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Does the moon influence sleep in small-scale societies?

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ABSTRACT

Objectives: The lunar cycle is expected to influence sleep-wake patterns in human populations that have greater exposure to the environment, as might be found in forager populations that experience few environmental buffers. We investigated this "moonlight" hypothesis in two African populations: one composed of hunter-gatherers (with minimal environmental buffering) and the other rural agriculturalists (with low-to-moderate environmental buffering).
Setting: Research was conducted on Hadza hunter-gatherers from the Sengele community near Lake Eyasi in northern Tanzania and in Mandena, Madagascar, in a rural community of approximately 4000 farmers.
Participants: Thirty-one adult Hadza and 21 Malagasy adults were recruited.
Measurements: We used the CamNtech Motionwatch 8 actigraph and generated data on an epoch-by-epoch, 1-minute basis.
Results: In general support of *the moonlight hypothesis*, we uncovered an association between sleep-wake patterns and lunar cycle (ie., moonlight) for Hadza hunter-gatherers. However, the direction of the effect was opposite to what we predicted: as the potential for exposure to moonlight increased, activity generally shifted to a pattern of less nighttime activity and greater daytime activity. No significant effects were found in the Malagasy agriculturalists.
Conclusions: The proposal that human behaviors are linked with moon phase is a popular belief that persists despite the absence of consistent evidence. We provide the first direct evidence that lunar cycle is linked to sleep-wake pattern in a hunter-gatherer society, suggesting that moonlight does not inhibit sleep-wake patterns in the ways that electric lighting does.

Introduction

Few celestial objects have captured the human imagination as much as the moon. Abundant prehistoric and historical evidence suggests that the lunar cycle has powerfully affected human cultures for millenia, ranging from cave paintings marking moon phase in Lascaux some 30,000 years ago to early Roman lunar calendars.[1] Evidence suggests that some animals possess internal clocks that are influenced by lunar cycle,[2] yet we lack evidence showing a strong connection between moon phase and the biology and behavior of our species.[1,3]

Absence of evidence is not due to a lack of scientific interest, as research meant to disentangle the relationship between lunar cycle and human physiological and behavioral phenomena is myriad. It has been reported that psychosis, aggression, suicide, conception, birth, menstruation, and automobile accidents occur independently of the phase of the moon.[1] Yet, over the past three decades, a number of reports have linked sleep deprivation to mania and have even demonstrated that minor sleep loss can significantly increase the occurrence of seizures the following day.[4]

Researchers have actively been investigating to what extent lunar cycle influences sleep and mental and physical health. For example, reporting on sleep data generated from Swiss subjects in a circadian laboratory, Cajochen and colleagues[5] reported that slow-wave sleep decreased by 30%, time to fall asleep increased by 5 minutes, and electroencephalogram-assessed total sleep duration was reduced by

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20 minutes during the full moon. In response, Cordi and colleagues[3] countered that these findings could not be replicated in larger laboratory-based data sets from Germany and Switzerland and thus represent a case of false-positive results (ie, a type 1 error). Certainly, the issue at hand could be a false positive within the realm of statistical "error," but even more critically, nearly all studies of sleep are generated from so-called W.E.I.R.D. (ie, Western; educated; and from industrialized, rich, and democratic countries) [6] populations that live in radically different environments than the ones in which our ancestors evolved.

Commenting on how to overcome the main challenges to lunar-phase sleep research, Vyazovskiy and Foster[7] recommended that future research should (*a*) design original within-subject experiments and (*b*) disentangle specific mechanisms via a hypothesis-driven approach. Here, we propose to investigate sleep in nonindustrial populations living in natural environments as a third strategy to investigate the links between moon phase and human biology.

Foster and colleagues[1] speculated that individuals living in a nonindustrial society—characterized by a lack of 24/7 access to lighting—were more likely to have increased levels of activity during periods of greater moonlight. Indeed, nonindustrial societies are not shielded from other entrainment factors that influence circadian physiology; unlike industrial populations, nonindustrial populations do not possess insulated, temperature-controlled buildings that blunt noise and other ecological factors likely to influence sleep. It may be that the contradictory evidence reported in previous laboratory-based studies conducted in the cultural West is related to the fact that W.E.I.R.D populations are too masked from their entrainment queues—moonlight included—for such a relationship to be established.

In recent work, we used actigraphy to study sleep-wake patterns among an equatorial small-scale nonindustrial population of hunters and gatherers in Tanzania[8] and in a developing economy of agriculturalists.[9] In most hunter-gatherer societies, individuals work when they want to, electricity is absent, barriers to the environment are few, and individuals choose to sleep inside or outside of grass-hut domiciles to reduce thermoregulatory stress.[10] The Hadza are characterized as having a monophasic nocturnal sleep pattern that has a primary, early morning sleep bout with supplemental daytime napping.[11] Moreover, the sleep-wake patterns of individuals that habitually use a foraging subsistence strategy are assumed to be more closely linked to ancestral pathways. Therefore, although the Hadza are by no means perfect analogs to ancestral behavior and physiology, they do offer the best modern-day insight of past human sleep-wake activity, especially because they live in an ecological context that is similar to the one in which our ancestors evolved.[12]

In contrast, the Malagasy small-scale agriculturalists dwell in a developing economy that has predetermined demands on work output and that does not have ready access to electricity for night-time lighting but does have increasing access to cell phones and solar-powered and gas-powered generators.[9] The Malagasy are characterized by a bifurcated pattern of nocturnal sleep bouts with supplemental daytime napping.[9,11] These populations provide the opportunity for comparative testing given that they are characterized by stronger circadian rhythms than reported in W.E.I.R.D. populations,[9,11] yet they have markedly different subsistence patterns (with differing cultural demands on sleep-wake timing) and economic development.

The objective of this study was to test *the moonlight hypothesis*—that sleep-wake patterns in humans with hunter-gatherer subsistence patterns and greater environmental exposure are more heavily influenced by lunar cycle. Specifically, when compared to the Malagasy, we predict that Hadza will be characterized by stronger responses to moonlight exposure by (*a*) showing differences in sleep duration and nighttime activity during lunar phases associated with greater moonlight, (*b*) phase expression of chronotype (ie, a shift to

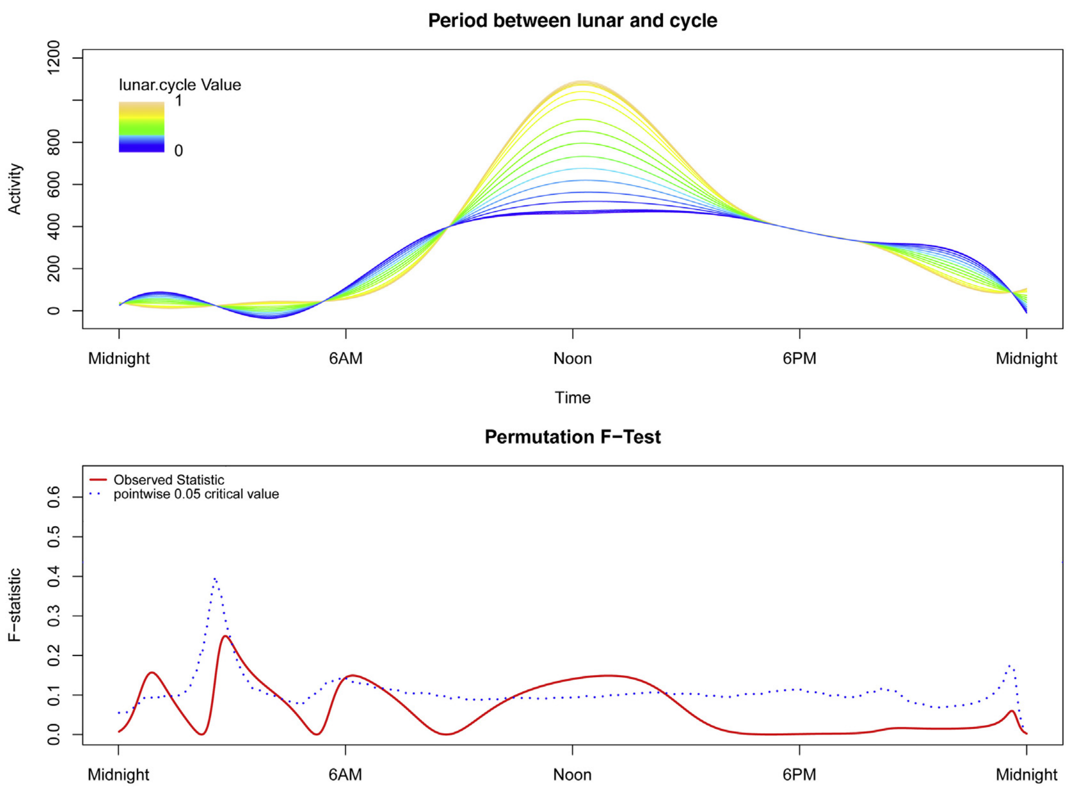

Fig. 1. An FLM analysis reporting the influence of lunar cycle in Hadza hunter-gatherer sleep-wake patterns. The general pattern showed that activity shifts relative to lunar cycle, with later lunar phase (ie, a more visible moon) being associated with less early morning activity and followed by more midday activity. The bottom panel illustrates that the pointwise critical value (dotted line) is the proportion of all permutation *F* values at each time point at the significance level of .05. When the observed *F* statistic (solid line) is above the dotted line, it is concluded that the two groups have significantly different mean circadian activity patterns at those time points.

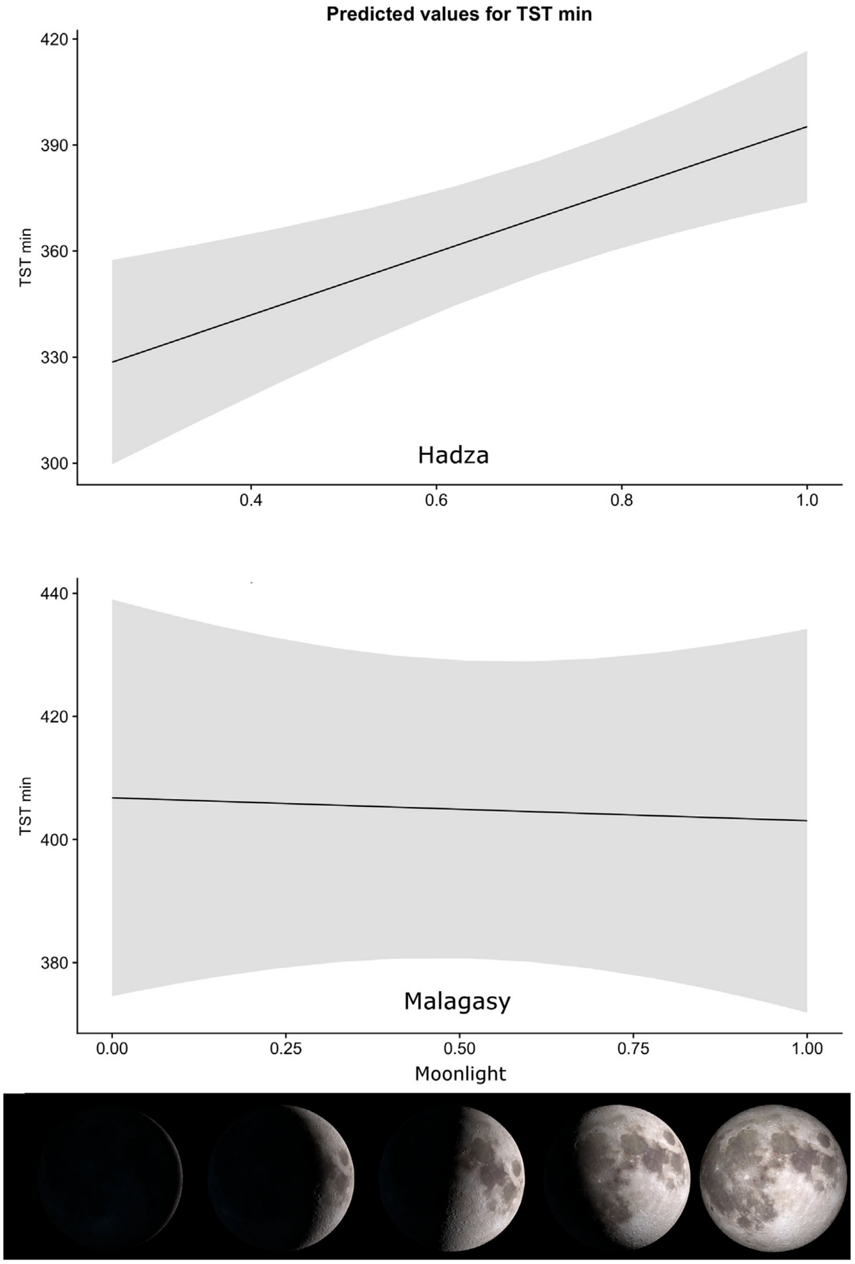

Fig. 2. A prediction plot for sleep duration (y-axis) in relation to moonlight (x-axis) based on the linear mixed-effects model. The Hadza experience less sleep during nighttime periods of greater moonlight, whereas the Malagasy showed no such effect.

earlier or later active periods during the circadian cycle) during lunar phase with greater moonlight, and (*c*) changes in sleep efficiency during lunar phases with greater moonlight.

Methods

Study participants

Among subtropical foragers, the Hadza are considered to be "median" hunter-gatherers, as they lie near the median value for most ecological and life history traits.[13,14] They dwell in an east African environment with an effective temperature of 17°C, and average annual temperature varies little across the year (mean ~28°C) but considerably between day and night (mean minimum = 14°C, mean maximum = 35°C). Traditionally, the dry season occurs between June and November, and the wet season occurs from December to May. In general, the habitat is savanna-woodland, with some rocky hills and brush that include marshlands.[14] The median local group home range for the Hadza is 122 km,[2] although range sizes are declining

Table 1
Linear mixed-effects model with chronotype (CPM) as the response variable for the Hadza population

Predictor	β	SE	Confidence interval	z	P
Age	−0.21	0.08	(−0.369, −0.056)	2.66	.008
Humidity	−0.12	0.06	(−0.232, −0.125)	2.18	.029
Lunar cycle	−0.36	0.09	(−0.534, −0.177)	3.90	<.001
Number of co-sleepers	−0.13	0.08	(−0.285, 0.022)	1.68	.093
Sex	0.03	0.08	(−0.138, −0.081)	0.31	.760
Temperature	−0.23	0.07	(−0.374, −0.081)	3.04	.002

Chronotype phase advances with greater lunar cycle in the Hadza. Positive coefficients indicate phase delays (ie, later "owl" chronotype), whereas negative coefficients indicate phase advance (ie, early "lark" chronotype). "Male" is the reference category for *Sex*.

Table 2
Linear mixed-effects model with chronotype (CPM) as the response variable for the Malagasy population

Predictor	β	SE	Confidence interval	z	P
Age	−0.01	0.07	(−0.139, 0.124)	0.11	.910
Humidity	−0.28	0.09	(−0.444, −0.106)	3.19	.001
Lunar cycle	−0.10	0.10	(−0.291, 0.085)	1.08	.281
Number of co-sleepers	−0.13	0.06	(−0.254, −0.002)	2.00	.046
Sex	−0.01	0.07	(−0.143, 0.139)	0.03	.978
Temperature	−0.18	0.07	(−0.318, −0.046)	2.63	.009

because of adjacent population pressure and globalization.[15,16] The Hadza exhibit high levels of sexual division of labor, with males acting as primary hunters and females as primary gatherers. Groups are characterized by central-place provisioning, with individuals returning to a central place to distribute food.[17] Estimates of the annual Hadza diet suggest that it consists of approximately 43% hunted foods (game animals, birds, and honey) and 57% gathered foods, including fruits, legumes, tubers, nuts, and seeds.[18] During the time of data collection, the Hadza were consuming a diet that was predominantly composed of wild foraged foods with small amounts of supplemented maize. Hadza volunteers were recruited from Sengele, a bush camp located near Lake Eyasi in northern Tanzania (latitude: 03°-04 S and longitude: 34°-36 E) and participated in the study during the rainy season, between January 21 and February 11, 2016.

Malagasy adults were recruited from Mandena, Madagascar (latitude: −14°-37 S and longitude: 49°-11 E). Mandena is a high-density, equatorial rural community of approximately 4000 people (within 1 km^2) and is located adjacent to the Marojejy National Park in northeastern Madagascar. The population is a small-scale agricultural society that is focused on rice and vanilla farming, along with domesticated animals that include cattle (zebu), pigs, and chickens. The village has no infrastructure for electricity, although some individuals in the village have generators or solar panels. Co-sleeping (ie, individuals sharing the same bed) is common. The study was conducted between July 2 and August 20, 2015, and July 1 and August 1, 2016. After data cleaning, the final number of nights studied were 389 nights for the Hadza and 498 nights for the Malagasy (total n = 887 nights). More details on previous sleep research performed with these participants are available in other recent publications.[8,10,11,19]

Data collection

We used the CamNtech Motionwatch 8 actigraph, which has a built-in triaxial accelerometer that logs motion data on an epoch-by-epoch basis. We collected data continuously on the minute, which is a commonly used epoch duration when inferring sleep-wake activity patterns in humans with actigraphy.[20–22] The CamNtech MotionWare 1.1.15 program was used to score sleep data. The software has a sleep detection algorithm that generates sleep quotas based on actigraphic counts. The algorithmic high-sensitivity settings are most reliable for determining sleep[19,23]; therefore, we used the high-sensitivity setting throughout this study. Although our previous work has demonstrated that it is possible to apply mobile polysomnography to field environments,[9] it can be challenging to generate large samples. Field actigraphy has been demonstrated as a valuable alternative to investigate sleep in populations living in the postindustrialized West [24,25] and also in the developing world,[11,22] including among small-scale foraging and mixed-subsistence populations.[11,26]

Meteorological variables (ie, temperature, relative humidity, and wind speed) were recorded at 5-minute intervals with Kestral 4000 pocket weather trackers (Nielsen-Kellerman Co). Baseline data (ie, ambient local weather) were recorded synchronously each day when we measured sleep. Photoperiod and lunar phase were obtained from the Astronomical Applications Department of the United States Navy (http://aa.usno.navy.mil/data). Lunar phase ranged from new moon (darkest period of moonlight = 0) to full moon (brightest period of moonlight = 1); thus, lunar cycle was used as a proxy for moonlight exposure, as we did not take into account night-to-night cloud cover (see study limitations below). Participants in both populations were given a sleep survey at the beginning of the study period to screen for healthy sleep and to assess the number of co-sleepers associated with each individual's sleeping site. All data protocols were approved by the institutional review board to ensure ethical standards.

Data analysis

We used *R* version 3.3.0[27] to conduct statistical analyses. Functional linear modeling (FLM) is a powerful analytical tool specifically designed for actigraphy time-series data analysis[28] and was used to

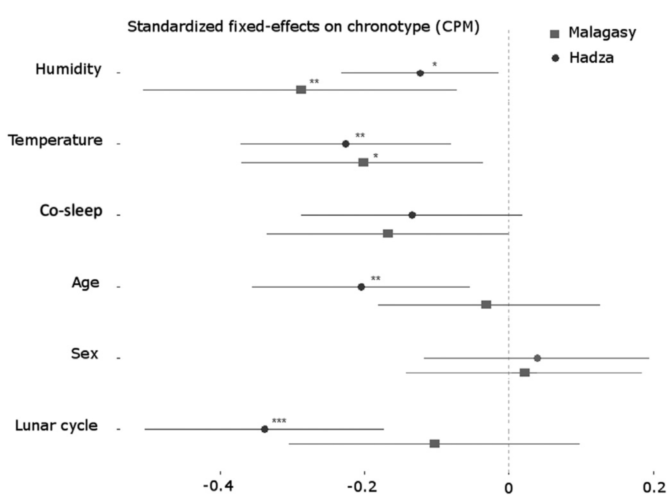

Fig. 3. A standardized fixed-effects plot illustrating the influence of lunar cycle on chronotype (CPM) in a hunter-gatherer and small-scale agricultural society. The Malagasy are the small-scale agricultural society (symbol = square), and the Hadza are the hunter-gatherer society (symbol = circle). Significance for a fixed effect is demonstrated when confidence intervals (indicated by horizontal lines) do not overlap with the dotted line at "0." This analysis showed that lunar cycle drives shifts in chronotype for the hunter-gatherer but not for the small-scale agricultural society. Asterisks indicate level of significance (*$P < .05$ to $P > .01$, **$P < .01$ to $P < .001$, ***$P < .001$). The units were scaled to permit comparability of the coefficients produces by the models.

compare individual activity patterns relative to the proportion of the moon that was directly sunlit as viewed from Earth. We implemented FLM by using a nonparametric permutation test method in the R package "actigraphy."[29] The *P* value is calculated by counting the proportion of permutation *F* values that are larger than the *F* statistics for the observed data and does not rely on distributional assumptions. Here, we used the pointwise test (with 500 permutations) that provides a curve which is the proportion of all permutation *F* values at each point in the time series.[28]

To assess the predictors of sleep and chronotype, we ran linear mixed-effects models using the lme4 package[30] for each response variable[1]: sleep duration or total sleep time,[2] chronotype or central phase measure (CPM), and sleep efficiency (the total time asleep divided by the total time in bed). In all models, we included the following fixed effects: age, sex, temperature, number of co-sleepers, humidity, and lunar cycle. Using the R "scale" function, these predictors were scaled to ensure comparability between coefficients and across models. To control for repeated measures, we included "subject" as a random effect. To increase the power of our models, we obtained coefficients based on optimization of the log-likelihood using shrinkage, which incorporates measurement error into the regression model and improves less certain estimates by pooling information from more certain estimates.[31] We used the MuMIn package[32] to average models with ΔAIC <10. Finally, we made statistical inferences using a combination of standardized coefficients, *P* values, and confidence intervals.

Results

In the Hadza, FLM revealed that a brighter moon (ie, later lunar phase and inferred greater exposure to moonlight) was strongly associated with (*a*) less activity between 00:00 and 02:00 and (*b*) more activity between 11:00 and 14:00, around midday (Fig. 1). In addition, the linear mixed-effects model showed that sleep duration increased with greater lunar cycle for the Hadza ($\beta \pm SE = 0.29 \pm 0.09$, $P = .001$, confidence interval [CI] = 0.11-0.46) but not the Malagasy ($\beta \pm SE = -0.10 \pm 0.10$, $P = .28$, CI = −0.29 to 0.08; see Fig. 2). In the Hadza, the linear mixed-effects model revealed that chronotype (CPM) was phase advanced with increasing *age, temperature,* and *lunar cycle* (Table 1). In contrast, the linear mixed-effects model for the Malagasy showed that CPM was not significantly influenced by lunar cycle but was phase advanced by increased humidity, number of co-sleepers, and temperature (Table 2). Thus, it can be inferred that chronotype phase advanced with greater exposure to moonlight in the Hadza but not in the Malagasy (Fig. 3). Finally, sleep efficiency was not significantly influenced by lunar cycle in either the Hadza ($\beta \pm SE = 0.02 \pm 0.07$, $P = .775$, CI = −0.12 to 0.17) or the Malagasy ($\beta \pm SE = -0.09 \pm 0.07$, $P = .23$, CI = −0.23 to 0.06).

Discussion

Does the moon influence human sleep? In general support of *the moonlight hypothesis*, we uncovered a link between sleep-wake patterns and lunar cycle for Hadza hunter-gatherers but not Malagasy small-scale agriculturalists. Intriguingly, the direction of the effect was based on patterns observed in some previous studies in post-industrial societies.[5] Specifically, FLM analysis of the Hadza showed that as the moon gets brighter, activity generally shifted to a pattern of less nighttime activity and greater daytime activity (Fig. 1). We interpret the data to suggest that increased activity during a new moon resulted in a rebound of less activity during the day. Corroborating this analysis, the linear mixed-effects models showed that sleep duration decreased as moonlight waned and that this association was only seen in the Hadza. Intriguingly, chronotype also shifted in the Hadza and not the Malagasy, but interestingly, as moonlight waned, chronotype phase delayed (became more "owl-like"; Tables 1 and 2; Fig. 2). We found no associations between sleep efficiency and lunar cycle in either population.

Thus, the major finding of this preliminary investigation supports the hypothesis that the Hadza activity pattern was correlated with lunar phase. Additionally, an important conclusion from this work is that moonlight does not inhibit sleep in the same way that electrically generated light does. However, the pattern was opposite to that predicted by previous laboratory work[5] and counter to expectations that (moon) light should increase nighttime activity. Informed by this outcome, we forward three hypotheses for future research. First, market agriculture may have more predictable and consistent demands of both daytime and nighttime sleep-wake activity patterns and thus mask any influence of lunar cycle. Second, it could be that sociocultural practices are responsible for this effect. For example, the *epeme dance*, a sacred Hadza ritual that was performed during the study period, is traditionally performed on nights when there is no moon in the sky.[14] As the ritual requires the surrounding area to be dark, it is acted out between the hours of full darkness throughout the night. The function of the ceremony is to act as a social adhesive and bring fortune to future hunting expeditions.[33] Thus, as in humans dwelling in developed economies, social and cultural behaviors may influence sleep patterns. Finally, predation could be driving these patterns, as moonlight has been shown to not only suppress activity in most nocturnal mammals (indicating the net effect of illumination may increase predation risk) but also increase activity of prey species that use vision as their primary sensory system.[34] Given that the Hadza (and ancestral populations) dwell in areas with prey species that rely on sight (eg, hunting cats), activity on nights with more light may make individuals more vulnerable to predators.

Several limitations to the study are worth noting. First, although both studies were performed in equivalent seasons (the *wet* season for the Hadza and the *austral-winter* for the Malagasy) when temperatures are lower and rainfall is higher, they do not account for across-season variation. Future studies should incorporate the influence of season on the response variables focused on in this study. Second, lunar cycle was used as a proxy for moonlight exposure; we did not take into account night-to-night cloud cover, which could have concealed visibility of the moon, reducing the strength of any effects (but unlikely to erase them completely). Third, we had a limited sample size. Finally, the results are not meant to represent *all* hunter-gatherers or small-scale agriculturalists; essentially, for the categorization of subsistence strategy, these represent an n of one for each population and thus only illustrate what is *possible* and not necessarily the *norm* for each society. Future work should explicitly survey participants to assess the range of nighttime behaviors exhibited in relation to changes in lunar cycle or greater exposure to moonlight. This fact underscores the importance of continued work on sleep in populations living in natural environments, where larger sample sizes are urgently needed to be generated in societies that remain extremely vulnerable to changes in cultural practice and local economic exposure.[15,16]

In summary, with 24-hour access to electrically generated light, humans in Western populations have altered their light environment in profound ways, resulting in desynchronized circadian rhythms that impair the central clock, muscle strength, bone structure, and immune function.[35] To cope with living in a brave new world without zeitgebers (ie, circadian queues), we have adopted coping strategies that include products or drugs with caffeine, amphetamines, anticholinergics, and melatonin to regulate our sleep-wake pattern in socially acceptable ways. This mismatch between our sleep physiology and environment remains poorly understood, and the lunar cycle's influence on behavior may be important for understanding multiple aspects of human health, disease, and mental illness.[36,37,38] Our findings suggest that moonlight influences human activity but in different ways than electrically generated light. Previous work has shown that lunar cycle influences mammalian behavior[39]; thus, research increasing our understanding of the lunar cycle on human sleep architecture[40] and health in small scale societies, such as those under study here, will likely shed some much needed light on an otherwise dark landscape.

Disclosure

The work described has not been published previously in any other journal.

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