Longitudinal observations call into question the scientific consensus that humans are unaffected by lunar cycles

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Abstract
Recent longitudinal observations show that human menstrual cycles, sleep-wake cycles and manic-depressive cycles can become synchronized with lunar cycles, but do so in uniquely complex and heterogeneous ways that are unlikely to have been detected by past studies. Past studies’ negative results have given rise to a scientific consensus that human biology and behavior are unaffected by lunar cycles. The recent observations show that synchrony can be temporary, and can occur with more than one type of lunar cycle, more than one phase of a lunar cycle and more than one resonant frequency of a lunar cycle. Given the variability of human responses to lunar cycles, aggregate analyses used in almost all previous studies would likely have cancelled out individuals’ responses and led to false negative results. In light of these observations, the question of lunar influence should be investigated further, with longitudinal observations and case-by-case analyses of individuals’ data.

KEYWORDS
depression, lunar, mania, menses, sleep, tidal

INTRODUCTION

Current scientific opinion regards beliefs about lunar influence on humans to be myths.[1–7] That opinion is a logical response to a multitude of studies published during the past 50 years that almost without exception have failed to confirm claims of lunar influence.[1–7]

Almost all past studies employed methods that appear to have been based on implicit assumptions that individuals’ responses to lunar influence would uniformly be synchronized with the moon’s 29.53-d synodic cycle (Figure 1B) and not any other lunar cycle, as well as with a particular phase of that cycle, such as the full moon, and not any other phase. Based on those assumptions, investigators analyzed group data in aggregate.[1–7]

Recent findings in longitudinal studies indicate that neither of those implicit assumptions is correct. The findings show that human biology and behavior can become synchronized with more than one type of lunar cycle, and with more than one phase of a lunar cycle (Figures 2–5).[8–13] They show further that there are differences among individuals, at a particular time, and within individuals, over time, in both the type and the phase of the lunar cycle with which they are synchronized (Figures 2–5).[8,10] The findings also show that episodes of synchronization with particular periods and phases of lunar cycles are not continuous, but rather are interrupted by shifts to different periods (Figure 5) and phases (Figures 2 and 3), and shifts to intervals when no synchronization occurs (Figures 2A, 4A, and 5).[8,10]

In aggregate analyses of group data, the heterogeneity and inconsistency of individuals’ responses to lunar cycles would tend to obscure evidence of lunar cycles in individual members. If, for example, one assumed that a group would be synchronized with the full moon phase of the synodic cycle and calculated an average profile of that cycle, the unwitting inclusion of individuals who were synchronized with other lunar cycles and different phases of lunar cycles, together with individuals who temporarily were desynchronized from lunar cycles, would flatten the profile, increase the variance at each of its points, and...
FIGURE 1  Schematic (A) shows how the earth’s rotation on its axis and its revolution around the sun combine with different aspects of the moon’s orbit to give rise to three cycles in the moon’s effects on luminance and gravity at the earth’s surface. (B) The 29.53-d synodic lunar cycle recurs as the moon makes a circuit through its new moon and full moon points of alignment (syzygies) with the earth and the sun. During this period, the moon’s luminance completes a single 29.53-d oscillation between its maximum (full moon) and minimum (new moon) values, while its contribution to gravity completes two 14.78-d oscillations between its maximum (full moon and new moon) and minimum (first and last quarter moon) values, which are associated with spring (higher) tides and neap (lower) tides, respectively. (C) The 27.32-d tropical cycle recurs as the declination of the plane of the moon’s orbit relative to the plane of the earth’s equator causes the moon to move back and forth between its northernmost (maximum standstill) and southernmost (minimum standstill) positions (lunistices) in the sky, which are associated with higher (tropic) gravitational tides. This cycle is responsible for the diurnal inequality of the two daily tides at many locations as direct tides alternate with centrifugal tides. (D) The 27.55-d anomalistic cycle recurs as the elliptical shape of the moon’s orbit causes it to move back and forth between its nearest (perigee) and farthest (apogee) distances from the earth. Approximately every 7 months, co-occurrences of syzygies and perigees give rise to so-called “supermoons” and the highest tides. Source: Figure 1 in [8]

In comparing results of the recent longitudinal studies with results of past studies of lunar influence, it is important to note that there are crucial differences between the types of data that were analyzed in the two types of studies. In the longitudinal studies, data points consisted of a separate time-series for each individual, of dates that were associated with a biological or behavioral phenomenon that was known to recur in a cyclic manner. In past studies, with few exceptions, data points consisted of the date of a single sporadic event that occurred in each individual, such as a birth, violent act, suicide, crisis call, emergency room visit, hospital admission, accident, post-surgical complication, or seizure. Of course, with a single data point, it is not possible to determine whether a cycle of any type occurred in any individual.

In light of the foregoing discussion, it is conceivable that the types of responses to lunar cycles found in longitudinal studies would have escaped detection by the methods used in past studies and thus led to false-negative results.

COMPLEXITY AND HETEROGENEITY OF HUMAN RESPONSES TO LUNAR CYCLES

Humans can become synchronized with different phases of lunar cycles

When menstrual cycles, sleep-wake cycles and manic-depressive cycles are synchronized with the moon’s 29.53-d synodic cycle, they can be synchronized with either its full moon or its new moon phase (Figures 2 and 3). Over time, an individual’s synchronization can shift from one phase to the other, and it can shift back and forth between the two phases (Figures 2B and 3A). Similarly, when menstrual cycles are synchronized with the 27.55-d anomalistic cycle (Figure 1D), they can be synchronized with either its perigee phase or its apogee phase.

Sometimes, an individual’s biological or behavioral rhythm exhibits a type of partial synchronization with the synodic cycle called relative coordination. During relative coordination, the strength of a lunar cycle is not sufficient to maintain steady synchronization of a biological or behavioral rhythm, but it continues to influence the behavior of the rhythm by alternately slowing and accelerating its oscillations as it passes in and out of phase with the lunar cycle (Figure 2A).

Humans can become synchronized with different types of lunar cycles

In addition to 29.53-d synodic lunar cycles (Figures 2 and 3), menstrual cycles and manic-depressive cycles can become
Menstrual cycles (A) and manic-depressive cycles (B) can synchronize with either full moon or new moon phases of the moon’s 29.5-d synodic cycle. Triple raster plots show times of (A) menses onsets (black squares) and (B) manic phases (black bars) and depressive phases (white bars) of mood cycles. In the plots, segments of the time series of each data set corresponding to the 29.53-d length of a synodic lunar month are shown successively beneath one another. In this and subsequent figures, the raster panels are plotted two additional times to the right of the original plot to bring out the underlying continuity of the data, which has been arbitrarily interrupted by division of the time series into raster-segments, and to facilitate visual inspection of the courses of the cycles across the plot. Times of full moons (white circles) and new moons (black circles) are shown below (A) or within (B) the plots. Horizontal lines on the right of each plot divide the plots into successive sections, which are discussed below. (A) In the second section of the plot, a recurring tendency of onsets of menses to become vertically aligned (arrows) indicates that they are weakly coupled to (relatively coordinated with) new moon phases of the synodic cycle. Vertical alignment of onsets of menses indicates that they are synchronous with new moon phases in the second section and full moon phases in the third section. (B) In the upper plot, vertical alignments of onsets of mania indicate that they are synchronous with the 29.53-d recurrences of full moon phases of the synodic cycle in the first and fourth sections and new moon phases in the second section. The diagonal course of onsets of mania in the third section indicates that they are synchronous with 44.3-d recurrences of alternating full and new moon phases (not shown). In the lower plot, vertical alignments of onsets of mania in second section and onsets of depression in the first and third sections indicates that they are synchronous with full moon phases of the synodic cycle. Several onsets of mania in the third section exhibit synchrony with new moon phases of the synodic cycle. Raster plots are adapted from Figure 3 (Subject 1) in [8] and Figures 7 (Patient 8) and S1 (Patient 10) in [10].

Synchronized with 27.55-d anomalistic lunar cycles or 27.32-d tropical lunar cycles (Figure 4). Over time, an individual’s synchronization can shift from one type of lunar cycle to another (Figure 5).

**Humans can become synchronized with different resonant frequencies of lunar cycles**

Manic-depressive cycles can become synchronized with different multiples of 14.78-d semi-synodic and 13.67-d semi-tropical cycles (Figure 1C). Thus, mood cycles can be synchronized with every single, or every second (Figures 2B and 4B), third, fourth (Figure 3A) or sixth lunar cycle, and every second mood cycle can become synchronized with every third lunar cycle (Figure 3B). During the course of illness, mood cycles can shift from one mode of synchronization to another (Figure 4B; Figure 5 in [10]).

**Synchrony with lunar cycles can be temporary**

Periods when menstrual cycles are synchronized with lunar cycles can be interrupted by periods during which no synchrony occurs (Figures 2A, 4A, and 5).
As they evolved, organisms developed a capacity to respond to cycles in their environment. These include phenomena such as cycles in physiology and behavior. In some cases, the adjustments were evoked directly by changes that were caused by environmental cycles.\cite{14,15}

In other cases, the timing of the adjustments was controlled by self-sustained biological rhythms that could be synchronized with environmental cycles and anticipate the changes that they caused.\cite{14,15}

Lunar clocks in humans

Many types of organisms have developed endogenous biological clocks that control the timing of their responses to lunar cycles in their environment. These include ∼12.4-h tidal (circa-tidal) clocks, ∼24.8-h lunar day (circa-lunadian) clocks, ∼14.8-d semi-month (circa-semilunar) clocks, and ∼29.5-d month (circa-lunar) clocks (reviewed in \cite{15}). A defining characteristic of these "circa-rhythms" is that they persist when they are isolated from the lunar cycles with which they normally are synchronized.

Human menstrual cycles appear to be the product of a ∼29.5-d circular lunar clock, because they continue to oscillate during intervals when their intrinsic period changes to such an extent that they no longer can be synchronized with monthly lunar cycles.\cite{8} The situation with human sleep-wake cycles and with manic-depressive cycles is less clear. It is well-established that the timing of sleep-onset and wake-onset are controlled by dual ∼24-h circadian clocks (reviewed in \cite{11}). In a recent longitudinal study, Casiraghi and colleagues found that sleep onset was delayed and sleep duration diminished near times of the full moon and the new moon.\cite{9} While it is plausible that the delay of sleep onset that occurred near the full moon was caused by a direct masking effect of moonlight on the expression of the circadian rhythm in sleep onset, the same could not be said of the delay of sleep onset that occurred near the new moon. A possible explanation is that sleep onset was delayed at those times by being temporarily entrained to 24.8-h recurrences of a passing lunar gravitational tidal cycle, whose amplitude and whose strength as a forcing cycle would have been greatest at the times of full moon and new moon spring tides. In this scenario, it is unclear whether entrainment of sleep onset to the tidal cycle would occur directly, or indirectly via entrainment of a 24.8-h circa-lunadian clock in humans. Another possibility is that the timing and amount of sleep were affected by a ∼14.8-d circa-semilunar clock in humans. Similar issues arise with respect to manic-depressive illness, because there is some evidence...
FIGURE 4  Menstrual cycles and manic-depressive cycles can synchronize with the moon’s 27.32-d tropical cycle. Triple raster plots show times of (A) menses onsets (black squares) and (B) manic phases (black bars) and depressive phases (white bars) of mood cycles. In the plots, segments of the time series of each data set corresponding to the 27.32-d length of a tropical lunar month are shown successively beneath one another and triple-plotted to the right. Vertical lines and hash marks indicate average times of minimum lunar standstills. Horizontal lines on the right of each plot divide the plots into successive sections. In the middle section of plot (A) and the second and fourth sections of plot (B), vertical alignments indicate that onsets of menses and manias, respectively, are synchronous with 27.32-d recurrences of minimum standstills of the tropical month. In the first, third, and fifth sections of plot (B), vertical alignment indicates that onsets of mania are synchronous with alternating full and new moon phases of every third 14.78-d semi-synodic lunar cycle. Plots are adapted from Figure 5 in [8] and Figure 4 (patient 8) in [10].

FIGURE 5  Synchrony can shift from one type of lunar cycle to another. Times of menses onsets (black squares) from the same data set are shown in two different raster plots. In the plots, segments of the time series of the data set corresponding to the 29.53-d length of the synodic lunar month (A) or the 27.32-d length of the tropical lunar month (B) are shown successively beneath one another and triple-plotted to the right. Times of new moons (black circles) and full moons (white circles) (A) and times of minimum lunar standstills (x’s) (B) are shown beneath the plots. (A) Vertical alignments (marked by black bars next to the right side of the plot) indicate periods during which menses onsets are synchronous with new moon phases and full moon phases of the synodic cycle. The arrow indicates an instance of transient slowing of the menstrual cycle associated with the phenomenon of relative coordination (see text). (B) Vertical alignments indicate periods during which menses onsets are synchronous with minimum lunar standstill phases of the tropical cycle. Plots are adapted from Figures 3 and 52 (Subject 1) in [8].
that effects of lunar cycles on manic-depressive cycles are mediated by their effects on sleep and circadian rhythms.[10–12,22]}

**Detection of lunar cycles by humans**

The medium through which synodic, anomalistic, and tropical lunar cycles could influence menstrual, sleep-wake, and manic-depressive cycles is unclear. While each type of lunar cycle affects both light and gravity, effects of the synodic cycle on light differ from its effects on gravity. The fundamental period of the moon’s luminance cycle is the 29.53-d full moon-to-full moon period of the synodic month. In contrast, the fundamental period of the moon’s gravitational cycle is the 14.78-d period of the full moon-to-new moon (and new moon-to-full moon) semi-synodic month. The findings that humans can become synchronized with either full moon or new moon syzygies of the semi-synodic cycle, and that manic-depressive cycles can be synchronized with several different resonant frequencies of semi-synodic and semitropical-cycles seem to indicate that the basic unit underlying the temporal organization of these cycles are the semi-synodic and semitropical gravitational cycles. Changes in the modern environment that have diminished the impact of moonlight would not interfere with the moon’s gravitational cycles; consequently, those cycles may play a more prominent role in the entrainment of lunar rhythms in humans who live in that environment. As discussed in the next section, an inversion in the relative influence of the moon’s luminance and gravitational cycles in that environment could explain how human responses to the moon became complex in the modern era.[10]

With regard to that possibility, it is important to note that the effect of variations in lunar gravity on an object as small as the human body have been compared to the weight of a mosquito.[6] The possibility that long-term variations of that size could be detected directly by biological mechanisms may seem unlikely, but it remains an open question.[23] More likely, perhaps, is that mechanisms might detect those variations indirectly through changes they induce in ambient geophysical variables, such as air pressure, cloudiness, geomagnetic field strength, or the abundance of cosmic rays or radon, which have been, or could be considered as intervening variables.[24–31]

Several candidates for biological substances and mechanisms that might detect and respond to lunar cycles have been proposed and investigated (see [15] for a thorough review and discussion of this topic). The light-regulated pineal hormone, melatonin, and the light-sensitive and magneto-sensitive molecule, cryptochrome, a component of the molecular machinery that generates circadian rhythms, have been a focus of interest in this regard. Although a causal relationship has not yet been demonstrated, both molecules exhibit changes that are correlated with lunar cycles in some organisms that respond to lunar influence. The circadian pacemaker and its photoperiod-responsive mechanisms also have been proposed as mediators of responses to lunar cycles.[10,11,15,31]
Functions of lunar cycles in humans

In many types of organisms, lunar rhythms most commonly serve to increase the efficiency of reproduction and/or to facilitate or avoid predation.\[14,15\] In the human case, it’s difficult to see how the complexity, heterogeneity, and transience of the lunar rhythms that were detected in longitudinal studies would serve any useful function. As a possible explanation, we speculate that lunar rhythms in humans once more closely resembled those in other animals, but that resemblance waned when humans altered their environment with innovations that interfere with the detection of moonlight, notably electric lighting and architectural barriers.\[8–10\] This explanation is the same as one proposed by Raison and colleagues to explain the lack of evidence of lunar influence in past studies.\[2\] In a comprehensive discussion of that issue, they noted that research on human responses to changes in photoperiod is consistent with that explanation: in natural and simulated natural lighting conditions, the human circadian pacemaker responds to seasonal changes in duration of the photoperiod as other animals do, but it ceases doing so in everyday urban environments.\[32,33\] Findings that lunar cycles affect menstrual cycles and sleep to a greater extent in semi-rural than in urban settings also are consistent with that explanation.\[8,9\]

In animals, a common function of lunar cycles is to increase reproductive success by synchronizing the reproductive physiology and behavior of males and females.\[14,15\] The finding that women’s reproductive physiology responds to lunar cycles raises the possibility that lunar cycles have a similar function in humans. For this to be so, it would be necessary for men’s reproductive physiology also to respond to lunar cycles, and to respond in a similar way. In this regard, it seems relevant that manic-depressive cycles in both men and women not only respond to lunar cycles, but also affect libido. Further research on these issues could have significant implications for fertility and contraception in humans.

The way forward

A limitation of existing longitudinal studies is their modest numbers of subjects. Their results need to be confirmed in case-by-case analyses of longitudinal data with methods used in biological rhythm research, such as spectral analyses of periodicities, circular statistical analyses of phases, and raster displays of raw data.\[8,9\] As a general practice, it may be fruitful to continue to focus on phenomena that are known to recur on a cyclical basis in individuals, such as menstrual cycles.

Macaques appear to be particularly promising animal models for this type of research, particularly those that have continuous, as opposed to seasonal, menstrual cycles. As described previously, frequency-distributions of menstrual cycle lengths, with peaks very close to the 29.5-d synodic lunar month, are virtually identical in macaques and humans (Figure 6A,B). If it can be confirmed that individual monkeys’ menstrual cycles can become synchronized with lunar cycles, even if only temporarily, as occurs in humans, then it will be possible to address a host of questions about the medium in which lunar cycles are transmitted, and the biological mechanisms that detect and respond to them. Answers to any of those questions could prove to be relevant to the human case.

The hypothesis that humans’ responses to lunar cycles have been disrupted or made more complex and heterogeneous by their exposure to increasingly bright and prevalent sources of artificial light could be tested by comparing long-term longitudinal observations of humans living in modern, urban settings with those of humans living in more natural settings. More definitive results could be obtained by comparing observations in highly controlled lighting conditions in laboratory environments with those in purely natural environments free of light pollution. The latter approach would be difficult, but not impossible, to achieve with humans, but could be accomplished more readily with macaques. In this regard, it is interesting to note that the data shown in Figure 6B were obtained in macaques living in a laboratory, while the data shown in Figure 6A were obtained in macaques living outdoors. These types of comparisons also could be used to identify the medium through which lunar cycles act upon humans. If humans’ responses to lunar cycles in a purely natural environment reverted to a more straightforward pattern like those in other animals, light pollution would be implicated as a cause of the complexity and heterogeneity of contemporary humans’ responses to lunar cycles. If lunar cycles persisted in humans living a controlled and fixed lighting environment, a medium other than moonlight would be implicated as an intervening variable in their responses to lunar cycles.

The findings to-date raise many other questions that could be addressed in future research, but lie beyond the scope of the present discussion. For example, does the capacity to respond to lunar cycles play a meaningful role in human biology and behavior, or is it a vestigial remnant of an adaptation that became maladaptive or irrelevant during the course of human evolution? Do men have menstrual (monthly) cycles? Is the complexity of human responses to lunar cycles evidence of a disorder? Is manic-depressive illness rooted in mechanisms that regulate the moon’s effects on reproduction? The answers to some of these questions would address the question of whether humans should be added to the list of organisms that are adversely affected by light-pollution.

CONCLUSION

The scientific consensus that humans are unaffected by lunar cycles is based on aggregate analyses of group data that are likely to have led to false negative results. The analyses were based on assumptions that are inconsistent with longitudinal observations that human responses to lunar cycles are complex and heterogeneous. The observations reveal that human menstrual cycles, sleep-wake cycles and manic-depressive cycles can become synchronized with more than one type of lunar cycle, and more than one phase of a lunar cycle. The findings raise new questions about the functions of lunar cycles in humans, the medium and the mechanisms through which they are produced, their role in...
health and disease, and their possible disruption by light-pollution. All of these questions point to avenues for future research. The findings highlight our kinship with other lifeforms and our evolutionary passage through the tidal zone.

CONFLICT OF INTEREST
The authors declare no conflicts of interest. The views expressed in this report do not necessarily reflect the views of the NIMH, NIH or the US Federal Government

DATA AVAILABILITY STATEMENT
Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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How to cite this article: Wehr, T. A., & Helfrich-Förster, C. (2021). Longitudinal observations call into question the scientific consensus that humans are unaffected by lunar cycles. BioEssays, 43, e2100054. https://doi.org/10.1002/bies.202100054