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Lunar cycle in homicides: a population-based time series study in Finland

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ABSTRACT

Objective To test whether homicides in Finland vary according to moon phases.

Design A time series study.

Setting Finland.

Participants 6808 homicides committed in 1961–2014.

Outcome Daily numbers of homicides.

Method The daily numbers of homicides were related to eight moon phases and the illuminated percentage of the moon disc using negative binomial regression. To identify lunar patterns, piecewise linear terms of lunar days were used, together with changes from one moon phase to another. Homicides were similarly regressed on quintiles of the illuminated percentage of the moon disc. A periodic term of length 29.53 days was included to detect cyclic patterns. The results were adjusted for sex, age, secular trend, distance from the moon, seasons, weekday, major holidays and temperature.

Results During the full moon, 15% less homicides were committed than during the new moon (RR 0.85; 95% CI 0.77 to 0.94) and 86% less during the lightest quintile of illumination compared with the darkest quintile (RR 0.14; 95% CI 0.04 to 0.50). Adjustments did not change the results. Piecewise linear regressions showed a significant decline in homicides at the full moon and a rise thereafter. The full moon drop in homicides was directionally similar for seasons, weekdays, sex, age and time periods, and it was particularly pronounced in the early part of period studied (1961–1974). Periodic regression showed a regular cyclic pattern of length 29.53 days (p~0.035).

Conclusions Contrary to current scientific opinion, an association exists between moon phases and homicides, and contrary to what has been previously assumed, homicides declined during the full moon, especially in earlier decades. However, the causality of the association remains elusive.

Strengths and limitations of this study

- The analyses were controlled for potential confounding by sex, age, secular trend, distance from the moon, seasons, weekdays, holidays and temperature.
- The data comprised a long time series from a national population.
- Limitations include that the exact time of death was not known, and homicides could not be broken down to premeditated murders and manslaughters, which may have different patterns.
- The association observed does not imply a causal relation between the moon phases and homicides.

INTRODUCTION

A number of studies have tried to identify lunar variations, the so-called 'Transylvania effect'[1] in various types of human activity such as aggressive behaviour,[2] assaults, crime,[3 4] homicides,[5–9] traffic accidents,[10] suicides[9 11] and mental disorders.[12] One line of thought has been that gravitational forces, which are greatest during the full moon and the new moon, would cause cyclic fluid shifts between body compartments and thereby trigger emotional disturbances, suicides and aggressive behaviour in predisposed individuals, as stipulated in the theory of 'biological tides'.[7] Other theories have considered moon-related variations in electromagnetic fields,[13] weather[14] and illumination[15 16] as potential factors, which could affect human behaviour and cause adverse health effects.

While the belief in lunar effects on humans is reportedly common, especially among healthcare personnel[12 17 18] and police,[19] it is not well supported by empirical evidence. Studies claiming such effects are said to be poorly conducted due to questionable data analysis, insufficient sample size, too short periods studied, data dredging or uncontrolled confounding by season, weekdays or holidays,[12 20–24] and their findings have not been replicated in other populations.[6 19 22] A comprehensive review[14] concluded that not even in theory can lunar factors interfere with human behaviour and discouraged further studies, as did some reviews and meta-analyses.[19 20] Thus, human beings would be impervious to lunar effects,[25] perhaps excepting the trivial fact that some activities are easier in moonlight[14] and accidents more likely to occur during the dark new moon nights.[26]

While many earlier works have studied potential effects of the full moon on aggression and homicides,[5–9 27] few studies have addressed this particular topic nowadays,[3 12] all with negative or equivocal results. The present paper sets out to retest the hypothesis that no association exists between the lunar cycle and

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homicides. The data comprise a 54-year time series of homicides in Finland, which is subjected to linear spline and periodic regressions to identify any lunar patterns.

METHODS

Data

The daily numbers of homicides in Finland during the period 1961–2014, classified by sex and age group, were obtained from Statistics Finland, the study period consisting of 668 lunar synodic cycles. The cases were defined as those deaths where homicide was recorded as the underlying cause (in 1961–1968 ICD-7 codes E964 and E980–E984; in 1969–1986 ICD-8 codes E960–E969; in 1987–1995 ICD-9 codes E960–E969; in 1996–2014 ICD-10 codes X85–Y09 and Y87.1). Annual populations were obtained from official statistical sources. Information on mean daily temperatures in 13 weather stations representing all regions of the country (South: Helsinki, Juupajoki, Kaarina, Lahti; Central: Seinäjoki, Jyväskylä; East: Mikkeli, Joensuu, Kuopio, Kajaani; North: Oulu, Rovaniemi, Sodankylä) was obtained from the Finnish Meteorological Office, missing observations (0.1%) being estimated by cubic spline regression with 3 df. Due to small daily numbers, no analysis by region could be conducted, and instead daily temperatures were averaged over the weather stations.

Statistical analysis

The daily counts were linked to eight lunar phases (new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, last quarter, waning crescent). The approximate days of the lunar synodic cycle were calculated based on radians (1 lunar day=2ϖ/29.53). Since the lunar synodic cycle is slightly irregular, with variation from 29.18 to 29.93 days, the illuminated percentage of the moon disc (0%–100%) was used as an additional explanatory variable. All measures were obtained using the lunar package available in the R software.

Crude homicide mortality by lunar phases was first expressed as the number of homicides per 100 000 person-years. Then the daily counts were regressed on eight lunar phases (a categorical variable), adjusting for sex, age (in classes 0-14, 15-64, 65+ years), secular trend (a third-degree polynomial), distance of the moon from the earth (in classes apogee, far, average, near, perigee), seasons (Winter: December to February; Spring: March to May; Summer: June to August; Autumn: September to November), weekdays, those public holidays which showed association with homicides (New Year, Midsummer Eve, Midsummer Day, Christmas Eve) and temperature. To allow for extra-Poisson variation caused by more than one person dying in the same incident, negative binomial regression was used. The goodness-of-fit test (the goodfit function in R) first showed a poor fit of daily homicides to negative binomial distribution (p~0.000), but after removing two outliers (8 and 10 school shootings committed by a single perpetrator each), the fit improved (p~0.124). All regressions were run with and without exclusion of these outliers, but the results were practically identical, and only results without exclusions are shown. The link function used was logarithmic, and the results were expressed as rate ratios (RR) and their 95% CIs.

The lunar association of homicides was also examined by regressing daily homicides on linear splines of lunar synodic days, using midpoints of moon phases as knots. This analysis retained the continuity of the explanatory variable (lunar day) but allowed for non-linearity of the association and also enabled piecewise comparisons of regression slopes and their changes from one phase to another. Homicides were similarly regressed on linear splines of the illuminated proportion of the moon disc, using quintile points of the illuminated percentage as knots, with a further study of changes of piecewise regression slopes between the quintiles. To reveal any regular lunar cyclicity in homicides, the daily counts were treated as a time series of 19 723 days, fitting a periodic term of 29.53 days in length, together with other periodicities (1 year, ½ year, 1/3 year, 1/4 year, 1 week and 1/2 week). The calculations were performed using R, V.3.1.0 (R Development Core Team, 2014, available at: http://www.R-project.org) and Stata, V.11 (StataCorp, College Station, Texas, 2009).

Patient and public involvement

No patients were involved in this study.

RESULTS

Descriptive data

The mean daily number of homicides was 0.35 (range 0–10) and mortality was 2.54 deaths per 100 000 person-years (table 1). Altogether, 751 homicides were committed during the full moon, compared with 831–895 during other lunar phases, with respective mortalities of 2.24 and 2.48–2.68 per 100 000 person-years. The distribution of days according to the illuminated portion of the moon disc was very uneven, with strong accumulations on the lightest and darkest ends of the illumination scale (figure SF1 in the online supplementary file). During full moon days, the moon was almost fully illuminated (96%–100%) and during new moon days, the moon was almost fully dark (0%–4%), while during all other phases, the illuminated percentage was distributed over broader ranges, that is, 26%–38% (table 1).

Homicides and moon phases

The left-hand panel of figure 1 compares crude homicide mortality by moon phases using rate ratios obtained from negative binomial regression with the moon phase as a categorical explanatory factor. Compared with the empty model (no explanatory factors), the p value from the likelihood ratio test was 0.028, indicating some difference in mortality between the moon phases. In particular, mortality during the full moon phase was 15% lower than

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Table 1 Moon phases and homicides

Moon phase (approximate days*)	Percentage of moon disc illuminated	Temperature (°C)†	Days (n)	Homicides per phase (n)	Mean number of homicides per day	Person-years × 10 000	Mortality/ 100 000 person-years	Adjusted rate ratio (RR)‡	
								RR	95% CI
New moon (27.7–1.9)	0–4	3.1	2467	883	0.358	3349.3	2.64	1.00	
Waxing crescent (1.9–5.5)	4–30	3.1	2465	889	0.361	3346.5	2.66	1.01	0.92 to 1.11
First quarter (5.5–9.2)	30–68	3.0	2467	857	0.347	3349.3	2.56	0.97	0.88 to 1.07
Waxing gibbous (9.2–12.9)	68–96	3.0	2461	895	0.364	3341.1	2.68	1.01	0.92 to 1.12
Full moon (12.9–16.6)	96–100	2.8	2466	751	0.305	3347.9	2.24	0.85	0.77 to 0.94
Waning gibbous (16.6–20.3)	70–97	3.0	2464	846	0.343	3345.2	2.53	0.96	0.87 to 1.06
Last quarter (20.3–24.0)	32–70	2.9	2465	831	0.337	3346.5	2.48	0.94	0.86 to 1.04
Waning crescent (24.0–27.7)	4–32	3.2	2468	856	0.347	3350.6	2.55	0.97	0.88 to 1.07
P~§								0.015	
Total		3.0	19 723	6808	0.345	26 777.1	2.54		

*Days 0.0–29.5 calculated based on radians with the full moon cycle of 2π and 1 day corresponding 0.213 radians.
†Mean daily temperature.
‡From negative binomial regression adjusting for sex, age, secular trend (third-degree polynomial), distance from the moon, seasons, weekdays, public holidays (New Year, Midsummer Eve, Midsummer Day, Christmas Eve) and temperature.
§From likelihood ratio test.

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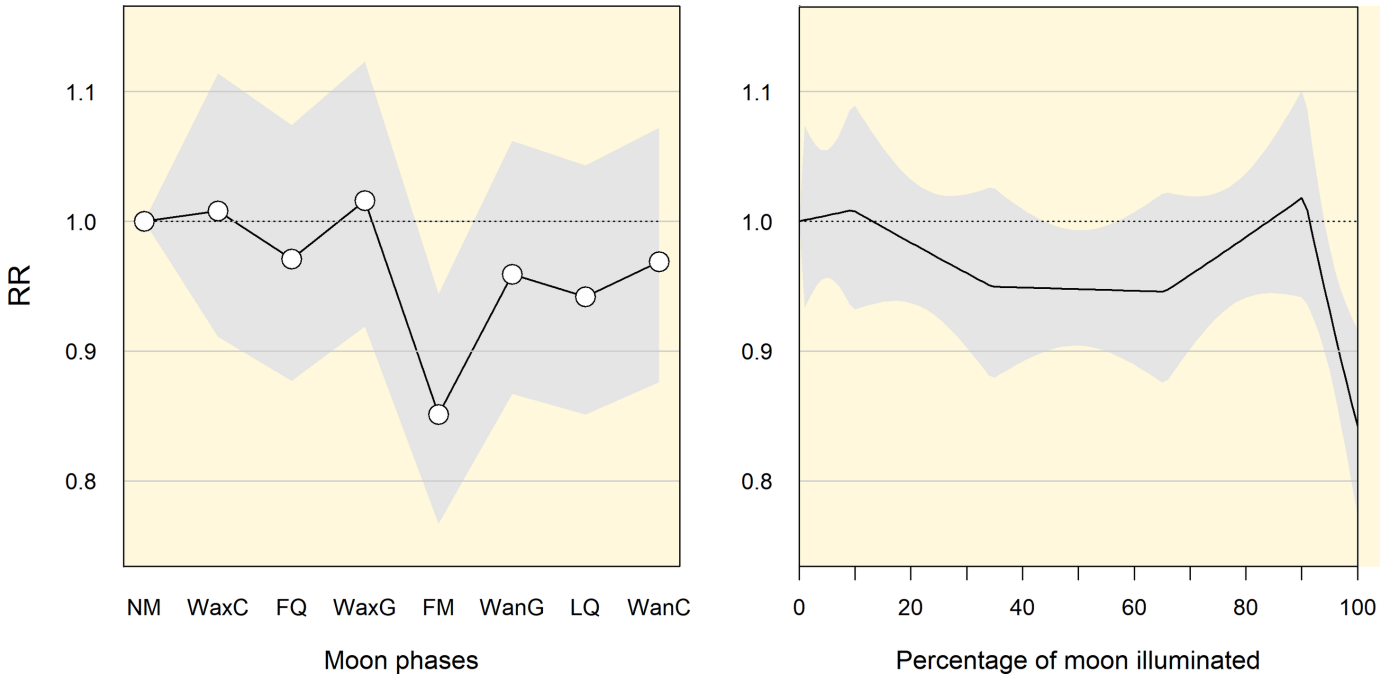

Figure 1 Rate ratio (RR) for homicides in Finland, 1961–2014, by moon phases (left) and by percentage of the illuminated portion of the moon disc (right). The shaded area shows the 95% confidence band of RR. The moon phases are: new moon (NM), waxing crescent (WaxC), first quarter (FQ), waxing gibbous (WaxG), full moon (FM), waning gibbous (WanG), last quarter (LQ) and waning crescent (WanC). P values from likelihood ratio test: 0.028 for moon phases, 0.022 for percentage of moon disc illuminated.

that during the new moon (RR 0.85, 95% CI 0.77 to 0.95), while during no other phase did RR deviate from the reference level. The adjusted RRs (table 1, table ST1 in the online supplementary file) remained almost similar to the unadjusted ones.

Figure SF2 in the online supplementary file reviews the consistency of the lunar pattern of homicides by subgroups and shows an almost invariably low RR during full moon across years, seasons, weekdays, sex and age. The homicide dip during the full moon was particularly steep in 1961-1974 (RR 0.77; 95% CI 0.61 to 0.96) compared with other periods, and it was also low among women (RR 0.72; 95% CI 0.60 to 0.88), in spring (RR 0.79; 95% CI 0.64 to 0.97), autumn (RR 0.78; 95% CI 0.63 to 0.97) and in days other than weekend days (RR 0.82; 95% CI 0.71 to 0.95). However, all likelihood ratio tests for interaction between lunar phase and these stratification factors were non-significant at a 0.05 level, indicating a failure to reject the null hypothesis that the overall patterns are uniform over the strata.

Table 2 shows the piecewise regression slopes (change of RR per lunar day) and their changes from one moon phase to another. Just before the full moon, that is, on approximate lunar days 11–15 (waxing gibbous to full moon), the homicide rate declined by 6% per 1 lunar day (RR 0.94; 95% CI 0.91 to 0.98), and immediately after that, that is, on days 15-19 (full moon to waning gibbous) it rose again by 5% per day (RR 1.05; 95% CI 1.01 to 1.09). A different parametrisation in the right-hand column of table 2 shows that during the lunar days 11-15, the curve turned down by 8% (RR 0.92; 95% CI 0.86 to 0.99) compared with the preceding interval (days 7–11), and the upturn that followed during the next interval was 11% (RR 1.11; 95% CI 1.04 to 1.20).

Homicides and the illuminated proportion of the moon

Homicide mortality is also shown in relation to the illuminated proportion of the moon disc in the form of linear splines of the illuminated percentage (right-hand panel of figure 1). Compared with the darkest stage (0% illuminated), the crude RRs remained relatively unchanged over the quintiles I-IV of illumination but declined steeply during the lightest quintile, down to 0.84 (95% CI 0.77 to 0.92) at the fully illuminated moon.

The piecewise regression slopes (change of RR per one percentage unit illuminated) in table 2 were not significant in quintiles I–IV, but the slope parameter was significantly small in the lightest quintile (RR 0.14; 95% CI 0.04 to 0.50), indicating a steep decline in homicides, with the RR 90% smaller than that in the preceding quintile (RR 0.10; 95% CI 0.02 to 0.53).

Periodic regression

Table 3 summarises the periodic regression of homicides fitting the first-order sinusoid terms for the lunar synodic cycle together with other periodicities and adjusting for the secular trend. The periodicities of 6 and 3 months proved insignificant at 0.05 level and were omitted. The periodic components are shown graphically in figure SF3 in the online supplementary file. The pattern is dominated by wide-amplitude 7 and 3.5-day cycles, corresponding to their large positive cosine and large negative

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Table 2 Adjusted* rate ratios (RR) and their 95% CIs from piecewise negative binomial regression of homicides on lunar days and on percentage of moon disc illuminated

			Relative change in RR versus preceding interval	
	RR†	95% CI	RR	95% CI
Intervals between midpoints (day) of moon phases				
New moon (0) to waxing crescent (3.7)	1.00	0.95 to 1.05	–	
Waxing crescent (3.7) to first quarter (7.4)	0.98	0.94 to 1.02	0.98	0.91 to 1.06
First quarter (7.4) to waxing gibbous (11.1)	1.02	0.98 to 1.06	1.04	0.97 to 1.12
Waxing gibbous (11.1) to full moon (14.8)	0.94	0.91 to 0.98	0.92	0.86 to 0.99
Full moon (14.8) to waning gibbous (18.5)	1.05	1.01 to 1.09	1.11	1.04 to 1.20
Waning gibbous (18.5) to last quarter (22.1)	0.98	0.94 to 1.02	0.93	0.87 to 1.00
Last quarter (22.1) to waning crescent (25.8)	1.03	0.98 to 1.07	1.05	0.98 to 1.13
Waning crescent (25.8) to new moon (29.5)	1.00	0.95 to 1.05	0.97	0.90 to 1.05
P~‡	0.047		0.047	
Quintiles of illuminated percentage of moon disc				
I (0.0% to 9.6%)	1.10	0.31 to 3.88	–	
II (9.6% to 34.5%)	0.78	0.48 to 1.27	0.71	0.14 to 3.56
III (34.5% to 65.5%)	0.99	0.67 to 1.45	1.26	0.57 to 2.80
IV (65.5% to 90.5%)	1.34	0.82 to 2.19	1.36	0.61 to 3.00
V (90.5% to 100.0%)	0.14	0.04 to 0.50	0.10	0.02 to 0.53
P~‡	0.011		0.011	

*Adjusted for sex, age, secular trend (third-degree polynomial), distance from the moon, seasons, weekdays, public holidays (New Year, Midsummer Eve, Midsummer Day, Christmas Eve) and temperature.
†Relative change per 1 day, or relative change per one percentage unit of illumination.
‡From likelihood ratio test.

sine terms (table 3), with somewhat lower amplitude 1-year and 4-month cycles. The 29.53-day lunar cycle is also significant and most influenced by its negative sine term. The model-predicted composite pattern of homicides incorporating all significant periodicities is illustrated in figure 2, together with the lunar periodicity alone. The pattern is shown for the 538th lunar cycle (14 August to 11 September 2004), during which homicide mortality was close to the average mortality during the whole study period. The lunar cycle is overshadowed by the weekly swings but is still significant, the model-estimated peak and trough locating on approximately second and 17th lunar days. The trough of the estimated mortality curve was 9% lower than the estimated peak (95% CI 5% to 13%).

DISCUSSION

Most studies on lunar effects on humans have produced negative results, including those focused on homicides,[5 6 9 19 20 28] although some negative findings may be due to type II error.[29] Positive findings have been reported for aggravated assaults,[2] crimes,[30] poison centre calls,[31] extremely violent behaviour[17] and general practice consultations.[1] The observations reported as positive have been attributed to selective sampling, erroneous definitions of lunar phases, too short periods studied, flawed data analysis, confounding, type I error or data dredging.[6 14 20] The present study based on a time series of 19 723 days and 668 lunar cycles found an unequivocal lunar pattern in homicides that was not confounded by sex, age, secular trend, distance from the moon, seasons, weekdays, holidays or temperature, and the finding was consistent across relevant subgroups. The analysis also revealed a regular lunar pattern in homicides. Since the data comprised the entire national population, they cannot be distorted by biased sampling. The results do not support the notion emanating from previous research that no association exists between the moon and homicides.

The study of Lieber and Sherin,[7] based on two independent samples from the USA, is sometimes referred to as the only one to have observed a statistically significant variation of homicides by lunar phases.[20] The authors linked homicides to lunar phases using time of injury, but if time of death was used instead, the association disappeared.[8] Thus, the present study is the first one to show that homicidal deaths vary according to the moon phases. The pattern was still unexpected, since homicides reduced during the full moon while a bimodal rise during the full moon and the new moon was found in the above study.[7] Violent behaviour[17] and aggravated assaults[2] have also been reported to increase during the full moon,

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Table 3 Periodic regression of daily homicides, 1961–2014

Term	Coefficient	z	P value for adding terms*
Secular trend			0.000
x	−0.631	−0.320	
x^2	−25.944	−13.455	
x^3	−5.127	−2.671	
12 months			0.057
Sin(x)	−0.018	−0.964	
Cos(x)	−0.040	−2.198	
4 months			0.021
Sin(x)	−0.051	−2.780	
Cos(x)	−0.005	−0.281	
7 days			0.000
Sin(x)	−0.051	−2.712	
Cos(x)	0.172	9.564	
3.5 days			0.000
Sin(x)	−0.060	−3.276	
Cos(x)	0.100	5.474	
29.53 days			0.035
Sin(x)	−0.038	−2.085	
Cos(x)	−0.028	−1.540	

x=days 1…19 723.
*From likelihood ratio test.

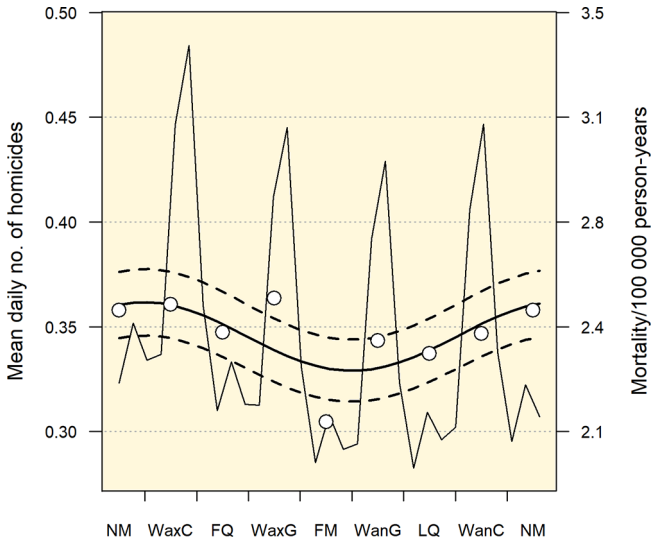

Figure 2 Regular periodicity of daily homicides in Finland assessed by periodic regression. Model-predicted numbers of homicides during the lunar cycle 14 August to 11 September 2004 are shown. Thin line describes the multicycle periodicity composed of the lunar cycle (29.53 days; p~0.035), 12 months (p~0.057), 4 months (p~0.021), 7 days (p~0.000) and 3.5 days (p~0.000). Thick lines represent the lunar periodicity alone (dashed lines: 95% confidence band). White circles indicate the observed mean numbers and mortality of homicides during the entire study period. The moon phases are: new moon (NM), waxing crescent (WaxC), first quarter (FQ), waxing gibbous (WaxG), full moon (FM), waning gibbous (WanG), last quarter (LQ) and waning crescent (WanC).

which is relevant here, since violence and assaults represent the same criminal act as homicide, except that the victim survives. No previous study has found any significant decline in homicides during the full moon, although such declines have been reported for emergency contacts,[24] trauma,[26] traffic accidents[10] and alcohol intake.[32]

Limitations of this study include the fact that homicides were assigned to moon phases using the day of death, while factors decreasing homicides during the full moon would start to influence some time before that. The resulting inaccuracy cannot be great, since approximately 85% of homicide victims in Finland are found dead or die within 24 hours.[33] Comparable figures have been reported from the USA[6 34] and Europe.[35] An additional source of error is that the exact time of the day of the homicide was not known, since potential effects of moonlight should be different by night and day.[36] A further limitation is that homicides could not be broken down to premeditated murders and manslaughters, the timing of which may be influenced by different factors. Even though an association was found between the moon phases and homicides, the study design and available data do not allow any causal conclusions to be drawn.

Any positive findings based on empirical data may be due to type I error, that is, a departure from the null hypothesis when no true difference exists. This is sometimes offered as an explanation for allegedly positive findings in studies claiming lunar effects, especially those failing to fulfil the criteria for causality, for example, consistency of the finding across subgroups of the data. The credibility of the present finding is corroborated by the similarity of the pattern and its similar directionality, in successive time periods, seasons, weekdays, in men and women and different age groups, with the homicide drop mostly occurring during the full moon. The decline in homicides during the full moon was confirmed by phase-by-phase analysis and by analysis of successive illumination quintiles. The possibility of a coincidental finding is also reduced by the long time period, relatively large sample size and the largest number of lunar synodic cycles ever studied. In theory, it is possible that small sample sizes in many previous studies have led to type II errors, preventing any recognition of true effects.[29]

While investigations reporting an increase in adverse human behaviour during full moon mostly refer to some geophysical explanation,[14] those observing a decrease in such phenomena during full moon have had more difficulty to explain their findings. Thus, studies noting a decrease in emergency contacts[24] and traffic accidents[10] during the full moon did not contemplate the underlying reasons at all, while de Castro and Pearcey[32] assumed that the decrease in alcohol intake with increasing moonlight could be attributed to some moon-related biological

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rhythm. A Dutch study[26] noting a statistically significant decline of 2% in traffic accidents during the full moon, attributed this to better visibility due to moonlight, an explanation regarded as trivial by some.[14] As a brighter environment may deter criminal acts,[16] moonlight could have played a role in the prominent full moon dip in homicides in 1961-1974 when one-half of Finns lived in countryside compared with one-fourth nowadays when most people live in cities and an artificially lit environment. However, the causal role of moonlight remains unclear also because most homicides in this country are committed indoors,[33] and the actual lighting conditions in each case were not known.

The seasonality of homicides with a summer peak, potential bimodality and the changes in the pattern since the 1870s has been reported previously,[37 38] but no study has decomposed the annual variation to shorter cycles. The concentration of homicides to weekends and the association with alcohol consumption is well known.[39] The present study controlled for the effect of weekdays but not for alcohol consumption in lack of daily data. Any regular 3.5-day cycle in homicides has not been reported previously and it warrants further study.

Why homicides decreased during the full moon is not easily explained. One might speculate that the full moon, so clearly perceived and distinguished from other moon phases by virtue of its fully illuminated disc and short duration, may have some superstition-based meaning in peoples' minds that refrains potential lunar phobic perpetrators from committing the act. The belief that the moon affects human behaviour is common among healthcare personnel, police[17–19] and the general public.[40] The victim's behaviour might play a role, too. As in most cases, the victim and the perpetrator know each other and have been in dispute before,[33] potential homicide victims who feel themselves threatened may avoid moonlight to protect themselves, or they may believe that something unfortunate could happen during the full moon. Some might see the drop in homicides during the full moon as an atavistic remnant from the animal kingdom where certain prey animals suppress their activity in moonlight to hide themselves from predators, or perhaps, their enhanced visual acuity in moonlight would help them detect predators.[41] However, factors other than moonlight may play a role as well.

CONCLUSIONS

Homicides in Finland follow a detectable and regular cyclic pattern with a decrease during the full moon. This decrease, applied to all moon phases, would imply a decrease of approximately 20 homicides in an average year, that is, a decrease of 0.38 homicides per 100 000 person-years, compared with the average of 2.54/100 000 during the entire study period. Irrespective of what the underlying reasons may be, the prospects for prevention are limited, as most people dwell in towns nowadays and have less contact with the natural environment. Perhaps, this was reflected in little variation in homicides in the 2000s. In any case, the finding challenges the current scientific opinion that the lunar cycle and homicides are unrelated, and it questions the widely held belief that the full moon may provoke violent behaviour.

Contributors SN conceived the study idea, did all data analyses and wrote the manuscript.

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Competing interests None declared.

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Data sharing statement The data are confidential and cannot be shared.

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