Evidence of Periodicity in Ancient Egyptian Calendars of Lucky and Unlucky Days

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This article presents an experiment in time series analysis, specifically the Rayleigh Test, applied to the ancient Egyptian calendars of lucky and unlucky days recorded in papyri P. Cairo 86637, P. BM 10474 and P. Sallier IV. The Rayleigh Test is used to determine whether the lucky and unlucky days are distributed randomly within the year, or whether they exhibit periodicity. The results of the analysis show beyond doubt that some of the lucky days were distributed according to a lunar calendar. The cycles of the moon thus played an important role in the religious thinking of the Egyptians. Other periods found using the Rayleigh Test are connected to the civil calendar, the mythological symbolism of the twelfth hour of the day and possibly the period of variation of the star Algol.

1. Introduction

The roots of the ancient Egyptian civilization were nurtured by the yearly inundation of the Nile. The regularly occurring seasonal changes and the periods associated with natural phenomena inspired the Egyptians early on to invent various calendars, the impact of which is to a certain degree still evident in our present-day timekeeping.

The elementary and most commonly used calendar in ancient Egypt was the civil calendar, which divided the year into 12 months of 30 days each. Each complete civil year encompassed 365 days, as it also included 5 'days upon the year' which were inserted into the end of each year. The existence of such an Egyptian civil calendar is attested as far back in time as the Old Kingdom and was still in use in the Graeco-Roman period (Clagett 1995, 4–5).

A rather more complex phenomenon was the Egyptian lunar calendar, a device of timekeeping which has sparked a great amount of academic discussion but the principles of which are still under debate because of lack of hard evidence in Pharaonic Egyptian primary sources. The core of the existing evidence applies to a very late form of the lunar calendar, which was used in the Ptolemaic period (Clagett 1995, 23–8).

Since the aforementioned types of calendar apparently co-existed, they probably served different purposes in Egyptian society. The practical nature of the civil calendar most likely made it the ideal and principal timekeeping system of everyday business in the administrative and economic spheres. The lunar calendar, on the other hand, would have been helpful in predicting lunar phases and also those astronomical events which recurred on a yearly basis (the lunar New Year did not wander around the seasons, as the civil New Year did). Astronomical phenomena were linked with the change of seasons and were thus very important for the religious life of the Egyptians, and for securing the continuation of life in general. These aspects are combined in the celebration of the feast dates (Helck *et al.* 1975–92, II, 171–91).

Although it is not known who invented or upheld the various calendrical devices, where or when they were invented, the civil calendar can be seen as having mainly served the domain of officials and scribes, whereas the lunar calendar served the domain of the clergy. These domains were, however, in no way entirely separate or independent units in ancient Egyptian society. In the life of the common Egyptians at least one of the calendars, possibly both, was meaningful in keeping both work and feast in prescribed order. In this article we hope to elucidate

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some ideas that, if we have interpreted the existing data correctly, were important for the Egyptians in structuring the passage of time and determining the proper days for work, feast and various divine and magical powers.

Calendars of lucky and unlucky days, sometimes called hemerologies, occupied a place in ancient Egyptian divination. Nine primary sources containing full or partial calendars of lucky and unlucky days are known.[1] Most of these calendar texts can be dated to the New Kingdom. The language, however, is in most cases Middle Egyptian. Assigning good and ill omens to the days of the year was still a known practice in the Roman era.[2] Later, in medieval Latin texts, certain days could be found which were referred to as *dies aegyptiaci* (Helck *et al.* 1975–92, VI, 156).

In general, not much has been written on the subject. Previous research on the calendars of lucky and unlucky days include overview articles by Wreszinski (1913) and Brunner-Traut (1970). These articles mention the basic principles of the calendars and quote text passages that relate to the best-known Egyptian myths. Bakir's publication (1966) of P. Cairo 86637 gave access to possibly the most important single source for lucky and unlucky days. The most comprehensive study of the calendars is Leitz's (1994) *Tagewählerei*, which serves as the main reference work for this study.

The calendar of lucky and unlucky days is based on the belief that Egyptian myths represent recurrent events that possibly have an effect on everyday life. Examples of this are the daily (night *vs* day) and yearly (aggressive *vs* weak) life-cycles of the sun god, and the seasonal flooding of the Nile, which represents the primeval waters of Nun (Leitz 1994, 14). It is natural that these observed phenomena were considered of utmost importance to the well-being and fortune of the Egyptians. However, in the perspective of the calendars of lucky and unlucky days, the influence of the divine world upon man during any particular year is not restricted to only these major events. Mythological feast-days, days of battle or peace between gods, days of the arrival of the winds, and days with a certain lucky or unlucky number are also equally important for understanding this type of divination.

In the minds of the ancient Egyptians, gods' moods and attitudes were perceived to be directly visible and tangible phenomena. The understanding and knowledge of the proper place of every divine and mythological event in the yearly cycle, as it could be observed in nature, was a way to avoid the displeasure of the gods and thus an important social and religious issue for the Egyptians. In a society where the proper observance of form and ritual determined one's esteem and even one's eternal life, the hemerologies would have served to ease the confusion of man and work by providing a manual of power, success and luck. However, when Drenkhahn studied the possible effect of the calendar of lucky and unlucky days on dates for official travels, battles and workdays at Deir el-Medina (Drenkhahn 1972), she found no solid evidence of the dates of the calendar's prognoses having notably influenced these matters. The question whether the calendars ever were part of the official religion thus remains open. They did, however, survive at least as an item of folklore, as the practice of classifying days as lucky and unlucky was well known up to Roman times.

In the hemerologies, a *prognosis* is assigned to each day of the year. The prognosis is a judgement as to whether the day is lucky or unlucky — good (*nefer*) or bad (*aha*).[3] In most calendars three prognoses are given for each day of the year. As these occasionally differ from each other, it seems that the day was perceived as consisting of three independent units as far as luck was concerned (Leitz 1994, 480). Day 15 of the first month of the Akhet-season in P. Cairo 86637 rto V, 4 (Leitz 1994, 28) is, for example, presented as: 'Good! Bad! Bad!' The morning of the aforementioned day would thus have been considered good, whereas the midday and evening were ill-omened. The mathematical analysis and results presented in this study rest upon the assumption that the days listed in the hemerologies indeed were divided into three independent units. This is the only thing assumed *a priori*. A prerequisite for the analysis has also been, of course, that the tabulation of the given daily threefold prognoses was made to match the listing in the original source exactly. Time series analysis, especially the Rayleigh Test, which was applied to the prognoses tabulated from the known calendars of lucky and unlucky days, form the core of the discussion below. The sets of prognoses, which were each analysed individually, originate from P. Cairo 86637, P. BM 10474 (Budge 1922–23, I, pls. 31–2) and P. Sallier IV (Budge 1922–23, II, pls. 88–111; Leitz 1994, Tf. 55–79).

In this study the Rayleigh Test is used to determine whether lucky and unlucky days are distributed randomly within the year, or whether they exhibit strong indications of periodicity. The Rayleigh Test was chosen for this study because it is perhaps the most simple and widely used method to detect periodicity in a series of time points. In the past it has been used successfully in, for example, studies in astronomy and biology.[4]

2. The Egyptian civil calendar and the calendars of lucky and unlucky days

The setup of the calendars of lucky and unlucky days follows the format of the Egyptian civil calendar. Thus, the year consists of 365 days. It is divided into twelve months of 30 days each. Four months make one annual season (Akhet, Peret, Shemu). The months, as well as the days, are usually referred to with numbers. Written names of months seldom feature in calendars.[5] In addition to the twelve months, five 'days upon the year', which the Greek referred to as the *epagomenai*, complete the year (Clagett 1995, 4–5). In Egyptian these are called *heriu-renpet*. No prognoses are given for these last five days of the year.

The Egyptian civil year could not be fixed to the natural seasons, as the calendar year was only 365 days long. It fell out of step with the solar year, the better approximation of which, 365.25 days, was instated in Egypt during the Roman era. This being the case, it is quite interesting to note that some of the omens of the hemerological calendars, the structure of which derive from the civil calendar, are related to the annual seasons. Thus, when the Nile is said to be welcomed on the first day of the year, I Akhet 1 in the P. Cairo 86637 (rto IV, 4), it seems feasible that when this text was originally compiled, a feast for the rise of the Nile (*shesep iteru*) was indeed celebrated on that date.

The rise of the Nile is a phenomenon which is not tied to a fixed date within the solar year. As such it may be seen as opposed to astronomical events, such as the solstices, equinoxes or the heliacal risings[6] of stars. The civil calendar date for the heliacal rising of a star would, for example, in four years have moved one day forward from its proper place whereas the time for the rise of the Nile, which varies somewhat regarding its onset from one year to the next, would be approximately in its right calendric place for longer.

Calendars of lucky and unlucky days, or hemerologies, assign the days of the year, or actually three parts of each day, a prognosis good (*nefer*) or bad (*aha*). On a good day there is joy, success in tasks undertaken and good omens for children born on such a day. On bad days, problems arise in matters related to health and work. Furthermore, children born on days which are considered bad are under threat of death from various causes, for example sickness. For good days the calendars often prescribe the making of a feast or offering to the gods. This may be interpreted in two ways. The gods might be more approachable on such a day, or some traditional feast date might be the cause of the prognosis 'good' and the encouraged feasting. For the bad days of the year, the calendars advise one not to go out on the road or, in some cases, not to eat a certain dish (for example, fish on I Akhet 22, the date of the gods taking the form of fish in a version of the myth of the Destruction of Mankind: Maystre 1941, 58–73; Lichtheim 1976, 197–9), or to abstain from action in general (Brunner-Traut 1970, 334).

The precise manner and the extent of the use of hemerologies is unknown, and the prognoses presented in various manuscripts differ from each other. This might be partially related to the wandering seasons. Several feasts (*heb*) are mentioned in the course of the year. 'The Birth of Ra-Horakhti' (*mesut ra-herakhty*) is, for example, mentioned in P. Cairo 86637 (rto IV, 4) as the New Year's feast. It is most likely that a feast fixed to the civil calendar's new year's day is meant rather than a feast for the winter solstice.[7] No astronomical start of the year, such as 'The Opening of the Year' (*uepet renpet*) or 'The Coming Forth of Sothis' (*peret sepdet*) is explicitly mentioned in the calendars. However, 'The Coming Forth of Sopdu' (*peret sepdu*) is mentioned in P. Cairo 86637 (vso VII, 9), on day IV Shemu 4 (Leitz 1994, 398–9). Sopdu is written without the star determinative so it is not Sopdet/Sothis but a different god. Leitz suggests that 'The Coming Forth of Sothis' coincides with the New Year's feast (Leitz 1989, 31).

The calendars give the prognosis 'good-good-good' for every beginning of the month. This is to be expected, as the beginning of a month embodies the important monthly feast. The feast of Hathor, for example, begins the month following after the month called Hathor (Weill 1926, 112–26). Thus it may be concluded that the 30-day period corresponding to the period of one month in the civil calendar determined some of the prognoses for the days of the year.

3. Time series analysis

In this study, three calendars of lucky and unlucky days (P. Cairo 86637, P. Sallier IV, P. BM 10474) have been tested for possible periodicity present in the prognoses. The other known texts on calendars of lucky and unlucky days are unfortunately not suitable for periodicity testing. Some are too short for the discovery of reliable and interesting periodicities, as is the case with fragmentary New Kingdom material. Others have a different approach to the year altogether, as is the case with the Middle Kingdom calendar P. Kahun, in which only the prognoses for a single 30-day period are given, to be used as the standard for every month of the year.

P. Cairo 86637 (abbreviated as C in Tables 1–2) is the most complete of the selected calendars. For the analysis only the so-called main calendar in the manuscript (rto III–XXX, vso I–IX) is used. The prognoses for all days of the year (except the epagomenal days, or where the text is destroyed) are given in the aforementioned main calendar. It also contains references to myths and feasts, suggestions for activities, and present prohibitions. The papyrus, but not the main calendar, additionally contains references to the epagomenal days. There are also fragmented alternative versions of the calendar for the time period I–II Akhet in P. Cairo (rto I–II, vso XXI–XXIV: Leitz 1994, 2). These fragments are unfortunately too short to be used for time series analysis. The date of the papyrus P. Cairo 86637 is, according to Brunner-Traut, the ninth regnal year of Ramses II (Helck *et al.* 1975–92, VI, 156).[8] The provenance of the manuscript is taken to be Deir el-Medîna (Bakir 1966, 1).

P. Sallier IV (= papyrus BM 10184, abbreviated as S in Tables 1–2) contains a parallel text to the Cairo main calendar. The papyrus is partially destroyed, but the dates from I Akhet 18 to I Shemu 12 have survived. As there are some corrections made in the hieratic text of this manuscript, it has been suggested that the text may have been used as a writing exercise (Helck *et al*. 1975–92, VI, 156). It is dated to the 56th regnal year of Ramses II (P. Sallier IV, vso. XVII, 1).

P. BM 10474 (abbreviated as BM in the Tables 1–2) is best known because of the Instruction text of Amenemope, which is recorded on the recto side. On the verso prognoses are given for all days of the year. However, this particular calendar includes neither descriptions of feasts nor instructions, as do the Cairo and Sallier calendars (Leitz 1994, 1–2).

In each of these three calendars, which have served as our test material, every single day is divided into three parts. Each part is given its own prognosis. We have calculated time points to the individual parts of each day of the year in order to transform the prognoses into a numerical series of time points.

Time series analysis determines the degree of randomness and periodicity of a set of chosen time points. The points would be fully periodical if the value of each time point t_i were the period P multiplied by an integer (plus some arbitrary epoch t_0):

$$t_i = t_0 + iP,\ i = 0,1,2,\ldots \quad (1)$$

If, for example, the days having the set of prognoses 'good-good-good' (GGG) are distributed so that the prognosis of every odd-numbered day is GGG, the prognosis GGG is periodical with the period $P = 2$ days. If the time point of the first prognosis GGG was $t_{i=1} = 5$ days, the prognosis GGG would be found at time points $t_{i>1} = 7$ days, 9 days, 11 days, etc.

A tabulation of the prognoses from the selected sources shows that a totally regular distribution does not exist here. This is because a periodical and a random ('noise') component are mixed in the calendars. The random component stems from the fact that the prognoses were determined according to a number of different phenomena. Some were related to the feast days, some associated with the phase of the moon and some with the magical fortune and misfortune inherent in the number itself of the day.[9] With regard to the latter a slight regularity is observed on certain dates (i.e. a certain day number of each month). These receive without exception a prognosis GGG (day 1) or SSS (bad-bad-bad[10], day 20).

The aforementioned periodicity may stem from the set-up of the earliest known calendar of lucky and unlucky days, P. Kahun (XVII, 3), which consists of a table of prognoses for the 30 days of one single civil month, considered to apply for every month of the year (Helck *et al.* 1975–92, IV, 713). Another possibility is that the regularly occurring 'feasts of the sky' (*hebu nu pet*) were always tied to a constant day number of each month (Spalinger 1996, 1–10; Helck *et al*. 1975–92, II, 171–91). The first day of each month is, of course, also the day when the month feasts were celebrated.

A casual look at the list of prognoses will provide only limited information regarding periodicity. More can be discovered by a statistical test. Such a test requires that one determines the exact numerical value of the time point of each presented prognosis.

This may be done, for example, as follows: for each whole day its date (day number) is used, starting from the beginning of the year. The time point of the prognosis for I Akhet 1 is thus $t = 1$, for II Akhet 1 $t = 31$, and so on.

4. The time points for parts of the day

In order to create the time series when testing the prognoses of different parts of the days, three individual time points have to be assigned for each day.

Based on our general knowledge of Egyptian timekeeping, a calendar date was to begin at dawn. The exact time seems to have been about an hour before sunrise (Clagett 1995, 48–50). Moreover, day and night were both perceived to comprise 12 hours. Different types of clocks, such as shadow clocks and star clocks, operated on the basis of a time concept with a 12-hour day and a 12-hour night.

Although the calendars of lucky and unlucky days give a prognosis for three individual parts of the day, they do not divulge much information on precisely how these time periods were divided. A careful reading of the texts may, however, provide one with some clues.

Leitz tabulated all examples of days with a different prognosis for a different part of the day, such as GGS in P. Cairo 86637 (rto IV, 5), day I Akhet 8. The text instructs one not to go out during the night (*gereh*). The day I Akhet 25, in the parallel text P. Sallier IV (rto II, 4), has the instruction to stay inside for the evening (*ruha*). The prognosis for this day is the same as for the previously mentioned one: GGS. Thus it would seem that evening and night were included in the third period of the day.

If the appearance of Seth during dawn (*hedj-ta*) of day II Peret 14 (rto XXIV, 5–6, in P. Cairo 86637; rto XVII, 3–4, in P. Sallier IV) was meant to indicate an observation of planet Mercury in the morning sky, as suggested by Krauss, the cause of unluckiness would have been seen before dawn (Krauss 2002, 196–9). The prognosis for this day is SGG, so the morning is considered unlucky in this case.

Overall, it would seem that the first third of a day refers to the morning, including a period of morning twilight, the second to the mid-part of the day, whereas the third prognosis covers the evening and dusk. Whether the night (*gereh*) was also included in this third prognosis remains an open question.

Regarding the chosen time points one may thus assume that the day-time is divided into morning (hours 1–4), mid-day (hours 5–8) and evening (hours 9–12), assuming that the three parts are of equal length. The accuracy of this assumption does not have important consequences for the results of our analysis.[11]

The time between sunset and sunrise varies according to the geographical latitude of the observing site, and the declination of the sun (which varies according to season). We adopt the intermediate geographical latitude $\phi = 26°41'$, from Middle Egypt. When calculating the time points, the beginning of the first hour will here be fixed to sunrise and the end of the last hour to sunset, with full awareness of this not being exactly what the ancient Egyptians did. For the statistical analysis such a crude approximation is, however, sufficient, as the purpose here is to generate one time point which is included in the prognosis. The time point could be chosen from any epoch within the morning, within the mid-day and within the evening, and the results of the analysis would be effectively the same.

The time points may thus be calculated as follows. The time between sunrise and sunset l_d can be calculated from the half day arc[12] H with the equation $l_d = 2H$. The half day arc H is easily obtained from the equation

$$\cos H = -\tan \phi \tan \delta, \qquad (2)$$

using the intermediate latitude $\phi = 26°41'$. The angle δ here is the declination of the sun. A simplified equation is precise enough to solve the declination of the sun: let N be the day number counting from the Gregorian new year's day (January 1). In the northern hemisphere the shortest day will occur for $N = 355$ (winter solstice, December 21) (Cooper 1969, 3).

$$\delta = -23.45° \cos ([360/365]N+10) \qquad (3)$$

Accepting the concordance in Leitz's *Tagewählerei,* let $N = 187$ correspond to the Egyptian day I Akhet 1. The concordance was based on the astronomical calculations of Leitz and Krauss, concerning the solstices, the feast of Meskhenet (possibly an observation of the lower culmination of the star γ Ursae Majoris), the mention of 'the eye of Horus the Elder' (possibly an observation of the planet Venus in the evening sky), and the appearance of Seth on the prow of the solar bark (possibly an observation of the planet Mercury in the morning sky) (Krauss 1990, 54; 2002, 196–9; Leitz 1989, 7–17; 1994, 6–8).

Let the integer part of each time point be the number of the day as counted from the Egyptian New Year. The decimal part for the first time point will be taken as the middle of the four hours of the morning: $l_d/(6 \times 24\text{h})$, the decimal part for second time point will be taken as the middle of the four mid-day hours: $3l_d/(6 \times 24\text{h})$, and the decimal part for the third time point will be taken as the middle of the four evening hours: $5l_d/(6 \times 24\text{h})$.

The decimal part of the time points never exceeds 0.5, because the longest time between sunset and sunrise in Egypt is *c.* 14 hours and the maximum interval of the middle-of-the-evening point as counted from sunrise is $5 \times 14\text{h}/(6 \times 24\text{h}) = 0.49$.

5. The time point series

The purpose of the time series analysis is to discover possible periodicity of the distribution of the time points. In this study, the time point series are created from a tabulation of the days, and parts of days, for which the same hemerological prognosis is given. The prognosis is either good (*nefer*, G) or bad (*aha*, S). The day is divided into three parts, and each different part can receive a different prognosis, so parts of days as well as whole days are both tested with the same triad of prognoses.

The prognoses are tabulated from P. Cairo 86637 (C), P. BM 10474 (BM), and P. Sallier IV (S). A small number of prognoses in C, BM and S differ from each other. The time points calculated from each different source are tested separately. All the sources are read according to Leitz's *Tagewählerei*. Prognoses destroyed or otherwise illegible are not included in any time series.

There are eight triads of prognoses (GGG, GGS, etc.) possible for each day. Certain combinations, such as SGS or GSG, are only used in the calendars one or two times. This is not enough to create a meaningful time series (a series with fewer than four time points being quite insufficient for the analysis). After all eight possible triads were tabulated from sources C, BM and S, 13 series of time points based on prognoses for whole days (see Tables 1 & 2, Time series 1–13) were accepted.

Then 24 different sets of prognoses for parts of days were tested. First we take into account only their appearance at a given position in the day (Tables 1 & 2, Time series 14–31), and then we take into account all possible positions in the day (Tables 1 & 2, Time series 32–7).

6. The Rayleigh Test and the statistical test

The Rayleigh Test was chosen for the time series analysis experiment from several possibilities. It is a method often applied to the analysis of problems concerning temporal periodicity *vs* randomness or spatial directedness *vs* randomness in the fields of astronomy, geology and biology. For example, the migration of birds is detected with the Rayleigh Test by calculating the test statistic based on the observed flight directions of the birds. If a certain direction has an exceptionally high rate of occurrence, it yields a high value of the test statistic and the start of the migration is thus detected (Batschelet 1981, 52–4).

The Rayleigh Test is historically based on a solution to Pearson's problem of random walk. In Pearson's random walk, a walker commences from a starting point and takes a series of steps, each of which has a length of 1 unit and is taken in a random spatial direction. It can be shown by simulation that by taking n such steps, the walker has a certain probability Q of reaching a given distance r from the starting point (Greenwood & Durand 1955, 233–4).[13] This particular test may be presented as follows:

A series of time points t_i ($i = 1, \ldots, n$) will be analysed, where n is the number of time points t_i (see Table 1, column 2). The Rayleigh Test utilizes unit vectors. The time points are transformed into unit vectors which point to a phase angle calculated from the tested period P. The phase angle of the vector is connected to the phase of the time point with the period P.

The phase Φ_i of a time point with the period P is calculated

$$\Phi_i = \mathrm{FRAC}\,[\,(t_i - t_1)\,P^{-1}\,], \tag{4}$$

where FRAC removes the integer part from the value of $(t_i - t_1) \times P^{-1}$, leaving the decimal part as the result. The decimal part is the phase $0 \leq \Phi_i < 1$ of the time point t_i with the period P.

If time points are separated exactly by the period P, all time points t_1, t_2, … will then have the same phase $\Phi_1 = \Phi_2 = \ldots$ with the period P. All the vectors representing these time points will have the same phase angle.

If the first time point is $t_1 = 2$ and the second $t_2 = 3$, then with the period $P = 1$ the phases Φ_1 and Φ_2 are equal. The phases of the time points with this period are the same, because the time points are separated exactly by the period P.

By multiplying the phase Φ_i with 2π, the phases are transformed into phase angles θ_i:

$$\theta_i = 2\pi \times \Phi_i. \tag{5}$$

The phases are transformed to phase angles for the calculation of the Rayleigh Test statistic

$$z = n^{-1}[(\Sigma \cos \theta_i)^2 + (\Sigma \sin \theta_i)^2]. \tag{6}$$

The Rayleigh test statistic z is not exactly a sum of unit vectors [cos θ_i, sin θ_i]. However, if the unit vectors [cos θ_i, sin θ_i] point in the same phase angle direction, then the value z is large (indicating periodicity with P). In the opposite case, z is small, and then the θ_i distribution is more or less random (i.e. no periodicity with P).

The cumulative distribution function of the test statistic z is known to be (Kruger *et al.* 2002, 933–4)

$$P(z \leq z_0) = F(z_0) = 1 - e^{-z_0}. \tag{7}$$

The cumulative distribution function is based on the behaviour of the test statistic when the phases are randomly distributed. Here z_0 represents a calculated test statistic and z represents a test statistic for a random case. Large values of the test statistic are rare in random cases (when the phases are randomly distributed, i.e. the time points display no periodicity). When z_0 is large, the probability of the test statistic being less than z_0 in a random case approaches 1 (=100% probability). Generally, the value $F(z_0)$ is the probability that the value of test statistic z in a random case is smaller than or equal to the test statistic z_0 calculated from the time point series t_i.

The null hypothesis H_0 is

H_0: '*The phases* Φ_i *of the time points* t_i *with the period* P *are randomly distributed between 0 and 1*'.

This H_0 is rejected according to a *preassigned significance level* γ. Here the preassigned significance level is chosen to be $\gamma = 0.01$. This parameter γ is the chosen fixed probability of falsely rejecting H_0.

When the test statistic z_0 for the time series with the chosen period P is calculated, the *critical level*

$$Q = P\,(z > z_0) = e^{-z_0} \qquad (8)$$

is needed. This critical level is then compared with the preassigned significance level γ to decide how strongly the data contradict the null hypothesis H_0. The value Q is the probability that the value of the test statistic z in a random case exceeds z_0. The null hypothesis H_0 is rejected (and periodicity is accepted) if and only if $Q \leq \gamma$. If $Q > \gamma$, the null hypothesis H_0 is not rejected (no periodicity found).

If we were to test the occurrence of a single ($m = 1$) period P, only the equations (1)–(8) would be needed. However, in the case of this study all periods between 1.5 days $\leq P \leq$ 180 days are of interest and are therefore tested. Shorter periods than our chosen limit of 1.5 days would only yield trivial periodicity, because the difference of the time points is already periodical (due to the daily nature of the prognoses) at 1 day. Longer periods are not interesting because the longest Time series spans only 360 days and the chosen maximum period of 180 days allows only two revolutions in the phase.

We want to know how many statistically independent periods should be tested inside the chosen period interval. Between frequencies $[f_{min}, f_{max}]$, where $P = f^{-1}$, only a number m of independent tests are made, where

$$m = (f_{max} - f_{min})/f_0 \qquad (9)$$
$$f_0 = 1 / (t_n - t_1). \qquad (10)$$

It is unnecessary to test two frequencies separated by less than f_0, because the phase distributions of the time points with these two frequencies are almost the same (Jetsu & Pelt 1996, 587–94).

When testing the time series for a number of periods ($m > 1$), a high value for the test statistic in a random case is more probable, because of the larger number of tests. The probability (in other words, the critical level Q) for z to exceed z_0 in m independent tests is

$$Q = 1 - (1 - e^{-z_0})^m. \qquad (11)$$

Hence for any tested period 1.5 days < P < 180 days we first calculate the test statistic z_0. Then we reject H_0, if and only if the above critical level fulfills $Q < \gamma = 0.01$.

7. Results of the analysis

Time series 1–37 were analysed with the Rayleigh Test. The tested period interval was 1.5 days $\leq P \leq$ 180 days. The three best periods detected in each Time series 1–37 are given in Table 2.

The preassigned significance level for rejecting H_0 was $\gamma = 0.01$. This null hypothesis was rejected in only 11 cases and the presence of true periodicity with that particular period P was accepted. For these 11 periodicities, we give the value of the critical level (i.e. Q) in Table 2. The errors σ_P for these significant periodicities are also given in Table 2. These error estimates were calculated with the bootstrap method described by Efron & Tibshirani (1986, 54–77) and Jetsu & Pelt (1996, 587–94).

From the sixth column of Table 2 it can be seen that the periods *c.* 30 days and *c.* 7.5 days are the most common best periods $P_{best,1}$ in all Time series. However, in Time series 1–31, these periods are not significant. Nor is other significant periodicity found in these Time series. For the rest of this study, insignificant periods are not discussed any further.

Significant periods were found only from Time series 32–7, which are based on the prognoses for parts of days, i.e. when all possible positions of the prognosis within each day were included in the Time series. These are the Time series with the largest number of time points.

For the discovery of periodicity, a large number of time points is indeed crucial because the periodical 'signal' is hidden in the 'noise' from prognoses determined by criteria (e.g. the first date of every month being GGG) other than the period in question.

The period *c.* 7.5 days is the best period in Time series 33, 34 and 36. It is significant in all Time series 32–7. Thus it is accepted as a genuine periodicity. The probability (Q) of randomness for this period is extremely low, especially in Time series 36 (prognosis

Table 1. *The analysed time series and their selection criteria.*

Time series no.	No. of time points	Source	Prog-nosis	Object of prognosis
1	176	C	GGG	Whole day
2	131	S	GGG	Whole day
3	187	BM	GGG	Whole day
4	6	C	GGS	Whole day
5	5	S	GGS	Whole day
6	18	BM	GGS	Whole day
7	7	C	GSS	Whole day
8	13	BM	GSS	Whole day
9	106	C	SSS	Whole day
10	76	S	SSS	Whole day
11	128	BM	SSS	Whole day
12	4	C	SSG	Whole day
13	5	S	SSG	Whole day
14	192	C	G	Morning
15	219	BM	G	Morning
16	139	S	G	Morning
17	114	C	S	Morning
18	134	BM	S	Morning
19	84	S	S	Morning
20	188	C	G	Midday
21	210	BM	G	Midday
22	141	S	G	Midday
23	121	C	S	Midday
24	146	BM	S	Midday
25	85	S	S	Midday
26	187	C	G	Evening
27	192	BM	G	Evening
28	139	S	G	Evening
29	86	S	S	Evening
30	122	C	S	Evening
31	164	BM	S	Evening
32	564	C	G	All
33	618	BM	G	All
34	418	S	G	All
35	355	C	S	All
36	442	BM	S	All
37	252	S	S	All

Table 2. *The results of the Rayleigh Test for Time series 1–37. The source and prognosis from Table 1 are given in columns 2 and 3. The number of time points is* n*, the number of independent frequencies is* m *and the three best periods from the test are* $P_{best,\,1}$, …, $P_{best,\,3}$. *In the cases where* $Q \leq \gamma = 0.01$*, the value of* Q *and the error estimate* σ_P *are given, the latter as calculated with the bootstrap method.*

Time series	Source	Prog-nosis	*n*	*m*	$P_{best,1}$	$P_{best,2}$	$P_{best,3}$
1	C	GGG	176	237	7.472	29.40	1.540
2	S	GGG	131	162	7.426	29.93	2.493
3	BM	GGG	187	237	29.38	7.472	14.10
4	C	GGS	6	75	4.200	22.13	5.452
5	S	GGS	5	95	4.000	2.000	4.635
6	BM	GGS	18	219	3.208	3.283	17.58
7	C	GSS	7	113	2.110	1.901	2.481
8	BM	GSS	13	179	7.724	3.861	2.286
9	C	SSS	106	228	30.17	1.557	2.795
10	S	SSS	76	157	90.3	2.407	1.712
11	BM	SSS	128	234	7.502	3.180	14.07
12	C	SSG	4	226	1.555	2.803	14.88
13	S	SSG	5	83	4.858	3.598	2.067
14	C	G	191	237	29.32	7.480	1.540
15	BM	G	218	237	7.483	14.096	3.181
16	S	G	138	162	7.439	30.21	13.910
17	C	S	113	232	30.12	2.824	7.485
18	BM	S	133	234	7.498	3.181	14.098
19	S	S	83	157	14.075	1.543	2.840
20	C	G	187	237	29.50	1.540	7.468
21	BM	G	209	237	7.484	29.28	3.181
22	S	G	140	162	30.02	3.165	7.421
23	C	S	120	232	30.38	7.468	2.823
24	BM	S	145	234	7.498	30.17	3.180
25	S	S	84	157	2.407	3.165	1.710
26	C	G	186	237	29.36	1.540	64.20
27	BM	G	191	237	29.30	7.484	14.073
28	S	G	139	162	7.425	2.493	1.669
29	S	S	85	157	7.449	2.406	3.165
30	C	S	121	234	97.4	30.29	4.209
31	BM	S	163	234	7.506	30.21	100.9
32	C	G	564	237	29.39±0.24	7.483±0.021	2.851±0.002
					$Q = 8.087 \times 10^{-6}$	$Q = 1.863 \times 10^{-3}$	$Q = 3.250 \times 10^{-3}$
33	BM	G	618	237	7.484±0.016	14.079	29.21
					$Q = 3.679 \times 10^{-4}$		
34	S	G	417	162	7.430±0.030	29.97	3.165
					$Q = 8.859 \times 10^{-3}$		
35	C	S	354	234	30.27±0.27	7.486±0.021	2.824
					$Q = 1.679 \times 10^{-4}$	$Q = 2.203 \times 10^{-3}$	
36	BM	S	441	234	7.500±0.015	30.28	101.0
					$Q = 4.792 \times 10^{-7}$		
37	S	S	252	157	2.406±0.003	7.446±0.027	3.166±0.007
					$Q = 1.446 \times 10^{-3}$	$Q = 2.871 \times 10^{-3}$	$Q = 4.944 \times 10^{-3}$

S, source BM). In Time series 32, 33, 35 and 36 the period is close to, or exactly 7.5 days. In Time series 34 and 37, based on P. Sallier IV, the detected period is *c.* 7.45 days.

The period of 7.5 days is one fourth of a civil calendar month, which was usually divided into three decades (periods of ten days). However, in the calendars of lucky and unlucky days, we found that the division into four 'weeks' appears to be more significant than the weak signs of a division into three, to be discussed below. The period of 7.45 days is neither exactly one fourth of the civil month, nor one fourth of a lunar month (7.383 days). It may be possible that these two periods are somehow mixed with each other producing the resulting period.

The period *c.* 30 days is the best period of the Time series 32 and 35. It was found to be significant only in these two Time series. The period *c.* 30 days appears in many tests where it is not actually significant. Note also that 30 days means four revolutions with the period of 7.5 days.

Two different periods close to this value of 30 days also seem to exist. The exact value is <30 days in Time series based on the prognosis G. The tests for Time series based on prognosis S give a value ≥ 30 days.

The latter period, concerning unlucky days, is most likely due to the 30-day civil calendar month, but the period <30 days, concerning lucky days, is most likely evidence of the prognoses' connection to the phases of the moon. A synodic month, the time between two nearest occurrences of the same phase of the moon, such as two full moons, has the mean length 29.531 days. This value is very close to the best period of Time series 32, $P_{\text{best},1} = 29.39 \pm 0.24$. The best period of Time series 32 is definitely not the same period due to the 30-day civil calendar month seen in Time series 35, according to the error estimate. The period of 29.39 days received an extremely low *Q*-value, which means that the probability of a random coincidence in this case is eight in a million.

Whereas the period based on prognosis S is probably unrelated to the synodic month, the results for the prognosis G are strongly suggestive of the prognoses being partially based on the synodic month. This would mean that the lucky days were partially fixed to a phase of the moon.

The existence of a lunar calendar in Egypt is well known only from a number of Late Period sources, such as the assortment of double dates given in Ptolemaic temples (Depuydt 1997, 218–41; Parker 1950, 24–9). Evidence of such a calendar in earlier periods is, however, scarce and somewhat disputed. Parker suggested a lunar calendar, which would have existed before the civil calendar (Depuydt 1997, 15–17; Parker 1950, 56). The problem with such a suggestion is, however, that it then becomes necessary to postulate an earlier lunar calendar contrasting with the lunar calendar used in the Late Period.

The months of such a lunar calendar would have alternated between 29 and 30 days. It would most likely have been divided into four 'weeks' in accordance with the four distinct phases of the moon (Clagett 1995, 3–4; Parker 1974, 52–3).[14] Again, it is curious that both prognoses G and S exhibit very strong periodicity at *P c.* 7.5 days, which is not the lunar month divided into four, but the civil month divided into four. It is possible that an early practice of determining luckiness and misfortune operated partially on the basis of a lunar month, which was divided into four phases of the moon. A later system of lucky and unlucky days based on the civil calendar could have adopted this division of the month in four phases despite the fact that the 'weeks' of the civil month will be out of step with the phases of the moon.[15]

The best period in Time series 37 is $P_{\text{best},1}$ *c.* 2.4 days (2 + 2/5 = 12/5). The prognosis S occurring five times with this period makes up a 12-day sequence, which is repeated in more or less the same way throughout the year. Therefore 30 of these 12-day sequences fit exactly within the time frame of a civil year, epagomenal days excluded. This may be related to the magical numbers 30 (for the civil calendar month) and 12 (for the hours of the day).

Time series 32 shows a significant period $P_{\text{best},3}$ *c.* 2.85. This period is close to that of Algol's (β Persei) changing brightness. Algol's magnitude is 2.3^{m} at its brightest and 3.5^{m} at its dimmest. At its brightest Algol is thus over three times brighter than at its dimmest, and the variability can be detected with the naked eye.[16] This remarkable variability is due to Algol being an eclipsing binary star where, today, one of the stars eclipses the other with the period $P = 2.86739$ days. The theory, mentioned but not endorsed by Frieboes-Conde, Herczeg and Hog, of a gradual increase over time by the period would make the period in *c.* 1500 BC equal to the one detected in Time series 32 (Frieboes-Conde *et al.* 1970, 88).

There is a high possibility of Algol having been observed in Egypt, where its declination *c.* 1500 BC was approximately +23°.[17] While there is no identification of the star Algol in Egyptian documents or painted images, it might have to be decoded from a possible indirect reference to it, its epithet or title. Algol, if identified, would probably have been counted as one of the decan stars (because of its declination it is a rising and setting, 'unwearying', star). Perhaps its dim phase would indeed have been perceived as a good omen, yet any proposal of Algol having had an influence on the calendars of lucky and unlucky days must be considered tentative. Possible affirmation of the identification of Algol will certainly need more detailed study in the future.

Finally, results for Time series 37 also show significant periodicity at $P_{\mathrm{best},3}$ *c.* 3.16 (3 + 1/6 = 19/6). This period could be related to the best period of the same Time series, $P_{\mathrm{best},1}$ *c.* 2.4. After one decade (ten days), a time point has the same phase with these two periods, but a difference of one revolution. This cycle of misfortune in ten day-periods is the only evidence of the decade being used for determining the prognoses in the calendar of lucky and unlucky days.

With this result all of the significant periods have been dealt with. Some of the other (non-significant) periods apparent in Table 2 are the periods found to be significant in other Time series, but some may be spurious (i.e. unreal) periods P', which can be predicted from two other existing 'real' periods P_1 and P_2 in the time series.[18]

8. Conclusions

As far as we are aware, this is the first time that time series analysis has been applied as a methodological aid in an egyptological study focusing on ancient Egyptian calendars of lucky and unlucky days. The Rayleigh Test was employed for determining the periodicity of time series based on good and bad prognoses given in P. Cairo 86637, P. BM 10474 and P. Sallier IV.

In total 37 different Time series were created. These are tabulated in Table 1. In Time series 1–31, no significant periodicity was found. However, in Time series 32–7, eleven cases of significant periodicity were found where the critical level for rejecting the null hypothesis reached $Q \leq \gamma = 0.01$. Many of the good prognoses in the Cairo Calendar can now thus be confirmed as being in accordance with certain phases of the moon. The identified period of the synodic month is found, although it is 'buried' under the noise created by prognoses determined by feast days, local traditions and beliefs based on various natural phenomena. Although the first day of each month, for example, was a feast day which occurred regularly, the period of 30 days is definitely not the best periodicity in the good prognoses of the Cairo calendar. The period 29.5 of the synodic month is much more significant (and very significant, $Q = 8 \times 10^{-6}$). As 29.5 days is the time between the occurrences of two of the same phases of the moon, the period in question may be identified as the synodic month. The time series analysis thus shows quite clearly that some of the prognoses presented by the calendars of lucky and unlucky days were distributed according to a lunar calendar. This despite the fact that the set-up structure of these calendars are based on that of the civil calendar.

The 30-day period found from the prognosis bad, on the other hand, appears to be in accordance with the 30-day civil calendar month. This means that the same phase of each civil calendar month was usually ill-omened. But with regard to the 20th day of each civil calendar month receiving the prognosis bad-bad-bad, for example, it may be noted that one entirely bad day on the same date of each month is not enough to constitute a periodicity significant in the analysis; the periodicity attested in this study was determined by the distribution of all the prognoses bad present in the source.

The 7.5-day period found in both good and bad prognoses (time series from sources P. Cairo 86637 and P. BM 10474) is not quite the time between two consecutive phases of the moon. It correlates, nonetheless, with ¼ of the civil calendar month which is known to have been divided into three decades. In this analysis the decades show up weaker in the prognoses compared to this extremely strong 7.5-day period. The period discovered in P. Sallier IV is *c.* 7.45, somewhere between two phases of the moon and one fourth of the civil month.

The periods 2.4 and 3.16 found in one time series lead to a time point having the same phase but the difference of one revolution after one decade. This appears to be the only evidence of the decade being used to determine the prognoses in the calendar of lucky and unlucky days. The period 2.4 could alternatively have a relation to the myths of the hours of the day and the night, since with this period the prognosis bad makes 12 × 30 revolutions in a year. The sun is at its oldest and weakest in its 12th hour — representing the moment when chaos is victorious over order (Leitz 1994, 472–3).

There exists no evidence of ancient Egyptian observation of Algol or calculation of its period, but the attested period 2.85 is very near to Algol's (β Persei) period of variation. If this correlation exists, the Egyptians would have been the first in history to note Algol's variation period.

Finally, the periodicities found in the calendars are proof of the lunar cycles and possibly the Algol's cycle of variability having an influence on determining ancient Egyptian lucky and unlucky days. In effect, this means an influence on overall religious life, through the extremely influential feast dates. The presence of a lunar calendar in the religious and civil life of the New Kingdom is supported by this evidence in a unique way.

The discoveries reached by this study contribute to our understanding of the logic behind the calendar of lucky and unlucky days in particular, and the popular religion of Egypt in general, especially pertaining to the myths attributed to the feast dates. The results affirm Leitz's and Krauss's notion of astronomical events having influenced the calendar of lucky and unlucky days, and additionally contribute to a wider understanding of the meaning of astronomical phenomena in ancient cultures and the history of astronomy itself.

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Notes

1. P. Kahun (XVII, 3); P. BM 10474 (vso.); P. Leiden I 346; O. Malinine; P. Golénischeff; O. Turin CGT 57304; P. BM 10184 (rto.) = P. Sallier IV (rto.); P. Cairo 86637; P. Turin CGT 54016 (vso.). (Helck *et al.* 1975–92, VI: 154–5). An updated listing of hemerologies discards P. Turin CGT 54016, but adds O. Gardiner 109 as a source (Leitz 1994).
2. For example, Herodotus's *History*: 2. 82, transl. D. Grene, 1988.
3. 'widrig, schlecht' (Erman & Grapow 1926–63, 216).
4. The possible periodicity in the ages of terrestrial impact crater record was studied in Jetsu & Pelt 2000, 415–18. Applications of these methods in biology are discussed by Batschelet 1981.
5. For a good overview on month names, see Depuydt 1997.
6. Heliacal rising refers to the event when one observes a star in the morning sky after a certain period of invisibility. Circumpolar stars are visible every night of the year, but non-circumpolar stars are invisible during part of the year.
7. Convincing arguments for this feast's original relation to winter solstice are presented in Spalinger 1995, 17–32 and Wells 1994, 1–37.
8. The titulature of Ramses II is clearly readable in vso XIX, 1. However, no regnal year features in the facsimile or the discussion presented in Leitz (1994, 6).
9. Ten independent systems of categorization are suggested by Leitz (1994, 452–79).
10. S for German 'schlecht' is used to denote the prognosis bad. This marker (rather than B for bad) is chosen in order to facilitate comparison with Leitz (1994, appendices).
11. We have repeated the test using many different ways of dividing the day into parts, and it has had very little or no effect on the results.
12. A day arc of a celestial body means the time lapsed from its rise to its setting.
13. The Rayleigh Test statistic z is related to Pearson's random walk by the equation $z = nr^2$.
14. New moon occurs when the moon is in the same section of the sky as the sun. The moon is thus not to be seen during the night. A couple of days later the Moon has moved to the east of sun. This shifting of location is enough for it to be seen in the evening sky, where it appears as a crescent opening to left when observed in the northern hemisphere. A week after the new moon, exactly the right half of the moon is lit by the sun, and the moon is said to be in its first quarter. A week later, full moon occurs, and yet a week later, the last quarter, when the left half of the moon is in the morning sky. As a crescent waning day by day, the moon fades from view. The feast calendars include at least a feast for the new moon (*pesedjentiu*) and a feast for the full moon (*iah wer*).
15. In parallel, the 'feasts of the sky', *hebu nu pet*, often have names pointing to a lunar origin (*pesedjentiu*, *iah wer*, …). However, as they recur on a certain day of each civil month, they are practically independent of the phase of the moon that the name refers to.
16. In no other case than Algol's would it seem likely that the variability of a star would be a part of mythology or tradition of an ancient culture, because when limit-

ing consideration to stars bright enough for naked eye observing and regular enough variability, in all other cases a diligent observance over many consecutive nights would be necessary to calculate the period of variability. Algol's eclipse, on the other hand, can be estimated during a single night's good observation. If the star clock system was under regular use at any point during Egyptian history, there is a very good chance that star clock observers would have noted the behaviour of Algol, which, as noted, would have been counted as one of the decan stars. The variability of Algol can hardly pass unnoticed by people living in an environment, in which the sky is often clear. It is evident that, for example, the people of northern Siberia have been aware of Algol's variability and the well-known phenomenon is an essential part of their mythology and sky lore (Pentikäinen 1998, 72–5).

17. Declination for the Ramesside era has been corrected from the value for Epoch 2000.0 taking into account the proper motion and precession and using the equations given in Karttunen *et al.* (2000, 55–8).
18. $P' = [P_1^{-1} + k_1(k_2P_2)^{-1}]^{-1}$, $k_1 = \pm1, \pm2, \ldots$ $k_2 = 1, 2, \ldots$ (Jetsu & Pelt 2000, 417).

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