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Disruptions of circadian rhythms in an age of global urbanisation – have they been studied closely enough?

Zaburzenia rytmu circadialnego w epoce globalnej urbanizacji – czy poświęcono im wystarczająco wiele uwagi?

Jacek J. Pruszyński[1], Irena Padzińska-Pruszyńska[2], Małgorzata Górczak[2], Inga Włodarczyk-Pruszyńska[3]

[1]School of Public Health, Centre of Postgraduate Medical Education, Warsaw

[2]Warsaw University of Life Sciences, Center of Cellular Immunotherapies

[3]University Clinical Center of the Medical University of Warsaw

Abstract

Technology has been developing rapidly and, at the same time, urbanisation keeps progressing in countries of the Global North and the Global South alike. This has exposed humans to various threats which have not existed before. Even though we, as a society, realise most such threats are there, the awareness of the fact that there are factors which might disrupt the functioning of our internal biological clocks governing our circadian rhythm is still insufficient, especially among the elderly. The purpose of this study is to carry out a review of information related to the dangers of being exposed to an environment where various factors interfere with our physiology and behaviour by means of disrupting our biological rhythms and thus exert a negative impact on our overall physical health. Such factors also affect our mental health, leading to a reduction of our well-being levels. (Gerontol Pol 2024; 32; 32-40) doi: 10.53139/GP.20243204

Keywords*: circadian rhythm, biological clock, light pollution, melatonin, diseases of affluence, the elderly*

Streszczenie

Rozwój techniczny w połączeniu z postępującą urbanizacją mającą miejsce zarówno w krajach globalnej północy jak i południa stał się przyczyną narażenia na różnorodne, niespotykane wcześniej zagrożenia. Choć istnieje społeczna świadomość większości z tych niebezpieczeństw, to wiedza o czynnikach zakłócających prawidłową działalność zegara biologicznego, który reguluje rytm circadialny jest wciąż niewystarczająca, zwłaszcza wśród starszej wiekiem populacji. Celem niniejszego opracowania jest przegląd informacji dotyczących niebezpieczeństw wynikających z przebywania w warunkach, w których różnorodne czynniki, poprzez desynchronizację rytmów biologicznych powodują zaburzenia procesów fizjologicznych oraz behawioru wywierają negatywny wpływ nie tylko na zdrowie fizyczne współczesnej populacji, ale również na jej stan psychiczny, co odbija się negatywnie na ich dobrostanie. (Gerontol Pol 2024; 32; 32-40) doi: 10.53139/GP.20243204

Słowa kluczowe*: rytm circadialny, zegar biologiczny, skażenie światłem, melatonina, zagrożenia cywilizacyjne, osoby starsze*

Introduction

It cannot be disputed that technological progress has given modern societies unprecedented levels of comfort and convenience. However, the industrial revolution – the underlying cause of today's prosperity – is also associated with moving away from behavioural patterns which used to be typical for humans. In developing societies, the migration of people from rural areas to ever-expanding cities resulted in people spending most of their time in enclosed spaces instead of more natural environments. This not only severs their connection to the biome within which their ancestors lived and functioned but also disrupts their connection to the na-

Adres do korespondencji / Correspondence address: Jacek J. Pruszyński; School of Public Health, Centre of Postgraduate Medical Education, 61/63 Kleczewska St., 01 826 Warsaw ☎ (+48 22) 560 11 60 jacek.pruszynski@cmkp.edu.pl
ORCID: Jacek J. Pruszyński 0000-0003-2123-6488, Irena Pruszyńska 0000-0003-0784-8066, Małgorzata Górczak 0000-0001-5383-6096, Inga Włodarczyk-Pruszyńska 0000-0003-2719-1815

tural daily rhythms of the external world [1]. The global urbanisation creates new types of environmental pollution of which the general public is mostly unaware, even though they cause major health-related issues. The light pollution is a good example of this [2]. It is estimated that a considerable portion of the planet's population, including most people living in the Global North, is affected by artificial light both during the day and at night [3]. Such lighting, whose intensity and spectrum differs from natural light, affects our living conditions and has a negative impact on organisms whose evolution was influenced by the natural cycle of light and darkness. One of the consequences of this is a disruption of the functioning of human biological clock [4,5] and the resulting de-synchronisation of biological rhythms [6]. This is due to excessive lighting at night coming from sources such as street lights, car headlights, illumination inside buildings, and light emitted by the displays of TV sets, PCs, tablets, and mobile phones as those have become a permanent part of life not only for adults and young people but also for children [7,8].

Circadian rhythm

The cyclical nature of forces causing such phenomena as the circulation of the Earth around the Sun, the Earth's revolution around its own axis, and the circulation of the Moon around the Earth exerts a considerable impact on organisms inhabiting our planet [9]. The presence of light and dark periods following each other in sequence is a core factor impacting the conditions of life on Earth. While the duration of those periods might change together with seasons, there is always a light period and a dark period in a 24-hour day on Earth. As sun rises and sets, plankton embarks on its vertical migration, moving up or down, flowers on plants open and close, and animals sleep or seek sustenance [10]. The behavioural patterns and metabolism of organisms on Earth change depending on the conditions in their environment and sometimes even in anticipation of certain circumstances. This suggests the existence of a biological clock measuring the passage of time and issuing the relevant commands to the body [11]. The molecular mechanism of that clock is based on negative and positive feedback loops which enable and disable the transcription of certain genes called clock genes. Their protein products act as transcription factors for another group of genes (referred to as CCG, clock-controlled genes). The main loop of the clock is a negative feedback loop whose end product (protein) hampers the expression of its own gene [12-14].

Jean-Jacques d'Ortous de Mairan, a French astronomer, was the first to suspect that we might be conditioned to follow our daily rhythms instead of just passively responding to natural light or thermal cycles. He noticed that the *mimosa* plant opened up and folded its leaves every day even if it was constantly kept in the dark [15]. That discovery suggested there was an internal biological mechanism which determined the behaviour of the plant's leaves based on the time of the day – this happened independently from the presence or absence of sunlight. Further work carried out by researchers whose interest was piqued by that discovery led to the emergence of chronobiology – the scientific investigation of the role of time in the progress and regulation of physiology and behavioural patterns in humans and animals [16].

Research has proven that the cyclical nature of physiological processes and behavioural patterns are both based on rhythms dependent on the biological clock which is programmed to anticipate the night/day cycle in order to ensure optimum behaviour [17]. Due to the fact that the rhythms governing various processes in living organisms do not correspond to 24-hour cycles exactly, such rhythms came to be known as circadian (from Latin: *circa* – around, *dies* – day) [18]. They are considered the basic units of time by which the biological clock functions and they play an important role in adaptation to one's environment [19]. The fact that circadian rhythms still impact living organisms even when they are in an environment making it impossible to discern the time of day (e.g. in constant darkness) suggests that they are endogenous/internal in nature. If external stimuli are insufficient to regulate an organism's biological cycles (e.g. if there is no light which is the main factor used for such synchronisation), the circadian rhythm of that organism tends to lengthen or shorten a little which manifests itself as it feeling sleepy or hungry at times differing from those dictated by its biological clock under regular circumstances [20]. Research was carried out in the 1960s and 1970s in order to pinpoint the location of the biological clock and it was determined that, at least in mammals, it is in the suprachiasmatic nuclei (SCN from Latin: *nuclei suprachiasmatici*) of the hypothalamus [21]. It is there that the master clock is located, in charge of sending signals to its subordinate organs about the time of the day so as to adjust their levels of activity to the environment. The effectiveness of that clock depends on the adjustment of the body to the periodically changing external conditions (which are influenced by the day/night cycle and seasons of the year) so there is a communication link between the central mechanism located in SCN and sources of external data. The term Zeitgeber (German for "time-giver") is typically used in chronobiology [22]. It refers to the environmental impulses which synchronise the operation of the biological clock with the external environment. The main "giver of time" for SCN is light. Information about light levels is collected in the retina by a small set of specialised receptor cells whose function is not otherwise related to vision. From there, it is transmitted to SCN and then to the pineal gland which, in humans, is located in the 3rd ventricle of the brain [23]. The pineal gland, being able to synthesize melatonin (5-Methoxy-N-acetyltryptamine) which is a functional neuroendocrine transmitter, participates in converting visual (light) stimuli to hormonal signals, contributing to bringing the interior functions of the body into sync with the light/dark period outside.

Melatonin – the signal that the night has not ended

The production of melatonin is largely dependent on the exposure of the retina to intense light – the largest quantities of melatonin are produced at night and only trace amounts of it during the day [24]. The intensification of melatonin (the "dark hormone") production during the dark period of the 24-hour cycle signals to cells of the body that it is night time. The nightly increase of melatonin production can be observed not only in humans and other diurnal animals (e.g. dogs, farm animals, most birds) but also in species which feed, move, or socialise after darkness falls (mice, rats, owls, bats). As nocturnal animals consider information about increased melatonin production a signal to start being more active, the function of melatonin should not, contrary to popular belief, be reduced to it being the "sleep hormone" [25].

The effects of melatonin

Melatonin acts as an endogenous synchroniser capable of stabilising and/or reinforcing many biological rhythms. In diurnal animals, an increase of melatonin production correlates to a decrease of their core temperature and a lowering of their rate of metabolism so as to make it possible to regenerate energy resources. In addition to governing the cycles of sleep and wakefulness and the changes to the body associated with those, melatonin also has a pleiotropic function, influencing the secretion of multiple hormones (including prolactin, lutropin, follitropin, somatotropin, the thyrotropin-releasing hormone, the adrenocorticotropic hormone, and glucocorticosteroids) [26]. It adjusts the level of activity of the immune and cardiovascular systems and removes free radicals [27-30]. It has also been suggested that it functions as a neurotrophic factor [31]. There is research confirming the impact of melatonin on the reproductive system of animals in the wild [32]. Thanks to a well-tuned internal clock, they are able to not only recognise the time of day but also anticipate the progression of seasons which, in turn, allows them to modify their physiological processes accordingly and adjust their behaviour to the external environment. Recognising that the days are becoming longer or shorter makes it possible for animals in the wild to mate at times ensuring that their offspring are born at an opportune moment [33]. For those species whose embryos develop fast, when night becomes shorter and, consequently, the time for which melatonin is produced in the pineal glans also shortens, their reproductive system is activated and the animal receives a signal to start looking for a mate. Reproductive functions in larger mammals living in the wild – in whom pregnancy lasts several months – are regulated in the opposite way to the one described above. For them, the signal to activate gonads and form couples comes when days start to become shorter and melatonin is secreted into the blood for longer periods of time per day so as to ensure that their offspring are born at a time when food is plentiful and temperature outside facilitates survival [34]. There is evidence confirming that melatonin has considerable impact on the animal world and there is research indicating that it might also play a part in regulating reproductory processes in humans [35,36].

Disruptions of the level of melatonin and their possible relation to illness

Disrupted levels of melatonin concentration are detected in people suffering from various disorders. Lowered levels of melatonin were noticed in some research in patients suffering from depression, schizophrenia, as well as in alcoholics, even after they have refrained from consuming alcohol for several years, and in people affected by the cluster headache syndrome, and in some Alzheimer patients [37,38]. A similar correlation was noticed in the case of some tumours such as: anal cancer, endometrial cancer, cervical cancer, stomach cancer, and thyroid cancer [39]. There is also some data confirming reduced melatonin levels in patients suffering from breast cancer, lung cancer, and prostate cancer: a correlation was found between the stage of the disease and the maximum level of concentration of melatonin with the latter dropping in patients suffering from advanced tumours [40]. Some data indicate that the secretion of melanotropin is reduced in patients suffering from the coronary heart disease [41] and the chronic kidney disease [42]. Conversely, increased melatonin concentration was detected in women suffering from functional hypothalamic amenorrhoea [43] or from hyperlactatemia [44], as well as in men suffering from some types of infertility [45]. The maximum nightly level of melatonin may also drop with age [46,47]. Even though there is some research suggesting that the variation of levels of melatonin in blood plasma might be related to the degree of pineal gland calcification rather than to a given person's age in strictly chronological terms [48], it is believed that higher levels of melatonin in elderly people might play a part in healthy ageing and longevity [49].

Possible implications for therapeutics in the future

The discovery of the role of circadian rhythms and the emergence and progress of chronobiology have made it possible to develop procedures aimed at remedying for the discrepancies between the circadian rhythm and the desired sleep / wakefulness schedule [50]. As there is evidence confirming that a disruption of circadian rhythms might have a detrimental impact on the overall health of an individual and/or might be related to the onset and progression of many common diseases, future research into that subject may lead to the development of effective chronotherapy solutions, considerably improving the efficiency of treatment for certain disorders [51,52].

Discussion

Research indicates that American people spend, on average, 87% of their time in enclosed rooms and around 6% of their time in various means of transport [53,54]. People in other developed countries tend to spend almost 90 per cent of their day (21 hours out of 24) in enclosed spaces [55]. The COVID-19 pandemics and the restrictions related to mobility imposed by some governments resulted in a phenomenon referred to as anthropause, the slowing-down of human activity [56] which further reinforced such way of living. This has led to a situation where in some societies the total time people spent outdoors has become an insignificantly small portion of their day. So small, in fact, that it hardly is worth taking into account in compilations presenting all places a person visits [57]. The urban lifestyle – typical for societies whose current form was shaped by the industrial revolution and major population movements – has become so appealing that it not only results in the number of people living in cities continuing to increase [58,59] but also in an urban-like lifestyle being adopted by people living in more rural areas [60,61]. All this leads to people spending the majority of their time in places where there are various types of artificial light sources and being, consequently, almost entirely deprived of the option to stay in total darkness. This has a major impact on the functioning of their biological clock – it has been demonstrated that even weak and diffused light whose intensity cannot be visually detected by humans can influence the human circadian rhythm [62]. In addition to that, the urban lifestyle mentioned above means that the term "free time" has become almost synonymous with "time spent in front of some sort of a display." This phenomenon is further reinforced by the development of high technologies which make it possible to create virtual realities, new forms of mobile telephony, top class personal computers, and smart TV sets [63,64]. Because the functioning of our biological clock, our wakefulness, and the physiology of our sleep are affected so much by light, whose sources include displays and screens, using computers and smartphones for too many hours and too often has become a concerning phenomenon, as has watching too much television, especially late at night [65,66].

Unfavourable health consequences also follow if time spent in front of various types of screens replaces the time we would otherwise have spent on other activities. This phenomenon can already be observed even among young children: as many as 30% of pre-school children and from 50% to 90% of school children and teenagers overuse multimedia and consequently does not engage in other activities. This is particularly evident in a considerable reduction of the amount of time assigned to physical activity out of doors [67] and a reduction of the amount of sleep they get [68]. Devices with displays emitting artificial light are present in the bedrooms of 75% of children and around 60% of iGen teenagers claim that they use such devices before going to sleep [70]. This results in them ending their days later and in sleeping shorter [71]. The situation is similar in the case of adults: they, too, spend considerable amounts of time indoors – whether working or relaxing by means of watching TV or surfing the Internet. They are also affected by the health-related issues resulting from insufficient exposure to daylight [72] and they, too, suffer the negative consequences of exposure to sources of artificial light, especially light whose wavelength falls between 380 and 440 nm (blue-violet light) such as light emitted by devices such as laptops, phones, tablets, TV sets, and household and urban lighting [73,74]. An additional harmful habit some of us have developed is switching on the TV at night, after awakening from sleep [75] because the impact of such light at night where the pineal gland is the most active results in unfavourable changes to its functioning [76] which, in turn, brings about a considerable reduction of the level of melatonin in the blood [77]. The negative impact of such detrimental stimuli is further exacerbated in the elderly due to changes taking place as part of the ageing process. The increasing inability to cope with basic life-related tasks independently and the social isolation of the elderly who tend to spend most of their time at home results in them suffering from loneliness [78]. The stress that this causes further disrupts the functioning of their biological clock. The issue is further compounded by the fact that 40% to 70% of the elderly suffer from chronic insomnia [79] as a result of other chronic diseases affecting them [80]. All this contributes to a further disruption of their circadian rhythm.

The biological clock – if it is allowed to function in line with the day/night cycle – is capable of regulating many physiological processes by means of causing circadian fluctuations impacting the transcription and translation processes. The daily rhythm imposed on the body by the biological clock has considerable impact on vital life processes and parameters such as sleep, consumption of meals, secretion of hormones, blood pressure, and bodily temperature [81]. Correct activity of the clock genes has an impact on metabolism by controlling the process of gluconeogenesis, as well as on susceptibility to insulin and changes to the concentration of glucose [82]. If the functioning of the internal clock is disrupted – especially for an extended period of time – the organism thus affected suffers from irregularities related to internal processes and its adjustment to the external environment. This, in turn, leads to major negative health-related consequences [84]: an increased risk of widespread 21st-century diseases such as tumours, neurodegenerative disorders, and metabolic disorders [85].

Conclusions

Maintaining correct circadian rhythm is of vital importance for proper functioning of the body because it makes it possible for the body to synchronise many of its internal processes with the time of day and enables it to prepare itself for cyclical changes affecting its environment. Thanks to its ability to respond to external stimuli (sunlight being the most important such stimulus), the central biological clock of the body generates circadian rhythms and uses coordinating signals to control the effector structures of the body. Disruptions of the functioning of the biological clock due to new types of harmful environmental factors (including light pollution) not only has a negative impact on the quality of life but could also lead to the occurrence of many illnesses and diseases. A very common issue related to a disruption of circadian rhythms is insomnia (which is especially widespread among the elderly). Knowledge about the function of the biological clock and the circadian rhythms it generates could improve diagnostics and therapy related to a wide range of diseases and could also be used to promote behavioural patterns facilitating well-being and correct functioning among people of every age.

Konflikt interesów/ Conflict of interest
Brak/ None

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