tivity is much greater still. Hence it appears that the nervous system produces a considerable sharpening of auditory responsiveness—a neural action that has been assumed to occur in the discrimination of sounds in the auditory systems of man and other higher animals (*2*). This assumption has been made for the higher animals because in them—just as we find for the cicada—the peripheral actions of the ear show a much smaller degree of specificity than that exhibited in higher levels of performance. It is interesting to find the auditory nervous system performing this same role of the refinement of sensory information in animals so far apart in the biological series.

We now come to the question of the biological significance of sound production and hearing in the cicada. It was early appreciated that a function in mating is served. It was said at first that the female hears the sound produced by the male and seeks him out, but according to the extensive observations of Alexander and Moore the matter is more complicated. The males first react to one another and become segregated by species in particular sites in the tree tops. There they are joined by females of the same species, and mating takes place.

Still to be explained is the presence of two or more species in the emergence and thus in the general area before the sorting by species has been achieved. We offer the following hypothesis.

An emerging brood of cicadas encounters a serious problem of predation by birds. It has already been suggested that the coordinated emergence, within a few weeks, of millions of insects that have spent 13 or 17 years underground has the purpose of protecting some of the members from predation by the presence of overwhelming numbers. Sympatry of two or three species would of course contribute to the numbers. Still, a mere multiplication of one species would be just as effective.

Our observations on the behavior of predatory birds in two different localities containing large groups of cicadas have led us to another explanation. When a group is actively producing their sounds we find few birds in the area—often none in the center of the area and only a small number around the fringes. Certain birds—especially grackles—were observed to fly into the area, snatch a cicada, and at once fly away to eat it. When the sun was obscured by clouds, and sound production was less, there were more birds in the area and they stayed longer. In early morning or on cloudy days when the light was low and the temperature was depressed the sound production was feeble or absent. Then the birds entered the area freely and remained until they had gorged themselves.

Our theory is that the noise produced by the cicadas acts as a repellant to bird predators. It does so both because it is intense and thus painful to the ears and because it interferes with normal communicative processes among the birds. We measured the sound level on the ground beneath tall trees filled with singing cicadas as 800 dyne/cm^2. Obviously in the tops of the trees the level was higher, and must have reached 1000 dyne/cm^2 or more. For our ears this sound level is dangerously high. Some of us after spending several minutes in the area experienced ringing in the ears and partial deafness for some hours afterward.

If the cicada's sounds have a repellent effect on predators, the coexistence of two or three species becomes meaningful. Two species like *M. septendecim* and *M. cassini* with different frequencies of sound production can better jam the area acoustically than one species could by itself. The frequencies covered by the two peaks of Fig. 1 is just the range within which birds hear well; one of these peaks by itself would constitute much less annoyance and would leave some bird species relatively undisturbed.

Thus it seems to us that cicadas have developed a sympatric pattern of emergence involving two or three species whose sound productions are different and complementary so far as repellent effect is concerned, and that at the same time they have developed auditory capabilities that allow them to hear and respond to their own species exclusively. They are sympatric in sound production but isolated acoustically for mating purposes.

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Human Circadian Rhythms in Continuous Darkness: Entrainment by Social Cues

Abstract. *Three groups of two subjects each were kept in underground chambers, first for 4 days in an artificial light-dark cycle, and thereafter for 4 days in complete darkness. They lived on a rigorous time schedule. Physiological as well as psychological functions were measured at 3-hour intervals. There were no differences in the results between the two sections of the experiment. Social cues are sufficient to entrain human circadian rhythms, and absence of light has no immediate effect on the functions measured.*

There is ample evidence that diurnal rhythms are based on endogenous processes which have properties of self-sustained oscillations (*1*). Under constant conditions, the rhythm continues with a period which differs, in general, slightly from 24 hours—hence the term "circadian" rhythm (*2*). Under natural conditions, circadian rhythms are entrained to 24 hours by periodic factors in the environment, called entraining agents or *Zeitgebers*. Cycles of illumination intensity and, to a lesser degree, cycles of environmental temperature are the most important Zeitgebers for animals (*3*). It has been suggested that in man also light is an important Zeitgeber or that it is, at least, responsible for the entrainment of some human rhythms, such as that of the plasma level of 17-hydroxycorticosteroids (*4*). Prolonged darkness has been claimed to result in disappearance of the rhythm in some functions (*5*) or in immediate changes in the rate of increase or decrease: "The normal morning increase in urine and electrolyte excretion was much lessened by the absence of light, and its effects were apparent for the rest of the day"

Table 1. Mean values and standard deviations of rectal temperature and of urinary excretion of three substances from six subjects, kept for 4 days in an artificial light-dark cycle (LD) and for 4 days in continuous darkness (DD).

Cycle	Excretion			Rectal temperature (°C)
	Catecholamines (μg/hour)	17-OHCS (mg/hour)	Sodium (mg/hour)	
LD	2.07 ± 0.53	0.86 ± 0.15	251.6 ± 31.4	37.04 ± 0.16
DD	1.88 ± 0.52	0.91 ± 0.23	323.0 ± 28.1	37.00 ± 0.13

(*6*). On the other hand, the importance of a light-dark cycle has been questioned, especially for the rhythm of 17-ketosteroids (*7*), and both knowledge of time of day and social communication have been claimed as sufficient entraining agents for man (*8*). If light-dark cycles were necessary for the entrainment of, or for the full expression of, human circadian rhythms, the normally observed rhythm should be altered in conditions of continuous darkness, showing changes in either range of oscillation ("amplitude") or phase or period. We tested this hypothesis by measuring rhythmic functions of six male subjects (age 23 to 30 years), who were first kept for 4 days in an artificial light-dark cycle and thereafter were kept for 4 days in continuous darkness.

The subjects were enclosed in groups of two in an underground sound-proof room. They lived on a rigorous schedule, with rest time in bed from 23:30 to 7:30. In the first part of the experiment, lights were on from 7:30 to 23:30; in the second part there was no light at all for 96 hours. Meals or snacks, respectively, were offered at 8:30, 11:30, 14:30, 17:30, and 20:30. Urine samples were collected at 3-hour intervals, beginning at 8:00 of day 1. Immediately after the subjects urinated, we made several psychomotor tests. The subjects were wakened for tests at 2:00 and at 5:00. The two parts of the experiments were separated by 2 days during which the subject's night sleep was not interrupted, measurements being made only during daytime. All other conditions, including light, were the same as in the first 4 days.

The following substances were analyzed in the urine samples: Na, K, Ca; epinephrine, norepinephrine, dopamine, vanillylmandelic acid; and 17-hydroxycorticosteroids (17-OHCS). Body temperature was recorded continuously by means of a rectal probe. Psychomotor tests included speed of tapping, hand grip strength, and time estimation. The time necessary for one test session was 10 minutes for each subject. During the first part of the experiment, night tests were made in darkness; during the second part, there was no light for any of the tests.

Parts of the results are presented in Fig. 1. The absolute values of urinary excretion have been converted into percent deviations from the 4-day means. Continuous lines represent measurements made in presence of a light-dark cycle (LD); dotted lines are the measurements made in continuous darkness (DD). In the two conditions, the rhythm of rectal temperature as well as the rhythm of urinary excretion of total catecholamines (*9*), of 17-OHCS (*10*) and of sodium are nearly identical with regard to phase and amplitude. There is also no significant difference in the absolute values. The 4-day means, averaged for the six subjects, are given in Table 1. With the exception of a small decrease in mean value for Na and Ca and in range of oscillation for time estimation, we did not detect systematic differences between LD and DD in the measurements mentioned above.

Of course, minor deviations of the period from 24 hours could not have been detected. However, it has been shown in many experiments that human circadian rhythms tend to have periods close to 25 hours or longer when they are "free running," and they can do so even in the presence of a Zeitgeber (see below). The close similarity of the continuous and dotted curves shown in Fig. 1 does not support the hypothesis of such an external desynchronization. We furthermore tested phase and amplitude of the basic oscillation for most of the functions measured, adapting sine functions to the raw data by least-square techniques. We could not find any systematic differences between the two parts of the experiment. This mathematical analysis again speaks against desynchronization and against the above-mentioned immediate effects of darkness on rhythm parameters.

We conclude from these results that a light-dark cycle is not necessary to entrain human circadian rhythms, at least for 4 days. Also the complete exclusion of light for 96 hours has no significant influences on mean values of most of the physiological and psychological functions measured. This

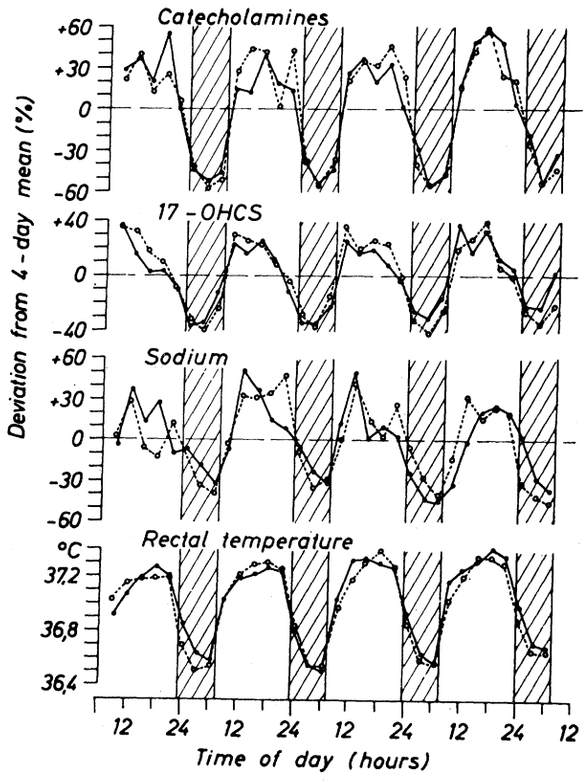

Fig. 1. Circadian rhythms of urinary excretion (total catecholamines, 17-hydroxycorticosteroids, and sodium) and of rectal temperature. Mean values of six subjects kept first in an artificial light-dark cycle (continuous lines, closed circles), thereafter in continuous darkness (dotted lines, open circles). Shaded area represents sleep time.

observation does not exclude, of course, the possibility that rhythm parameters might be altered after a longer sojourn in darkness. An increase in amplitude and in mean value of the excretion of 17-OHCS has been observed in synchronized subjects who had lived first for 6 days in continuous illumination and thereafter for 6 days in continuous darkness (*11*). Our results indicate that knowledge of time of day, living routine, and social communication are powerful Zeitgebers for the human circadian system. This corroborates our earlier demonstration that there occurs mutual (social) entrainment between members of a group that is enclosed in isolation without time cues (*12*). However, our experiment adds the new information that human circadian rhythms can be entrained to 24 hours by social cues from the environment. This is also of interest in view of the fact that the presence of a clock alone is not sufficient to entrain an otherwise isolated subject (*13*). Finally, the conclusion that light—at least artificial light—is a rather weak Zeitgeber for man is supported by the observation that human subjects, kept in isolation, tend to "free run" with a circadian period of more than 24 hours in the presence of an artificial 24-hour light-dark cycle (*14*). In our experiment, social cues apparently were sufficient to entrain human circadian rhythms, and the absence of artificial light did not change mean phase and range of the socially entrained circadian system during 4 days.

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Experimental Design and Data News Service

M. Tribus (*1*) expressed the need for "a greater variety of carefully planned observations instead of a greater number," and he warned about "blindly seeding every cloud" while he stressed that "the instrumentation plan should be very thorough." These ideas deserve practical implementation—by the cloud scientists themselves and by those who approve grants for fiscal support. The following comments (*2*) point the way toward one practical procedure—namely, a data news service.

Weather modification attempts will not merit the description "experiment" nor justify status as "scientific" unless they are competently designed and are objectively and thoroughly reported. Inadvertent omissions of some data in the ultimate final report, editing of data to gloss over defects, or failure to anticipate legitimate statistical objections about the experimental design leave the way open for undesirable controversy (*3*) and the bitter charge of "charlatan."

Financial support of weather modification experiments must often come from people who, as Condon (*4*) has observed, cannot distinguish objectively between science and pseudoscience. To gain support for genuine science, it is imperative for conscientious scientists not only to design such experiments according to the best modern concepts and to arrange for the acquisition of all needed data not already available but also to assume responsibility for the prompt and complete collection and dissemination of all data.

Full written disclosure and definition of the experiment [as advocated by Braham (*5*)] before actual operations begin will ensure objectivity when the results are discussed. Similarly, prompt and periodic (weekly) collection of all data for a region considerably larger than the target area itself will avoid belated attempts to gather data, which result in loss (*6*), oversight, omission, or distortion.

The on-site inspections and other fact-finding procedures advocated by Lovasich *et al.* (*7*) will be more effective when applied during the planning and during the development of experiments than when these procedures are applied years later, when no opportunity exists for improving either the experimental design or the physical measurements of meteorological variables (*8*).

Most importantly, progress toward resolving the uncertainties that continue to plague weather modification attempts (*9*) will come with the adoption of a new standard procedure for giving worldwide notice of impending experiments together with opportunity for criticism of the experimental design, followed by giving the world scientific community access to all data as fast as they are produced. Such "experimental design and data news service" should properly call for fiscal support by the experimenters, for it would ensure the acceptability of their data and ensure early contributions by the rest of the scientific community. Results would then be easier to apply, and action by professional specialists at the peak of their expertise would be expedited. Meteorologists could function to produce more reliable data, and statisticians could rely upon these data to extract more meaningful results and conclusions.

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