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Michał Zimecki
Instytut Immunologii i Terapii Doświadczalnej im. Ludwika Hirszfelda

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The lunar cycle: effects on human and animal behavior and physiology

Cykl księżycowy: wpływ na zachowanie ludzi i zwierząt i ich fizjologię

Michał Zimecki

Department of Experimental Therapy, The Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, Wrocław, Poland

Summary

Human and animal physiology are subject to seasonal, lunar, and circadian rhythms. Although the seasonal and circadian rhythms have been fairly well described, little is known about the effects of the lunar cycle on the behavior and physiology of humans and animals. The lunar cycle has an impact on human reproduction, in particular fertility, menstruation, and birth rate. Melatonin levels appear to correlate with the menstrual cycle. Admittance to hospitals and emergency units because of various causes (cardiovascular and acute coronary events, variceal hemorrhage, diarrhea, urinary retention) correlated with moon phases. In addition, other events associated with human behavior, such as traffic accidents, crimes, and suicides, appeared to be influenced by the lunar cycle. However, a number of reports find no correlation between the lunar cycle and human reproduction and admittance to clinics and emergency units. Animal studies revealed that the lunar cycle may affect hormonal changes early in phylogenesis (insects). In fish the lunar clock influences reproduction and involves the hypothalamus-pituitary-gonadal axis. In birds, the daily variations in melatonin and corticosterone disappear during full-moon days. The lunar cycle also exerts effects on laboratory rats with regard to taste sensitivity and the ultrastructure of pineal gland cells. Cyclic variations related to the moon's phases in the magnitude of the humoral immune response of mice to polivinylpyrrolidone and sheep erythrocytes were also described. It is suggested that melatonin and endogenous steroids may mediate the described cyclic alterations of physiological processes. The release of neurohormones may be triggered by the electromagnetic radiation and/or the gravitational pull of the moon. Although the exact mechanism of the moon's influence on humans and animals awaits further exploration, knowledge of this kind of biorhythm may be helpful in police surveillance, medical practice, and investigations involving laboratory animals.

Key words: **lunar cycle • reproduction • melatonin • immune response**

Streszczenie

Rytmy biologiczne, takie jak sezonowy, księżycowy i dobowy mają istotny wpływ na zachowanie i procesy fizjologiczne ludzi i zwierząt. Jak dotąd, wpływ cyklu księżycowego na fizjologię ludzi i zwierząt nie doczekał się osobnego opracowania. Niewiele jest prac na ten temat. Cykl księżycowy ma wyraźny wpływ na reprodukcję człowieka, w szczególności zaś na płodność, menstruację i częstość urodzin. Poziom hormonu szyszynki-melatoniny koreluje z cyklem menstruacyjnym. Częstość przyjęć do szpitali z powodu: ataków serca, krwawień dojelitowych, ostrej biegunki i zatrzymania oddawania moczu jest także regulowana przez fazy księżyca. Ponadto, inne zdarzenia związane z zachowaniem człowieka, takie jak liczba wypadków drogowych, przestępstw kryminalnych i samobójstw są także pod kontrolą faz księżyca. Istnieje jednakże wiele opracowań, które nie potwierdzają powyższych obserwacji. Dotyczą one wpływu faz księżyca na reprodukcję oraz częstości przyjęć do szpitali. Badania na zwierzętach ujawniły, że cykl księżycowy wpływa na poziom hormonów już u owadów. U ryb zegar księżycowy wpływa na reprodukcję (czas tarła) i angażuje oś podwzgórze–przysadka mózgowa–gonady. U ptaków dobowe zmiany w poziomie melatoniny i kortykosteroidów znikają w czasie pełni księżyca. Cykl księżycowy wpływa również na wrażliwość smakową szczurów, a także na ultrastrukturę komórek szyszynki. Opisano także rytm w wielkości humoralnej odpowiedzi immunologicznej u myszy na poliwinylopirolidon oraz erytrocyty owcy. Sugeruje się, że za rytm biologiczny, indukowany przez zmiany faz księżyca, są odpowiedzialne zmiany w poziomie melatoniny i steroidów. Uwolnienie neurohormonów może być indukowane przez promieniowanie elektromagnetyczne lub grawitacyjne przyciąganie księżyca. Chociaż mechanizm działania księżyca na procesy fizjologiczne człowieka i zwierząt wymaga ostatecznego wyjaśnienia, to akceptacja tego zjawiska i wiedza na jego temat może być przydatna w nadzorze policyjnym, praktyce szpitalnej i badaniach naukowych na zwierzętach laboratoryjnych.

Słowa kluczowe: **cykl księżycowy • reprodukcja • melatonina • odpowiedź immunologiczna**

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Author's address: Michał Zimecki, Department of Experimental Therapy, The Institute of Immunology and Experimental Therapy, Polish Academy of Sciences,, Weigla 12, 53-114 Wrocław, Poland; e-mail: zimecki@iitd.pan.wroc.pl

Human and animal activities, physiological processes, and behavior are subject to alterations caused by circadian rhythms, lunar cycles, and seasonal changes. Circadian [12] and seasonal rhythms [30,36] are well described, but the effects of the lunar cycle on humans and animals have been much less explored. The aim of this article was to review available data regarding effects of the lunar cycle on human and animal physiology, with particular attention paid to alterations in the immune response of experimental animals.

Effects of the lunar cycle on humans

Fertility, menstruation, and births

The possibility of a lunar effect on the menstrual cycle was investigated in 312 university students [8]. Of 312 women, 68 experienced lunar-period cycles (29.5 days). Forty-seven women of that group menstruated in the light half of the month; therefore, ovulation tended to occur in the dark phase of the lunar period, defined as the half cycle of the month from the last quarter through the new moon. Even women with irregular menses tended to ovulate during the dark phase of the lunar period. The author speculated that the lunar cycle is associated with the natural rhythm of electromagnetic radiation, which has an effect on the human menstrual cycle. In another study comprising 826 female volunteers [18] with normal menstrual cycles, a large proportion (28.3%) menstruated around the new moon, while at other times during the lunar month the proportions of menstruation were lower (8.8–12.6%) ($p<0.01$). Also, the differences in 6-hydroxymelatonin level between menstruation and ovulation were significant ($p<0.01$). Two of three volunteers had their zenith in the period of the new moon and nadir 3–4 days prior to the full moon, indicating a correlation between melatonin level and the menstrual cycle.

It also appeared that the lunar cycle has an impact on fertility and births. Data from 140,000 live births in New York City in 1968 showed small but systematic variations in births over a period of 29.53 days (the length of the lunar cycle), with peak fertility in the 3rd (last) quarter [7]. The timing of the fertility peak in the 3rd quarter suggests that the period of decreasing illumination immediately after the full moon may precipitate ovulation. An analysis of 5,927,978 French births occurring between 1968 and 1974 revealed three kinds of rhythms, one being a weekly rhythm, characterized by the lowest number of births on Sunday, and an annual rhythm, with the maximum number of births in May and the minimum in September–October [10]. In addition, a statistical analysis of the distribution of births within the lunar month showed that more babies were born between the last quarter and the new moon and fewer were born in the first quarter of the moon cycle. The observed differences were statistically significant. On the other hand, in an Italian study performed at the Fano Hospital in the years 1993–1994, deliveries clustered around the full moon phase [9]. Interestingly, the number of hospitalized spontaneous abortions were affected by perigean lunar positions (206-day periodicity) [44]. However, no significant effects of the lunar cycle on the number of deliveries were found in Austrian [45] and American [3,26] studies.

Hospital admissions

Several reports describe the effects of the lunar cycle on the frequency of hospital admissions due to various causes.

An influence of the lunar cycle was found in a two-year follow-up study of mortality due to cardiovascular emergencies (a total of 1,437 cases) [40]. The periodicity was, in addition, affected by solar activity (spots, eruptions, etc). The maximum and minimum mortality curves shifted in their time phases so that during periods of high solar activity minimum mortality was nearer to the new-moon and full-moon phases, while maximum death rate approached the first and last lunar quarters; during medium and low periods of solar activity the mortality maximums and minimums shifted counter-directionally to the moon's orbit around the Earth. Others studied the incidence of acute coronary events and admission patterns in emergency medical and cardiology departments [31]. Data from 1999 to 2001 were analyzed. Admissions on full-moon days were compared with those on new-moon days. There was increased incidence of acute coronary events associated with new-moon days ($p=0.005$). In another, prospective study, 447 consecutive patients with gastrointestinal hemorrhage were admitted over a period of two years [39]. The admissions were allocated to their corresponding day of the lunar cycle, and full-moon and non-full-moon days were compared. The results of that study suggested an increase in the number of admissions during the full moon, especially in men and in patients experiencing variceal hemorrhage. However, the wide variation in the number of admissions throughout the lunar cycle could limit an interpretation of the results. Others analyzed 753 cases of acute infectious diarrhea in adults in 1981–1990 in Kosice [25]. The group comprised 352 cases of bacillary dysentery, 305 patients with salmonellosis, 72 with campylobacteriosis, and 24 with yersiniosis. It appeared that statistically fewer patients were hospitalized ($p<0.0001$) during the full moon, quarter-moon, and new moon. In the intervals there were periods with short-term increases in daily admissions by 25%. The authors had no explanation for this phenomenon, but suggested that knowledge of it may improve the organization of the health service. A retrospective study of 815 patients with urinary retention admitted to two hospitals during a period of over three years showed no association between urinary retention and circadian, monthly, or seasonal rhythm [33]. However, significantly higher ($p<0.001$) retention was observed during the new moon in comparison with other phases of the lunar cycle. Lunar phases also affected patient requests for appointments at a thyroid outpatient clinic [49]. Requests for follow-up appointments had their highest peak three days after the full moon and requests for new appointments were most frequent five days afterwards. A rise in oral and maxillofacial emergencies was registered in the latter part of the seven-day period surrounding the full moon [6]. However, the correlation was not statistically significant. On the other hand, in a number of studies no influence of the lunar cycle on the incidence of emergency cases [47,48], cardiopulmonary arrest [2], survival of breast cancer patients [35], and surgical quality [14] was found.

Accidents, crimes, and suicides

Lunar periodicity can affect other human activities, as reflected by traffic accidents, crimes, suicides, and other behaviors. In one study, daily data on traffic accidents over a four-year period were compared with daily records of barometric pressure and synodic lunar cycle [1]. No significant variations in the number of accidents were found in relation to barometric pressure, but an impact of lunar periodicity was observed for one of the years under consideration. The number of accidents occurring during the full-moon day was lowest, the highest occurring two days before the full moon. Accidents were more frequent during the waxing than during the waning phase, but no significant differences were noted when the lunar month was divided into the four intervals of the lunar cycle. The incidence of crimes reported to three police stations in different towns in the period of 1978–1982 was also studied [43]. The incidence of crimes committed on full-moon days was much higher than on all other days, i.e. new-moon days and seven days after the full moon and new moon. The author concluded that the increased percentage of crimes on full-moon days may be due to "human tidal waves" caused by the gravitational pull of the moon. Suicides were also under the influence of the lunar cycle [16]. Studies in Ohio (1972–1975) were tabulated by year, month of year, day of week, lunar phase, and holiday occurrence. Only lunar phase demonstrated a significant correlation with suicide rate ($p<0.01$): an increase was observed with respect to the new moon but not for the full moon. A complex study evaluated by computer was conducted in Dade County, Florida [19]. Homicides and aggravated assaults demonstrated statistically significant clustering around the full moon. Psychiatric emergency room visits clustered around the first quarter and showed a significantly lower frequency around the new and full moons. The existence of a biological rhythm of human aggression which resonates with the lunar synodic cycle was postulated. Interestingly, sex differences in the frequency of calls to a crisis call center dependent on the lunar month were found [17]. An increase in calls was recorded from females and a decrease from males during the new-moon period, and there were proportionally more calls from males a fortnight later. Probably indirectly related to human behavior, the full moon was also associated with a significant ($p<0.001$) increase in animal bites to humans observed in 16,621 patients attending an accident and emergency department during 1997–1999 in an English city [4]. Lastly, the moon cycle had no effect on human daily rhythm, wake-up, and to-sleep times [5].

Animal studies

Insects and lower vertebrates

A study conducted on honeybees showed a 29.5-day rhythm regarding triacyloglycerols and steroids in the hemolymph as well as body weight peaking at the new moon [24]. Studies on fish [37,38,41] demonstrated that fish physiology is influenced by lunar periodicity and correlates with hormonal changes. Correlation between hormonal changes in the testis and lunar periodicity was studied in *Siganus argenteus*, which spawns synchronously around the last-quarter moon [37]. Weekly changes in sperm motility peaked around the last-quarter moon. The pH and osmolarity of the seminal fluid increased and decreased around the same lunar phase, respectively. These results suggest that the testis of this species develop according to the specific lunar phase. Experiments with addition of human chorionic gonadotropin or steroids to testicular fragments led to the conclusion that the lunar cycle clock influences the higher part of the hypothalamus-pituitary-gonadal axis [37]. A study on the golden rabbitfish *Siganus guttatus*, which spawns synchronously around the first-quarter moon during the reproductive season, showed daily fluctuations of melatonin concentration in the blood, which were low during the day and high at night [41]. In addition, plasma melatonin concentration at the new moon was higher than at full moon. When the fish were exposed to moonlight at midnight of both these moon phases, the melatonin concentration decreased to the control levels. These results show that the fish possibly perceive moonlight intensity and that plasma melatonin fluctuates according to brightness at a certain time of night. Fish kept in constant darkness or light at night did not spawn. It is possible that night conditions are related to synchronous gonadal development and spawning in the golden rabbitfish. The effects of moonlight exposure on plasma melatonin rhythms were also demonstrated in the seagrass rabbitfish *Siganus canaliculatus* [38]. When the fish were exposed to the four lunar phases, plasma melatonin levels around the new moon were significantly higher than during the first quarter and the full moon. The synchronous rhythmicity of melatonin levels in the plasma supports the hypothesis that the seagrass rabbitfish perceives moonlight intensity and responds with secretion of melatonin into the blood stream.

Reptiles and birds

Reports on the effects of the lunar cycle on the physiology of amphibians and reptiles are lacking. Amphibians [36] and reptiles [27–29] are subject to seasonal changes due to hibernation in winter. In the case of the turtle *Mauremys caspica*, spring increases cell proliferation in response to mitogens [27–29], and in autumn, proliferation and ADCC- and NK-mediated cytotoxicity [28] demonstrated their lowest values. The increased cell proliferation correlated with low levels of corticosterone and testosterone [29]. In the night-migrating skylark *Alauda arvensis*, the main nocturnal movements take place during the waxing phase of the moon [15]. The effects of moon phase and age on diurnal rhythms of plasma melatonin and corticosterone in free-living Nazca boobies (*Sula granti*) on the Galapagos Islands were studied [42]. Nazca boobies showed a diurnal variation with higher concentrations at 00:00 and 16:00 h. The diurnal variations in melatonin concentrations disappeared during full moon, suggesting that natural light levels at night can suppress melatonin secretion in Nazca boobies. Maximal melatonin concentrations tended to decline in older birds (10–19 years). The birds showed a clear diurnal variation in basal plasma corticosterone, with a peak in the early morning, before the active period begins, and low concentrations throughout the day. As in the case of melatonin, there were no diurnal variations in corticosterone at full moon, which may be due, as the authors suggest, to different activity patterns in response to food availability or changes in the circadian system. No correlation between corticosterone and melatonin levels were found. The authors conclude that the lunar cycle affects the hormone levels in Nazca boobies both directly and indirectly. First, melatonin rhythms can be directly affected by the light intensity associated with the full moon. Second, prey availability may change foraging patterns and can therefore indirectly alter corticosterone secretion in Nazca boobies.

Mammals

Even in mammals, data on the effects of light/dark, seasonal, and lunar cycles on physiology are scant. Investigations were carried out mostly in rodents. In the Indian palm squirrel *Funambulus pennanti*, seasonal changes in several immune parameters, such as total blood leukocytes, blastogenic response of blood, and thymus and spleen lymphocytes were studied [11]. The authors found that, in parallel with melatonin, all the parameters increased during the months of April to November. The lowest values occurred during January to March (reproductively active phase). Injection of melatonin during their inactive phase (March) increased all the immune parameters, while pinealectomy during November decreased them significantly. The authors suggest that melatonin is immuno-enhancing for this tropical squirrel. Studying a rat strain with individual differences in the threshold of excitability of the nervous system, researchers found that excitable rats showed rhythmical changes of taste sensitivity to a bitter substance, phenylthiocarbamide, related to the lunar rhythm [32]. Others investigated the influence of light/dark, seasonal, and lunar cycles on serum melatonin levels and synaptic bodies, ultrastructural organelles, of the pineal gland of the rat [23]. The experiment was carried out in winter and repeated in spring. Each season, one group of animals was killed during the new moon and a second group during the full moon days; in addition, half of both groups was studied in the photophase and the other half in the scotophase. The results showed that the number of synaptic ribbons (a type of synaptic body) and serum melatonin levels were higher during scotophases, winter, and full moon days. The synaptic spherules (another type of synaptic body) showed a light predominance during winter, whereas a predominance of intermediate synaptic bodies was found only during scotophases.

Variations in the magnitude of the immune response in laboratory animals remain mostly unexplained. Thus, evaluation of the immunotropic effects of various compounds may be not conclusive. The author's studies on the regulation of the humoral immune response to a synthetic B cell-dependent antigen, polyvinylpyrrolidone (PVP), by prostaglandins (PG) showed 12-week cycles of high and low responsiveness [50]. Peaks in the number of cells forming antibodies to PVP in culture occurred every third full moon (Figure 1).

It is unlikely that this was due to periodic changes in sex hormones since male mice were used. Moreover, the mice were used at the same age (six weeks), which rules out the possibility that these changes were the result of biological rhythms of a single individual undergoing its development. The immune response to PVP *in vivo* underwent changes similar to the antibody response to another B-dependent antigen, DNP-ficoll [50]. Interestingly, in the period of low antibody response, PG inhibitors enhanced the immune response, but inhibited it in the period of high immune response. The application of PG inhibitors during the lowest level of antibody production (close to background levels) was ineffective in enhancing the immune response. The effects of the lunar cycle on the antibody response to a T-dependent antigen, sheep erythrocytes (SRBCs), was also analyzed [52] and showed a regular cycle (13 peaks

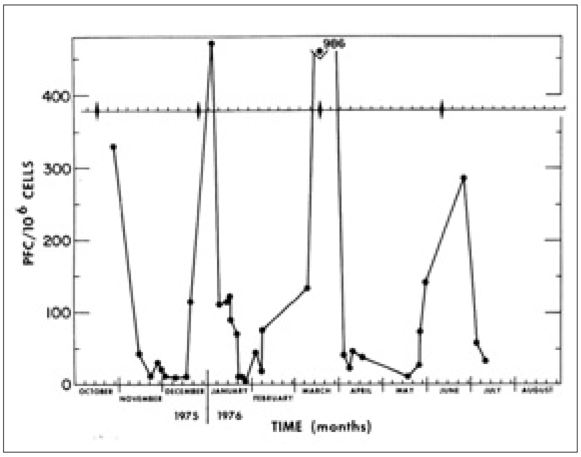

Figure 1. The *in vitro* immune response to PVP. Whole spleen cell cultures were exposed to 10^{-4} µg PVP and assayed for PFC after 4 days of culture. The data are reported as the mean of PFC/10^6 spleen cells and represent individual experiments performed over several months

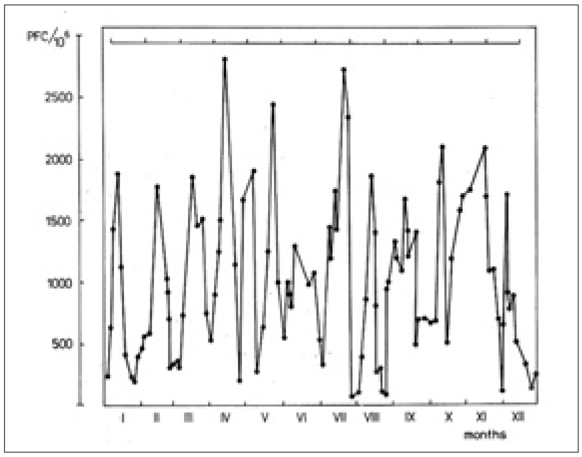

Figure 2. Seasonal variations in the magnitude of the humoral immune response of mice to SRBC *in vivo* registered in the years 1978–91

in the year, corresponding to 13 lunar months, with peak responses around the full moon days) (Figure 2). In addition, two distinct peaks in the anti-SRBC response in mice were registered in March and October [53].

Acceptance of the existence of such immune response variability has important implications. When interpreting experimental data, investigators should be aware of the magnitude of the control immune response on a given day. In particular, the immunoregulatory character of some compounds may be verified only after performing a series of experiments over a longer time period [46] and it strictly depends on the control immune response on the given day, resulting in stimulation, no effect, or suppression. Even the immunosuppresory effects of cyclosporine A are dependent on variability in the humoral and cellular immune response [54].

At this stage of investigation, the exact mechanism of the lunar effect on the immune response is hard to explain. The prime candidates to exert regulatory function on the immune response are melatonin and steroids, whose levels are affected by the moon cycle. Functional and pharmacological inhibition of melatonin synthesis resulted in depressed immune function *in vivo* [20]. Exogenous, evening administration of melatonin enhanced antibody formation and was also antagonized by the opioid receptor blocker naltrexone, indicating that the neurohormone regulates the immune response via opioid peptides [21]. Exogenous melatonin also completely counteracts the effect of acute-anxiety-restraint stress on thymus weight and antibody response to SRBC [22]. Melatonin treatment increased, in addition, the affinity and decreased the density of glucocorticoid and progestin receptors in non-immunized mice [34]. There is also evidence that the rise in corticosterone levels decreases T-dependent antibody response [13]. It is therefore tempting to speculate that the biorhythm observed in the antibody response to SRBC [52] could be due to lower levels of endogenous steroids around the full-moon days. On the other hand, the response to PVP was not affected by changes in steroid levels [13] which makes interpretation of the biorhythm in the immune response to PVP difficult. It is, however, possible that in this case, T-suppressor cells controlling the anti-PVP response are affected [51]. Although the immunostimulatory action of melatonin is well documented, it does not explain the peak responses at full-moon days when melatonin levels are low [18,38,41,42]. No direct correlation exists between melatonin and endogenous steroid levels, either [42]. Whereas a direct effect of lunar light may have significance in the fluctuation of physiological processes in free-living animals, it is unlikely that laboratory animals, kept in an isolated place (an animal facility) with a 12/12 h light/dark cycle, could also be subject to such effects. Other types of the moon‘s activity suggested by some authors, such as electromagnetic radiation [8] and the gravitational pull [43], would more likely be the primary causes of the described rhythms. It is also likely that laboratory animals which do not perceive lunar light, in contrast to free-living animals, have elevated concentrations of melatonin during full-moon days, as was shown in laboratory rats [23]. In such a case, the elevated antibody response in murine models could be explained [50,52]. There are indications that the cycling moon initiates neurohormonal activity in the hypothalamus and the pituitary gland [28]. Surprisingly, however, moon-induced cyclic changes in the steroid levels can also be observed in the honeybee, whose nervous system is much less complex [16].

In summary, the exact mechanism by which the moon affects behavior and physiology still has to be clarified. The hitherto accumulated data indicate that knowledge of the rhythms elicited by the lunar cycle may be helpful in police surveillance, hospital practice, and animal laboratory research.

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