synchronized general forms but would have the maximum about 19% higher than the minimum for the first year and 14% for the second. Expressing the degree of reproducibility of the synodic monthly pattern of variation in terms of the computed coefficient of correlation between values for the corresponding synodic monthly days (FM $\pm$ 14 days) for the 2 years there was obtained: $r = +0.52$; $t = 3.15$; $n = 29$; $P < .005$.

Since essentially no hamster activity occurs during the daily illuminated period, and since the highest daily values of the month occur 4 days after Full Moon and a day or two after New Moon, the results are equivalent to the expectation from a mean bimodal lunar-day variation in the hamster possessing one maximum shortly before moon-rise and a second shortly after moon-set.

Discussion. The present study confirms the earlier indications of a significant lunar component in spontaneous motor activity in mammals. Despite the absence of any obvious adaptive significance in this case, the fact that the hamsters were shielded from variations in natural nighttime illumination, and the lack of any other obvious lunar cues, the 2 hamsters responsible for most of the data of the second year were extraordinarily phase-synchronized in their lunar variation with 2 hamsters contributing the data for the first year. The only plausible explanation seems to be that all 4 hamsters were influenced by the same subtle, pervasive goephysical periodism from which they were not screened, and this effected the varying degrees of spontaneity.

These results suggest that hamsters, like the marine organisms, possess a deep-seated, fundamental sol-lunar rhythmic complex. In these land-dwelling forms away from ocean tides, however, it is improbable that the lunar component is normally involved in timing special adaptive behavioral patterns comparable to those for seashore forms. The normal diurnal rhythms and the circadian (deviating slightly from 24-hour) ones which are observed under some kinds of experimental conditions such as unvarying illumination and temperature, appear from their normal phase-setting response to a 24-hour lighting schedule to depend upon the solar-day timing component. However, experimental conditions have been reported under which the lunar-day rhythmic component of hamsters(4) and a rat(2) has appeared to gain timing control, and hold for extended periods that behavioral pattern which was ordinarily a diurnal adaptation. This last suggests that the lunar-component of land-dwelling forms potentially can be coded with a complex behavioral pattern, as normally occurs in marine intertidal species.

Cogent evidence has been advanced that the sol-lunar rhythmic complex is derived as a biological response to pervasive geophysical correlates of the solar-lunar tides of the atmosphere(9).

A further significance of this demonstrated lunar relationship in hamsters, and its probable exogenicity, is an implication of it. Since any lunar geophysical variation would be expected to be smaller than comparable solar-day and annual ones, and even than day-to-day meteorologically-correlated fluctuations in closely related geophysical parameters, the existence of a 15% lunar variation makes it seem likely that mammals in our ordinary laboratory environments are steadily and substantially influenced by variations in pervasive geophysical factors, both aperiodic and periodic. It suggests that regulatory mechanisms are steadily operative in compensating for their larger influences to permit maintenance of the usual, relatively constant, steady state.

In view of the several recent simple, experimental demonstrations of responsiveness of widely different kinds of organisms to very weak magnetic fields of the order of strength of the earth's(7,10) the extraordinary similarity in form and phase of the hamster monthly variation to the very recently reported monthly variation in the daily K_p index of geomagnetic activity(11) is suggestive of some relationship.

Summary. Further evidence is submitted that a terrestrial mammal, the hamster, has a deep-seated lunar rhythmic component which appears to be derived directly in response to subtle, pervasive geophysical variations. This is reflected in the degree of spontaneous activity and hence would obviously be importantly reflected in standard metabolic rate. The mean monthly range for the motor activity is more than 15%. This suggests that a sol-lunar rhythmic complex such as is now well-established for marine intertidal species occurs also in non-marine forms. It also suggests strongly that fluctuations in hitherto largely disregarded pervasive, weak geophysical variations have substantial influences upon mammals.

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