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**Research Articles**

# Sunspot Dynamics Are Reflected in Human Physiology and Pathophysiology

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**Abstract**

Periodic episodes of increased sunspot activity (solar electromagnetic storms) occur with 10–11 and 5–6 year periodicities and may be associated with measurable biological events. We investigated whether this sunspot periodicity characterized the incidence of Pap smear-determined cervical epithelial histopathologies and human physiologic functions. From January 1983 through December 2003, monthly averages were obtained for solar flux and sunspot numbers; six infectious, premalignant and malignant changes in the cervical epithelium from 1,182,421 consecutive, serially independent, screening Pap smears (59°9″N, 4°29″E); and six human physiologic functions of a healthy man (oral temperature, pulse, systolic and diastolic blood pressure, respiration, and peak expiratory flow), which were measured ~5 times daily during ~34,500 self-measurement sessions (44°56″N, 93°8″W). After determining that sunspot numbers and solar flux, which were not annually rhythmic, occurred with a prominent 10-year and a less-prominent 5.75-year periodicity during this 21-year study span, each biological data set was analyzed with the same curve-fitting procedures. All six annually rhythmic Pap smear-detected infectious, premalignant and malignant cervical epithelial pathologies showed strong 10-year and weaker 5.75-year cycles, as did all six self-measured, annually rhythmic, physiologic functions. The phases (maxima) for the six histopathologic findings and five of six physiologic measurements were very near, or within, the first two quarters following the 10-year solar maxima. These findings add to the growing evidence that solar magnetic storm periodicities are mirrored by cyclic phase-locked rhythms of similar period length or lengths in human physiology and pathophysiology. Key Words: Cervical infections—Cervical premalignancy—Geo-solar magnetic interactions—Pap smear—Schwabe cycle—10-year rhythm. Astrobiology 11, 93–103.

## 1. Introduction

Primarily, photic biological timekeeping is a core property of life on Earth. Circadian biological timekeeping clocks with common elements have emerged ubiquitously over several billion years, having been conserved phylogenetically from bacteria to plants to insects to mammals—with some evolutionary divergence of different gene products (homologs) of the core oscillator components—because endogenous daily timekeeping provides fitness and survival advantage (Gachon *et al.,* 2004; Bell-Pedersen *et al.,* 2005; Looby and Loudon, 2005; Sandrelli *et al.,* 2008; Harmer, 2009). Circadian rhythms are important regulatory processes, which almost universally are used to harmonize physiology and behavior with the environmental 24 h geophysical cycles of light and temperature caused by daily changes in the relationship of Earth and the Sun. Rhythmic, latitude-dependent, annual changes in solar/terrestrial relationships, that is, seasonal light and temperature changes, which have occurred in all non-equatorial locations for presumably as long as the aforementioned daily changes, have induced a range of circannual timekeeping mechanisms (Zucker *et al.,* 1991; Lincoln *et al.,* 2003, 2006). Infra-annual, regular, nonphotic, intrasolar magnetic events, which have been identified as sunspot cycles of 10–11 years in length, have likewise accompanied presumably the entire span of terrestrial biological evolution (Brown, 1976).

Many physiologic functions, as well as Pap smear–defined histopathologic signs of cervical epithelial human papillomavirus (HPV) infection and resultant cervical cancer, occur

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with strong seasonal patterns (Rietveld *et al.,* 1997; Hrushesky *et al.,* 2005, 2006). Peak incidences (rates/1000) of HPV, premalignant and malignant cervical changes in Pap smears occur during the summer months (Rietveld *et al.,* 1997). This circannual HPV rhythm is positively correlated with the annual sunlight fluency and UVB exposure at the global location of the screened population (Hrushesky *et al.,* 2006). Ultraviolet B not only activates many viruses, both *in vitro* and *in vivo,* including HPV (Taylor *et al.,* 2003), which causes human cervical cancer, but also suppresses cellular immune defenses against cancer and bacterial, fungal, parasitic, and viral infections, both locally and systemically (Goettsch *et al.,* 1993; Bos, 1997; Selgrade *et al.,* 1997). Annual rhythms in physiologic function have also been tied to regular seasonal daylight length changes in temperate latitudes (Farner, 1985; Sposito *et al.,* 2000; Halberg *et al.,* 2004; Hrushesky *et al.,* 2005; Al-Tamer *et al.,* 2008). In addition, a wide variety of circannual rhythms in clinical symptoms and diseases, including cardiovascular morbidity and mortality, respiratory illness, sexually transmitted diseases, depressive disorders, and cancer, have been reported (*cf.,* Sothern, 2006a), For example, breast cancer has been shown to be a seasonal disease (Cohen *et al.,* 1983; Ross *et al.,* 1997), and the amplitude of this annual rhythmicity increases exponentially as the population residence diverges from the equator (Oh *et al.,* 2010).

The Schwabe solar cycle in the number of solar magnetic storms, as reflected in sunspot number temporal patterns, occurs, on average, with a prominent 10–11 year (circadecadal) and a less prominent 5–6 year (circahemidecadal) cyclicity (Gnevyshev, 1977; Usoskin and Mursula, 2004). The main solar cycle length can vary from 9.8 to 12.0 years, depending on the epoch, with a mean length of 11.1 years. This solar cycle is a major driver of electromagnetic space weather, wherein heliomagnetic phenomena modulate solar irradiance and the flux of short-wavelength solar radiations (*e.g.,* ultraviolet radiation, X-rays). These internal magnetic solar events indirectly modulate the flux of high-energy galactic cosmic rays that enter the Solar System by regularly perturbing our geomagnetic fields (Foukal *et al.,* 2006). As a result, these nonphotic infra-annual solar cycles are not without biological consequences in both plants and animals (Halberg *et al.,* 2004). Certainly, periodic increases in solar energetic particle flux may pose major threats to space travelers who lack the protective blanket of Earth's magnetic field (Badhwar *et al.,* 1997; Turner and Baker, 1998).

We wondered whether these periodic changes could be reflected by measurable changes in biological organisms tucked beneath their protective geomagnetic shield. To investigate this, we compared cycles in monthly sunspot and solar flux numbers between 1983–2003 with monthly population rates/1000 of screening-discovered, Pap smear–defined, cervical epithelial infections, pre-cancer, and cancer, as well as monthly circadian means and amplitudes of six physiologic functions of a healthy man obtained five times per day by self-measurements over the identical 21-year span. Photic annual rhythms in these same data were also analyzed for reference. These unique data are, herein, provided to the astrobiology community for inspection, further analysis, and possible publication of additional insights they may provide to the authors with complementary perspectives and expertise that we do not share.

## 2. Materials and Methods

### 2.1. Cervical Pap smear data

The database consists of all cervical epithelial Pap smear results produced in the Leiden Laboratory in the Netherlands over 252 consecutive months (21 years) between January 1983 and December 2003. This institution is involved in the Dutch National Cervical Cancer Screening Program and covers one-third of the adult female population of southern Holland, with both urban and rural women of all adult ages fully represented (Boon and Suurmeijer, 1996). These cervical pap smears are virtually independent screening samples. All abnormalities found at screening were reported to the patient's gynecologist and followed up elsewhere, which thereby removed each affected individual from the screening population. The recommended frequency of screening Pap smears in Netherlands is once every 4–5 years. During these 21 years, 1,182,421 smears were processed, read, and reported by the same expert technical staff, and each abnormal smear was reviewed by one of us, a pathologist and laboratory director (M.E.B.). The monthly (corrected for monthly durations) frequency (per thousand examined smears) of six medically relevant, routinely identified, cervical epithelial cytopathologic abnormalities included *Trichomonas vaginalis, Actinomyces urogenitalis, Chlamydia trachomatis,* HPV, cervical epithelial dysplasia (pre-cancer mild, moderate, and severe) and cervical carcinoma (*in situ,* micro-invasive, and frankly invasive) (Supplementary Table S1; Supplementary Data are available online at www.liebertonline.com/ast).

In 504,093 smears between 1983 and 1991, epithelial abnormalities were reported as mild, moderate, or severe dysplasia or atypia (six categories), or as carcinoma *in situ,* microinvasive carcinoma, or frankly invasive cervical cancer (three additional categories). By international convention, after 1991 (678,328 smears), the three atypia categories were abandoned, and all significant epithelial abnormalities were subsequently folded into six, rather than nine, categories. Cytopathologic signs of venereal HPV, *Trichomonas vaginalis*, *Actinomyces urogenitalis*, and *Chlamydia trachomatis* cervical epithelial infections were also identified and recorded throughout the entire 21-year span (Boon and Suurmeijer, 1996).

### 2.2. Nomenclature of identified histopathologic premalignant and malignant cervical epithelial abnormalities

Over the 21 years of this study, three terms were used in this screening lab for histopathologically abnormal uterine epithelium: atypia, dysplasia, and carcinoma *in situ.* Atypia in this Leiden laboratory is equivalent to borderline malignant change in the United Kingdom, and atypical cells of unknown significance (ASCUS) in the United States. This is the first and least abnormal identifiable state along the histopathological path toward cancer. Dysplasia is the same as dyskariosis in the United Kingdom and a squamous intraepithelial lesion (SIL) in the United States. This abnormality demonstrates nuclear and cytoplasmic changes more severe than atypia and is often graded from least to most abnormal (D1, D2, D3) across the degrees of abnormality. Carcinoma *in situ* is the most severe form of dysplasia, worse than D3, but still not frankly invasive (Boon and Suurmeijer, 1996).

### 2.3. Longitudinal physiologic data

Physiologic data were collected by a normotensive male biomedical scientist (R.B.S.) living at 44°56″N, 93°8″W (St. Paul, Minnesota, USA), who has performed physiologic self-measurements for more than four decades, beginning in 1967 at the age of 20.5 years. Variables measured include oral temperature, pulse, systolic and diastolic blood pressure (BP), respiratory rate, and peak expiratory flow, among others; details and procedures are described elsewhere (Halberg *et al.,* 1972; Sothern, 1974, 1994, 2006b). Data collected from January 1983 to December 2003 (21 years) consist of ~210,000 values acquired during ~34,500 self-measurement sessions (five sessions performed daily). All variables were analyzed by the single cosinor procedure to estimate the circadian (*i.e.,* 24 h) mean, amplitude, and phase of each variable measured (see analysis section below). The monthly circadian means and circadian amplitudes were computed as measures of the 24 h variability associated with the well-known circadian rhythm in these physiologic variables (Supplementary Table S2). The time span for the monthly physiologic circadian means and amplitudes was selected to cover the same 252 months as the monthly cervical pathology and solar information, and each series of monthly means was subjected to identical time series analyses. Both the physiologic data and cervical pathology data were collected with no foreknowledge of this project.

### 2.4. Solar flux and sunspot numbers

Solar flux data were taken from the National Geophysical Data Center (NGDC) in Boulder, Colorado, USA, with radio telescopes at Ottawa (1947–1991) and Penticton (1991–present), British Columbia, Canada. Daily solar flux density at 2800 mHz is measured and reported at approximately 1700 UT in solar flux units. One solar flux unit is equivalent to $10^4$ jansky ($10^{-22}$ W/m$^2$Hz). Adjusted values, corrected for variations resulting from the eccentric orbit of Earth around the Sun, were used in the present study (NOAA, 2003).

Sunspot data were taken from the Solar Influences Data Analysis Center (SIDC) of the Royal Observatory of Belgium, Brussels, Belgium (SIDC-team, 2003). The SIDC calculates and broadcasts the sunspot index, called the *International Sunspot Number,* for each day, month, and year. The sunspot number represents the number of observed sunspots and sunspot groups on the solar surface and is computed according to the Wolf Sunspot Number Formula: $R = k\ (10g + s)$, where $g$ is the number of sunspot groups (regions), $s$ is the total number of individual spots in all the groups, and $k$ is a scaling factor that corrects for visual conditions at various observatories. The SIDC collects the observations from as many stations as possible worldwide, determines the appropriate $k$ factor for each of them, and then extracts an overall *International Sunspot Number* from all these observations. Average monthly values of solar flux (adjusted) and sunspot numbers from January 1983 to December 2003, which are available online, were used (Supplementary Table S3).

### 2.5. Data detrending

It is well known that the incidence of various Pap smear–detected cervical abnormalities in populations of the developed world change over time as health care accessibility and quality change. On average, some 4,692 Pap smears were examined monthly throughout the 21 years of study. Significantly more smears were examined, however, in the summer and late autumn and early winter months. There was also an increasing number of the total smears performed per year. These data were, therefore, standardized prior to analysis by expressing monthly incidence as the rate of each abnormality detected per thousand smears inspected during that month. All 252 consecutive normalized monthly means for rates of Pap smear abnormalities were subsequently tested for a trend over the entire 21-year span of data collection by simple linear regression; and, if significant, data were detrended by subtracting the trend from the original values and adding the overall mean value back to the residuals to create a detrended time series prior to rhythm analysis for annual, 5.75-, and 10-year rhythms.

It is also evident that aging is associated with long-term trends in all physiologic functions. Solar flux, sunspot numbers, and all physiologic data were thus identically detrended, if necessary. Removing any trend from the 21-year data span enables a more reliable analysis of any true fluctuations in a time series unbiased by any trend.

### 2.6. Periodicity analysis

To uncover underlying rhythms and describe the shape and relationships of these recurring patterns across time in the data sets, each time series was analyzed for each candidate periodicity by multiple component least-squares cosinor analysis (Nelson *et al.,* 1979), with use of the Chronolab statistical package (Mojón *et al.,* 1992). This method of time series analysis tests for the presence of a cosine-shaped pattern of an *a priori* defined period length in each data set. If significant, it confirms the presence of a recurring cycle or rhythm in the data, as opposed to random variation or a trend occurring across the entire observation span. Cosinor analysis is analogous to the linear regression testing by "least squares" of a best-fitting straight line to a data set when searching for a linear increasing or decreasing trend and subsequently determining the probability that the slope of the best-fitting line is different from zero. Using the same technique, the cosinor method fits a best-fitting cosine function instead of a straight line. The probability that the amplitude of the cosine function best fitting these data is greater than zero is calculated based upon the reduction in variance about the fitted cosine compared to the total variance about the arithmetic mean (flat line). If the zero-amplitude hypothesis can be rejected with 95% certainty, statistical significance of a modulation that approximates the length (period) of the cosine is accepted at $p \leq 0.05$.

Rhythm parameters of "mesor," "acrophase," and "amplitude" can then be derived from the cosine model used. The "mesor" is the mean of the rhythm and represents the middle value of the fitted cosine. The series mesor and mean are identical if the data are equidistant across the sampling span, but they are not identical if sampling is irregular or the time span is not an integral number of the longest period being fitted, or both. The 252 monthly data analyzed in each of these data series are equidistant across the total 21-year

span. The "acrophase" is the time from a phase reference (0°) to the peak of the cosine function that best describes the data. In our analyses, the fitted periods of 10, 5.75, and 1 years (always equal to 360°) are each referenced to midnight of January 1, 1983. The "amplitude" is the height of the best-fitting cosine function from the mesor to the acrophase and is one-half of the full variation from trough to peak of the cosine, which indicates a predictable range of change.

Cosinor analysis can also be used to fit more than one period in a concomitant multi-component analysis to better detect separate periodicities or better characterize patterns in the data (Ayala *et al.*, 1990; Fernández *et al.*, 2009). Over the 21-year observation span, the periods of the best-fitting cosines that approximate the average lengths for oscillations in the sunspot and solar flux data were 10.0 and 5.75 years. Since our hypothesis was that similar oscillations in the pathophysiologic data might exist, a 10-year (87,660 h) period was invariably fit to each data series. Concurrent fitting of 5.75-year (50,404.5 h) and 1-year (8,766 h) periods was also performed. Multiple-component linear least-squares analysis allows rejection of the zero-amplitude hypothesis for each individual component rhythm tested, as well as for the overall model, and concurrently provides amplitudes and acrophases for each period fit to these data. In the case of the data series investigated herein, fitting the 10-year period plus the two additional periods of 5.75 years and 1 year enhanced the quality of curve-fitting and rhythm detection for several variables.

## 3. Results

Table 1 demonstrates time series analyses of 252 monthly mean values of solar data and each measured physiologic and pathophysiologic variable over the entire 21-year span from 1983–2003.

### 3.1. Solar periodicities

Both 10-year and 5.75-year periodicities in sunspot dynamics are significant, but with the amplitude of the 5.75-year periodicity in solar flux and sunspot number 1/18 as robust as the amplitude of the 10-year component. No annual rhythm was found to exist in sunspots or solar flux.

### 3.2. Pap smear periodicities

Each pathological cervical epithelial abnormality also occurs with a statistically significant 10-year periodicity, while most also reveal annual rhythms, and a few occur with a 5.75-year periodicity.

### 3.3. Physiologic periodicities

Monthly 24 h means and circadian amplitudes of each of the six measured physiologic functions form time structures strongly tuned to the 10-year periodicity. Most of these functions also reflect the weaker 5.75-year periodicity, while five of six of the time structures of these physiologic variables occur with strong annual periodicity as well.

### 3.4. Periodicities of multiple components

Figure 1 demonstrates what some of the complex, multi-component time structures look like for one representative pathologic variable (cervical epithelial premalignant dysplasia, pre-cancer) and one representative physiologic variable (systolic BP). The top panel depicts the raw detrended data, the middle panel the best-fitting reconstructed cosine, and the bottom panel overlaps those curves with the raw data. The time structures of each of these variables include strong 1-, 5.75-, and 10-year periodicities.

The reconstructed curves shown in Fig. 2 demonstrate the relative timing and amplitudes of the 10-year and 5.75-year periodicities in solar flux and sunspot numbers. No annual rhythm exists. Likewise, Fig. 2 displays the complex multi-component time structure of HPV infection, cervical epithelial carcinoma and dysplasia (pre-cancer), as well as one bacterial (*Chlamydia*) and one fungal (*Actinomyces*) cervical epithelial infection. This depiction of the relative amplitudes and phases of these 1-, 5.75-, and 10-year components also demonstrates that the nonphotic 10-year rhythm is often at least as prominent as the photic annual one, for many of the measured endpoints.

### 3.5. Phase relationships of observed periodicities

Figure 3 portrays the phasing maxima of each of the cervical epithelial abnormalities (Fig. 3A) and the daily means (Fig. 3B) and amplitudes (Fig. 3C) (95% confidence interval of the phases added when cosine-fitting significant) of all measured physiologic variables within the 10-year (top) and 5.75-year (bottom) solar cycles. All six cervical epithelial abnormalities peak near, or from several months to some three years following, the solar maxima. The circadian means of oral temperature, respiration, and diastolic BP peak during the first quarter following the solar maxima, while systolic BP peaks during the second quarter. Pulse peaks in the quarter immediately preceding the 10-year solar maxima, which implies that its trough occurs two quarters later when systolic BP is highest.

Even though the 5.75-year rhythm in biological variables is weaker than the 10-year rhythm, the phase relationships of five of six of the cervical pathologic rhythms and at least four of the circadian means and amplitudes of the physiologic function rhythms overlap or occur very near the 5.75-year solar maxima. While most of the variables peak near, or following, the solar maxima, some clearly occur later than others, which perhaps indicates unique mechanisms.

## 4. Discussion

A large sunspot, that is, a dark area on the surface of the Sun, was observed at the time of Charlemagne's death in 813. Astronomers of the royal court causally linked these phenomena in their writings. It was not completely clear to them whether the Sun was paying tribute to the great man or whether the sunspot had affected him. Since all living things are influenced by the Sun directly or indirectly, we are not surprised to find that human time structures reflect low-frequency nonphotic, solar rhythms. It is surprising to us, however, that the apparently unsensed Schwabe cycle of solar storms is as prominently reflected in biological time structures of a population of more than a million Dutch women and a single longitudinally monitored man, as are the usually obvious and keenly sensed photic solar fluency and day/night length changes that directly transmit annual time cues to virtually every non-equatorial life-form and

Table 1. Comparison of Cycles in Monthly Solar Data, Cervical Diseases in Holland, Circadian Mesors and Circadian Amplitudes from Self-Measures by a Healthy Man over 21 Years (1983–2003; $N = 252$; Summary at Solar-Related Periods Fit Concomitantly in Multi-Component Cosine Model)

| | | *Cosinor Analysis* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Variable* | *Period Years* | *%R* | *p* | *Mesor(M) ± SE* | *Amp(A) ± SE* | *2A%M* | *aØ* | *(95% Limits)* |
| **SOLAR DATA** | | | | | | | | |
| Sunspots | 10.00 | 70.7 | <0.001 | 71.3 ± 1.61 | 59.9 ± 2.33 | 168% | −280° | (−276°, −284°) |
| | 5.75 | 4.0 | <0.001 | | 11.5 ± 2.38 | 32% | −71° | (−49°, −93°) |
| | 1.00 | 0.1 | 0.566 | | 2.4 ± 2.27 | 7% | −215° | - |
| Solar Flux | 10.00 | 71.5 | <0.001 | 129.0 ± 1.53 | 58.9 ± 2.22 | 91% | −282° | (−278°, −286°) |
| ($\times 10^{-1}$) | 5.75 | 4.5 | <0.001 | | 13.0 ± 2.25 | 20% | −88° | (−69°, −107°) |
| | 1.00 | <0.1 | 0.877 | | 1.1 ± 2.15 | 2% | −357° | - |
| **CERVICAL DISEASES**[†] | | | | | | | | |
| Dysplasia | 10.00 | 8.9 | <0.001 | 13.97 ± 0.27 | 2.11 ± 0.40 | 30% | −58° | (−37°, −79°) |
| | 5.75 | 7.6 | <0.001 | | 1.94 ± 0.40 | 28% | −53° | (−31°, −75°) |
| | 1.00 | 6.1 | <0.001 | | 1.75 ± 0.38 | 25% | −208° | (−183°, −232°) |
| Carcinoma | 10.00 | 10.7 | <0.001 | 1.32 ± 0.05 | 0.38 ± 0.17 | 58% | −311° | (−291°, −331°) |
| | 5.75 | 0.8 | 0.423 | | 0.09 ± 0.07 | 14% | −359° | - |
| | 1.00 | 7.5 | <0.001 | | 0.32 ± 0.07 | 48% | −196° | (−172°, −219°) |
| Trichonomas | 10.00 | 3.4 | 0.031 | 4.98 ± 0.09 | 0.35 ± 0.13 | 14% | −321° | (−279°, −4°) |
| | 5.75 | 6.1 | <0.001 | | 0.51 ± 0.14 | 20% | −85° | (−56°, −113°) |
| | 1.00 | 2.5 | 0.031 | | 0.34 ± 0.13 | 14% | −354° | (−311°, −36°) |
| Actinomyces | 10.00 | 7.0 | <0.001 | 8.22 ± 0.15 | 0.88 ± 0.21 | 21% | −286° | (−259°, −313°) |
| | 5.75 | 2.2 | 0.121 | | 0.42 ± 0.22 | 10% | −41° | - |
| | 1.00 | 1.2 | 0.202 | | 0.37 ± 0.21 | 9% | −105° | - |
| HPV | 10.00 | 6.5 | <0.001 | 4.93 ± 0.18 | 1.08 ± 0.26 | 44% | −4° | (−337°, −32°) |
| | 5.75 | <0.1 | 0.997 | | 0.02 ± 0.27 | 1% | −91° | - |
| | 1.00 | 5.6 | <0.001 | | 1.04 ± 0.26 | 42% | −220° | (−192°, −248°) |
| Chlamydia | 10.00 | 20.6 | <0.001 | 1.89 ± 0.10 | 1.10 ± 0.14 | 116% | −57° | (−43°, −71°) |
| | 5.75 | 2.3 | 0.116 | | 0.29 ± 0.14 | 31% | −180° | - |
| | 1.00 | 1.8 | 0.063 | | 0.33 ± 0.14 | 35% | −327° | - |
| **CIRCADIAN MESORS OF SELF-MEASUREMENTS BY A HEALTHY MAN**[‡] | | | | | | | | |
| Oral Temp | 10.00 | 3.4 | 0.008 | 97.84 ± 0.01 | 0.03 ± 0.01 | 0.06% | −342° | (−306°, −19°) |
| | 5.75 | 1.3 | 0.127 | | 0.02 ± 0.01 | 0.04% | −202° | - |
| | 1.00 | 9 | <0.001 | | 0.04 ± 0.01 | 0.08% | −183° | (−161°, −205°) |
| Pulse | 10.00 | 21.3 | <0.001 | 74.43 ± 0.2 | 3.19 ± 0.28 | 8.57% | −213° | (−203°, −222°) |
| | 5.75 | 32.3 | <0.001 | | 3.90 ± 0.29 | 10.48% | −73° | (−65°, −80°) |
| | 1.00 | 2.3 | 0.003 | | 0.96 ± 0.27 | 2.58% | −168° | (−136°, −200°) |
| Respiration | 10.00 | 53.3 | <0.001 | 10.36 ± 0.02 | 0.6 ± 0.03 | 11.58% | −346° | (−340°, −353°) |
| | 5.75 | 0.9 | <0.001 | | 0.16 ± 0.03 | 3.09% | −304° | (−278°, −330°) |
| | 1.00 | 1.5 | 0.014 | | 0.1 ± 0.03 | 1.93% | −200° | (−162°, −239°) |
| Peak Flow | 10.00 | 2.4 | 0.038 | 706.04 ± 0.7 | 2.56 ± 1.00 | 0.73% | −20° | (−336°, −64°) |
| | 5.75 | 0.6 | 0.310 | | 1.57 ± 1.02 | 0.44% | −273° | - |
| | 1.00 | 2.2 | 0.064 | | 2.31 ± 0.98 | 0.65% | −182° | - |
| Systolic BP | 10.00 | 19.6 | <0.001 | 123.86 ± 0.13 | 1.60 ± 0.19 | 2.58% | −47° | (−34°, −60°) |
| | 5.75 | 17.4 | <0.001 | | 1.52 ± 0.19 | 2.45% | −72° | (−58°, −86°) |
| | 1.00 | 5.1 | <0.001 | | 0.84 ± 0.19 | 1.36% | −39° | (−15°, −64°) |
| Diastolic BP | 10.00 | 6.8 | <0.001 | 82.29 ± 0.66 | 0.15 ± 0.15 | 0.36% | −6° | (−339°, −32°) |
| | 5.75 | 22.2 | <0.001 | | 1.37 ± 0.16 | 3.33% | −80° | (−68°, −93°) |
| | 1.00 | 10.6 | <0.001 | | 0.97 ± 0.15 | 2.36% | −39° | (−21°, −56°) |
| **CIRCADIAN AMPLITUDES OF SELF-MEASUREMENTS BY A HEALTHY MAN**[‡] | | | | | | | | |
| Oral Temp | 10.00 | 18.8 | <0.001 | 0.96 ± 0.01 | 0.08 ± 0.01 | 16.67% | −123° | (−108°, −137°) |
| | 5.75 | 3.4 | 0.003 | | 0.04 ± 0.01 | 8.33% | −114° | (−82°, −146°) |
| | 1.00 | 0.5 | 0.450 | | 0.01 ± 0.01 | 2.08% | −125° | - |
| Pulse | 10.00 | 6.6 | <0.001 | 8.51 ± 0.12 | 0.99 ± 0.18 | 23.27% | −125° | (−104°, −145°) |
| | 5.75 | 24.8 | <0.001 | | 1.73 ± 0.18 | 40.66% | −93° | (−81°, −104°) |
| | 1.00 | 0.8 | 0.243 | | 0.29 ± 0.17 | 6.82% | −175° | - |
| Respiration | 10.00 | 17.5 | <0.001 | 2.26 ± 0.02 | 0.15 ± 0.02 | 13.27% | −353° | (−336°, −9°) |
| | 5.75 | 7.0 | <0.001 | | 0.09 ± 0.02 | 7.96% | −91° | (−64°, −118°) |
| | 1.00 | 4.4 | <0.001 | | 0.08 ± 0.02 | 7.08% | −184° | (−155°, −213°) |

(*continued*)

Table 1. (Continued)

| | | Cosinor Analysis | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Variable* | *Period Years* | *%R* | *p* | *Mesor(M) ± SE* | *Amp(A) ± SE* | *2A%M* | *aØ* | *(95% Limits)* |
| Peak Flow | 10.00 | 11.3 | <0.001 | 11.18 ± 0.16 | 1.38 ± 0.23 | 24.69% | −277° | (−259°, −296°) |
| | 5.75 | 6.4 | <0.001 | | 1.05 ± 0.23 | 18.78% | −232° | (−208°, −255°) |
| | 1.00 | 1.4 | 0.123 | | 0.46 ± 0.22 | 8.23% | −25° | - |
| Systolic BP | 10.00 | 0.3 | 0.550 | 6.66 ± 0.09 | 0.14 ± 0.13 | 4.20% | −53° | - |
| | 5.75 | 0.4 | 0.515 | | 0.15 ± 0.13 | 4.50% | −306° | - |
| | 1.00 | 25.2 | <0.001 | | 1.12 ± 0.12 | 33.63% | −26° | (−14°, −39°) |
| Diastolic BP | 10.00 | 1.2 | 0.074 | 6.62 ± 0.14 | 0.45 ± 0.19 | 13.60% | −335° | - |
| | 5.75 | 7.7 | <0.001 | | 0.92 ± 0.20 | 27.79% | −253° | (−230°, −277°) |
| | 1.00 | 1.5 | 0.124 | | 0.39 ± 0.19 | 11.78% | −55° | - |

†Units for disease = rate/thousand screening. Data is detrended prior to analysis. HPV = Herpes/Genital Wart. Single Cosinor = least-squares fit of cosines to 252 monthly values between 1983 and 2003.

‡Subject, R,B,S, (age 36–57 y), self-measured variables 5–6 times daily during waking from Jan 1, 1983, to Dec 31, 2003 (21 y). Total data: oral temp, $n = 34{,}506$; pulse, $n = 34{,}521$; respiration, $n = 34{,}518$; peak flow, $n = 33{,}625$; BP, $n = 34{,}488$ (peak flow and BP in triplicate). Data during illness or travel removed prior to the analyses summarized herein. Analyzed values represent circadian means (Mesors) by month from 24 and 12 h multiple-component cosine analysis of all data by month. Each series detrended prior to analysis by the least-squares fit of cosines to 252 monthly values between 1983 and 2003. Each time-series was analyzed for periodicities by multiple-component cosine with trial periods of 10, 5.75, and 1 y fit concomitantly. %R = percent of variability accounted for by cosine. Mesor = rhythm-adjusted mean; Amplitude (Amp) = 1/2 peak-trough difference of fitted cosine; 2A%M = double amplitude as % of mesor. Acrophase (aØ) reference (0°) = 00:00 h, Jan 1, 1983 (360° = fitted period). CL = Confidence Limits (shown if $p \leq 0.05$).

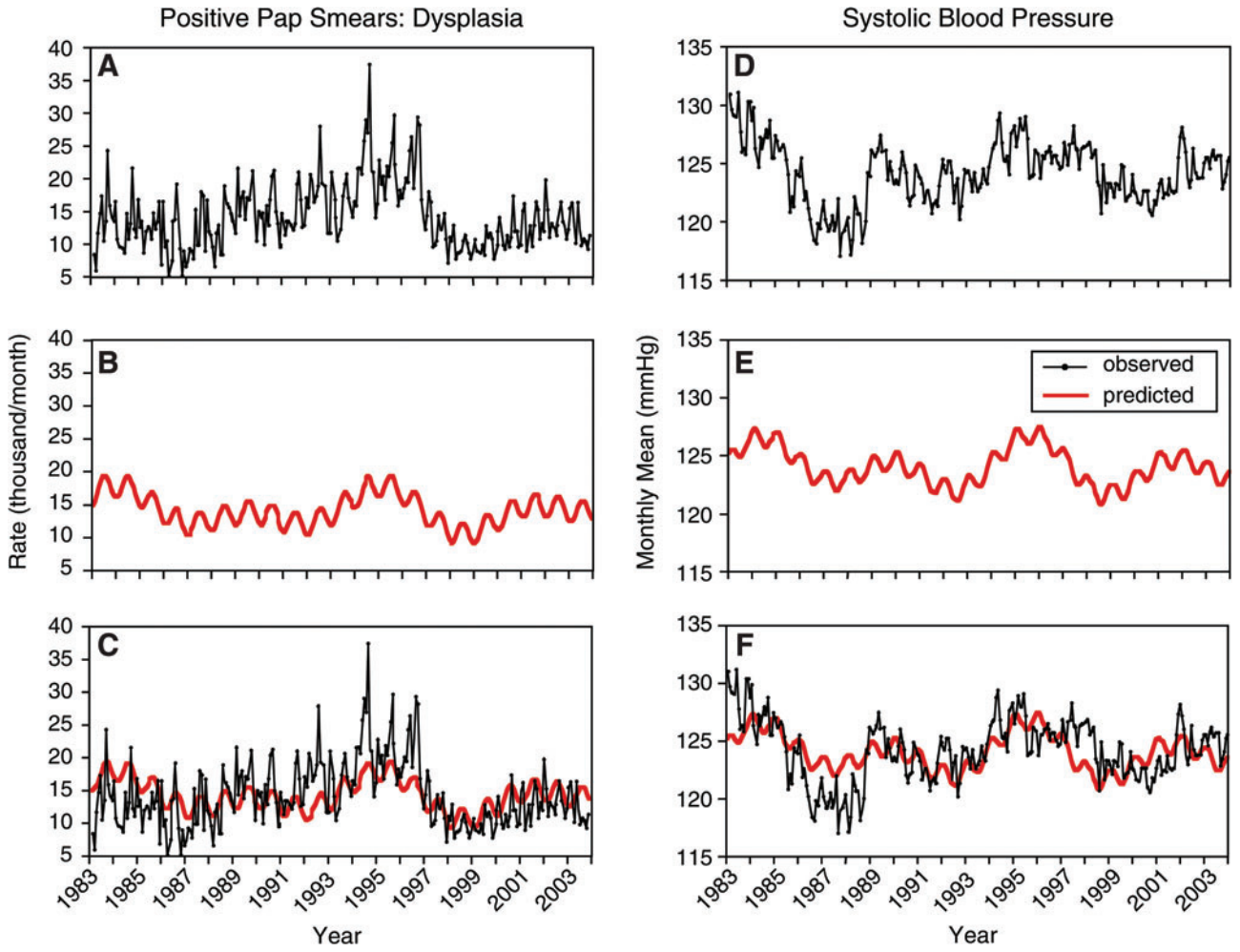


**FIG. 1.** (**A**) Dysplastic cervical epithelial changes for 252 months from 1983–2003 (detrended data). (**B**) Multi-component 10.0-, 5.75-, and 1-year cosine fit on dysplasia. (**C**) Fitted and observed values of dysplasia. (**D**) Systolic blood pressure of a healthy man for 252 months from 1983 to 2003 (detrended data). (**E**) Multi-component 10.0-, 5.75-, and 1-year cosine fit on systolic blood pressure. (**F**) Fitted and observed values of systolic blood pressure. Color images available online at www.liebertonline.com/ast.

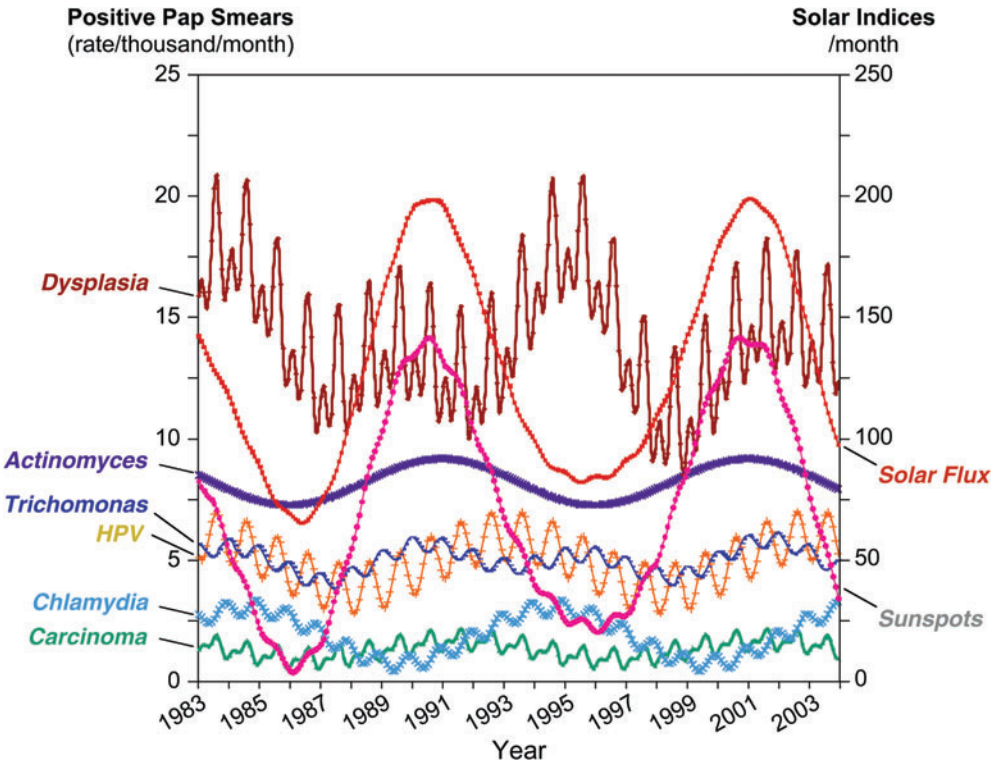


**FIG. 2.** Multi-component 10.0-, 5.75-, and 1-year cosine fit for solar flux, sunspot number, cervical dysplasia, cervical carcinoma, HPV, *Actinomyces, Trichomonas,* and *Chlamydia*-positive Pap smear monthly values from 1983 to 2003. Color images available online at www.liebertonline.com/ast.

circadian time cues to almost all life-forms. If, and how, the solar magnetic storms responsible for these sunspot signals are apparently transmitted to living things is not clear. Plausible biophysical pathways include UV irradiation, solar protons, heavy charged particles, geomagnetic storm-induced gravitational field changes, fluctuations, and resonance signals.

We do know, however, that these solar phenomena perturb geomagnetic fields, and we know that the paramagnetic element, iron, is present in all living cells. There has been speculation about such biological sensing mechanisms for several decades (Brown *et al.,* 1955; Brown, 1976). Recent groundbreaking studies have demonstrated molecular mechanisms by which fruit flies orient themselves within and respond to magnetic fields. This mechanism employs a *Drosophila* light-sensitive, phylogenetically conserved, core circadian clock gene component, *Cry* (cryptochrome), which, in the presence of light, is essential to transduction of magnetic field information (Ritz *et al.,* 2000; Gegear *et al.,* 2008). Electro-sensitive saltwater fish may alternatively sense fields through electromagnetic induction, while other migrating animals employ chemical magneto-reception, either through magnetite-containing organelles or magnetite-linked chemical reactions (Leask, 1977; Kirschvink and Gould, 1981).

Population biologists have reported other 10–12 year rhythms, including approximately 10-year rhythms in birth and death statistics (Halberg *et al.,* 2000). Physiologic measurements such as heart rate, BP, temperature, and respiration have documented various low-frequency temporal patterns (Maruta *et al.,* 1987; Sothern *et al.,* 1993; Weydahl *et al.,* 2002; Cornélissen *et al.,* 2010a). Multi-year rhythms in the waxing and waning of infectious epidemics are the rule rather than the exception (Davis and Lowell, 2006). These are usually explained by pathogen/population feedback interactions and have generally not been adequately examined for possible links to Sun-based nonphotic geomagnetic perturbations (Hrushesky *et al.,* 2005, 2006). Peaks in solar radiation associated with the 10–11 year solar cycle have been implicated as a possible cause for genetic disruption of all life by means of direct mutation and immunologic stress, since even the resultant 1–2% increase in UV radiation at ground level during sunspot cycle peaks is a significant stress to an organism's DNA repair mechanisms and can, thereby, be a modulator of disease (Davis and Lowell, 2006). A temporal association between infra-annual cycles in heliogeophysical activity and the rate of skin malignant melanoma in Europe and North America has been observed (Dimitrov *et al.,* 2008). Birth-dependent cancer mortality on three continents spanning 180 years has also been linked to a 17-year oscillation, a so-called sunspot double cycle, in cosmic radiation (Juckett, 2009).

There are medical implications to these observed time structures. There is the possibility that Pap smear screening specificity and sensitivity for both malignant and infectious diseases is predictably greater or lesser during particular solar cycle stages, and this should be considered. If these findings are relevant to individual women, the timing of a screening Pap smear within these solar cycles may contribute to whether an abnormality is discovered. The subsequent timing within these cycles of follow-up Pap smears may then also contribute to whether the previously discovered abnormality apparently resolves or progresses. Since BP, peak

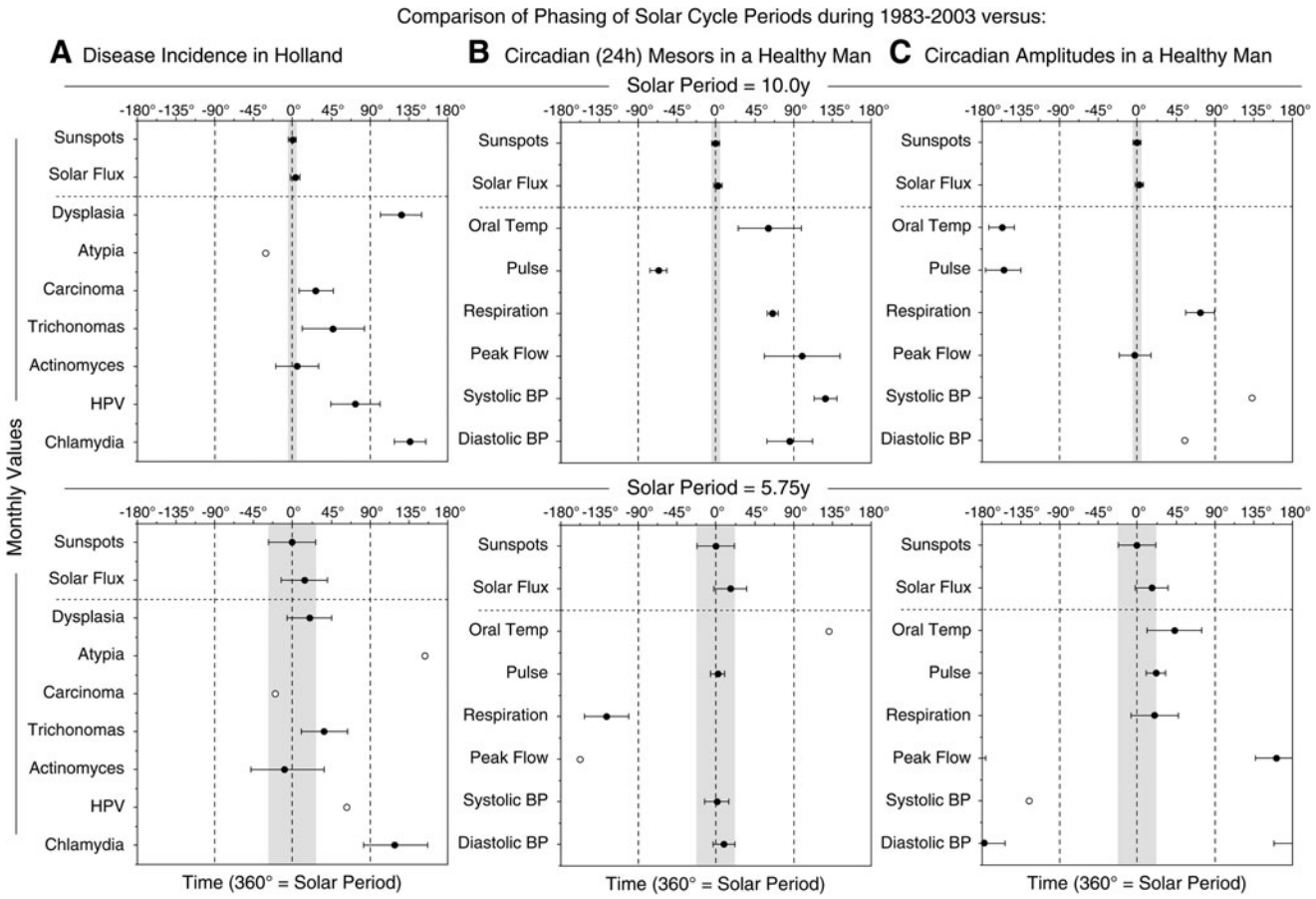


**FIG. 3.** Comparison of 10.0-year and 5.75-year solar cycle periods with cervical disease incidence in Holland (**A**), circadian mesors (**B**), and circadian amplitudes (**C**) of self-measured physiologic variables in a healthy man from 1983 to 2003. Peak (acrophase [Ø] ± 95% Limits) of best-fitting cosine to detrended data. Mesor (24 h mean) from best-fitting 24 and 12 h cosine to physiologic data by month. 360° = fitted period. Shaded area = 95% Confidence Limits for Sunspots Ø (Sunspot peak = 0°). Symbol for Ø filled (●) if $p \leq 0.05$ or open (○) if $p > 0.05$ from cosine fitting.

respiratory flow, and other physiologic functions may also normally vary rhythmically during these nonphotic solar cycles, periodic reevaluation of the need for, and dosage of, anti-hypertensive agents and anti-bronchospastic medication should also be considered.

By what mechanisms might the observed pattern in sunspot activity be linked to changes in health status? Increases in sunspots are accompanied by changes in the amount of light and a range of other types of radiation that reach Earth, as well as changes in weather patterns, all of which, due to complex causal chains of various lengths, complexity, and duration, might affect the physiology of the individual as reflected in vital signs and the balance between microorganisms or precancer and endogenous protective mechanisms. A periodic disturbance of this balance might be reflected by the appearance of certain cervical epithelial cellular changes associated with infection and malignancy and by changes in pulmonary and cardiovascular function. Sunspot patterns affect weather patterns, and weather has behavioral, biological, and medical effects. Weather patterns and resulting patterns of prevailing global winds and currents also affect the global spread of many microorganisms. It is conceivable that solar storm–induced weather cycles could cyclically impact both human physiology and the likelihood of human infection, such as approximately 11-year Schwabe cycle–associated influenza pandemics (Hayes, 2010).

Increased solar fluency that accompanies sunspot peaks increases light exposure of Earth's population of living organisms. Light, *per se,* has behavorial, endocrinologic, immunologic, and physiologic effects in living things, including human beings. For example, as a population phenomenon, a study of more than 320,000 citizens over a 29-year period found that those born near peaks of solar cycles lived an average of 1.5 years *less* than those born in non-peak years; the authors concluded that this must involve radiant energy, probably UV light (Lowell and Davis, 2008). It is possible that population light exposure changes could contribute to the physiologic and pathophysiologic rhythms we have observed. Light, for instance, modulates daytime vitamin D levels and nighttime melatonin levels, each of which inversely affects the host-cancer balance (Grant, 2002; Schernhammer and Hankinson, 2005). Increases in radiation load during regular temporal spans of low geomagnetic protection and high flux of energetic particles increases the risk of DNA damage in living things, including human cells, bacteria, and viruses. Because the chain of events between radiation exposure and observed outcome may be protracted and of variable duration and complexity, the population hit

may apparently be "out of sync" with the observed effect. The various observed lags between peak population exposure and observed outcomes means that the mechanistic chain differs from one exposure outcome pair to the next.

Consideration of possible causality is reasonable. Causality in living systems is, however, complex and time dependent. The study of biological rhythms that originate in the near Cosmos and are set and reset by rhythmic relationships of Earth's surface and the Sun have prepared researchers for the possibility that additional solar periodicities might also cause biological effects (Cornélissen *et al.,* 2010b; Halberg *et al.,* 2010). The study of the complex multifrequency time structure of biological systems has, however, conferred upon us a complex and nuanced understanding of the nature of cause and effect. Complex systems responsible for human heart rate or the balance between infectious agents and infection or cancer in the cervical epithelium are tuned by many causes, and each of these causes has many complementary effects. Different causes are more or less important in the chain at different phases of the relevant cycles (circadian, menstrual, seasonal, Schwabe). A clear causal sequence at one phase may be irrelevant to a specific effect at a different cycle phase. Most simple, uniform "constant" cause and effect relationships, that is, "*reactive homeostasis,*" are oversimplified cases or artifacts of experimental paradigms constructed specifically to force the living system to behave and appear constant. The complexity and cycle stage dependency of cause and effect relationships, that is, "*predictive homeostasis*" (Moore-Ede, 1986), in no way diminishes the reality, importance, or relevance of these relationships.

It is, nonetheless, important to freely admit that, although solar activity may have the same temporal pattern as these human time structures, a causal connection may not exist. Relevant interventional, mechanism-defining experiments across several 10–11 year solar cycles that could settle this argument are hard to imagine and would be difficult to carry out, although analysis of pre-existing databases may give further clues as to the extent of the influence of environmental nonphotic cycles on additional aspects of health and disease. These circadecadal and circahemidecadal solar, physiologic, and pathophysiologic rhythms may indicate something potentially important about the physiologic and biomedical implications of our geomagnetic relationships with the internal dynamics of our Sun. Such information, if understood, could, in principle, result in better forecasting models of incidence trends and the understanding of disease etiology. The optimal timing of disease-specific screening, diagnosis, treatment, and prevention strategies within these long and predictable biological cycles holds potential benefit at no cost and without risk (Halberg *et al.,* 2009). Ignoring biological time structures, on the other hand, may continue to increase unnecessary risk and cost. Penultimately, were causality to be established, the possibility of developing effective magnetic prevention strategies and therapeutics becomes potentially real.

Finally, special implications to the astrobiological and space travel communities exist within these data. Energetic particles pose not only an important problem for terrestrial life when sudden coronal events and depleted geomagnetic protection coincide, but may also be a major constraining factor in planning long-range missions beyond low earth orbit. The diverse scientific community that comprises astrobiology has the necessary mix of talent in physics, radiation physics, geomagnitism, geochemistry, paleontology, and the molecular biology of unicellular and multicellular life in extreme environments with which to begin to untangle the multiple variables embedded in multidecadal environmental data sets, such as those considered in this report. We herein make available to this unique scientific community two data sets that were obtained as part of both individual perseverance and organized compulsive record-keeping across a time span far longer than the usual 3–5 year event horizon of most funding agencies. We make these data freely available to everyone in the hope of contributing to future "data mining" work from multiple disciplines that is beyond our current capabilities. In addition, the entire >4 decade–long (from 1967 to present) original self-measured data series is available online for such scholarly purposes upon request to the second author (R.B.S.) at sothe001@umn.edu.

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## Author Disclosure Statement

No competing financial interest exists for any author.

## Abbreviations

BP, blood pressure; HPV, human papillomavirus; NGDC, National Geophysical Data Center; SIDC, Solar Influences Data Analysis Center.

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