Effects of lunar phase on sleep in men and women in Surrey

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SUMMARY
Recently, evidence has emerged that the phases of the moon may modulate subjective sleep quality and polysomnographically assessed sleep structure in humans. We aimed to explore further the putative effects of circa-lunar periodicity (~29.5 days) on subjective and objective parameters of human sleep in a retrospective analysis. The baseline sleep recordings of 205 (91 males and 114 females; mean age = 47.47 years, standard deviation =19.01; range: 20–84 years) healthy and carefully screened participants who participated in two clinical trials in the Surrey Clinical Research Centre were included in the analyses. Sleep was recorded in windowless sleep laboratories. For each study night, we calculated the distance, in days, to the date of the closest full moon phase and based on this distance, classified sleep records in three lunar classes. Univariate analysis of variance with factors lunar class, age and sex was applied to each of 21 sleep parameters. No significant main effect for the factor lunar class was observed for any of the objective sleep parameters and subjective sleep quality but some significant interactions were observed. The interaction between lunar class and sex was significant for total sleep time, Stage 4 sleep and rapid eye movement (REM) sleep. Separate analyses for men and women indicated that in women total sleep time, Stage 4 sleep and REM sleep were reduced when sleep occurred close to full moon, whereas in men REM duration increased around full moon. These data provide limited evidence for an effect of lunar phase on human sleep.

INTRODUCTION

Sleep is influenced by environmental cycles, and one of the most important recurring factors in our environment is the daily cycle of light and darkness. Endogenous self-sustaining circadian oscillators have evolved to allow organisms to predict these daily light–dark cycles. It is now well established that endogenous circadian rhythms affect sleep timing and sleep structure, even when shielded from the environmental cycles (Dijk and Czeisler, 1995), and the molecular basis and neuroanatomical pathways involved have been elucidated in part (Mohawk *et al*., 2012).

The lunar cycle is another predictable environmental cycle, and there is evidence that in some species endogenous timing systems allow these species to predict and be synchronized to lunar periodicity (~29.5 days). In fact, the underlying molecular and genetic bases of these 'lunar' timing systems have been demonstrated in a number of marine species (Kaiser *et al*., 2011; Tessmar-Raible *et al*., 2011).

In humans, lunar phase could potentially affect sleep through direct effects of moonlight on sleep or through an internal lunar timing system, which is entrained by the lunar cycle and affects sleep. This latter effect may also include synchronization of the menstrual cycle by the lunar cycle (Cutler, 1980; Law, 1986). The first mechanisms may play a role in field studies, but not in those laboratory studies in which sleep is recorded in windowless rooms. The latter mechanism may imply that any effects of lunar phase are more prominent in premenopausal women than in men.

In humans, evidence for the influence of moon cycles on sleep as derived from subjective reports, actigraphy and polysomnography (PSG), however, is mixed. Recently, interest in a possible effect of lunar phase on human sleep has re-emerged. Cajochen *et al.* (2013), in a *post-hoc* analysis of 64 nocturnal sleep recordings of 33 healthy volunteers, reported that the phase of the moon cycle during which sleep was recorded influenced sleep structure. In particular, it was reported that electroencephalogram (EEG) slow-wave activity (SWA) during non-rapid eye movement (NREM) sleep, an indicator of deep sleep, decreased by 30%, sleep latency increased by 5 min and EEG-assessed total sleep time (TST) decreased by 20 min around the time of the full moon. In this carefully conducted study in which many variables were assessed, recordings were made while the relatively small number of participants were shielded from the external light environment, including moonlight, suggesting the existence of an endogenous component to this effect of lunar phase.

In another small retrospective study of 47 healthy young participants, a decrease in TST around the full moon phase was reported (Smith *et al*., 2014), which is in accordance with the findings of Cajochen *et al.* (2013). In addition, this study reported that REM sleep latency was longer around the new moon phase which is, however, at variance with Cajochen *et al.*'s (2013) study, in which it was found that the latency to REM was longest around full moon. According to the data of Smith *et al.* (2014), the sleep of men was more affected than the sleep of women; this in contrast to the study by Cajochen *et al*., in which no sex differences were reported.

Cordi *et al.* (2014), in a re-analysis of polysomnographically recorded sleep in three large samples of healthy participants ($n = 470, 757, 870$), did not find any significant main effects of lunar phase on 11 investigated sleep parameters. Of note, this report included a longitudinal study in which sleep recordings of the same individual were collected at various lunar phases.

In a first study of the potential effects of lunar phase on sleep in patients ($n = 319$) with sleep disorders, Turányi *et al.* (2014) reported associations between the lunar cycle and sleep. In this study, it was reported that full moon was associated with lower sleep efficiency, decreased deep sleep and increased REM sleep latency, in accordance with the Cajochen *et al.* (2013) data in healthy participants. In these sleep data of patients there were indications that changes in sleep parameters in association with lunar phase were more pronounced in women than in men, which is in contrast to the larger sensitivity of men reported by Smith *et al.* (2014).

The aim of the present study was to examine further the putative effects of circa-lunar periodicity on both objective and subjective features of human sleep in a large sample of healthy men and women across a wide age range.

METHODS

Participants

Sleep recordings from 205 participants (91 men and 114 women; mean age 47.47, standard deviation = 19.01; range = 20–84 years) were interrogated retrospectively for an effect of lunar phase at which the recording was made on sleep characteristics. The participants were healthy and screened carefully, and admitted to the Surrey Clinical Research Centre, University of Surrey, Guildford, UK. The participants included in the current analyses participated in one of two larger studies (Dijk *et al*., 2010, 2012), and for the current analyses the baseline data of these studies were re-analysed. Each participant contributed with one baseline night to the pool and all participants had spent at least one adaptation night in the laboratory. Studies were approved by a local ethics committee and all participants gave written informed consent prior to participation.

Procedures

Inclusion/exclusion criteria have been described in detail in the original reports (Dijk *et al*., 2010, 2012). In summary, eligibility to enter the studies was determined through full medical history and electrocardiogram and routine laboratory tests. Psychiatric screening included the Mini International Neuropsychiatric Interview (MINI; Sheehan *et al*., 1998) and the Mini Mental State Examination (MMSE; Folstein *et al*., 1975) for older subjects only. Older participants with a MMSE score ≤25 were excluded.

For participants to be eligible it was required that they had a history of going to bed between 22:00 and 00:00 hours on at least 5 or 7 nights weekly, with a sleep duration of 6.5–8.5 h. They had to be moderate or non-caffeine users (<300 mg of caffeine daily) and moderate drinkers or abstainers: no more than two glasses (118 mL per glass of wine) or two bottles of beer (354 mL per bottle) per day. Caffeine was not available to the participants while in the unit and the participants were instructed not to consume alcoholic beverages 48 h prior to attending the unit. Participants smoking more than five cigarettes per day, or the nicotine equivalent, and those who were unable to refrain from smoking during the residential stages of the study were also excluded. All participants underwent a clinical PSG screening in the laboratory to exclude sleep apnea and periodic leg movement disorder. Subjects with an apnea–hypopnea index of $>15\ h^{-1}$ or a periodic leg movements arousal index $>15\ h^{-1}$ were excluded prior to the studies. Each participant completed the Pittsburgh Sleep Quality Index (PSQI; Buysse *et al*., 1989) and participants with a PSQI score >5 were excluded.

Compliance with sleep–wake schedules was evaluated by sleep diaries as well as continuous actigraphy during a 2-week period prior to the study and throughout the study period.

Participants were classified into three age groups: young (20–30 years; $n = 66$), middle-aged (31–64 years; $n = 75$) and older (65–84 years; $n = 64$).

Astronomical data (lunar phase) were acquired from the United States Naval Observatory astronomical applications department data services (http://aa.usno.navy.mil/data/) and used to assign a lunar phase to the date of the sleep recordings.

Several classification schemes for lunar phase may be used to study the effects of lunar phase on human sleep. For example, the lunar cycle can be subdivided into eight or four equal circa-lunar bins of approximately 3.7 and 7.4 days each. In these analyses, ascending and descending parts of the lunar cycle are considered separately. Alternatively, the analysis may focus on full moon, and the classification is based on distance from full moon, i.e. ascending and descending phases are treated similarly. To maximize the comparison with previous publications (e.g. Cajochen *et al.*, 2013) we followed the latter approach, and lunar phases were classified into three lunar classes: lunar phase class 1 (±0–4 days around the time of full moon), lunar class 2 (waxing and waning moon periods, ±5–9 days around the time of full moon) and class 3 (new moon, ±10–14 days around the time of full moon).

Measures

Polysomnography

Sleep was recorded under stringently controlled conditions in windowless, sound-attenuated and temperature-controlled sleep laboratories. All recordings were made between 23:00 and 07:00 hours.

A referential montage EEG as defined by the 10–20 international system (C3–A2, C4–A1, O1–A2, O2–A1, Fpz–A1, Fz–A1, Cz–A1 and Oz–A1), as well as electro-oculogram and submental electromyogram, were used in the PSG recordings and all signals were recorded on a digital acquisition system (Compumedics Ltd, Abbotsford, Victoria, Australia). An experienced technician (RPSGT) staged the recordings according to standard criteria (Rechtschaffen and Kales, 1968). At the time of scoring, 'lunar phase' was not a research question and therefore it can be assumed that recording and scoring were completed while the relevant members of staff were 'blind' to lunar phase.

After transformation to European Data Format, PSG recordings were imported into VitaScore (Temec BV, Kerkrade, the Netherlands) for spectral analysis. Following artefact removal by an experienced technician, power spectral analysis was performed by applying a fast-Fourier transform routine on 4-s windows. SWA, i.e. power density in the 0.75–4.5 Hz range and sigma activity, i.e. power density in the 12–15.0 Hz range were computed for NREM sleep.

Assessment of subjective sleep quality

Subjective sleep quality was assessed by a 100-point Visual Analogue Scale (VAS; 0–100, 100 is worse) in the morning on waking.

Statistical analysis

To characterize our sample, the uniformity of our recording across lunar class, age and sex was investigated with chi-square tests. To detect effects of lunar phase, a three-way analysis of variance (ANOVA) was used to examine main effects and interactions for lunar class, age and sex as fixed factors and selected sleep parameters as dependent variables (sleep variables are shown in Table 2).

Post-hoc tests were performed when main effects or interactions were significant, and the Bonferroni correction was applied for multiplicity. Results were considered statistically significant at the $\alpha = 0.05$ level. All analyses were performed in SPSS version 22.0 (IBM, Armonk, NY, USA).

RESULTS

Distribution of the sleep recordings across the lunar classes according to gender and age groups is shown in Table 1. Age and gender groups were well represented in each of the lunar classes, but the overall distribution was not uniform ($\chi^2 = 8.145$, $P = 0.017$). In particular, in lunar class 3, there were fewer women ($n = 5$, adjusted residual = −2.5) and more men in the young group ($n = 13$, adjusted residual = 2.5).

Table 1 Sample distribution by lunar classes, age and sex

Lunar class (days before/after full moon)	*Sex*	*Age group* Young (%)	Middle-aged (%)	Older (%)	*Total (%)*
1 (±0–4)	F	9 (32.1)	9 (32.1)	10 (35.7)	28 (100)
	M	9 (37.5)	11 (45.8)	4 (16.7)	24 (100)
	Tot.	18 (34.6)	20 (38.5)	14 (26.9)	52 (100)
2 (±5–9)	F	15 (35.7)	8 (19)	19 (45.2)	42 (100)
	M	15 (51.7)	8 (27.6)	6 (20.7)	29 (100)
	Tot.	30 (42.3)	16 (22.5)	25 (35.2)	71 (100)
3 (±10–14)	F	5 (11.4)	24 (54.5)	15 (34.1)	44 (100)
	M	13 (34.2)	15 (39.5)	10 (26.3)	38 (100)
	Tot.	18 (22)	39 (47.6)	25 (30.5)	82 (100)
Total sample	F	29 (25.4)	41 (36)	44 (38.6)	114 (100)
	M	37 (40.7)	34 (37.4)	20 (22.0)	91 (100)
	Tot.	66 (32.2)	75 (36.6)	64 (31.2)	205 (100)

Age groups: young (20–30 years), middle-aged (31–64 years), older (65–84 years). F, females; M, males; Tot., total.

The investigated sleep parameters included all those for which significant effects of lunar phase were reported previously.

The three-way ANOVA did not detect a statistically significant main effect for the factor lunar class for any of the 21 investigated sleep parameters (Table 2). In fact, none of the nominal *P*-values for the main effect of lunar phase approached significance. The least squares means and standard error of the 21 sleep parameters for the effect of lunar class are presented in Table 3. In this overall analysis, a statistically significant main effect for the factor age was found for 17 of 21 sleep parameters analysed (Table 2). Significant age effects were observed for SWA, sigma activity, TST, Stages 1–4 sleep, slow wave sleep, non-REM sleep, REM sleep, REM sleep latency, wake after sleep onset, number of awakenings and sleep efficiency. A significant main effect for the factor sex was found for 11 of 21 sleep parameters analysed (Table 2). Significant sex effects were observed for SWA, sigma activity, TST, Stages 1, 2 and 4 sleep, wake after sleep onset and sleep efficiency.

In this overall analysis, we detected several statistically significant interactions between lunar class and other factors. Thus, the interaction between lunar class and sex was statistically significant for TST, REM duration and % and Stage 2 % and 4 duration and % (Table 2). In addition, the three-way interaction between the factors lunar class, age and sex was significant for the duration of REM sleep (Table 2).

To further illustrate the potential effects of lunar phase on sleep we computed the effects of lunar phase in men and women (see Table S1) and plotted these values for TST, Stage 2%, Stage 4% and REM% sleep (Fig. 1). Bonferroni corrections yielded a significant reduction around full moon of TST relative to new moon in women, but a similar effect was not observed in men. Also, women spent significantly less time in Stage 4 and REM sleep around full moon compared to other phases but these effects were not significant when Stage 4 and REM sleep were expressed as % of TST. In men, a similar effect of lunar phase on Stage 4 was not observed. Men had increased time in REM sleep around full moon relative to the waxing/waning and new moon.

In a second analysis, the interactions of lunar phase and age were computed. The middle-aged group spent significantly more time in Stage 4 and REM sleep during lunar class 2 (waxing/waning) than lunar class 3 (new moon). The number of awakenings was significantly lower during the waxing/waning moon compared to the other phases (Table S2).

In a final analysis, we explored the extent to which effects of lunar phase were present in each of the age groups separately in men and women (Table S3). Older women spent significantly less time in REM sleep around full moon compared to new moon. Around waxing/waning moon REM sleep time increased significantly relative to new moon in the middle-aged group. No similar effects were observed in the young women. Also, young men's REM sleep time was significantly longer during full moon than during the waxing/waning phases. No similar effects were observed in either in the middle-aged or older men.

Table S4 shows the effect sizes (partial η^2) of lunar phase by age and sex for each of the sleep variables computed from the three-way ANOVA. No large contributions to the variance were observed for any of the lunar phase interactions. However, there were medium-sized effects for lunar × age and REM%, time spent in REM sleep and number of awakenings. Medium-sized effects were also observed for lunar × sex and time spent in REM sleep.

Table 2 Sleep variables by factors lunar class, age and sex in the total sample

	Lunar class		*Age*		*Sex*		*Age × sex*		*Lunar × age*		*Lunar × sex*		*Lunar × age × sex*	
Variable	F *(df = 2)*	P	F *(df = 2)*	P	F *(df = 1)*	P	F *(df = 2)*	P	F *(df = 4)*	P	F *(df = 2)*	P	F *(df = 4)*	P
Log SWA (μV²)	0.776	0.462	35.710	**<0.001**	33.771	**<0.001**	1.613	0.202	2.220	0.068	1.682	0.189	0.475	0.754
SWA (% PTOT)	0.085	0.919	23.479	**<0.001**	4.496	**0.035**	0.243	0.784	0.936	0.444	1.646	0.196	0.844	0.499
Log sigma activity (μV²)	1.551	0.215	10.337	**<0.001**	9.183	**0.003**	0.074	0.929	1.005	0.406	0.972	0.380	1.201	0.312
Sigma activity (% PTOT)	1.031	0.359	1.089	0.339	2.155	0.144	1.472	0.232	1.463	0.215	1.363	0.258	0.452	0.771
TST	0.208	0.813	11.698	**<0.001**	4.131	**0.044**	0.865	0.423	0.879	0.478	4.831	**0.009**	1.618	0.171
Stage 1 (%)	1.477	0.231	5.558	**0.005**	14.726	**<0.001**	9.482	**<0.001**	2.286	0.062	0.061	0.941	0.339	0.852
Stage 2 (%)	0.096	0.908	13.097	**<0.001**	5.809	**0.017**	3.630	**0.028**	1.267	0.285	3.331	**0.038**	1.005	0.406
Stage 3 (%)	1.153	0.318	5.104	**0.007**	1.533	0.217	2.418	0.092	1.360	0.249	1.865	0.158	1.282	0.279
Stage 4 (%)	1.020	0.362	25.796	**<0.001**	9.290	**0.003**	4.557	**0.012**	2.165	0.075	3.175	**0.044**	0.275	0.894
Stage 4 (min)	1.449	0.237	39.042	**<0.001**	14.362	**<0.001**	5.315	**0.006**	2.665	**0.034**	4.955	**0.008**	0.224	0.925
SWS (%)	0.694	0.501	15.490	**<0.001**	9.910	**0.002**	6.559	**0.002**	1.937	0.106	0.607	0.546	0.874	0.480
NREM (%)	0.263	0.769	3.152	**0.045**	0.171	0.679	0.565	0.570	1.567	0.185	2.206	0.113	2.370	0.054
REM (%)	0.277	0.759	6.146	**0.003**	0.449	0.504	2.521	0.083	3.350	**0.011**	4.974	**0.008**	1.661	0.161
REM (min)	0.709	0.493	9.255	**<0.001**	0.188	0.665	3.116	**0.047**	3.404	**0.010**	8.060	**<0.001**	2.944	**0.022**
REM latency (min)	0.313	0.732	9.211	**<0.001**	0.118	0.732	2.052	0.131	1.013	0.402	1.343	0.263	2.120	0.080
WASO (min)	1.604	0.204	33.075	**<0.001**	4.797	**0.030**	0.170	0.844	1.068	0.374	1.681	0.189	1.805	0.130
LPS (min)	0.549	0.579	0.048	0.953	0.003	0.956	0.244	0.784	0.297	0.880	1.623	0.200	0.419	0.795
NAW	0.421	0.657	8.844	**<0.001**	1.610	0.206	1.443	0.239	3.865	**0.005**	0.256	0.774	1.627	0.169
SE (%)	0.503	0.606	25.053	**<0.001**	5.988	**0.015**	0.721	0.488	0.681	0.606	2.447	0.089	1.494	0.206
SOL (min)	0.587	0.557	0.762	0.468	0.443	0.506	0.043	0.958	0.572	0.683	1.393	0.251	0.496	0.739
Subjective sleep quality	2.110	0.124	0.282	0.755	0.325	0.569	0.089	0.915	1.000	0.409	0.262	0.770	0.576	0.680

For a description of the variables see note to Table 3.
LPS, latency to persistent sleep; PTOT, percentage of total power; TST, total sleep time; SE (%), sleep efficiency; SOL, sleep onset latency; SWS, slow wave sleep; SWA, slow wave activity; REM, rapid eye movement; NREM, non-REM; WASO, wake after sleep onset; NAW, number of awakenings. Significant p values are in bold font.

Table 3 Sleep variables and lunar phase

Variable	Lunar class 1 (±0–4 days around the time of full moon) Mean	SE	Lunar class 2 (±5–9 days around the time of full moon) Mean	SE	Lunar class 3 (±10–14 days around the time of full moon) Mean	SE
Log SWA (μV^2)	3.30	0.03	3.34	0.02	3.34	0.02
SWA (% PTOT)	62.95	0.68	63.31	0.60	63.07	0.57
Log sigma activity (μV^2)	1.69	0.03	1.76	0.03	1.71	0.03
Sigma activity (% PTOT)	1.74	0.12	1.90	0.11	1.69	0.10
TST	409.37	6.06	414.39	5.34	411.07	5.11
Stage 1 (%)	7.17	0.48	6.69	0.42	7.69	0.40
Stage 2 (%)	49.85	1.19	49.16	1.05	49.42	1.00
Stage 3 (%)	8.86	0.57	8.38	0.50	9.44	0.48
Stage 4 (%)	12.50	0.89	14.18	0.78	13.57	0.75
Stage 4 (min)	51.03	3.43	58.76	3.02	56.15	2.89
SWS (%)	21.36	1.08	22.57	0.95	23.01	0.91
NREM (%)	71.21	1.30	71.72	1.15	72.42	1.10
REM (%)	22.07	0.79	21.94	0.70	21.38	0.67
REM (min)	91.42	3.33	91.42	2.93	87.17	2.81
REM latency (min)	84.61	6.45	90.85	5.69	85.92	5.44
WASO (min)	43.24	4.40	40.27	3.88	49. 679	3.72
LPS (min)	17.29	2.43	19.26	2.14	16.17	2.05
NAW	20.28	1.29	18.82	1.14	19.92	1.09
SE (%)	87.93	1.02	87.32	0.90	86.60	0.86
SOL (min)	15.47	2.06	17.73	1.82	15.17	1.74
Subjective sleep quality	44.10	3.45	39.67	3.05	34.89	2.92

Log SWA (μV^2), slow wave activity in log scale; SWA (% PTOT), slow wave activity in percentage of total power (0.25–32 Hz); log sigma activity (μV^2), sigma activity in log scale; sigma activity (% PTOT), sigma activity in percentage of total power (0.25–32 Hz); Stage 1 (%)–Stage 4 (%), sleep stages 1–4 (in percentage of total sleep time); Stage 4 duration (min), stage 4 sleep in minutes; NREM, non-rapid eye movement (REM) sleep (sum of sleep stages 2–4 in percentage of total sleep time); REM (%), REM sleep in percentage of total sleep time; REM duration (min), REM sleep in minutes; SWS, slow wave sleep (sum of Stages 3 and 4 in percentage of total sleep time); WASO, wake after sleep onset; LPS, latency to persistent sleep; NAW, number of awakenings; SE (%), sleep efficiency (100 × TST/TIB); VAS Likert scale-like (0–100, 100 is worse). Data represent least squares mean (LSMEAN) and standard error (SE) as estimated by the three-way analysis of variance (ANOVA) (see Table 2); SOL, sleep onset latency.

In none of these analyses did we observe evidence for an effect of lunar phase on subjective sleep quality.

DISCUSSION

The present study explored further the possibility of an effect of circa-lunar periodicity on human sleep in a substantial data set obtained in carefully screened healthy participants. The recordings were made in an environment which shielded the participants from exposure to moonlight, although the participants had access to natural light during the day. The uniformity of the distribution of age and sex groups across the lunar phases was reasonable, and a substantial number of recordings was obtained at each lunar phase. The methodology for recording, scoring and analysing the sleep data was strictly standardized. The observed effects of age and sex on sleep are in accordance with previous observations (Dijk *et al.*, 1989; Manber and Armitage, 1999; Ohayon *et al.*, 2004), and demonstrate that the analyses are sufficiently sensitive and the sample is sufficiently large to identify the effects of these factors on sleep.

In contrast to Cajochen *et al.* (2013), Smith *et al.* (2014) and Turányi *et al.* (2014), but in accordance with the three studies reported in Cordi *et al.* (2014), no significant main effects for lunar phase were observed for any of the 21 sleep variables investigated. It should be noted that the present study and the Cordi *et al.* (2014) studies are among the largest studies, with a good distribution of sleep recordings, age and sex groups across the lunar phases. Comparison of the sleep variables for which a main effect of lunar phase was detected across the recently published studies does not reveal a consistent pattern, although it could be argued that the one consistent theme is that sleep is worse around full moon (see Table S5). It should be noted, however, that significant effect on subjective sleep quality was detected in only one of these recent studies.

In the present analyses there was some evidence that sex interacted with the effects of lunar phase on sleep, such that women slept less and had less Stage 4 and REM sleep around full moon but the effects on Stage 4% and REM% were not significant. The TST effect is reminiscent of the effects reported for men and women combined by Cajochen

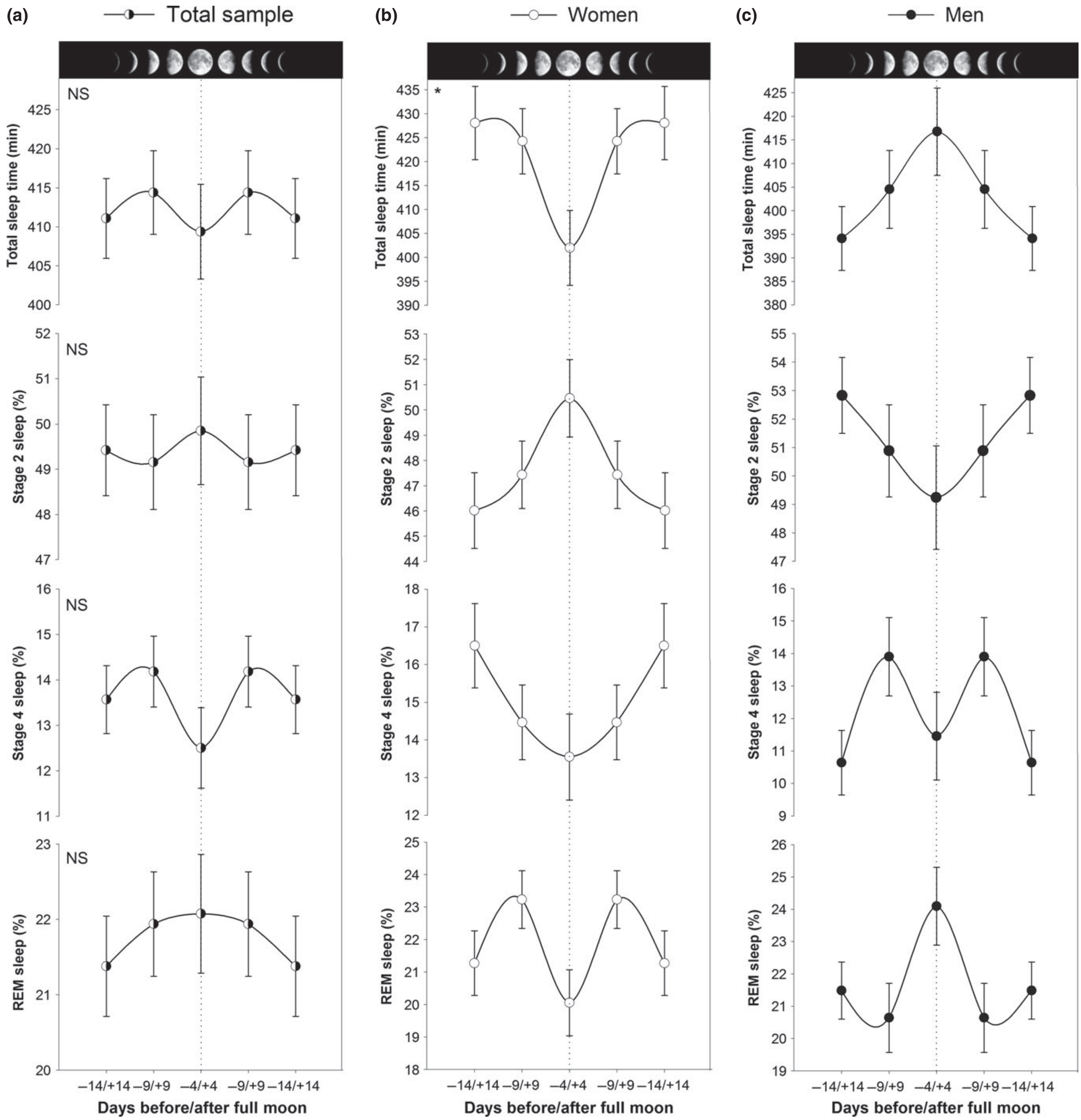

Figure 1. The influence of lunar phase on total sleep time, Stages 2 and 4 sleep (%) and rapid eye movement (REM) sleep (%) in the total sample (panel A), in women (panel B) and in men (panel C); least squares means (LSMEANS) and standard errors of the mean (SEMs) as estimated by the three–way analysis of variance (ANOVA). Data are double-plotted according to lunar classes (LC) 0–4, 5–9 and 10–14 days distant from the nearest full moon phase. For all the variables presented in figure, the interaction between lunar phase and sex was significant. *Significant *post-hoc* contrasts, LC1 (−4/+4 days) versus LC3 (−14/+14 days). NS = significant. See Table S1 for all sleep variables separately for men and women.

et al. (2013) and Smith *et al.* (2014), and the Stage 4 effect is in the same direction as the effect on Stage 4% reported by Cajochen *et al.* (2013) and the SWS% effects reported by Turányi *et al.* (2014). In women, we observed less REM sleep when sleep occurred around full moon, which is consistent with the data by Turányi *et al.* (2014), although the effects in men are not the same in these two studies. Cajochen *et al.* (2013), Cordi *et al.* (2014) and Smith *et al.* (2014) did not observe effects on REM duration or REM% in either men or women, although analyses of REM latency provided some evidence for reduced REM sleep propensity in some of these studies. Comparison of these sex–lunar phase interactions on TST, Stage 4/SWS and REM sleep measures across studies, however, does not reveal a consistent pattern, with men reported to be more sensitive to lunar phase in one study and women being more sensitive to the effects of lunar phase in two others (see Table S5). Furthermore, our analyses of these sex effects by age group does not reveal a clear age dependency, and the number of significant effects in each of the age groups appears to primarily reflect the sample size (see Table S3).

This lack of significant main effects in our study and the absence of consistency of sex–lunar phase interactions may be related to limitations of these studies. These include the retrospective and cross-sectional nature of the analyses and timing of the sleep recordings, which was often fixed, rather than adjusted to the habitual sleep timing of the individuals. In the analyses presented the lunar cycle was classified into three classes, and it may be that different classification schemes are more sensitive. We have not used an alternative classification scheme, because the number of observations would be too small for robust statistical analyses.

In our study, only good sleepers were included. The participants were all healthy, did not suffer from sleep disorders and did not have sleep complaints. It may be that poor sleepers or those suffering from sleep disorders are more sensitive to the effects of lunar phase (Turányi *et al*., 2014), and this could explain the absence of any significant main effect of lunar phase in the present study.

Many of the women (64 of 114) were aged >50 years and most likely to be postmenopausal. It may be that lunar phase effects are most prominent in premenopausal women, assuming that lunar phase effects are mediated by phase locking of the menstrual cycle (which was not assessed in the present study) to the lunar cycle.

It may also be argued that effects of lunar phase on sleep require exposure to 'moonlight'. It should be noted, however, that large actigraphy and sleep diary studies in which participants were sleeping at home have, in general, not provided clear evidence for an effect of lunar phase, with some positive results reported in one study (Röösli *et al*., 2006) but not in another (Zeitlhofer *et al*., 2004).

Further studies, and in particular longitudinal laboratory studies such as those which were successful in quantifying effects of the menstrual cycle on sleep (Driver *et al*., 1996), are needed to establish the effects of moon phases on sleep in men and women. At present, the effects of lunar phase on human sleep appear not to be of a magnitude that could confound our standard laboratory protocols.

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AUTHOR CONTRIBUTIONS

CDM compiled and analysed the data, together with our statistician Dr Sigurd Johnsen, prepared the figures and drafted the manuscript. GA helped with data collection, compiling the data and lunar phase information. DJD conceived the study, oversaw the analyses and the writing of the manuscript.

REFERENCES

Buysse, D. J., Reynolds, C. F. III, Monk, T. H., Berman, S. R. and Kupfer, D. J. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatr. Res*., 1989, 28: 193–213.

Cajochen, C., Altanay-Ekici, S., Münch, M., Frey, S., Knoblauch, V. and Wirz-Justice, A. Evidence that the lunar cycle influences human sleep. *Curr. Biol*., 2013, 23: 1485–1488.

Cordi, M., Ackermann, S., Bes, F. W. *et al.* Lunar cycle effects on sleep and the file drawer problem. *Curr. Biol*., 2014, 24: R549–R550.

Cutler, W. B. Lunar and menstrual phase locking. *Am. J. Obstet. Gynecol*., 1980, 137: 834–839.

Dijk, D.-J. and Czeisler, C. A. Contribution of the circadian pacemaker and the sleep homeostat to sleep propensity, sleep structure, electroencephalographic slow waves, and sleep spindle activity in humans. *J. Neurosci*., 1995, 15: 3526–3538.

Dijk, D.-J., Beersma, D. G. and Bloem, G. M. Sex differences in the sleep EEG of young adults: visual scoring and spectral analysis. *Sleep*, 1989, 12: 500–507.

Dijk, D.-J., Groeger, J. A., Stanley, N. and Deacon, S. Age-related reduction in daytime sleep propensity and nocturnal slow wave sleep. *Sleep*, 2010, 33: 211.

Dijk, D.-J., Stanley, N., Lundahl, J. *et al.* Enhanced slow wave sleep and improved sleep maintenance after gaboxadol administration during seven nights of exposure to a traffic noise model of transient insomnia. *J. Psychopharmacol*., 2012, 26: 1096–1107.

Driver, H., Dijk, D.-J., Werth, E., Biedermann, K. and Borbely, A. Sleep and the sleep electroencephalogram across the menstrual cycle in young healthy women. *J. Clin. Endocrinol. Metab*., 1996, 81: 728–735.

Folstein, M. F., Folstein, S. E. and McHugh, P. R. *Mini-Mental State: A Practical Method for Grading the Cognitive State of Patients for the Clinician*. Pergamon Press, Oxford, 1975.

Kaiser, T. S., Neumann, D. and Heckel, D. G. Timing the tides: genetic control of diurnal and lunar emergence times is correlated in the marine midge *Clunio marinus*. *BMC Genet*., 2011, 12: 49.

Law, S. P. The regulation of menstrual cycle and its relationship to the moon. *Acta Obstet. Gynecol. Scand*., 1986, 65: 45–48.

Manber, R. and Armitage, R. Sex, steroids, and sleep: a review. *Sleep*, 1999, 22: 540–555.

Mohawk, J. A., Green, C. B. and Takahashi, J. S. Central and peripheral circadian clocks in mammals. *Annu. Rev. Neurosci*., 2012, 35: 445.

Ohayon, M. M., Carskadon, M. A., Guilleminault, C. and Vitiello, M. V. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*, 2004, 27: 1255–1274.

Rechtschaffen, A. and Kales, A. *A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages* *of Human Subjects*. US National Institute of Neurological Diseases and Blindness, Neurological Information Network, Bethesda, MD, 1968.

Röösli, M., Jüni, P., Braun-Fahrländer, C., Brinkhof, M., Low, N. and Egger, M. Sleepless night, the moon is bright: longitudinal study of lunar phase and sleep. *J. Sleep Res*., 2006, 15: 149–153.

Sheehan, D., Janavs, J., Baker, R. *et al.* MINI-Mini International Neuropsychiatric Interview-English version 5.0. 0-DSM-IV. *J. Clin. Psychiatry*, 1998, 59: 34–57.

Smith, M., Croy, I. and Waye, K. P. Human sleep and cortical reactivity are influenced by lunar phase. *Curr. Biol*., 2014, 24: R551–R552.

Tessmar-Raible, K., Raible, F. and Arboleda, E. Another place, another timer: marine species and the rhythms of life. *BioEssays*, 2011, 33: 165–172.

Turányi, C. Z., Rónai, K. Z., Zoller, R. *et al.* Association between lunar phase and sleep characteristics. *Sleep Med*., 2014, 15: 1539–1546.

Zeitlhofer, J., Klösch, G., Saletu, B. *et al.* Is there a lunar effect on subjective and objective ratings of sleep quality. *J. Sleep Res*., 2004, 13: 822.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Sleep variables by lunar phase and sex.

Table S2. Sleep variables by lunar phase and age group.

Table S3. Sleep variables by lunar phase, sex and age group.

Table S4. Effect sizes for the effect of lunar phase by age and sex for each of the sleep variables.

Table S5. Summary of lunar phase effects in recent studies.