Bad Sleep? Don't Blame the Moon!

A Population Based Study

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Word count:

Full title: 10 (56 characters)

Abstract: 248

Main text: 3404

Number of tables: 4

Figures: 1

References: 32

Supplementary tables: 5

Abstract

Introduction: The aim of this study was to evaluate if there is a significant effect of lunar phases on subjective and objective sleep variables in the general population.

Methods: 2125 subjects (51.2% women, age 58.8 ± 11.2 years) participating in a population-based cohort underwent full polysomnography (PSG) at home. Subjective sleep quality was evaluated by a self-rating scale. Sleep EEG spectral analysis was performed in 759 participants without significant sleep disorders. Salivary cortisol levels were assessed at awakening, 30 minutes after awakening, at 11:00 a.m. and at 8:00 p.m. Lunar phases were grouped into full (FM), waxing/waning (WM) and new moon (NM).

Results: Overall, there were no significant differences between lunar phases regarding subjective sleep quality. We found only a non significant ($p=0.08$) trend towards a better sleep quality during the NM phase. Objective sleep duration was not different between phases (FM: 398 ± 3 min, WM: 402 ± 3 min, NM: 403 ± 3 min; $p=0.31$). No differences were found regarding other PSG-derived parameters, EEG spectral analysis or in diurnal cortisol levels. When considering only subjects with apnoea/hypopnoea index $<15/h$ and periodic leg movements index $<15/h$ we found a trend towards shorter total sleep time during FM (FM: 402 ± 4 , WM: 407 ± 4 , NM: 415 ± 4 min; $p=0.06$), and shorter stage N2 duration (FM: 178 ± 3 , WM: 182 ± 3 , NM: 188 ± 3 min; $p=0.05$).

Conclusion: Our large population-based study provides no evidence of a significant impact of lunar phases on human sleep.

Keywords: Moon, sleep, cortisol, EEG spectral analysis

1. Introduction

“...her power to enamour, to mortify, to invest with beauty, to render insane, to incite to and aid delinquency...” Ulysses, James Joyce.

In human history and in different cultures, there has been the strong belief that the moon can affect health, including sleep, with people reporting difficulty in falling asleep and remaining asleep when the moon is full. Increased nightlight during full moon could partly explain these complaints when humans slept in caves, but this hypothesis would not hold nowadays in our curtained homes.

The evidence of an effect of lunar cycles on human biology and sleep was reported to be largely based on folklore or myths, with little robust scientific evidence¹. Nevertheless, more recent studies based either on sleep electroencephalography (EEG) or on subjective sleep evaluations have yielded conflicting results²⁻⁶. This might be due to the fact that not all key variables had been controlled for and that further studies were deemed necessary⁷.

Thus, the aim of our study was to shed new light on the possible effects of the lunar cycle on sleep. We analyzed subjective sleep quality and objective sleep duration and structure in a large, unselected middle-aged general population sample. In a subgroup of subjects without significant sleep disorders and free of sleep medication or significant alcohol consumption, EEG microstructure was also analyzed using spectral analysis. As some studies also suggested that moon phases could affect mood and consequently sleep, salivary cortisol as a measure of biological stress response, was also evaluated.

2. Methods

2.1. Study design

The HypnoLaus Sleep study is based on the first follow up of the epidemiologic CoLaus/PsyCoLaus study described previously ⁸⁻¹⁰. Briefly, the CoLaus study included a random sample of 6733 subjects (range age: 35 to 75 years) representative of the residents of Lausanne city (Switzerland) between 2003 and 2006. The distribution of age groups, gender, and zip codes of participants were similar to the source population ⁸. The first aim of this cohort was to investigate the prevalence of cardiovascular risk factors in the general population and to identify their genetic determinants. All participants were also invited to undergo an extensive psychiatric evaluation (PsyCoLaus) ¹⁰. HypnoLaus evaluated the subjective and objective sleep characteristics of this population ⁹. During the first follow up of the cohort, five years after baseline, all subjects who responded underwent a new physical (n=5064) and psychiatric (n=4002) examination and were given questionnaires by trained interviewers. These included questions on demographic, medical, and treatment history as well as smoking and alcohol consumption. Sleep-related complaints and habits were investigated using the Pittsburgh Sleep Quality Index, ¹¹ the Epworth Sleepiness Scale, ¹² as well as the Berlin Questionnaire for sleep disordered breathing ¹³. The CoLaus/PsyCoLaus and HypnoLaus studies were approved by the Ethics Committee of the University of Lausanne and a written informed consent was obtained from all participants at the baseline and for the follow-up assessments.

2.2. Polysomnography

Three thousand and fifty-one consecutive CoLaus/PsyCoLaus subjects were invited to undergo a full night in-home polysomnographic (PSG) recording, and 71.1% accepted. The subjects who

underwent PSG were similar in terms of age (-0.3 years) and gender (+1.6% males) to the whole CoLaus cohort. No selection of subjects was made based on the sleep questionnaires and the investigators were blind to the questionnaires' results. During a visit at the Center for Investigation and Research in Sleep (University Hospital of Lausanne, Switzerland), certified technicians equipped the subjects with a PSG recorder (Titanium, Embla® Flaga, Reykjavik, Iceland) between 5 and 8 pm. All sleep recordings took place in the patients' home environment and included a total of 18 channels: EEG (F3/M2, F4/M1, C3/M2, C4/M1, O1/M2, and O2/M1), right and left electrooculography, surface electromyography channels (one submental region, two anterior tibialis muscle), electrocardiogram, nasal pressure, thoracic and abdominal respiratory inductance belts, body position, oxygen saturation, and pulse rate ¹⁴.

All PSG recordings were visually scored by two trained sleep technicians (DA and NT) using Somnologica software (Version 5.1.1, by Embla® Flaga, Reykjavik, Iceland) and reviewed by a trained sleep physician (JHR). Random quality checks were performed by a second physician (RH). Quality control for concordance rate between the two PSG scorers was implemented periodically to ensure that both scorers achieved at least a 90% level of agreement for sleep stages and respiratory events and an 85% level of agreement for arousals ¹⁵. Sleep stages and arousals were scored according to the 2007 AASM criteria ¹⁴. The oxygen desaturation index (ODI) represents the number $\geq 3\%$ oxygen saturation drops per hour of sleep.

Apnoeas/hypopnoeas were scored according to the AASM 2013 rules ¹⁶. The average number of apnoeas/hypopnoeas per hour of sleep (apnoea/hypopnoea index [AHI]) was calculated. Periodic leg movements during sleep (PLM) were scored according to the official World Association of Sleep Medicine standards ¹⁷ and expressed as number of PLM per hour of sleep (PLM index, PLMI).

2.3. Sleep EEG spectral analysis

Sleep microstructure was analyzed using sleep EEG spectral analysis in a subgroup of the population, selected on the absence of medication interfering with sleep structure and/or duration (sleeping pills, antidepressants, neuroleptics), less than 2 glasses of wine consumed 4 hours prior to sleep, sleep duration >5 hours, sleep efficiency >80%, AHI less than 15/h, and PLMSI less than 15/hour. Signals were filtered by a high-pass filter (EEG and EOG: -3 dB at 0.5 Hz; EMG: 10 Hz), a low-pass filter (EEG: -3 dB at 35 Hz, EMG: 70 Hz), and a notch filter at 50 Hz. Data were sampled at 256 Hz. The EEG power spectra of consecutive 30-s epochs (average of 4-s epochs interval with 50% overlap, fast Fourier transform routine, Hamming window, frequency resolution 0.25 Hz) for NREM sleep (stages N2 and N3), and REM sleep were calculated using PRANA[®] software (Phitools, Strasbourg, France). All artifacts were removed from spectral analysis. NREM-REM cycles were defined according to Feinberg and Floyd¹⁸. NREM/REM spectral analysis was calculated only for the maximum first four sleep cycles. Delta (0.75-4.5Hz), theta (4.75-8Hz), alpha (8.25-11Hz), slow spindles (11.25-13Hz), fast spindles (13.25-15Hz), and beta (15-25Hz) bands were calculated. EEG power spectra were normalized by dividing the power in each 0.25Hz bin by total power for NREM and REM sleep over 0.75-30Hz frequency range.

2.4. Subjective sleep quality

Subjective sleep quality of the recorded night was evaluated by the participating subjects with a self-rating scale completed immediately after getting up in the morning. Sleep quality was rated in four categories: “Excellent”, “Good”, “Average”, and “Bad”. In addition, for analysis, subjects were split in two groups: those who reported “Excellent” and “Good” sleep quality *vs.* those who

reported “Average” and “Bad” sleep quality. Alcohol and sleep medication intake before the PSG recording were also documented.

2.5. Cortisol levels

Participants of the first psychiatric follow-up investigation received little swabs (Salivettes, Sarstedt, Leicester, UK) for salivary cortisol collection at awakening, 30 minutes thereafter, at 11:00 a.m. and at 8:00 p.m. Cortisol measurements were taken independently from the PSG. The cortisol analyses refer to the actual moon phase when the probes were taken. Saliva cortisol samples were collected using cotton swabs (“Salivette”, Sarstedt) and immediately frozen at -20°C and sent for biochemical analysis. Samples then were centrifuged at 3,000 rpm for 5 min, which resulted in a clear supernatant of low viscosity. Salivary cortisol concentrations were measured using commercially available chemiluminescence-immunoassay with high sensitivity (IBL International, Hamburg, Germany), with intra- and interassay coefficients of variation <8%, as described previously^{19, 20}. We compared between groups cortisol levels at awakening, the cortisol awakening response (calculated by subtracting cortisol at time 1 from cortisol at time 2) and the average of the four measures.

2.6. Lunar phases

Moon phases for the city of Lausanne were obtained for the different dates of interest from www.timeanddate.com/worldclock/astronomy.html. When a value was not available (which occurred in less than 1% of cases), it was extrapolated from the two adjacent ones. As some authors have suggested that the effect of moon could be due to a “tidal effect”, the average

distance between the moon and earth (in kilometers) was also collected for each day. Lunar phases were defined as previously^{2, 5} into full moon (± 4 nights from full moon), waxing/waning moon (± 5 to 9 nights from full moon), and new moon (± 10 to 14 nights from full moon). For correlation analysis, the percentage of illuminated moon (0%= new moon, 100%=full moon) was also used.

2.7. Statistical analysis

Statistical analysis was conducted using Stata (Stata Corp, College Station, TX, USA) version 13.1. Results were expressed as number of participants and (percentage) or as mean $\pm$ standard deviation, unless otherwise stated. Bivariate comparisons were performed using chi-square or oneway analysis of variance. For sleep quality, multivariable analyses were performed using logistic regression and the results were expressed as odds ratio (OR) and (95% confidence interval). Quantitative variables were considered as continuous. For PSG parameters, spectral EEG data and cortisol levels, multivariable analyses were performed using analysis of variance and the results were expressed as multivariable-adjusted mean $\pm$ standard error. Multivariable analysis were adjusted for gender, age, alcohol consumption (yes/no), sleep medicines (yes/no). PSGs were recorded between Mondays and Fridays. As Saturday is generally considered to be a day off, the day of week (Friday versus other week days) was also considered as a covariate. Statistical significance was considered for $p < 0.05$ ²¹. As co-morbid sleep disorders, such as respiratory disturbances and periodic leg movements, are highly prevalent⁹ and could obscure the lunar effect on sleep, we performed these analysis in the whole population and in a subgroup of subjects with no significant sleep disordered breathing (AHI $< 15/h$) and with a PLMSI $< 15/h$ (overall and stratifying by gender).

3. Results

3.1. Characteristics of the sample

Technical problems resulting in insufficient data for PSG scoring were encountered in 60 cases of the 2168 participants (2.8%), 54 PSG were repeated and 6 subjects declined to repeat the study. Thirty-seven (1.7%) were further excluded because of missing data for sleeping pills or alcohol consumption, resulting in 2125 participants with complete PSG (51.2% women, mean age 58.8 ± 11.2 years), of which 759 (60% women, mean age 53.6 ± 9.2 years) also had spectral EEG data. The selection procedure is summarized in **figure 1**. Due to missing data or incomplete questionnaires subjective sleep quality of the recorded night was available for 1991 subjects. In the overall sample, women reported taking sleeping pills more frequently (11.2% vs. 6.1%, $p < 0.001$) and consuming alcohol less frequently (78.3% non drinkers vs. 68.3%, $p < 0.001$) than men, while no gender differences were found regarding age, day of PSG and lunar phase (not shown).

3.2. Subjective sleep quality

We did not find significant differences with regard to subjective sleep quality between groups according to lunar phase. A non significant trend towards a better sleep quality was found in subjects recorded during a new moon phase when the subjects were pooled in two groups (“Excellent”/“Good” sleep quality vs. “Average”/“Bad” sleep quality): 43.2% of the subjects recorded during a new moon phase reported “excellent or good” sleep quality, compared to

37.3% of the subjects recorded during a waxing/waning lunar phase and 39.4% of those recorded during a full moon phase ($p=0.08$, **Table 1**).

When considering only subjects without significant sleep disturbances (subjects with AHI <15/h and PLMSI <15/h) we only found a significant trend towards a worse subjective sleep quality during waxing/waning phases compared to full moon in women when they were pooled in two groups (“Excellent”/“Good” sleep quality vs. “Average”/“Bad” sleep quality) (**Supplementary table 1**).

3.3. Objective sleep structure

No differences were found for sleep duration between the three “lunar class” groups. The total sleep time (TST) was 398 ± 3 min, 402 ± 3 and 403 ± 3 min for subjects recorded during a full moon, a waxing/waning and a new moon phase, respectively ($p=0.31$). Similarly, no differences were found for sleep onset latency, REM sleep latency, sleep efficiency, duration (in min) and percentage of the different sleep stages (N1, N2, N3, and REM), the arousal index or the number of stage shifts. Finally, no significant differences were found for the AHI, the ODI, or for the PLMSI (**Table 2**).

In those without significant sleep disturbances (subjects with AHI <15/h and PLMSI <15/h), results showed a trend towards shorter TST in subjects recorded during a full moon phase (FM: 402 ± 4 , WM: 407 ± 4 , NM: 415 ± 4 min; $p=0.06$), and they spent significantly less time in stage N2 (FM: 178 ± 3 , WM: 182 ± 3 , NM: 188 ± 3 min; $p=0.05$, **Supplementary table 2a**), but this difference was no longer significant when stratifying by gender (**Supplementary tables 2b, 2c**).

3.4. Sleep EEG spectral analysis

No differences were found for the different frequency bands between the three “lunar class” groups. In particular, no differences were found for the absolute or relative sleep EEG delta activity during NREM (**Table 3**).

3.5. Cortisol levels

In bivariate analysis, no significant association was found between moon phases and diurnal salivary cortisol levels, and similar findings were obtained after adjusting for age, gender and smoking status (**Table 4**). Furthermore, no significant correlations were found between salivary cortisol values and moon brightness or distance from earth (all $p > 0.14$, not shown).

We did not find either significant differences concerning cortisol measurements in subjects without sleep disturbances (subjects with AHI $< 15/h$ and PLMSI $< 15/h$, **Supplementary table 3**).

4. Discussion

To our knowledge, this is the largest study assessing the influence of lunar cycles on subjective and objective sleep parameters in an unselected, middle to older-aged general population sample. No evidence was found of any relevant lunar effect on all sleep parameters studied, nor on

diurnal salivary cortisol. In particular, subjects recorded during full moon did not report worse subjective sleep quality, and no differences were found regarding objective sleep parameters, or cortisol levels. However, after excluding subjects with significant sleep disturbances (subjects with $AHI \geq 15/h$ and $PLMSI \geq 15/h$) we found a trend towards shorter TST in subjects recorded during a full moon phase and they spent significantly less time in stage N2. Even if these differences were small and do not seem clinically meaningful, we cannot completely rule out the presence of a small effect of lunar phases on sleep obscured by the presence of co-morbid sleep disorders, or other environmental factors, in our study. Due to the number of tests performed these differences could also be due to chance.

The influence of moon cycles on health status has been reported for millennia. Even in the twentieth century, lunar cycles have been suggested to influence births,²² myocardial infarctions,²³ and psychiatric disorders²⁴ (thus the term *lunatic* or *lunaticism*; for a review, see²⁵), although most of these statements have not been confirmed^{26, 27}.

Several theories have been put forward to explain the association between the moon and diseases. The *tidal* theory claims that gravitational forces influence inner bodily fluids just as ocean tides²⁸. Still, no significant correlation between the moon's distance from earth and all parameters studied was found (not shown). The *night light* theory builds on the fact that sleep is affected by environmental factors and particularly by light²⁹. The increased moonlight during full moon would thus lead to partial sleep deprivation and thereby induce mania/hypomania in susceptible subjects³⁰ and increase the frequency of epileptic seizures³¹. Again, no significant association between moon brightness and all parameters studied was found.

Several recent studies have tried to correlate sleep parameters with changes in lunar phase. In a post-hoc analysis of 1145 sleep diaries of 31 subjects, Roosli *et al* reported that subjective sleep duration varied from 6 h 41 min at full moon to 7 h 00 min at new moon, and that complaints of fatigue in the morning were also associated with moon phase, with more tiredness at full moon ⁴. More recently, Cajochen *et al.* retrospectively analyzed sleep structure, EEG spectral activity during NREM, and secretion of melatonin and cortisol of 33 healthy volunteers, measured under controlled laboratory conditions ². They found that during a 0-4 days period around full moon, delta activity during NREM sleep, an indicator of deep sleep, decreased by 30%, sleep latency increased by 5 min, and the TST decreased by 20 min. These changes were associated with a decrease in subjective sleep quality and diminished endogenous melatonin levels, while cortisol levels differences did not attain significance. In another retrospective laboratory study of 47 healthy volunteers, TST was found to decrease by 25 minutes around the full moon relative to quarter moon ³.

These two last studies were conducted in-laboratory with controlled sound and light conditions which allows excluding a potential disturbing effect of nighttime light on sleep. The authors proposed that the effects of the moon on sleep can be the expression of an endogenous circalunar clock working in conjunction with the circadian clock. Still, although the highly controlled conditions of a circadian laboratory study protocol without time cues can allow to “unmask” potential lunar influences, these findings cannot be directly extrapolated to the general population. Further, in laboratory studies, only volunteers with good self-reported sleep were recruited. Finally, the results relied on a small number of participants.

In a recent retrospective, cross-sectional analysis of data from 319 patients undergoing diagnostic polysomnography, Turanyi *et al.* found that full moon was associated with less deep

sleep, lower sleep efficiency, and longer REM latency, even after adjustment for several covariables. The observed differences were more pronounced in women ⁶.

However, in a re-analysis of sleep EEG data from three large samples (470 sleep EEGs from 366 healthy participants in a light-controlled sleep laboratory, 757 sleep EEGs of 29 volunteers each of whom slept for 13–60 consecutive nights in the sleep laboratory and EEGs of 870 young, healthy volunteers who slept at home), Cordi *et al* were unable to replicate these findings. The authors concluded that there was no evidence whatsoever of a lunar influence on sleep ⁵. Similar to the findings by Cordi *et al*, we failed to find any statistically significant association between lunar phases and subjective or objective sleep parameters.

Our study has several strengths: it analyzed subjective sleep quality of almost 2000 subjects, objective sleep characteristics based on PSG of 2125 subjects of the general population, and spectral EEG data of a subgroup of 759 of these participants devoid of sleep pathology. Sleep was recorded in the habitual sleep environment at home of the participants, in order to ensure high ecological validity, and age and sex were uniformly distributed across lunar phases. The monocentric setting of the study allowed the uniform collection, processing, and analysis of the data. It is thus to date the largest and the most comprehensive single study assessing the associations between lunar phases and sleep. In addition, cortisol levels at awakening and at different time points during the day were measured, providing a supplementary biological marker of the response to stress. At the time of recording, participants and investigators were unaware of the a posteriori analysis related to the lunar hypothesis. Even if a cognitive bias cannot be completely excluded, the a posteriori analysis makes it rather unlikely. In addition, we took into account a large number of potential confounders.

Our analyses have several limitations worth acknowledging. They are based on cross-sectional data, and future studies should build upon the present findings by incorporating longitudinal analyses. Also, our analyses relied on a single PSG, and it might be preferable to conduct multiple PSGs to account for within-participant variation. Ideally, the same subject should be recorded at each of the lunar phases more than once; however it would be difficult to implement such a procedure within the framework of a large epidemiological study. Moreover, the cortisol profile was established during the psychiatric follow-up exam which frequently took place several months before or after the PSG recording. Still, as a significant number of participants did not provide the exact timing of awakening, it was not possible to calculate the area under the curve for cortisol levels³². Finally, we could not take into account if the participants slept with an open curtains or the amount of cloudiness, which could have shaded the moonlight. Still, restricting the analysis to the months of May to September (less clouds) led to similar results as those related to the whole 12-month period (not shown).

In conclusion, our study provides no scientific evidence for the widely popular belief that lunar phase and human sleep are related and perhaps represents “the great tragedy of science: the slaying of a beautiful hypothesis by an ugly fact” (Thomas Huxley, 1825-95).

Acknowledgements

The study was funded by the Faculty of Biology and Medicine of Lausanne, the Lausanne University Hospital (CHUV), the Swiss National Science Foundation, the Leenaards Foundation, GSK and the Ligue Pulmonaire Vaudoise. We would like to thank Ian Graham for his assistance in preparing this manuscript, and Vincent Mooser and all other investigators of CoLaus/PsyCoLaus study, who made the Hypnolaus study possible. The authors would like to express their gratitude to the Lausanne population who volunteered to participate in the Hypnolaus study.

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Figure 1: Selection procedure of the participants

Tables

Table 1. Subjective sleep quality, for full moon, waxing/waning moon and new moon (n=1991)

	Full moon (n=592)	Waxing/waning moon (n=716)	New moon (n=683)	P-value
Subjective quality				
Excellent	26 (4.4)	22 (3.1)	26 (3.8)	0.29
Good	207 (35)	245 (34.2)	269 (39.4)	
Average	284 (48)	352 (49.2)	313 (45.8)	
Bad	75 (12.7)	97 (13.6)	75 (11.0)	
Subjective quality				
Excellent + good	233 (39.4)	267 (37.3)	295 (43.2)	0.08
Average + bad	359 (60.6)	449 (62.7)	388 (56.8)	
Average + bad vs. other	1 (ref.)	1.10 (0.87 to 1.38)	0.84 (0.67 to 1.06)	§

Results are expressed as number of participants and (%). Statistical analysis by chi-square or logistic regression (§) adjusting for gender, age, alcohol consumption (yes/no), sleep medicines (yes/no), and day of week

Table 2. Sleep parameters for full moon, waxing/waning moon and new moon (n=2125)

	Full moon (n=641)	Waxing/waning moon (n=755)	New moon (n=729)	P-value
Total sleep time, min	398 ± 3	402 ± 3	403 ± 3	0.31
Latency to sleep, min	18.1 ± 0.9	16.5 ± 0.8	18.9 ± 0.9	0.13
Sleep efficiency, %	84.3 ± 0.4	84.4 ± 0.4	85.0 ± 0.4	0.31
Nb awakenings, nr/h	24.7 ± 0.5	25.5 ± 0.5	25.1 ± 0.5	0.53
Arousal index, nr/h	21.2 ± 0.4	21.5 ± 0.4	21.2 ± 0.4	0.82
Nb of stage shifts, nr	138 ± 2	143 ± 2	141 ± 2	0.15
WASO, min	76.3 ± 2	76.5 ± 1.9	72.8 ± 1.9	0.32
REM latency, min	93.9 ± 2.4	94.8 ± 2.2	97.2 ± 2.3	0.59
Stage N1, min	46.5 ± 1	47.7 ± 0.9	46.4 ± 0.9	0.58
Stage N2, min	185 ± 2	188 ± 2	188 ± 2	0.39
Stage N2, %	46.2 ± 0.4	46.6 ± 0.4	46.5 ± 0.4	0.67
Stage N3, min	78.8 ± 1.3	76.8 ± 1.2	80 ± 1.2	0.14
Stage N3, %	19.9 ± 0.3	19.3 ± 0.3	19.9 ± 0.3	0.17
REM, min	87.9 ± 1.1	89.6 ± 1.0	88.6 ± 1.1	0.52
REM, %	21.9 ± 0.2	22.1 ± 0.2	21.7 ± 0.2	0.52
ODI3, nr/h	14.7 ± 0.6	14.8 ± 0.5	14.9 ± 0.5	0.95
AHI, nr/h	15.5 ± 0.6	15.5 ± 0.5	15.8 ± 0.5	0.91
PLMSI, nr/h	13.1 ± 0.9	13.9 ± 0.8	14.7 ± 0.8	0.41

WASO: Wake after sleep onset; REM: Rapid-eye-movement-sleep; ODI3: Oxygen desaturation index >3%; AHI: Apnea-hypopnea index; PLMSI: Periodic leg movement index. Results are expressed as multivariable adjusted mean $\pm$ standard error. Statistical analysis by ANOVA adjusting for gender, age, alcohol consumption (yes/no), sleep medicines (yes/no), and day of week.

Table 3. Spectral EEG parameters for full moon, waxing/waning moon and new moon (n=759)

	Full moon (n=231)	Waxing/waning moon (n=265)	New moon (n=263)	P-value
Delta	364 ± 11	373 ± 10	388 ± 10	0.28
Theta	48 ± 2	49 ± 2	48 ± 2	0.88
Alpha	26 ± 1	27 ± 1	26 ± 1	0.41
Beta	6 ± 0.2	6.2 ± 0.2	5.9 ± 0.2	0.58
Slow spindles	9.4 ± 0.3	10 ± 0.3	9.7 ± 0.3	0.44
Fast spindles	8.2 ± 0.3	8.3 ± 0.3	8.3 ± 0.3	0.98
rDelta	74.9 ± 0.4	74.6 ± 0.4	75.5 ± 0.4	0.25
rTheta	10.5 ± 0.2	10.4 ± 0.2	10.2 ± 0.2	0.46
rAlpha	5.6 ± 0.2	5.8 ± 0.1	5.4 ± 0.2	0.25
rBeta	1.4 ± 0.1	1.4 ± 0.1	1.3 ± 0.1	0.24
rSlow spindles	2.2 ± 0.1	2.2 ± 0.1	2.2 ± 0.1	0.58
rFast spindles	2 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	0.60

Results are expressed as multivariable adjusted mean ± standard error. Statistical analysis by ANOVA adjusting for gender, age, alcohol consumption (yes/no), sleep medicines (yes/no) and day of week. r refers to relative EEG power.

Table 4. Effect of moon phases on salivary cortisol (n=2121)

	Full moon (n=674)	Waxing/waning moon (n=687)	New moon (n=760)	P-value *	P-value †	P-value ‡
At awakening						
Unadjusted	19.7 ± 10.1	18.6 ± 12.4	19.1 ± 11.8	0.21	0.22	0.16
Adjusted §	19.7 ± 0.4	18.5 ± 0.4	19.1 ± 0.4	0.19	0.38	0.11
Cortisol awakening response						
Unadjusted	7.8 ± 13.3	7.6 ± 14.3	8.5 ± 12.3	0.40	0.38	0.11
Adjusted §	7.7 ± 0.5	7.7 ± 0.5	8.4 ± 0.5	0.48	0.33	0.50
Average of all measures						
Unadjusted	15.6 ± 5.3	14.9 ± 6.2	15.3 ± 5.1	0.10	0.33	0.50
Adjusted §	15.6 ± 0.2	14.9 ± 0.2	15.3 ± 0.2	0.09	0.32	0.05

Free salivary cortisol levels were assessed at awakening, 30 minutes thereafter, at 11:00 a.m. and at 8:00 p.m. Values in nmol/l. Results are expressed as mean ± standard deviation or as multivariable adjusted mean ± standard error. § adjusted for gender, age and smoking status (yes/no). Statistical analysis by ANOVA. *, p-value comparing groups; †, p-value for linear trend; ‡, p-value for quadratic trend.

Supplementary table 1. Subjective sleep quality, for full moon, waxing/waning moon and new moon, in subjects free of sleep disturbances (AHI<15/h and PLMSI<15/h), overall and stratified by gender.

	Full moon	Waxing/waning moon	New moon	P-value
All subjects, N	255	294	299	
Subjective quality				
Excellent	6 (2.4)	8 (2.7)	7 (2.3)	0.34
Good	108 (42.4)	99 (33.7)	122 (40.8)	
Average	111 (43.5)	149 (50.7)	143 (47.8)	
Bad	30 (11.8)	38 (12.9)	27 (9.0)	
Subjective quality				
Excellent + good	114 (44.7)	107 (36.4)	129 (43.1)	0.10
Average + bad	141 (55.3)	187 (63.6)	170 (56.9)	
Average + bad vs. other	1 (ref.)	1.42 (1.00 to 2.02)	1.06 (0.75 to 1.50)	§
Women only, N	163	177	191	
Subjective quality				
Excellent	4 (2.5)	6 (3.4)	6 (3.1)	0.33 ‡
Good	76 (46.6)	61 (34.5)	74 (38.7)	
Average	67 (41.1)	85 (48.0)	93 (48.7)	
Bad	16 (9.8)	25 (14.1)	18 (9.4)	
Subjective quality				
Excellent + good	80 (49.1)	67 (37.9)	80 (41.9)	0.11 ‡
Average + bad	83 (50.9)	110 (62.2)	111 (58.1)	
Average + bad vs. other	1 (ref.)	1.66 (1.06 to 2.60)	1.51 (0.96 to 2.36)	§
Men only, N				
Subjective quality				
Excellent	2 (2.2)	2 (1.7)	1 (0.9)	0.42 ‡
Good	32 (34.8)	38 (32.5)	48 (44.4)	
Average	44 (47.8)	64 (54.7)	50 (46.3)	
Bad	14 (15.2)	13 (11.1)	9 (8.3)	
Subjective quality				
Excellent + good	34 (37.0)	40 (34.2)	49 (45.4)	0.21 ‡
Average + bad	58 (63.0)	77 (65.8)	59 (54.6)	
Average + bad vs. other	1 (ref.)	1.05 (0.57 to 1.93)	0.69 (0.37 to 1.26)	§

Results are expressed as number of participants and (%). Statistical analysis by chi-square, Fisher's exact test (‡) or logistic regression (§) adjusting for gender (all subjects only), age, alcohol consumption (yes/no), month and day of week

Supplementary table 2a. Sleep parameters for full moon, waxing/waning moon and new moon, in subjects free of sleep disturbances (AHI<15/h and PLMSI<15/h)

	Full moon (n=279)	Waxing/waning moon (n=316)	New moon (n=327)	P-value
Total sleep time, min	402 ± 4	407 ± 4	415 ± 4	0.06
Latency to sleep, min	22.6 ± 1.6	23.7 ± 1.5	25.6 ± 1.5	0.41
Sleep efficiency, %	86.8 ± 0.6	86.9 ± 0.5	87.3 ± 0.5	0.82
Nb awakenings, nr/h	21 ± 1	21 ± 1	22 ± 1	0.72
Arousal index, nr/h	16.0 ± 0.4	15.6 ± 0.3	15.6 ± 0.3	0.68
Nb of stage shifts, nr	124 ± 2	129 ± 2	131 ± 2	0.12
WASO, min	62.4 ± 2.8	63.1 ± 2.7	62.0 ± 2.6	0.95
REM latency, min	83 ± 3	85 ± 3	83 ± 3	0.88
Stage N1, min	38 ± 1	40 ± 1	40 ± 1	0.36
Stage N2, min	178 ± 3	182 ± 3	188 ± 3	0.05
Stage N2, %	44.2 ± 0.5	44.7 ± 0.5	45.1 ± 0.5	0.43
Stage N3, min	91 ± 2	89 ± 2	89 ± 2	0.72
Stage N3, %	22.8 ± 0.5	22.0 ± 0.4	21.8 ± 0.4	0.25
REM, min	95 ± 2	96 ± 2	98 ± 2	0.50
REM, %	23.4 ± 0.3	23.4 ± 0.3	23.3 ± 0.3	0.94
ODI3, nr/h	6.4 ± 0.3	6.0 ± 0.2	6.3 ± 0.2	0.49
AHI, nr/h	6.2 ± 0.2	5.8 ± 0.2	6.2 ± 0.2	0.47
PLMSI, nr/h	2.5 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	0.98

WASO: Wake after sleep onset; REM: Rapid-eye-movement-sleep; ODI3: Oxygen desaturation index >3%; AHI: Apnea-hypopnea index; PLMSI: Periodic leg movement index. Results are expressed as multivariable adjusted mean ± standard error. Statistical analysis by ANOVA adjusting for gender, age, alcohol consumption (yes/no), month, and day of week.

Supplementary table 2b. Sleep parameters for full moon, waxing/waning moon and new moon, in subjects free of sleep disturbances (AHI<15/h and PLMSI<15/h), women

	Full moon (n=181)	Waxing/waning moon (n=188)	New moon (n=207)	P-value
Total sleep time, min	418 ± 5	413 ± 5	428 ± 5	0.08
Latency to sleep, min	15.1 ± 1.6	14.4 ± 1.5	18.2 ± 1.5	0.17
Sleep efficiency, %	88.0 ± 0.6	86.9 ± 0.6	88.1 ± 0.6	0.31
Nb awakenings, nr/h	21 ± 1	20 ± 1	20 ± 1	0.93
Arousal index, nr/h	15.6 ± 0.4	14.8 ± 0.4	14.9 ± 0.4	0.38
Nb of stage shifts, nr	123 ± 3	124 ± 3	128 ± 3	0.46
WASO, min	58 ± 3	64 ± 3	59 ± 3	0.48
REM latency, min	85 ± 3	88 ± 3	83 ± 3	0.54
Stage N1, min	37 ± 1	36 ± 1	37 ± 1	0.75
Stage N2, min	185 ± 4	185 ± 3	194 ± 3	0.11
Stage N2, %	44.1 ± 0.6	44.7 ± 0.6	45.0 ± 0.6	0.56
Stage N3, min	96 ± 2	92 ± 2	94 ± 2	0.62
Stage N3, %	23.1 ± 0.6	22.5 ± 0.6	22.3 ± 0.6	0.60
REM, min	101 ± 2	100 ± 2	103 ± 2	0.49
REM, %	24.0 ± 0.4	23.9 ± 0.4	23.9 ± 0.4	0.98
ODI3, nr/h	5.7 ± 0.3	5.0 ± 0.3	5.5 ± 0.3	0.14
AHI, nr/h	5.6 ± 0.3	5.0 ± 0.3	5.4 ± 0.3	0.21
PLMSI, nr/h	2.5 ± 0.3	2.6 ± 0.3	2.1 ± 0.3	0.30

WASO: Wake after sleep onset; REM: Rapid-eye-movement-sleep; ODI3: Oxygen desaturation index >3%; AHI: Apnea-hypopnea index; PLMSI: Periodic leg movement index. Results are expressed as multivariable adjusted mean ± standard error. Statistical analysis by ANOVA adjusting for gender, age, alcohol consumption (yes/no), month, and day of week.

Supplementary table 2c. Sleep parameters for full moon, waxing/waning moon and new moon, in subjects free of sleep disturbances (AHI<15/h and PLMSI<15/h), men

	Full moon (n=98)	Waxing/waning moon (n=128)	New moon (n=120)	P-value
Total sleep time, min	378 ± 7	395 ± 6	394 ± 7	0.19
Latency to sleep, min	15.2 ± 1.7	15.4 ± 1.4	11.9 ± 1.5	0.19
Sleep efficiency, %	84.9 ± 1.0	86.4 ± 0.9	86.1 ± 0.9	0.51
Nb awakenings, nr/h	22 ± 1	23 ± 1	24 ± 1	0.34
Arousal index, nr/h	16.4 ± 0.6	16.8 ± 0.6	17.0 ± 0.6	0.82
Nb of stage shifts, nr	126 ± 4	135 ± 4	137 ± 4	0.13
WASO, min	70 ± 5	64 ± 5	67 ± 5	0.71
REM latency, min	78 ± 5	79 ± 4	84 ± 4	0.62
Stage N1, min	40 ± 2	46 ± 2	45 ± 2	0.09
Stage N2, min	168 ± 5	177 ± 4	177 ± 4	0.26
Stage N2, %	44.1 ± 0.9	44.8 ± 0.8	45.0 ± 0.8	0.71
Stage N3, min	84 ± 3	81 ± 3	82 ± 3	0.77
Stage N3, %	22.6 ± 0.8	20.8 ± 0.7	21.0 ± 0.7	0.19
REM, min	86 ± 3	91 ± 3	89 ± 3	0.55
REM, %	22.6 ± 0.6	22.7 ± 0.5	22.3 ± 0.5	0.87
ODI3, nr/h	7.6 ± 0.5	7.8 ± 0.4	7.6 ± 0.5	0.96
AHI, nr/h	7.1 ± 0.4	7.3 ± 0.4	7.4 ± 0.4	0.91
PLMSI, nr/h	2.5 ± 0.4	2.0 ± 0.4	3.1 ± 0.4	0.14

WASO: Wake after sleep onset; REM: Rapid-eye-movement-sleep; ODI3: Oxygen desaturation index >3%; AHI: Apnea-hypopnea index; PLMSI: Periodic leg movement index. Results are expressed as multivariable adjusted mean ± standard error. Statistical analysis by ANOVA adjusting for gender, age, alcohol consumption (yes/no), month, and day of week.

Supplementary table 3. Effect of moon phases on salivary cortisol, in subjects free of sleep disturbances (AHI<15/h and PLMSI<15/h), overall and stratified by gender

	Full moon	Waxing/waning moon	New moon	P-value *	P-value †	P-value ‡
All subjects, N	155	165	190			
At awakening						
Unadjusted	19.2 ± 1.0	19.8 ± 1.0	19.1 ± 0.9	0.87	0.94	0.61
Adjusted §	19.1 ± 1.0	20.1 ± 1.0	19.0 ± 0.9	0.71	0.93	0.41
Cortisol awakening response						
Unadjusted	9.3 ± 1.0	9.6 ± 1.0	10.8 ± 0.9	0.53	0.30	0.73
Adjusted §	9.2 ± 1.0	9.8 ± 1.0	10.7 ± 0.9	0.57	0.30	0.92
Average of all measures						
Unadjusted	15.5 ± 0.4	15.8 ± 0.4	15.3 ± 0.4	0.77	0.83	0.50
Adjusted §	15.4 ± 0.4	15.8 ± 0.4	15.3 ± 0.4	0.63	0.81	0.36
Women						
At awakening						
Unadjusted	19.2 ± 1.0	19.8 ± 1.0	19.1 ± 0.9	0.87	0.94	0.61
Adjusted §	19.1 ± 1.0	20.1 ± 1.0	19.0 ± 0.9	0.71	0.93	0.41
Cortisol awakening response						
Unadjusted	9.3 ± 1.0	9.6 ± 1.0	10.8 ± 0.9	0.53	0.30	0.73
Adjusted §	9.2 ± 1.0	9.8 ± 1.0	10.7 ± 0.9	0.57	0.30	0.92
Average of all measures						
Unadjusted	15.5 ± 0.4	15.8 ± 0.4	15.3 ± 0.4	0.77	0.83	0.50
Adjusted §	15.4 ± 0.4	15.8 ± 0.4	15.3 ± 0.4	0.63	0.81	0.36
Men						
At awakening						
Unadjusted	18.7 ± 0.9	19.3 ± 0.9	18.1 ± 0.8	0.66	0.63	0.45
Adjusted §	18.5 ± 0.9	19.1 ± 0.9	18.5 ± 0.8	0.86	0.96	0.58

Cortisol awakening response						
Unadjusted	9.4 ± 1.1	8.6 ± 1.1	11.3 ± 1.1	0.20	0.21	0.21
Adjusted §	9.5 ± 1.2	8.8 ± 1.2	11.0 ± 1.1	0.35	0.32	0.31
Average of all measures						
Unadjusted	15.2 ± 0.5	14.9 ± 0.5	15.4 ± 0.5	0.79	0.72	0.57
Adjusted §	15.0 ± 0.5	15.0 ± 0.5	15.5 ± 0.5	0.68	0.46	0.67

Values in nmol/l. Results are expressed as mean ± standard deviation or as multivariable adjusted mean ± standard error. § adjusted for gender (overall only), age, month and smoking status (yes/no). Statistical analysis by ANOVA. *, p-value comparing groups; †, p-value for linear trend; ‡, p-value for quadratic trend.