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Slightly more births at full moon

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Abstract. A popular belief holds that the number of births highly increases when the moon is full. To test this belief, we use a 50-year data set of 38.7 million births in France. The signal includes quasi-periodic and discrete components that need to be subtracted. This is done using a non-linear Gaussian least-squares method. It results in residuals with very good statistical properties. A likelihood ratio test is used to reject that the residual means for the 30 days of the lunar month all equal 0 (p-value = 5×10^{-5}): the residuals show very small but highly significant variations in the lunar month due to an increase of births at full moon and the day after. The reason for the very small increase of birth at full moon is not investigated but can be suspected to result from a self-fulfilling prophecy.

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1. Introduction

In many countries, beliefs linked to the full moon, such as increase in homicides, accidents, emergency admissions, sleep and psychiatric disorders, are widespread. Meta-analyses on these topics mostly show that the data do not support such beliefs [14, 15]. In particular, the supposed increase in human births at full moon is among the most easily testable beliefs as it is the one of those we have the most data. While most studies on this topic show no correlation between lunar phases and the number of births, studies that claim to document correlations are inconsistent with each other and based mostly on inappropriate statistical tests [3, 6, 7, 9, 10]. If the phenomenon exists, it thus seems difficult to observe, even in a large sample set.

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For many years, we wanted to get our own answer and have analysed French births data. The raw data showed a slight increase of births around full moon days. But it was nor high or small enough to conclude in any way, and most of all, we were very skeptic about such a lunar effect. We mainly thought that the excess of births would be removed by eliminating fluctuations related to the various public holidays. We tried a lot of classical methods to analyse these data, and to subtract the weekly, seasonal, and holiday-related signal (Multivariate Regression, Singular Spectrum Analysis, Empirical Mode Decompositions, ...). An excess of births always persisted. Moreover, these methods are not able to model all the complexity of the signal to remove: they are linear, or they do not allow the periods of the components to be exactly fixed, or they do not handle comb-like functions, etc. This convinced us for the need to develop a more powerful specific non-linear correction (1). It results in residuals with very good statistical properties (normality, stationarity, and even compatibility with a multinomial law). To our surprise, this correction does not eliminate the excess of births at full moon. Indeed, the residual excess is well above what is usually necessary to conclude in its significance.

Moreover, there exists numerous statistical methods used in the involved literature, and we were wondering which ones were appropriate. Thus, we reexamined the relationship between births and lunar phases, following recommendations to avoid weak or false statistical inference [17]:

(1) We use a very large sample, covering a long period of time, and accurate data.
(2) We remove non linearly the effect of several confounding variables in order to get residuals with good statistical properties.
(3) We perform global statistical tests, such as a likelihood ratio test and a multiple Student test with family-wise error rate control.

In this paper, we provide the detailed analysis of a long series of birth data, and to the best of our knowledge, it is the first time that a surplus of births on full-moon days is observed (in mean), with a statistical significance high enough to leave no doubt.

2. Material and Methods

Our data set is the number of births in metropolitan France for each of the 18,263 days from January 1, 1968, to December 31, 2017, collected by the French National Statistics and Economic Studies Institute (INSEE) and freely available at https://www.insee.fr/fr/statistiques/fichier/4647540/T79jnais.xlsx (today, for the years 1968-2019). It includes all births, irrespective of the onset of labor (spontaneous or induced) or mode of giving birth (spontaneous or instrumental). The total number of births is 38,741,555, or a daily average of 2121.3 (empirical standard deviation = 243). This time signal has several visible components, usually qualified by “trend and seasonality” (Figure 1): a trend, annual and weekly, interaction components between the two, and a comb-like component including “particular days” (these particular days are mostly national holidays, see Supplementary Appendix for details). The long-term amplitude variability is clear: seasonal fluctuations decreased from ~1970 to 2010, while weekly and particular-day fluctuations increased from 1968 until the 1990s and then decreased (Figure 1b). Weekly fluctuations, mainly related to a decrease of births on the week-ends, together with the decrease of births on public holidays, are certainly due to a lower presence of medical staff, who acts on induced labor and instrumental births. Annual fluctuations are due to variations in conceptions, for example an increase in conceptions during August and Christmas holidays.

To detect a possible variation in the number of births per lunar phase, and to stay as close as possible to the 24-hour day, we divided the lunar month (29.53 days) into 30 classes of equal length in which the raw numbers of birth are distributed, with class 0 designating the full moon day (FM) and classes 15 and −15 the new moon. Overall, variations in the number of births along the lunar month are smaller than the standard deviation (Figure 1a). The usual statistical comparison tests (ANOVA, Kruskal–Wallis [12]) require assumptions that are unverified by the raw data (normality, independence, and same distribution in each group). However, when we use these tests (null hypothesis: the 30 samples come from the same distribution) they give p-values greater than 5 % (A p-value is the probability that an observed statistic could have been produced by chance, given an hypothesis on the random variable [8, §3.3]), and this even for the pic observed at FM. Accordingly, the raw data do not allow a conclusion in favor of a full moon effect.

It is thus crucial to remove the trend and seasonality components [2]. This requires a non-linear model with component amplitudes varying over time according to functions unknown in advance because of the complexity of the signal (Figure 1). For example, the number of Sunday births shows an abrupt slope change that is probably due to the national perinatal plan launched in January 1994. To account for the fact that periods are known and that amplitudes vary with time, we consider the following decomposition of the number of births $n(t)$ on day t:

$$n(t) = T(t) + \sum_{\omega_k} \left\{ a_k(t)\cos(\omega_k t) + b_k(t)\sin(\omega_k t) \right\} + \{1 + A(t)\} \sum_{p=1}^{P} \alpha_p I_p(t) + r(t) \tag{1}$$

where T denotes the trend, ω_k is the frequency of a component k of coefficients a_k and b_k, I_p is the indicator function of the particular day p (= 1 if t is the particular day p, 0 otherwise), α_p is its coefficient, and A expresses the variability of the particular days. The functions $T(t)$, $a_k(t)$, $b_k(t)$, and $A(t)$ are assumed to vary slowly over time. Residuals $r(t)$ are conventionally assumed to form a Gaussian white noise. The frequencies ω_k include weekly components ($\omega_k = 2\pi q/(7\text{days})$ with q integer), annual components ($\omega_k = 2\pi q'/(365.25\text{days})$ with q' integer), and components from the interactions between weekly and annual components ($\omega_k = 2\pi(q/(7\text{days}) \pm q''/(365.25\text{days}))$ with q'' integer). None of these frequencies are related to the lunar month.

To determine the best decomposition, we use a non-linear least-squares method [18] (see Supplementary Appendix) where the data are the 18,263 numbers $n(t)$, and the unknowns are the 12.3 million values of $T(t)$, $a_k(t)$, $b_k(t)$, and $A(t)$, plus the 22 values of α_p. In order to ensure that these functions vary slowly over time and make the least-squares problem overdetermined, each functional parameter is assumed to have a Gaussian covariance in time.

3. Results

The components of the adjusted model are illustrated in Figure 1b. The residuals mean is 0 and the standard deviation is 46.8. The Fourier transform no longer has an isolated peak (Figure 1c, red). The residuals are depicted in Fig. 1d. When averaged per lunar days, classes 0 and 1, i.e. FM and FM+1, have average surpluses of more then eight and seven births, which now far exceed the standard deviation (Figure 2b).

The conventional ANOVA comparison test shows that the averages of the 30 classes are not equal (Figure 2b, p-value = 3×10^{-5}). The ANOVA residuals successfully pass the various tests of normality (QQ-plot, Shapiro–Wilk), homoscedasticity (Levene test), and independence (Box–Ljung and Box–Pierce) necessary for the use of this test [2, 8, 12]. A likelihood ratio test [8] rejects that the 30 averages all equal 0 (p-value = 5×10^{-5}, see Supplementary Appendix).

To refine this result, it is advisable to test which means are different from 0. The residuals considered by class pass the aforementioned tests of normality and independence, allowing in turn 30 one-sample Student tests to be performed. The p-values all exceed 5 % except three: p-value(FM) = 7×10^{-6}, p-value(FM+1) = 6×10^{-5}, and p-value(FM+11) = 10^{-3}. An adjustment of these individual p-values is necessary to control the family-wise error rate (FWER) for multiple testing [8]. This criterion is used if conservatism is preferred to avoid false discoveries. The corrections of Bonferroni and Holm [8] lead to corrected p-values greater than 80 % except three: p-value(FM) = 2×10^{-4}, p-value(FM+1) = 2×10^{-3}, and p-value(FM+11) = 4×10^{-2}. If the first two p-values leave little doubt to conclude that the means for FM and FM+1 differ from zero, the third one is less convincing, and we consider that 4 % is not small enough to provide a clear opinion. Indeed, we think that very strong evidence is needed to be convinced that this quite unexpected behavior is not only due to full hasard. In addition, the probability that the means for FM and FM+1 take the observed values over two consecutive days is less than 3×10^{-8}. In conclusion, within the variation observed in Figure 2b, it is very unlikely that the excess at FM and FM+1 is due to the random fluctuations of the number of births throughout days. This conclusion is supported by the persistence of the excess in the last 45 years (Figure 2c). Moreover, tuning the parameters of the decomposition (1) does not significantly affect all these results.

4. Discussion

Without speculating on the possible reasons for these variations, their lack of continuity in the lunar month suggests that variations in lunar luminosity can be disregarded. Moreover, the main periods of the tides are diurnal and semi-diurnal, not 29.53 days, which rules out gravitation as a cause.

Observing an individual p-value(FM) of e.g. 10^{-3} on the raw data (disregarding the dependence between the data) would require a much longer time of observation: 300 years, again at the rate of 2121 births per day. On the residuals, it takes 40 years. This shows that observing an increase in births requires both a very large sample set and precise treatment of trend and seasonality components.

For this reason, many studies processing raw data find no association with full moon. In addition, a number of studies use the Fourier transform, which has low detection power on comb-like signals. Those that treat residuals include only a linear model or too few seasonality components [1, 4, 13].

Almost all studies that conclude positively on a correlation have tested birth uniformity over lunar-cycle classes through the χ^2 criterion. However, this approach is based on the assumption that the process of individual births is a strong white noise [16, §14], which is unverified. If it were, the standard deviation of the raw signal would be that of a multinomial of the total number of births distributed over the days of the series (= 46.1 in our case). Yet, it is essentially the trend and seasonality signal that contributes to the standard deviation of the raw signal (= 243 in our case). Unless the data have been reduced to a strong white noise, the χ^2 method is thus totally prohibited for this type of study [14, 16] (see Supplementary Appendix).

Only Charpentier and Causeur [4] find a positive correlation using a proper statistical method (despite variations in working days and non-working days not being considered) but they do not obtain a p-value that provides an indisputable argument.

With a data set for many births, and precise removal of identified influences on the data, we found a very small, but very probably not only due to full hasard, increase in the number of births on full-moon day and the day after. While we cannot explain the origin of this association, a self-fulfilling prophecy could be a good hypothesis to explore. The deficit of births on Fridays 13 and on the Leap days suggests that superstition may affect the number of births (see Supplementary Appendix). Moreover, a high proportion of hospital staff and the general population are receptive to the lunar belief [5]. Knowledge of type of birth, as contained in UK data [11], would be needed to address the possible influence of hospital staff [15].

There are many possible mechanisms for this fulfilling prophecy and it would be an entire project to study them. We have heard the exemple of a maternity ward that plans a larger staff for the full moon days. Since the data show that the number of births is correlated with the staff size, some maternity wards having this policy would suffice to enhance the global number of births at full moon. This is only one suggestion among others.

5. Figures

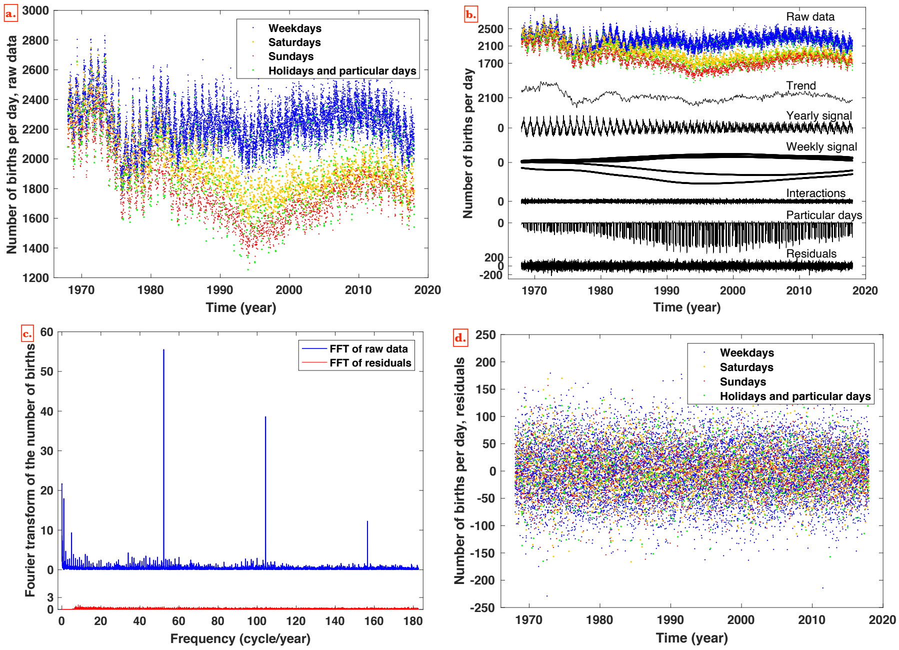

Figure 1. Number of births in France: from raw data to residuals.
(a) The daily number of births in France, from 1968 to 2017, per type of day, shows a yearly variation, with a maximum in springtime, together with fewer births on weekends and holidays.
(b) The daily number of births in France (top curve, same as (a)) is decomposed into the sum of components described in eq. (1), from top to bottom, in black: trend, yearly signal, weekly signal, interaction between yearly and weekly components, particular days (sum of indicator functions), and residuals $r(t)$. In the weekly signal, the points are clustered on what appears to be 3 curves: weekdays on the top curve, sundays on the bottom curve and saturdays on the middle one. The scales are the same for the raw data and all the components. In order to lighten the figure, we reported the scale of y-axis for the upper and bottom graphs only. The center of each plot is the only value reported each time on the y-axis.
(c) The Fourier transform of raw data (top) exhibits a yearly signal (peaks at k cycles/year, for k integer), a weekly signal (52.2 k cycles/year), and an interaction signal (sum and differences of previous frequencies). The Fourier transform of residuals (bottom) shows neither periodic signal nor trend.
(d) Same as (a) but for the residuals. They include no cycle, trend, or difference between type of day.

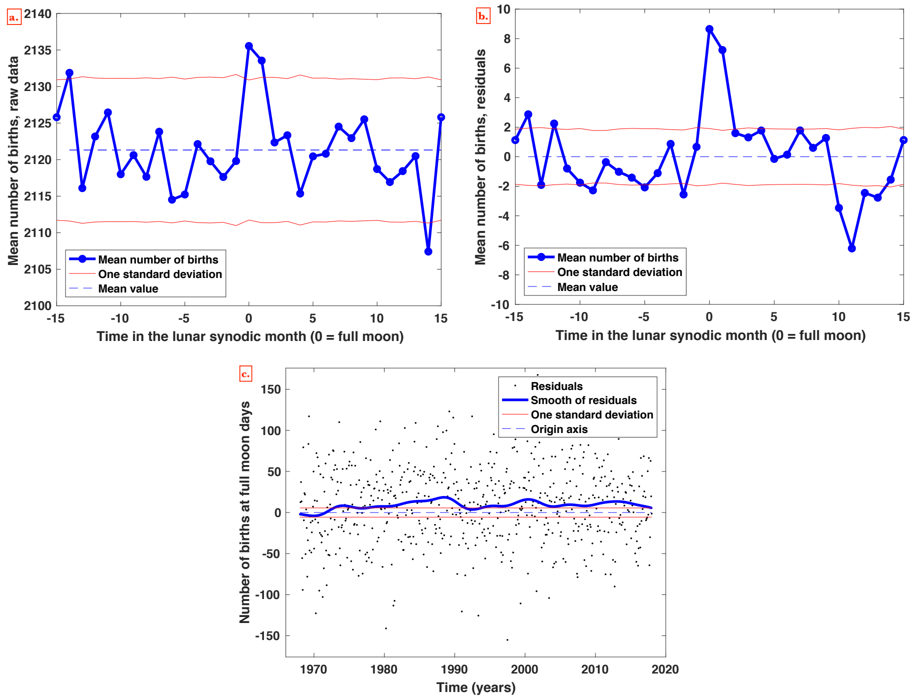

Figure 2. Mean number of births during the lunar month and the excess of births at full moon.
(a) Mean number of births and standard deviation of the mean during the lunar month. Based on these raw data, no lunar month effect is found. A weak peak is observed at FM with an amplitude that forbids to reach any statistical conclusion.
(b) Same as (a) but for residuals. The full-moon and day-after means now differ much more significantly from zero.
(c) Residuals for the 618 full moon days. The smoothing of the residuals is greater than one standard deviation at all times, except in the first 5 years, indicating that the positive bias at full moon persists over time.

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