The Influence of Light on Circarhythms in Humans

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Abstract The present review discusses two types of biological rhythms, namely, circadian rhythms and circannual rhythms. Humans possess a circadian rhythm of approximately 24 hours, which is regulated by neural and hormonal processes. The synchronisation of this rhythm with the solar day and night is maintained through entrainment mainly by light. Dark environments completely lacking windows may have a negative effect on well-being and work capacity. During shift work the biological clock tends to maintain its normal ‘diurnal’ rhythm, which may lead to extreme tiredness and increased risk of accidents. Negative effects such as these may be partially alleviated by means of bright light during the night. During air travel across several time zones there is little time for the biological clock to adjust, but the resulting ‘jet lag’ may possibly be overcome by means of appropriately timed exposure to bright light. In countries situated far from the equator, the biological clock may become seriously disrupted during the short days of the dark season. Characterised by fatigue, sadness and sleep problems, these seasonal affective disorders may be cured or alleviated by means of regular periods outdoors, better lighting indoors, or, in the most serious cases, light therapy.

Keywords: chronobiology, circadian rhythms, circannual rhythms, jet lag, seasonal affective disorder, shift work

Introduction

Change is fundamental to life itself, and when it repeats itself over and over again in the same manner, this is called a biological rhythm. Heart beat, for instance, constitutes such a rhythm or, rather, a multitude of closely interwoven rhythms. Some biological rhythms are extremely brief, whereas others may have a period of several years. One characteristic of a biological rhythm is that the length of its period is approximate rather than exact, hence the term circarhythm. Most biological rhythms are known to be guided by internal pacemakers, but they may also be attuned, within certain limits, by external factors. The present review will discuss two types of rhythms, namely, circadian rhythms and circannual rhythms. As indicated by their names, the former has a period of approximately 24 hours, and the latter of about one year.

Circadian Rhythms

During the evolution of life on earth, sunlight with its characteristic spectrum and variations between day and night has had a decisive impact on most existing life forms and their adaptation to their natural environments. As a direct consequence of this, humans display a circadian rhythm of approximately 24 hours including, amongst other things, sleep and wakefulness, body temperature, metabolism, hormone production, and fluctuations in attention and behaviour (Küller and Küller, 2001). The control of this rhythm depends partly on internal processes in the central nervous and endocrine systems, usually referred to as ‘the biological clock’. (This name may be misleading, since there is obviously a multitude of biological pacemakers in humans. Still, the term will be employed in this paper for the system regulating the circadian rhythm.)

For reasons of survival it is of the utmost importance that the biological clock be synchronised with the solar day and night, and in order for this to function the clock is entrained almost exclusively by access to natural daylight (although in the modern industrialised world artificial light has taken over part of this function) (Arendt, 1998; Wetterberg, 1994). The entrainment of the biological clock by light entering the eye is known to involve the retino-hypothalamic pathways and the suprachiasmatic nuclei, as well as the pineal gland (Brainard et al., 1997). According to most recent studies, entrainment occurs mostly during dawn and dusk, that is, the transition periods from night to day, or from day to night, mainly in terms of what is known as ‘phase advance’ or ‘phase delay’.
of the circadian rhythm (although the possibility of a sustaining effect of light during the middle of the day can not be completely ruled out). Accordingly, the length of the day and duration of daylight are of great importance in regulating the circadian rhythm, although this may be modified, to some extent, by exposure to artificial illumination (Czeisler et al., 1990).

In the pineal gland a so-called sleep hormone—melatonin—is produced, which seems to be of central importance for the entrainment of the circadian rhythm. Starting at dusk and ending at dawn, melatonin is synthesised almost exclusively during the night, provided there is sufficient darkness. However, as soon as the eye is exposed to light of sufficient brightness, the production of melatonin will be attenuated, and if this occurs in the morning or evening, a phase shift of the diurnal rhythm may result (Arendt, 1998; Vondrasova et al., 1999).

Research shows that melatonin, directly or indirectly, influences a number of other hormones in the pituitary, thyroid, and adrenal glands. Melatonin may also be involved in the immuno-defence system (Hardeland et al., 1995). Mediated by the adrenocorticotrophic hormone (ACTH) from the pituitary, the production of cortisol in the adrenal cortex also displays a pronounced circadian rhythm, with high levels during daytime and low levels during the night. Cortisol acts as a mobiliser of the human organism, both physiologically and mentally, and, somewhat simplified, cortisol may be conceived of as dominating during the high demands of daytime activity, whereas melatonin dominates recuperation and sleep during the night (Rivest et al., 1989). Several other hormones, such as the human growth hormone (GH), also display a pronounced circadian rhythm.

**Disruptions of the Circadian Rhythm**

**Shift Work and Jet Lag**

Shift work may cause serious disruptions of the biological clock, including extreme sleepiness and lack of concentration during the night and early morning, and an increased risk of accidents. One reason for this is that shift workers often retain their ‘daytime’ circadian rhythm and must therefore perform at their best although their bodies are ‘asleep’ (Akerstedt, 1995). Prolonged shift work may eventually result in a collapse of the entire circadian system and even contribute to gastrointestinal and coronary illness, leading to increased mortality. Studies during the past few years have shown that such disruptions may be avoided by the use of bright light during night-time. Successful attempts have been made to develop artificial lighting systems which simulate the daytime variation of natural daylight, for instance, in arctic research stations and space stations, but also in industrial environments. However, this requires that the shift workers are provided with undisturbed rest under dark and quiet conditions during the daytime. Furthermore, any artificial shift of the circadian rhythm must be seen in the broader context of being able to live a normal social life (Bougrine et al., 1995; Campbell, 1995; Czeisler et al., 1990; Eastman and Martin, 1999; Foret et al., 1998).

Also, travel by flight across time zones may result in serious chronobiological disruptions. The prevailing circadian rhythm can normally not be changed by more than one or a few hours per day. Therefore, it will often take several days or even a week before the individual becomes adjusted to the solar day and night at his or her destination. The sudden discrepancy between the biological and solar clocks resulting from air travel is usually referred to as ‘jet lag’. Attempts have been made to alleviate disruptions resulting from jet lag by accelerating the phase shift either by light therapy or by the oral intake of melatonin. At least one computer program has been developed with the specific aim of calculating the most effective timing of this therapeutic treatment. It is still too early to draw any firm conclusions regarding the outcome of these attempts (Boulos, 1998; Houpt et al., 1996; Samel and Wegmann, 1997).

**Circannual Rhythms and Seasonal Affective Disorder**

Recent research has also shown that the production of a number of hormones displays seasonal variations in humans living far north or south of the equator (Touitou and Haus, 1993). This seems to be the case for both melatonin and cortisol. As for melatonin, the peak in production appears to be phase advanced, that is, to occur earlier during the night, in summer than in winter (Arendt, 1998; Vondrasova et al., 1999). Field studies in southern Sweden show that the early morning production of cortisol diminishes during autumn and winter, but then increases already at the end of February, probably as a result of the corresponding increase in the length of the day. Other types of seasonal variations in cortisol have been found in other climatic zones (Küller and Wetterberg, 1996).

Deviations from the normal circadian rhythm, which usually occur during the dark season, may result in fatigue, sleep disorders and sadness. Excessive fatigue or even depression during autumn and winter is probably the result of the decrease in the number of daylight hours and the phase shift of the biological clock, whereas depression during spring may be associated with the return of daylight. When serious symptoms occur in the same individual on two or more consecutive years, the individual is diagnosed as having seasonal affective disorder (SAD) or, in milder cases, 'sub-SAD' (Rosenthal, 1998). A large proportion of the population living in the northern hemisphere suffers from winter fatigue during
the period November to February, whereas autumn fatigue (October-November) and spring fatigue (March-May) are much less common. The prevalence of SAD and sub-SAD has been documented in a large number of studies, amongst others, in Alaska, Denmark, England, Finland, Iceland, Norway, Saudi Arabia, Scotland, Sweden, Switzerland and the central USA, and, in the southern hemisphere during their dark season, in Antarctica, Argentina, Australia and South Africa (Küller et al., 2001).

Other kinds of seasonal variations have been identified, which may be related to seasonal variations in the length of day, namely, fluctuations in mental attention and in sociability, in body growth, birth rates, and the prevalence of suicide and homicide. As concerns general health, it has been observed that the number of sick days generally increases in northern countries during the winter, which may depend on a number of factors, such as, increased exposure to colds and infections, decreased intake of natural vitamins, decreased exposure to ultraviolet light, decreased physical activity, but possibly also as a consequence of chronobiological disorders (Küller and Wetterberg, 1996; Preti, 1997; Roenneberg and Aschoff, 1990a, b; Rusack et al., 1996; Tihonen et al., 1997).

By means of light therapy, mornings or evenings, it appears to be possible to correct various disruptions of the circadian rhythm, such as insomnia or early awakening. Light therapy during the autumn and winter has been successfully applied in the alleviation of fatigue and depression during these seasons. There is some element of disagreement regarding the timing of this treatment, but there is at least some consensus that bright morning light is effective in most cases of SAD. On the other hand, there is reason to believe that patients of different circadian types might benefit from light at different times of day. There is also some evidence that regular periods outdoor during daylight hours may be a good alternative to artificial light therapy (Beauchemin and Hays, 1996; Campbell et al., 1995; Dijk et al., 1995; Lam, 1998; Lewy et al., 1998; Terman et al., 1995; Wirz-Justice et al., 1996).

**Individual Differences in Vulnerability**

Differences in the chronobiological system exist both on the individual and group levels. SAD is more common in females than in males, and there may also be correlations with certain personality traits (Jang et al., 1997). In the blind there are obvious difficulties in entraining the biological clock to the solar day and night, and most severely visually handicapped have a circadian rhythm that is ‘free-running’, that is, solely dependent on internal pacemakers. Even elderly people with visual cataracts in both eyes run the risk of becoming ‘free-running’, especially if they spend most of their day indoors. In many of these cases, therapy with oral melatonin has been successfully employed (Lockley et al., 1997). There may also be differences between individuals living in different geographical regions. For instance, an uncommonly low propensity for seasonal affective disorder has been found in the Icelandic population (Magnusson et al., 2000). There may be genetic factors behind these differences.

**Lighting and Other External Factors**

Many of the biological and psychological effects of light seem to be related to both the character of the light source and to the ambient lighting environment. Dim or otherwise insufficient indoor illumination may influence not only mood and stress level, but also the work capacity of people in that environment. The illuminance level and distribution of indoor lighting are important, as well as the duration and timing of the exposure. In most indoor spaces the natural daylight through the windows adds to the effect of artificial light sources to form the total lighting environment. Even the spectral composition of the light may be of importance, however, there are different views on the advantages and disadvantages of different spectra regarding human well-being and performance (Boivin and Czeisler, 1998; Küller and Laike, 1998; Küller et al., 1999; Veitch and McColl, 2001). Even if light is the most important factor, the circarhythms may also be influenced, to some extent, by climatic factors and lifestyle (Honma et al., 1995; Molin et al., 1996). Although there are no conclusive results, the existence of effects resulting from electrical and magnetic fields can not be completely ruled out.

The results of some studies support the view that prolonged periods in windowless or otherwise dark environments may worsen the symptoms of SAD and sub-SAD, and contribute to increased fatigue, lack of energy, and affective disorders. Furthermore, lighting conditions indoors vary much less than natural daylight outdoors. These more static conditions may make the synchronisation between the biological and the solar clock more difficult, especially during the autumn, winter and spring, when fairly little light is entering through the windows. In a recent study it was found that seasonal disorders may be partially alleviated for those who work close to a window, or in brightly illuminated indoor spaces (Küller et al., 1999). Subterranean environments are among the most stable, both in terms of lighting and climatic conditions. The variations between day and night, and summer and winter, are generally extremely small, and there is no view of the outside world. One result of this is that those working underground display less pronounced seasonal variations, both in terms of emotions and hormones (Küller and Wetterberg, 1996).
Conclusions

Humans possess a circadian rhythm of approximately 24 hours, including sleep and wakefulness, body temperature and metabolism, which is regulated by neural and hormonal processes—the biological clock. The synchronisation of this clock with the solar day and night is maintained through entrainment by daylight—or artificial light—mostly during the morning and evening. In countries situated far from the equator, the biological clock may become seriously disrupted during the short days of the dark season. Characterised by fatigue, sadness, and sleep problems, these seasonal affective disorders may be cured or alleviated by means of regular periods outdoors, better lighting indoors, or, in the most difficult cases, light therapy.

For those who spend a great deal of time indoors, access to sufficient daylight through windows becomes important, especially during the dark season. Dark environments completely lacking windows may have a negative effect on personal well-being and work capacity. Today, an increasing number of windowless and subterranean environments are being built, not only for transportation and storage purposes, but also factories, supermarkets, hospitals, restaurants, hotels, and even major portions of office buildings are sometimes located underground. Undoubtedly, this trend will place new demands on indoor lighting.

All types of light within the visual range, both natural and artificial, have some influence on the biological clock, bright light being more effective than dim light, and white light or daylight being more effective than coloured light (possibly with some exceptions). In indoor spaces not only the light sources, but also a light ceiling, walls and floor, will contribute to increasing the effect. Although some non-visual effects of light have been known to science for a century or more, it is only recently that this knowledge has been brought to the eyes of the lighting community. It is high time that these facts were taken seriously and integrated into the rules regulating the design of indoor lighting environments, both in people’s homes and at their work-places. For instance, some studies suggest that the recommended levels of indoor illumination, which until now have been based solely on visual criteria, are too low during the winter mornings to entrain the circadian rhythm. New technical solutions need to be developed, which meet the demands not only of the visual, but also of the non-visual criteria, and which also consider individual variations and the need for personal control.

During shift work the biological clock tends to maintain its normal ‘diurnal’ rhythm, which may lead to extreme tiredness and increased risk of accidents. Negative effects such as these may be partially alleviated by means of bright light during the night. During air travel across several time zones there is little time for the biological clock to adjust, but jet lag may possibly be overcome by means of suitably timed exposure to bright light. Both shift work and air travel are characteristics of the modern industrialised society, and both will become even more common in the near future. More research is needed in order to gain a comprehensive understanding of the negative effects on health, not least in terms of individual vulnerability and response to different types of treatment.

References

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