Physical activity, subjective sleep quality and time in bed do not vary by moon phase in German adolescents

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SUMMARY

Lunar periodicity in human biology and behaviour, particularly sleep, has been reported. However, estimated relationships vary in direction (more or less sleep with full moon) if they exist at all, and studies tend to be so small that there is potential for confounding by weekly or monthly cycles. Lunar variation in physical activity has been posited as a driver of this relationship, but is likewise not well studied. We explore the association between lunar cycle, sleep and physical activity in a population-based sample of 1411 Germans age 14–17 years (46% male). Physical activity (daily minutes moderate-to-vigorous activity) was objectively assessed by accelerometry for a total of 8832 days between 2011 and 2014. At the same time, time in bed (h) and subjective sleep quality (1–6) were diaried each morning. In models corrected for confounding, we found that lunar phase was not significantly associated with physical activity, subjective sleep quality or time in bed in either sex, regardless of season. Observed relationships varied randomly in direction between models, suggesting artefact. Thus, this large, objectively-measured and well-controlled population of adolescents displayed no lunar periodicity in objective physical activity, subjective sleep quality or time in bed.

INTRODUCTION

Associations between human biology, behaviour and lunar cycle have been reported, with most research focused on sleep. However, reported associations are unclear. Many studies (Smith *et al.*, 2014) take place in sleep labs, which allow objective measurement of sleep characteristics and exclude moonlight as a possible driver of the effects: however, these tend to be small and thus perhaps confounded by secular variation. Conversely, larger studies (Sjödin *et al.*, 2015) generally lack objective measurements of sleep, and instead rely on self-reported sleep duration and quality.

More generally, neither the direction nor the existence of the lunar variation in sleep duration or quality is clear. Full moon is more often associated with poorer sleep (Turányi *et al.*, 2014), less sleep, or both (Cajochen *et al.*, 2013; Röösli *et al.*, 2006) even in studies where moonlight was excluded. At least one such study (Smith *et al.*, 2014) not only found that adults slept less at full moon, but also had higher cortical reactivity. However, this is not always the case: one large study of children (Sjödin *et al.*, 2015) found full moon to be associated with more sleep, not less. This study also observed a relationship with daily moderate-to-vigorous physical activity (MVPA), and suggested sleep quality as a possible intermediary. Furthermore, some large studies (Cordi *et al.*, 2014; Haba-Rubio *et al.*, 2015) find no lunar effects on sleep at all; others find no main effects, but only a few sex-specific interactions with either subjective or objective sleep parameters (Della Monica *et al.*, 2015).

If any of these associations, especially the one with physical activity, are real and not artefactual then they must be corrected for in studies of either sleep quality or physical activity. They may also suggest possible treatments for sleep disorders; more generally, lunar fluctuation in human biology is relevant to medical research even outside the field of sleep. Thus, we attempted to replicate the associations between lunar phase, physical activity and sleep in a large population of healthy German adolescents.

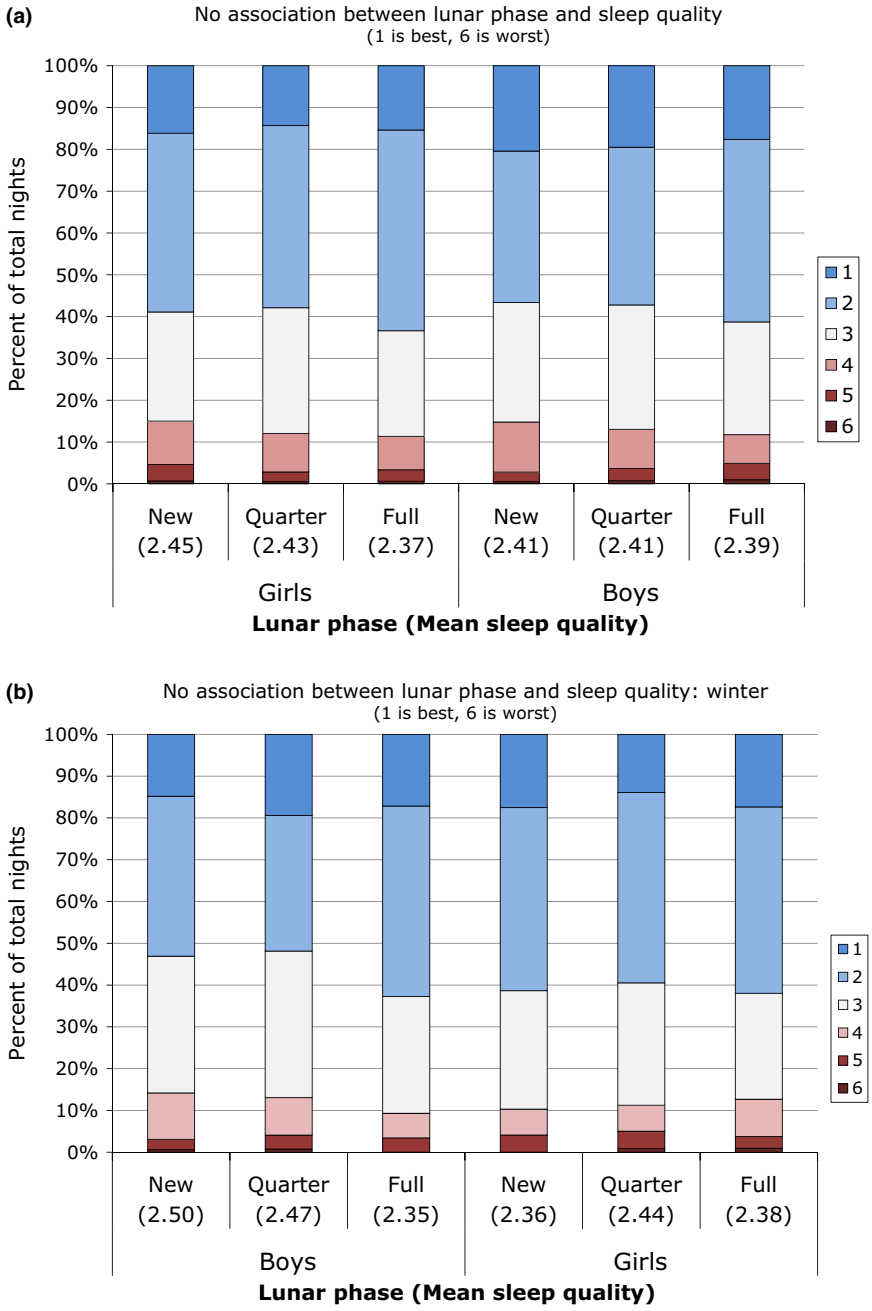

Figure 1. (a) No association between lunar phase and sleep quality. (b) No association between lunar phase and sleep quality: winter.

MATERIALS AND METHODS

This study used data from the 15-year follow-up of two birth cohorts: GINIplus and LISAplus. Methodological details on both studies are available at the study websites and published elsewhere (von Berg *et al.*, 2003; Chen *et al.*, 2007; Smith *et al.*, 2016a,b). Briefly, 7642 healthy full-term infants (52% male) were recruited at birth in the German cities of Munich and Wesel between 1995 and 1999. Both studies were approved by the respective local Ethics Committees (Bavarian General Medical Council, Medical Council of North-Rhine-Westphalia) and by written consent from participating families. Fifty-three percent of subjects were successfully recontacted at age 15 years, of which 59% consented to accelerometry; of these, 66% completed accelerometry and returned the device; 83% of these (1411) passed quality control including an adequate activity diary. These 1411 (46% male) are the subjects of the current study. Previous research (Smith *et al.*, 2016a,b) showed that at each stage of follow-up subjects were more likely to be female and urban (from Munich rather than Wesel), and less exposed to pre- and postnatal tobacco than the cohorts from which they were drawn.

Methods of assessment of physical activity by accelerometry have been previously published (Smith *et al.*, 2016a,b),

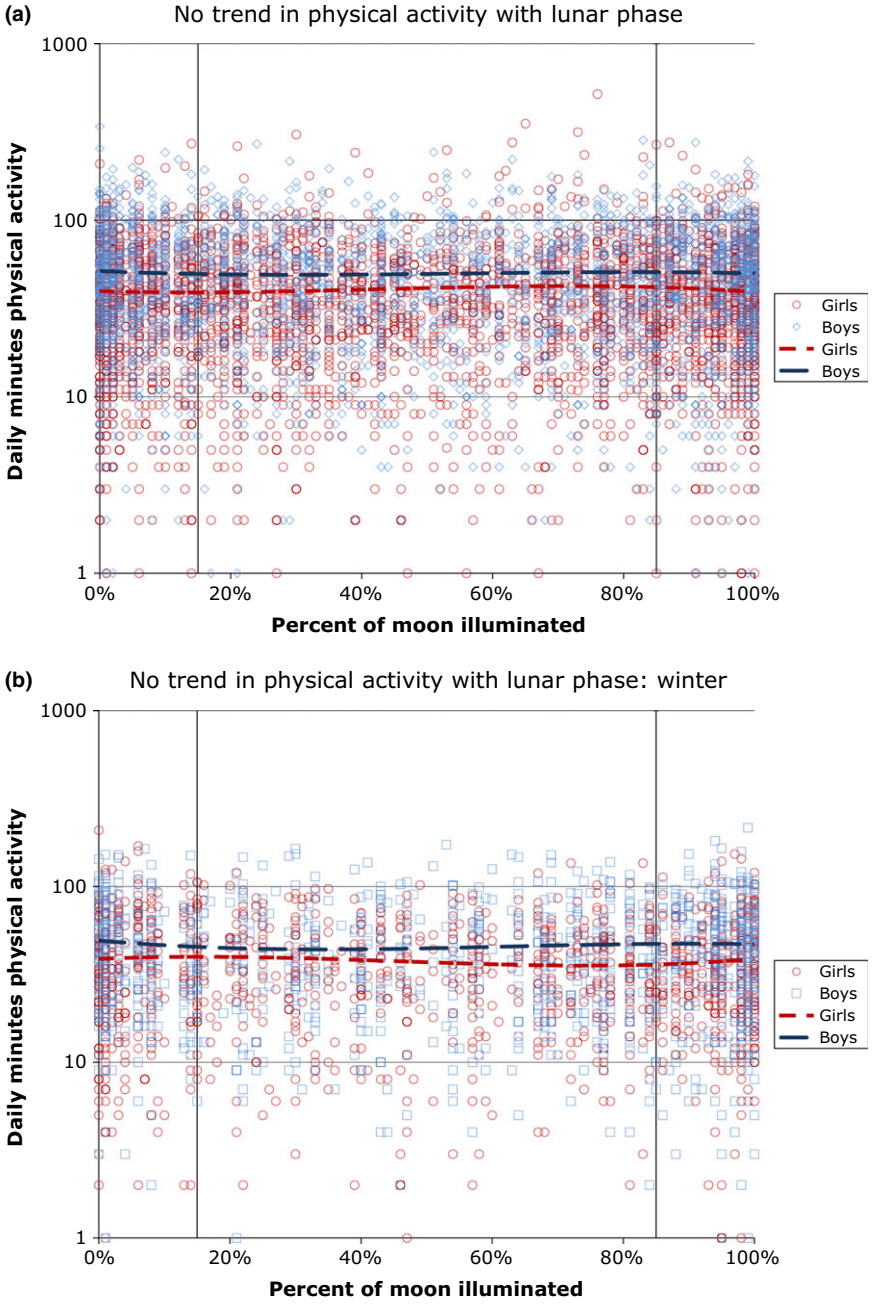

Figure 2. (a) No trend in physical activity with lunar phase. (b) No trend in physical activity with lunar phase: winter.

and are available open access. Briefly, a motion-sensing device was worn on the dominant hip during waking time for 1 week (mean 6.23 days, 14.7 h day^{-1}): measured accelerations were summed over each minute of wear to allow the categorization of that minute as sedentary, light, moderate or vigorous activity. Physical activity was quantified as mean daily minutes of moderate or vigorous activity, MVPA. During each day of accelerometry, subjects recorded the time they woke up and went to bed, from which we calculated time in bed. Subjective sleep quality the previous night was reported on an ordinal scale of 1–6, with 1 being the highest. Other diary data included participation in sport; time and reason of removing the monitor, such as for showering; and other daily activities. For details, see previous work (Smith *et al.*, 2016a,b).

Lunar data on fraction of the moon illuminated were downloaded from the US Naval Observatory and combined with the accelerometric data day by day. 'New moon' and 'full moon' were defined according to the 25th and 75th percentiles of moon illumination, namely 15 and 85% illuminated.

Day length in Germany, and thus the period in which the moon is visible, varies throughout the year. Thus, we performed sensitivity analyses limited to winter (November–February) when the moon is more visible and thus associations may be at their strongest.

Using generalized linear models, we modelled MVPA, time in bed or subjective sleep quality as functions of lunar phase, with subject as repeated measure to account for within-subject variation. Lunar phase was treated as either a three-level categorical predictor ('full moon' and 'new moon' compared with reference category, 'quarter moon') or a continuous 'percent of moon illuminated'. MVPA was modelled as log daily minutes; time in bed as hours; and self-reported sleep quality from 1 to 6 as categorical (cumulative logit; expressed as odds of having one unit better sleep.) All analyses were stratified by sex, and were corrected for age, height, body mass index, study centre, parental education, weekday and month, as in Refinetti *et al.* (2015).

Attached graphs present crude (uncorrected) comparisons, and are limited to weekdays because of the very strong effect of weekday versus weekend. Figs 1a, 2a, S1a and S2a show all months; Figs 1b, 2b, S1b and S2b are limited to wintertime (November–February).

RESULTS

Boys and girls got 45.5 (SD 22) and 37.6 (SD 23) min MVPA per day, about 30% less on weekends than on weekdays (Table 1). Over 70% of subjects participated in leisure sporting activity during accelerometry. The distribution of full and new moon was almost perfectly even, with boys and girls exposed to full moon 25 and 27% of the time, and new moon 24 and 24%.

Adolescents reported longer and better sleep on weekends than on weekdays. Boys and girls were in bed 8.6 (SD 1.2) h per night on weekdays; on weekends boys spent 9.7 (1.9) h while girls spent 10.2 (1.8) h. Self-rated sleep quality on weekends averaged 2.2 out of 6 for boys and 2.3 for girls, 2.4 and 2.4 on weekdays; 5th and 95th percentiles were 1 and 4 for both weekends and weekdays. Detailed data for weekdays are shown in Fig. 1a.

Lunar phase was not significantly associated (Table 2) with self-reported sleep quality (Fig. 1a and b), physical activity (Fig. 2a and b) or time in bed (Fig. S1a and b), and relationships remained non-significant when comparisons were limited to wintertime. Often new moon and full moon were more similar to each other than either was to quarter moon (reference category). Boys averaged 1.74% less MVPA at full moon, and 2.84% less at new moon, than at quarter moon ($P = 0.79$; Fig. 2a; Table 2). Likewise, boys averaged 0.15 more hours in bed at full moon than quarter moon, and 0.09 more at new moon ($P = 0.23$; Figures in Supporting information; Table 2). With regards to subjectively reported sleep quality, both sexes generally reported better sleep at new moon and worse at full moon, compared with quarter moon; however, girls in winter reported the best sleep at quarter moon (odds ratio per unit better sleep 0.90 for new moon and 0.96 for full, compared with quarter), full moon was no different from quarter for boys across the whole year (odds ratio 1.00), and the effect was never statistically significant (all $P > 0.40$).

Table 1 Study population characteristics

	Boys	*Girls*
N	655	756
Age at accelerometry, years	15.6 (0.52)	15.6 (0.52)
Height, cm	177 (7.4)	168 (6.2)
Weight, kg	64.6 (12)	59.0 (9.6)
Body mass index, kg m^{-2}	20.6 (3.1)	21.0 (2.9)
From Munich*	65	58
Parents highly educated†	70	71
Time in bed the previous night, weekday		
Duration, h	8.63 (1.1)	8.64 (1.1)
Quality (self-rated from 1 to 6)	2.40	2.42
Mean (5th, 95th percentiles)	1, 4	1, 4
Quality (self-rated from 1 to 6): percent of total		
1	21.4	16.6
2	43.3	49.3
3	32.0	31.0
4–6	3.4	3.1
Time in bed the previous night, weekend		
Duration, h	9.73 (1.9)	10.23 (1.8)
Quality (self-rated from 1 to 6)	2.19	2.34
Mean (5th, 95th percentiles)	1, 4	1, 4
Quality (self-rated from 1 to 6): percent of total		
1	29.6	24.9
2	46.1	44.3
3	21.4	27.6
4–6	2.9	3.2
Physical activity min per day,‡ weekday		
Sedentary	604 (112)	629 (102)
Light	268 (80)	251 (71)
MVPA	50.3 (37)	40.4 (32)
Physical activity min per day, weekend		
Sedentary	528 (121)	520 (107)
Light	242 (90)	231 (83)
MVPA	32.9 (37)	29.4 (36)
Any leisure-time sport during study, %	70	74
Moon phase		
Percent illuminated	49.6 (35)	50.5 (35)
Full (≥85% illuminated)	25	27
New (<15% illuminated)	24	24

Mean (SD) for continuous measures unless otherwise stated, % for binary.
MVPA, moderate-to-vigorous physical activity.
*Subjects from the GINIplus and LISAplus birth cohorts, living in either Munich (south Germany) or Wesel (north Germany). Populations profiled in Smith *et al.* (2016b).
†'Yes' if at least one parent entered university, 'no' otherwise.
‡Physical activity measured by 1-week accelerometry (minimum 3 weekdays + 1 weekend day per subject). Data handled using Freedson's algorithm for children (Freedson *et al.*, 2005).

On average, 49.7% of the moon was illuminated on days where subjects reported sport, and 50.2% on days without reported sport (data not shown), showing no tendency towards lunar-cycle variations in sporting activity.

DISCUSSION

We found no association between lunar phase and physical activity, time in bed or subjective sleep quality in adolescents. Observed levels of MVPA were very similar between our

Table 2 No association between physical activity, sleep and lunar phase

	MVPA‡ (min)				*Time in bed the previous night (h)*				*Self-reported sleep quality the previous night, 1–6 (odds of being one level better)*			
	Boys (n = 655)		*Girls (n = 756)*		*Boys (n = 655)*		*Girls (n = 756)*		*Boys (n = 646)*		*Girls (n = 736)*	
	% difference	P	*% difference*	P	*Difference*	P	*Difference*	P	*Odds ratio*	P	*Odds ratio*	P
All time												
Full moon	−1.74	0.79	1.31	0.68	0.15	0.23	0.03	0.92	1.00	0.84	0.96	0.89
Quarter moon (reference)	0		0		0		0		1		1	
New moon	−2.84		−2.91		0.09		0.02		1.07		1.02	
Percent of moon illuminated (0–1)	−0.53	0.93	8.39	0.16	0.04	0.75	0.04	0.63	0.92	0.41	1.00	0.83
	Winter (*N* = 569, 46% male)								*N* = 549, 47% male			
Full moon	1.10	0.62	3.39	0.83	0.06	0.86	−0.03	0.97	0.79	0.41	0.96	0.83
Quarter moon (reference)	0		0		0		0		1		1	
New moon	7.14		2.12		0.09		−0.01		1.02		0.90	
Percent of moon illuminated (0–1)	−7.25	0.42	−1.91	0.81	−0.06	0.71	0.03	0.80	0.85	0.50	1.18	0.44

All models corrected for age, height, body mass index, study centre, *parental education, †month, and weekday with subject as repeated-measure.
*Subjects from the GINIplus and LISAplus birth cohorts, living in either Munich (south Germany) or Wesel (north Germany). Populations profiled in Smith *et al.* (2016b).
†'Yes' if at least one parent entered university; 'no' otherwise.
‡Physical activity measured by 1-week accelerometry (minimum 3 weekdays + 1 weekend day per subject.) Data handled using Freedson's algorithm for children (Freedson *et al.*, 2005).

study and that of Sjödin *et al.* (2015), whose population is the most similar to our own; and we confirm the well-known tendency of adolescents to report more, and better, sleep on weekends.

One of the main strengths of our study is its large sample, which spans 4 years and allows us to correct for weekly and seasonal periodicity, which has potential to confound lunar effects. In addition to weekly periodicity, seasonal variation in sleep quality is known in northern populations. If a certain moon phase happens to coincide with weekday and/or summer in a given sample, then that phase will be associated with sleep and also perhaps with physical activity. This effect may be irreducible in small studies (Cajochen *et al.*, 2013; Röösli *et al.*, 2006), which cannot sample all possible combinations of weekday, moon phase and season.

However, it is possible that our study did not adequately capture variance in sleep. Quality was self-reported in a single question, duration was indicated only as time the subject intended to sleep, and daytime sleepiness was not reported at all. If subjects experienced greater difficulty falling asleep at some moon phases than at others, the metrics we used would not capture these effects. Furthermore, our subjects almost all attend school full-time, and therefore time devoted to sleeping does not reflect personal preferences. Lunar periodicity in sleep may be stronger in adults, who have more freedom to determine their schedules; however, Haba-Rubio *et al.* (2015) found no lunar effects in adults' electroencephalograms, polysomnography or sleep duration, and Refinetti *et al.* (2015) found no lunar periodicity in adults' physical activity, which suggests that the link between physical activity and sleep found by Sjödin *et al.* (2015) is also not always present. However, studies differ from each other in methods and population, and therefore some heterogeneity is to be expected.

Altogether, the lunar periodicity in sleep appears to be consistent with artefact. Observed relationships vary not only in strength but also in direction: some (Sjödin *et al.*, 2015) find more or better sleep at full moon, and others (Cajochen *et al.*, 2013; Röösli *et al.*, 2006) find less. This agrees with our findings: sometimes new moon and full moon were more similar to each other than either was to quarter moon, and relationships were often opposite for girls and boys or for 'all year' as compared with winter. However, we cannot rule out true population differences.

Furthermore, most studies of lunar effects use data previously collected for some other purpose. If many comparisons were done and only some were published, multiple-comparisons artefact may be a factor, especially for studies (Della Monica *et al.*, 2015) reporting only interactions with no main effects. This is particularly true as lunar data can be collected retrospectively: there is no need for any specific *a priori* hypothesis to prompt data collection.

CONCLUSIONS

Ours is at least the second-largest study (after Refinetti *et al*., 2015) to find no relationship between physical activity and moon phase, and one of a long string (Cordi *et al*., 2014; Haba-Rubio *et al*., 2015) that find no consistent association between moon phase and either subjective sleep quality or intended sleep duration. We extend these null effects to the long nights of a European winter. While previous studies have found lunar effects on sleep, those effects often differed in direction (Cajochen *et al*., 2013; Sjödin *et al*., 2015) and thus do not indicate any clear tendency in either direction, or else have been small and consistent with artefact (Della Monica *et al*., 2015). Thus, we confirm that lunar periodicity in human sleep or physical activity is far from proven.

AUTHOR CONTRIBUTIONS

MPS, JH & HS designed the analysis. MS, HS & JH Collected the data. MPS & JH Wrote the paper.

CONFLICTS OF INTEREST

No conflicts of interest exist.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

Figure S1. (a) Time in bed does not vary with lunar phase. (b) Time in bed does not vary with lunar phase; winter.

Figure S2. (a) No trend in mean sleep quality by lunar phase. (b) No trend in mean sleep quality by moon phase: winter.