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Bright Light Affects Human Circadian Rhythms

Rütger A. Wever, Jan Polášek, and Christina M. Wildgruber

Max-Planck-Institut für Psychiatrie, Arbeitsgruppe Chronobiologie, D-8138 Andechs, Federal Republic of Germany

Abstract. The relative effectiveness of external zeitgebers synchronizing circadian rhythms can be evaluated by measuring the size of the range of entrainment. The experimental approach to measure entrainment limits is the application of an artificial zeitgeber with slowly and steadily changing period. In human circadian rhythms, an absolute light-dark (LD) cycle with a light intensity during L of 1000 lux or less, results in an upper entrainment limit of 26.91 ± 0.24 hours. The same limit is reached in constant illumination when only informations are given to the subjects. Consequently, the LD cycle is effective mainly with its behavioral component characterized by the request of the light-dark alternation to go to rest. In experiments with the same experimental protocol but higher intensity of illumination during L (~4000 lux, i.e., exceeding the threshold beyond which melatonin excretion is suppressed in humans), human circadian rhythms can be synchronized within a much larger range; the upper entrainment limit is, with all overt rhythms measured, beyond 29 hours. This means that bright light has an effect on the human circadian system which is qualitatively different from that of dim light, and which is similar to the effect of light in most animal experiments. This finding has theoretical and practical implications.

Key words. Human circadian rhythms - Limits of entrainment - Bright light effects - Melatonin threshold.

INTRODUCTION

It had been shown in various experiments that human circadian rhythms - in contrast to most animal rhythms - are sensitive against light only to a small extent (Wever, 1979); this statement can only be considered in the range of light intensities applied so far in human circadian experiments, i.e., up to intensities of about 1000 lux. Under constant conditions, the period of freerunning rhythms is independent of the intensity of illumination (Wever, 1969); and a light-dark cycle is effective as a synchronizing zeitgeber only in a small range of about ± 0.5 hours (Wever, 1970).

If humans are exposed to an absolute light-dark cycle, i.e., with no chance to switch on any illumination during the scheduled dark-time, sleep-wake alternations are commonly synchronized within a wide range of periods (including 48 h), and the rhythms of the autonomous functions are synchronized between about 23 and 27 hours. If such a zeitgeber is applied with steadily changing period (5 or 10 min change per cycle), precise estimations of entrainment limits are possible. The summarizing inspection of 7 experiments with lengthening period results in an upper entrainment limit of the rectal temperature rhythm (± S.D.) of 26.91 ± 0.24 hours (Wever, 1983). This result is confirmed by the results of 15 more experiments where subjects had been exposed, for sufficiently long sections, to the same type of zeitgeber but with a constant period of 28 hours: all these subjects were synchronized with their sleep-wake but not with their rectal temperature rhythms (Wever, 1979). The additional consideration of 12 experiments with steadily shortening zeitgeber period results in a size of the range of entrainment of the rectal temperature of ± 2.30 ± 0.21 hours around the freerunning period (Wever, 1983).

The same entrainment limits were obtained in experiments where subjects are requested by acoustical signals but in constant illumination (Wever, 1982b). The conclusion is that the light-dark alternations have a twofold effect on human rhythms in the former type of experiments. Firstly, there is a direct physiological effect as it has been shown in many animals; and secondly, a behavioral one: when one knows that it becomes completely dark for a short while, dusk operates as a behavioral request to go to rest, and dawn as a request to stand up (Wever, 1982a). In the latter type of experiments, the same requests are given in another way without any contribution of a direct effect of light. The similarity in the results of both types of experiments compels the conclusion that, in the first type of experiments, the behavioral component of the light-dark cycle is predominantly responsible for the overall zeitgeber effectiveness, and that there is no space for a relevant additional contribution of a direct light effect. To be sure, this conclusion is justified only if it can be shown that there is no fundamental entrainment limit at about 27 hours.

In contrast to the conclusions mentioned, Czeisler et al. (1981) insist on a potent zeitgeber effectiveness of an artificial light-dark cycle in humans. From several sections in their experiments with an absolute light-dark cycle (with an L intensity of a few hundred lux), resulting in external synchronization, they conclude a high sensitivity against this light-dark cycle: "it is clear that the response of the human circadian system to a periodic LD cycle is not different from that of other mammals." Czeisler et al. (1981) also reclaim the results of our experiments as discussed above for their statements. However, they disregard the behavioral component of an absolute light-dark cycle in humans which is even obvious in their experiments. In contrast to the animal experiments, and coinciding with our experiments, darkness acted as a cogent determinant for rest; i.e., as a behavioral force for rest, and not as a zeitgeber which necessitates inherently the possibility to deviate in phase (as in the animal experiments).

Recently it had been shown that the excretion of melatonin in humans can be suppressed by light when its intensity exceeds a threshold of about 2500 lux (Lewy et al., 1980). All former circadian experiments with humans, however, had been performed with light intensities considerably below this threshold. This is in sharp contrast

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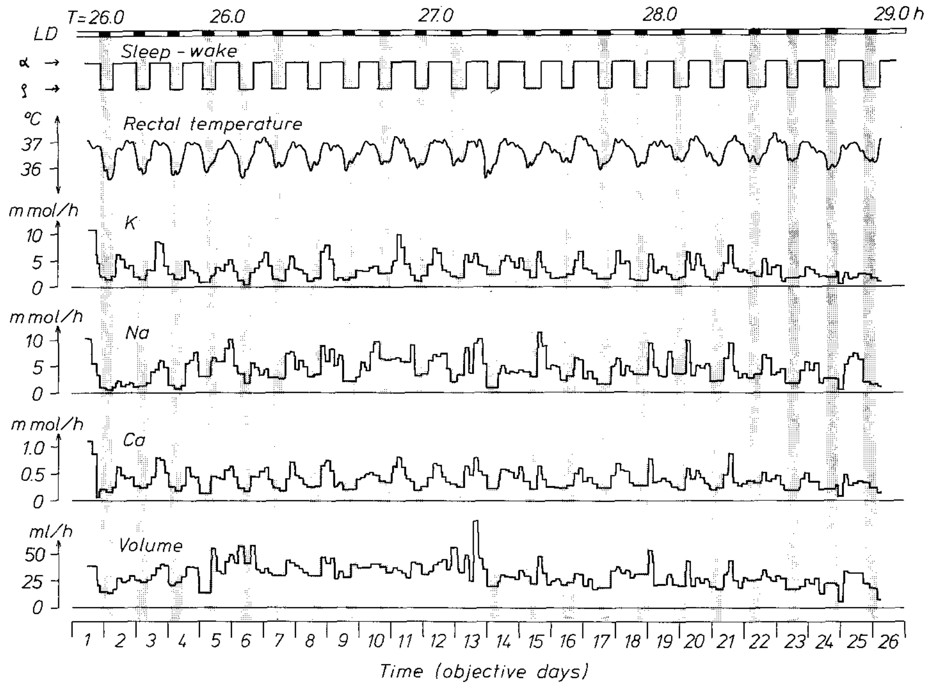

Figure 1: Circadian rhythm of a subject (S.L., ♂ 23 y) living without natural time cues but under the influence of an artificial zeitgeber with steadily lengthening period (upper border). Presented are the time courses of sleep-wake, rectal temperature, and four urine constituents. Shaded areas: dark-time of the zeitgeber.

to most animal experiments where the threshold for melatonin suppression is mostly in the range of 1 lux and where, consequently, the melatonin threshold was exceeded in most circadian experiments. Since melatonin had been shown to be relevantly concerned in the generation of circadian rhythmicity (Menaker et al., 1978), circadian experiments in humans with light intensities exceeding the melatonin threshold are of interest.

METHODS

Preliminary experiments with bright light were performed applying the common approach for evaluating upper entrainment limits; i.e., subjects were exposed to strong zeitgebers the period of which increased for 10 min per cycle; this means, the zeitgeber period lengthened, in the course of 4 weeks, steadily from 26 to 29 hours (Wever, 1979). After terminating, in every cycle, the common dawn (with incandescent bulbs), fluorescent tubes were switched on producing an intensity of about 1000 lux in the total experimental unit. Quarter an hour later, special mercury vapor lamps were switched on producing an intensity of about 4000 lux within an area of about 5 m^2 around the desk (measured at desk level). Before dusk, the bright light facilities were switched off in the reverse sequence. The subjects were asked to perform several tests, 6 times per light-time, lasting each for about 0.5 hours; for technical reasons (to push buttons), the tests had to be performed at the desk. Hence, it was guaranteed that the subjects were exposed to a light intensity exceeding the melatonin threshold for, at least, 3 hours per cycle.

RESULTS

In the first experiment, the upper entrainment limit of the rectal temperature rhythm was found at 27:20 hours, i.e., in about the same period range as in the former experiments with smaller light intensities. The inspection of the activity records (cf. Wever, 1979) and the interview with the subject showed that the subject stayed in the bright light area for not more than 3 hours per cycle; during the remaining time of day he moved into darker parts of his room where light intensity did not exceed the melatonin threshold. Three hours of bright light per day, consequently, may not be sufficient to rise the effectiveness of light on the human circadian system considerably.

In two more experiments, it was guaranteed that the subjects stayed in the bright light area for about 8 hours per cycle. In both these experiments, all measured rhythms in the subjects were synchronized to the zeitgeber during the whole experiment, i.e., up to a period of 29 hours. Figure 1 shows the results of one of these experiments. Not only sleep-wake (as in the former experiments) but also the vegetative rhythms of rectal temperature and the urine constituents followed the zeitgeber until the end of the experiment. Concurrent with the lengthening in the period, computer analyses show a slight but consistent decrease in the amplitudes and an advance in the acrophases relative to the zeitgeber, corresponding in all rhythms (except urine volume where is no reliable rhythmicity); both these changes are well known properties of rhythms inside the range of entrainment (Wever, 1979). In all previous experiments with the same experimental protocol but smaller light intensities, the vegetative rhythms broke off from the zeitgeber rhythm and the sleep-wake alternation around days 10 to 12 (i.e., around a period of 27 h), and in the further courses, they crossed the zeitgeber for not less than two full cycles (Wever, 1983). In the present bright light experiments, the entrainment limits obviously had not yet been reached; i.e., the upper entrainment limit