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Human Circadian Rhythms under the Influence of Weak Electric Fields and the Different Aspects of These Studies

by

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INTRODUCTION

Circadian rhythms of man have been proven to be of endogenous origin, just as those of other organism from unicellular ones up to primates (Aschoff, 1963). In a constant environment without time cues the rhythms continue autonomously with periods which deviate slightly from 24 hr. In the presence of environmental time cues, such as the diurnal change between light and dark, circadian rhythms become synchronized if the period of the time cues is within the range of entrainment around 24 hr.

Figure 1 shows the result of a human experiment performed under constant conditions. As can clearly be seen, the activity and body temperature rhythms shift gradually in relation to local time, resulting in a period of 25.3 hr. After 35 objective days, the subject had experienced subjectively only 33 days. The total phase shift of more than 360° indicates the autonomous nature of these rhythms (Wever, 1971b).

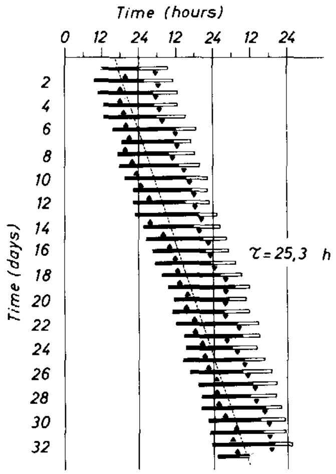

Fig. 1. Free-running circadian rhythm in a human subject, measured under constant conditions. Abscissa: local time; ordinate: successive periods. The rhythm of activity is represented by bars (black: activity; white: rest); the rhythm of rectal temperature is represented by triangles (▲: temporal position of a temperature maximum; ▼: temporal position of a temperature minimum). From Wever (1971b).

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In Fig. 1, out of a variety of measurements only the rhythms of activity and rectal temperature are shown; both rhythms have equal periods. In most subjects, not only these two rhythms but the rhythms of all measured variables, physiological as well as psychological ones, run synchronously to each other. However, in about 20% of the human subjects internal desynchronization occurs, i.e. the rhythms of different variables show different periods in the steady state (Aschoff, Gerecke and Wever, 1967). This desynchronization indicates a loss of coupling between different endogenous oscillators (Wever, 1972).

Figure 2 shows the result of another human experiment, performed again under constant conditions but with internal desynchronization; the activity period is much longer than the period of the rectal temperature rhythm. During the 25 objective days of the experiment, the subject had experienced subjectively only 18 activity days whereas his physiological variables showed 24 periods. In other subjects, internal desynchronization occurred not from the beginning of the experiment but spontaneously during the experiment, or with activity periods which were much shorter than the temperature periods. However, in all experiments, the periods of the rectal temperature rhythm were close to 25 hr. In 110 human subjects examined so far under constant conditions, these periods had an average value of 24.97 ± 0.41 hr ($\bar{x} \pm SD$) (Wever, 1971a).

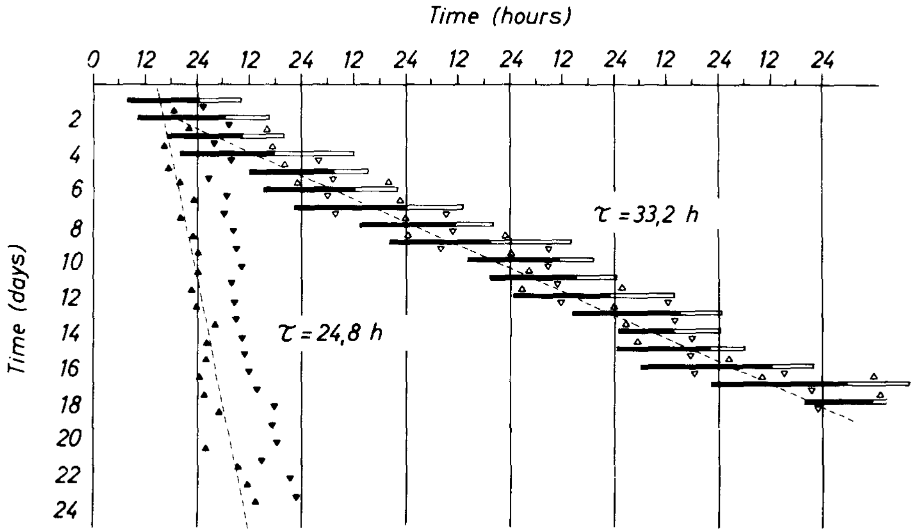

Fig. 2. Free-running circadian rhythm in a human subject, measured under constant conditions. Designations as in Fig. 1; white triangles: temporally correct repetitions of corresponding black triangles. Internal desynchronization during the total experiment. From Wever (1972).

In contrast to that what has been observed in most animals, changes in some environmental conditions (e.g. light intensity) have only small and irregular effects on the period of human circadian rhythms when measured under constant conditions (Wever, 1969). Thus, the intra-individual as well as the inter-individual variability in the free-running period of man is remarkably small.

METHODS AND MATERIALS

The investigations were performed in special underground isolation units (Wever, 1967), constructed to eliminate all environmental noises. Each of the two experimental units available consisted of a living room, a small kitchen, and a bath-room. There were no obvious differences between the two units; however, one of the units (room II) was shielded from external electric and magnetic fields, and furthermore, it was equipped with facilities for introducing any kind of artificial DC or AC, electric or magnetic field. These facilities were invisible, and their existence was unknown by the subjects. During the about 4 weeks of an experiment, the subjects had no contact with the outside environment except by letters. With only a very few exceptions, all subjects felt remarkably well during the isolation, and most of the subjects asked, after finishing the experiment, for another experiment.

RESULTS

Surprisingly, the results obtained in the two experimental rooms differed significantly in some respects (Wever, 1969). In room I, the free-running periods were shorter in the average (by 0.40 hr), and the inter-individual differences were smaller (by 50%) than in room II; moreover, all cases of internal desynchronization (c.f. Fig. 2) occured exclusively in room II. Because the electromagnetic shielding of room II is the only known difference between the two rooms, the hypothesis was formulated that the differences in the results were due to the natural electromagnetic fields which can penetrate only into room I. This hypothesis is based on statistically highly significant results, but additional experiments were conducted to test the hypothesis.

The hypothesis was tested by applying well defined artificial fields. All fields applied were weak in field-strength, and thus, could not be perceived consciously. The experiments were performed by exposing the subjects to an artificial field continuously for about two weeks, and then protecting them from all fields for another period of approximately two weeks; the temporal sequence of the periods with and without the field had been changed from experiment to experiment. Thus, each subject served as its own control (Wever, 1970).

Some preliminary experiments showed that DC electric (600 V/m) and magnetic (1.5 Oe) fields were without any effect. These static fields were neither able to shorten the period or to influence any other parameter of the rhythm, nor to prevent internal desynchronization (Wever, 1971a). Thus, DC fields which are present in our natural environment, cannot be responsible for the observed effects.

In contrast to DC fields, electric AC fields (10 cps, 2.5 V/m) are able to affect human circadian rhythms in the same manner as the natural fields (Wever, 1967). Figure 3 shows an example of a corresponding experiment; the subject lived under the influence of a continuously operating 10-cps-field during the second part of the experiment but under otherwise constant conditions during the entire experiment. As can be seen, the period is shorter with the field in operation than without it. All other experiments of this type confirmed this result; in 10 experiments, the period was shorter for 1.3 ± 0.7 hr ($\bar{x} \pm SD$) during the parts with the field in operation than without it ($p < 0.001$) (Wever, 1970). Moreover, the shortening effect of the field was the greater the longer the periods were in the absence of a field, resulting in larger inter-individual differences during the parts without field than during the parts when the field was in operation ($p < 0.001$) (Wever, 1971a). Finally, Fig. 3 shows internal desynchronization during the third part of the experiment beginning immediately after switching off the field. This influence of the field on the state of internal desynchronization was confirmed by many other

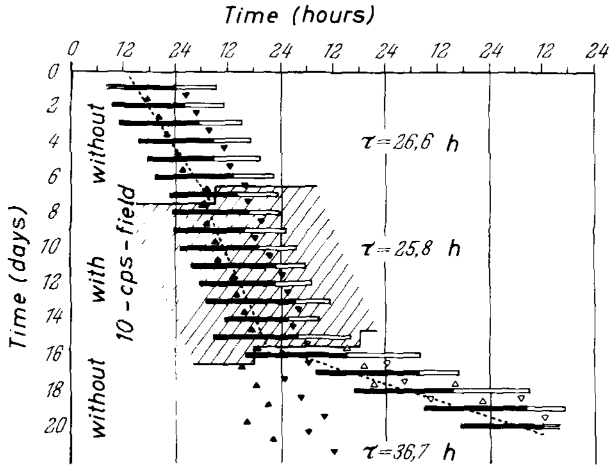

Fig. 3. Free-running circadian rhythm in a human subject, measured under constant conditions; without field during the first and third section, and under the influence of an artificial electric 10-cps-field during the second section. Designations as in Figs. 1 and 2. Internal desynchronization during the third section. From Wever (1968).

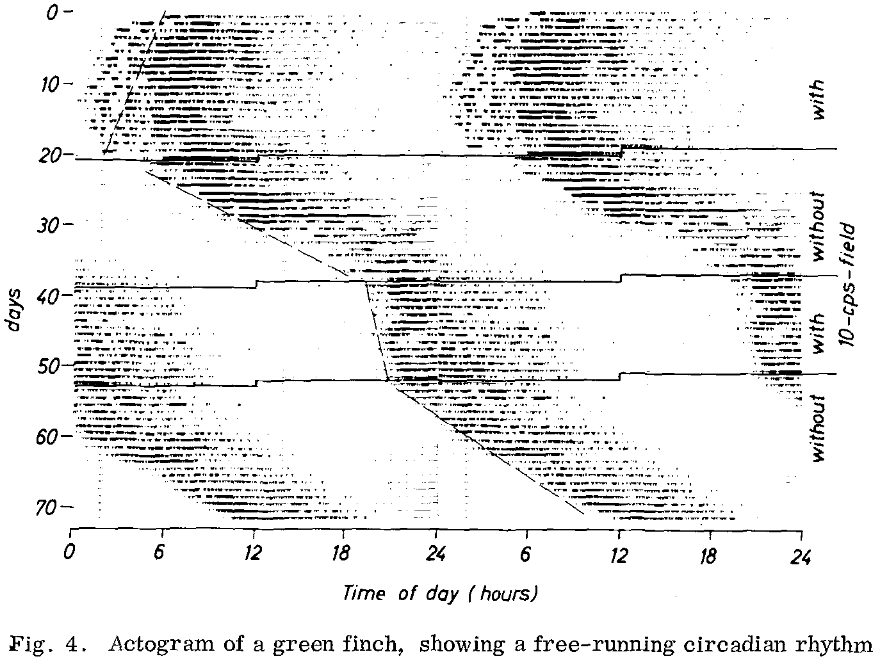

Fig. 4. Actogram of a green finch, showing a free-running circadian rhythm measured under constant conditions; under the influence of an artificial electric 10-cps-field during the first and third section, and without field during the second and fourth section. Abscissa: local time; ordinate: time of the experiment. For clarity, the activity records have been duplicated.

experiments ($p < 0.001$). In 22 subjects, internal desynchronization has been observed when they were protected from all fields, but this state has not yet been observed in any subject as long as the 10-cps-field was in operation. Moreover, if internal desynchronization occured spontaneously, it could be stopped by switching on the 10-cps-field (Wever, 1971a).

These remarkable results suggest the question as to whether the proven effect of 10-cps-fields on circadian rhythms is limited to man. Some preliminary animal experiments indicate that this is not the case (except for the effect on internal desynchronization which had never been observed in any animal). Figure 4 shows, as an example, results obtained with the green finch. The artificial 10-cps-field has been switched on and off several times and, as can be seen in Fig. 4, each switching on is accompanied by a shortening of the free-running activity period, and each switching off is accompanied by a lengthening of the activity period. This result is the same, even quantitatively, as that obtained in experiments with man.

CONCLUSIONS

These results show that an artificial electric 10-cps-field of low intensity has the same effect on human circadian rhythms as the natural electromagnetic fields: it shortens the free-running period, it diminishes the inter-individual differences in the periods, and it strenghtens the coupling between different rhythms preventing internal desynchronization. These results confirm the hypothesis mentioned above; that is, that fields of this kind are able to influence human circadian rhythms. Moreover, the similarity in the effects of the natural fields and the artificial 10-cps-field suggests that the low frequency fields which are generated in the earth's atmosphere (König, 1959), are the component within natural electromagnetic fields which are responsible for the observed effects.

Several aspects of the studies of human circadian rhythms under the influence of weak electric fields deserve further consideration:

(1) An artificial 10-cps-field of low intensity is the only physical stimulus which has been shown to have a consistent effect on human circadian rhythms. Using this field as a tool, the properties of human rhythms can be tested in the same manner as those of animal rhythms in which light is normally used as the controlling environmental stimulus. For instance, it can be shown with the field that changes in many parameters of human circadian rhythms are correlated to the period, just as in animal rhythms and as predicted from a special model of circadian rhythms (Wever, 1971b). Furthermore, artificial 10-cps-fields have also been applied as a periodically changing stimulus and, as such, can act as an entraining agent to circadian rhythms (Wever, 1967, 1970). This methodological aspect which disregards from the special peculiarities of the stimulus, was the primary one in the present investigations.

(2) Circadian rhythms have been shown to be very sensitive to low intensity electromagnetic fields. Using these rhythms as an indicator, the effectiveness of natural electromagnetic fields as well as of low intensity artificial 10-cps-fields on human beings has significantly been shown for the first time (Wever, 1967). This secondary aspect of the present investigation which deals with the special properties of the controlling stimulus, has been widely ignored in the past, but it may get superiority in the future.

(3) The demonstration of the sensitivity of circadian rhythms to low frequency, low intensity electromagnetic fields may help in the search for the basic mechanism underlying the circadian clock, which has been shown to be remarkably intensitive against most other physical stimuli (e.g. temperature). Moreover, this stimulus has been shown to influence not only the clocks of different organisms

in a similar manner (see above) but also different independent clocks within one organism in the same manner (Wever, in preparation). The consideration of these results may lead to new conceptions in the area of the clock mechanism.
(4) The present investigations arouses speculations concerning the usefulness of the natural electromagnetic fields for man. When these fields are absent, the free-running circadian period deviates more from 24 hr than under the influence of these fields. Since the range of entrainment in man is remarkably small (Aschoff, Pöppel and Wever, 1969), at least for the physiological variables (about $\pm$ 2 hr; Wever, 1973), this deviation can lead to external desynchronization. Moreover, the absence of natural fields weakens the coupling between different rhythms, and thus, can lead to internal desynchronization. It must be concluded from this that natural electromagnetic fields assist in stabilizing circadian rhythmicity; their presence may be advantageous for healthy men, at least with respect to their circadian rhythms. Where these fields are absent (e.g. under electromagnetic shielding, or in space), disadvantages can easily be avoided by substituting the natural fields by a weak electric 10-cps-field (Wever, 1970).

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