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Superposed epoch analysis of physiological fluctuations: possible space weather connections

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Abstract

There is a strong connection between space weather and fluctuations in technological systems. Some studies also suggest a statistical connection between space weather and subsequent fluctuations in the physiology of living creatures. This connection, however, has remained controversial and difficult to demonstrate. Here we present support for a response of human physiology to forcing from the explosive onset of the largest of space weather events—space storms. We consider a case study with over 16 years of high temporal resolution measurements of human blood pressure (systolic, diastolic) and heart rate variability to search for associations with space weather. We find no statistically significant change in human blood pressure but a statistically significant drop in heart rate during the main phase of space storms. Our empirical findings shed light on how human physiology may respond to exogenous space weather forcing.

Keywords

Space weather; Chronobiology; Heart rate; Blood pressure; Physiology; Magnetic storms; Space storms; Geomagnetic

Introduction

With only a slight touch of levity one may say that rhythms are one of the few constants in the biological regime. None of these rhythms seem more secure to us than the 24-h periodicity related to the earth's rotation and the day-night cycle of light and dark. It is a given that most organisms respond to daily variations in solar energy flux but there is evidence that these fluctuations also influence life at more elusive levels. Some organisms—the most interesting of all, the human organism—respond to subtle variations in solar activity and many respond to changes in the ambient magnetic field caused by space weather (Mavromichalaki et al. 2012).

Space weather is a scientific term used with increasing frequency in modern society. It refers to a suite of physical processes, originating at the sun and ultimately affecting human

activities on and around the earth. For instance, flares of electromagnetic radiation (X-rays, ultraviolet, visible light, infra-red, radio waves) and energetic electrically charged particles propagating from the sun impact the plasma and magnetic environment near-Earth.

The usual locus of discussion of space weather centers on power systems and pipelines, disruption of radio communication and GPS navigation, and upsets of satellite operation, to name just a few. Astronauts face real risks of excessive exposure to ionizing radiation that may lead to cancer. Are astronauts the only humans whose physiology is directly impacted by space weather?

We know that other creatures respond to variable space weather. For instance, bacterial life appears more robust during solar maxima, as reported in the case of cholera outbreaks by Chizhevsky (1938, 1940) and Gumarova et al. (2013, 2014). Possible space weather influences were reported on the circulation of rabbits (Chibisov et al. 2004). Humans under stress respond on a physiological level to geomagnetic field variations associated with space storms, as reported by Breus and Rapoport (2003). Ionizing radiation is also thought to be responsible for a higher incidence of adverse cardiovascular events (Delp et al. 2016). And there appear also to be space weather-related seasonal influences on the human heart (Cornélissen et al. 2002; Kleimenova et al. 2008; Mavromichalaki et al. 2012). As technological advances increase access to high temporal resolution physiological data, one can expect further attempts to elucidate intriguing chronoastrobiological connections.

Blood pressure and heart rate are primarily mediated by the heart, the workings of which are regulated by a self-generated bioelectrical signal. Because of the interaction of electricity and magnetism, there have been questions as to whether extrinsic electromagnetic disturbances may influence biophysical or even emotional markers (Mitsutake et al. 2004). Could the electrically modulated system of human blood circulation respond to changes in the ambient magnetic field from space? Here we explore that possibility.

We use a case study to explore subtle interactions between space weather and human physiology. We investigate the patterns of blood pressure and heart rate variability in the human organism over a decadal time scale to test the hypothesis that there exists a measurable connection between the sun-modified geophysical environment and metrics in human blood circulation.

Data

Our data consist of physiological and space weather time series. Time series of blood pressure and heart rate provide valuable health information and are used by some physicians to diagnose elevated disease risk factors and actual illnesses as well as to treat and/or prevent disease (Cornélissen et al. 2004). The physiological data in our study consist of a time series of an elderly man's (Dr. Franz Halberg¹) systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) measured automatically with varying frequency for approximately 16 years (Halberg et al. 2006). Table 1 gives basic statistics for these data used in this analysis.

¹ Dr. Halberg consented to being identified with these data.

The space physics data used in this research are from space storms. Space storms are fluctuations in the vicinity of the earth which are global in scope (Chapman 1919; Gonzalez et al. 1994). Storms feature dramatic auroral activity, ionizing particle injections into the atmosphere, together with electromagnetic fluctuations, and most notably reductions in the horizontal component of the magnetic field around the world. These are all produced from the interaction of magnetized plasma from the sun with the near-earth space plasma environment.

The space weather data used here consist of the ground-based geomagnetic index *SYM-H*, which serves as a clear and relatively unambiguous measure of the severity of space storms, (Wanliss and Showalter 2006). Space storms are the largest and most dynamic of magnetospheric phenomena. They are indicated by the intermittent switches from the mean to large negative values of the index (Wanliss and Reynolds 2003; Dobias and Wanliss 2009), which typically stays close to a value of zero nanotesla. Their global nature provides the main encouragement for our hypothesis that storms may play a role in human physiology (Halberg et al. 2006).

SYM-H has a uniform high temporal resolution of 1 min through the entire 16-year span examined here. Blood pressure and heart rate were measured with lower frequency, and gaps also were present within the physiological data. Whereas *SYM-H* comprises over seven million data points, the SBP, DBP, and HR data sets consisted of 82,950; 82,951; and 82,962 data points respectively. The resolution of physiological data varied throughout the duration of study, but the median time between measurements was 30 min.

Superposed epoch analysis

In order to realize the comparison of these two differing data sets, one with very high temporal resolution and one with relatively low temporal resolution and gaps, we need to suggest an appropriate statistical method. Various scientific disciplines have applied superposed epoch analysis (SEA) with success. For instance, SEA has been used to analyze data in space sciences (Zhang et al. 2006; Freeman and Morley 2009) and in environmental science (Adams et al. 2003; Swetnam and Betancourt 1990; Mass and Portman 1989; Brier and Bradley 1964), to name just a few.

SEA is a relatively simple, yet powerful and coherent, statistical technique. It has the advantage that even if there are gaps in one of the data sets, comparison is still possible provided there is sufficient overlap when data are available for both sets. Data from different time series are sorted into categories, and then means for different categories are compared. Given our data with gaps, SEA is an appropriate statistical technique to compare possible consequences on human heart rate and blood pressure.

SEA is useful when one has many available observations of some particular event and one is searching for reactions or responses to that event. Since the response may be overwhelmed by noise, it can be difficult to discern associations between the hypothesized input and output time series. However, when the noise is random, averaging will tend to reduce the influence of the noise and enhance the influence of the signal. In other words, the technique can reveal a common response to an event otherwise not readily detectable because of low

signal-to-noise ratios. SEA extracts the response from the accompanying noise by effectively amplifying the relative magnitude of the response signal by suppressing the noise. SEA operates by using individual lists of key events (defined as the zero epoch) and then constructing a vector of data centered around the key date for each event. These events are then assembled in a SEA composite matrix. The width of this matrix comprises the number of data points for each event, and its length equals the number of key epochal dates.

SEA, like any other statistical method, requires the formulation of null and alternative hypotheses. Statistical testing of the SEA results can be performed under an assumption that the hypothesis is true. If the results do not withstand the tests, the alternative hypothesis is concluded to be true.

One problem of SEA is the risk of finding a statistical coincidence with no physical meaning. For instance, the response signal may be vulnerable to leveraging as a result of a single large anomaly that overwhelms the superposed data when small sample sets are used.

Because of these potential issues of leveraging of a large event and other bias, we have employed not only the standard SEA analysis but an alternative SEA (Adams et al. 2003; Rao et al. 2017). This alternative SEA takes the composite matrix, centers it by the removal of the mean across its width, and normalizes anomaly values for each row by the magnitude of the largest anomaly magnitude in that row. This eliminates the potential that a large event will leverage and bias the overall SEA.

Analysis

Space storms are easily identified with *SYM-H* data. As shown in Fig. 1, storms can usually be identified by a sudden world-wide increase in the ground-based horizontal magnetic field by tens of nanotesla, that lasts several minutes to several hours, known as the initial phase, just prior to the zero-crossing point. Following the initial phase comes the main phase, which can last beyond a day, is usually on the order of tens of hours, and features large negative perturbations in the horizontal component on the order of hundreds of nanotesla. The storm main phase is easy to identify because it is a significant intermittent fluctuation from the mean signal and, following the initial phase spike, features nearly continuous decrease in the magnetic field. When the storm's main phase ends, the storm index reaches its minimum value. Subsequent to the main phase, the worldwide horizontal magnetic field slowly returns to pre-storm values during a recovery phase lasting several days (Wanliss 2005; Vichare et al. 2005).

The SEA method employed requires a key epochal event. We defined this by the most recent zero crossing prior to the minimum of *SYM-H*. Because they are otherwise difficult to identify in a consistent manner, we only consider storms whose main phase features deviations below -100 nT, a standard marker of severe space weather (Yokoyama and Kamide 1997; Hutchinson et al. 2011). Storms were identified with an automated approach to sort through the entire data set for intervals where *SYM-H* was less than -100 nT. We found 129 storms satisfying these criteria with corresponding physiological measurements.

The main phase of the space storm, which we take to begin at the zero crossing and end by the minimum of the index, is different in amplitude and time length for different storms. A SEA by Yokoyama and Kamide (1997) revealed that the main phase of intense storms averaged 14.0 ± 8.7 h and the recovery phase averaged 58.4 ± 29.2 h. We find the main phase of all storms in our data list averaged 13.8 ± 13.0 h (825 min) and the recovery phase averaged 61.9 ± 45.2 h. Because of the highly variable scales of the storm phases and because we wish to determine statistical connections with the physiological data, we do not simply superpose data on an identical timescale. Rather, we follow the methodology of Yokoyama and Kamide (1997) and Hutchinson et al. (2011), who adjusted individual storm phases to normalized phase time indices. We achieve this by shifting data timestamps, to ensure common points in the storm progression are superposed. Thus, the storms are scaled onto a normalized temporal grid. The common points are defined first as the minimum of *SYM-H*, which signifies both the end of the main phase and start of the recovery phase and the second common point as the zero crossing immediately prior to this minimum. This is shown by the tags and arrows in the example presented in Fig. 1.

As previously mentioned, in calculating the zero epoch, we use space weather *SYM-H* index data and define the start as the zero crossing descending to the disturbance of the storm main phase. These data have a higher temporal resolution than the physiological data. Therefore, it may be a concern that a blurring of SEA result will occur. For our investigation, the zero epoch is well specified in terms of the temporal scales we consider. Given the difference in the temporal scales (1 min for *SYM-H* and typically 30 min for the physiological data), we must be careful with the interpretation of the SEA results. An analogy will explain why care is necessary.

Suppose we wish to discover the typical path of a model car. We run multiple simulations of the car trajectory. As the simulation runs, we take pictures of the moving car in extremely low light conditions. If we know the exact moment the car begins to move and that the movement always begins at the same location, then the moment when it starts to move gives the exact position of the car in the frame. Because of the low light conditions, locating the car in any individual simulation is difficult. However, overlapping a series of such frames from different simulations raises the signal and destroys the noise, giving a sharp image of the object. But if the start of the vehicle is known imprecisely, and effects are on a shorter timescale than the error in zero epoch, the picture will become blurred and the blurring effect increases as the uncertainty in the initial location rises.

In the model car analogy, the lower temporal resolution of the physiological parameters suggests that the accuracy of the SEA results for *SYM-H* is many times better than the results for the physiological parameters. Indeed, the physiological data are binned into different intervals much shorter than the duration of the epoch. The difference in resolution for the space- and physiological data is not necessarily a weakness and does not mean we cannot learn about physiological consequences related to the space weather. The epoch over which we wish to perform SEA is the length of the storm main phase. Given that this is on the order of tens of hours, the measurement error of the zero epoch point is much smaller (on the order of 10 min) than the typical size of the interval in which we are interested in developing the process. One should take into consideration that the interval we consider

meets this requirement as storms felt on earth usually last more than a day (Baevsky et al. 1997; Otsuka et al. 2003). Even if the start time of the storm is not as precise as it could be, if an effect is found, this will reinforce rather than weaken the finding, since the physiological signal is much more noisy than the space weather signal.

For a successful SEA, we require physiological and space weather data to exist at the same period of time. Although there are 129 space storms, we find sufficient physiological data coverage for only 27 of these storms. A complete list of these storms is given in Table 2.

Figure 2 shows a sample of data used for our analysis for the space storm of 10 March, 2004. The minimum of *SYM-H*, at the end of the main phase (green vertical line), is -101 nT, at 05:30 UT. The bottom three panels show the associated physiological variables, the heart rate, systolic, and diastolic blood pressure, respectively. These data have been shifted and centered to the zero epoch time, illustrated by the vertical red line in the figure. In other words, the times of HR/BP data have been converted to UT to be aligned with the *SYM-H* data at the time corresponding to the zero crossing, then rescaled in the same manner as the *SYM-H* data. Note that the temporal resolution of the data is scaled according to practice common in the literature (Yokoyama and Kamide 1997; Hutchinson et al. 2011), as described above. We analyze only the epoch comprising the main phase (the interval between the vertical red and green lines) in Fig. 2 but for completeness also show data for the recovery phase. Since the recovery phase has a much higher standard deviation than the main phase, the effect of rescaling is clearly evident in the higher cadence following the end of the main phase (vertical green line).

In Fig. 3, we show the SEA results for the composited *SYM-H* matrix whose epoch times are listed in Table 2. Dashed lines show the standard deviation. Note that the standard deviation approaches zero at the zero epoch time since the data all centered on this zero-crossing time. In addition, the minimum of the space storm index is achieved at the end of the main phase which in each case was normalized to be 825 min after the zero crossing epoch, corresponding to an average main phase temporal width.

Because physiological variables were sampled less frequently than *SYM-H* and, in some windows, they were available only sparingly, we binned data to minimize statistical errors and eliminate possible statistical anomalies associated with uneven distributions. The physiological data windows were subdivided into intervals of equal length (bins), namely 40 min. All data points populating each interval were averaged, yielding a single value that was then associated with the mid-point of the 40-min bin interval. The binning process was not employed in the analysis of the *SYM-H*, since their high temporal resolution allows us to use these data to accurately determine the event time. For Fig. 3, inter-window averages (superposed epochs) were calculated point by point.

For each key epoch date, the typical window used in our analysis is 12 h before the key epoch date and 13.75 h afterwards. The smoothed windows of physiological data are then stacked, with each row containing before- and after-event information, and the number of rows corresponding to the total key times (Table 2).

Standard SEA simply involves averaging over each column of the composite matrix. A criticism of this methodology is that a single large anomaly can lead to an apparently significant response. To eliminate this source of possible bias, we employ a version of SEA (Adams et al. 2003) in which prior to stacking we first adjust each composite matrix row to remove any disproportionate weight accorded to any extreme case. This method involves taking each row corresponding to a particular event and dividing each value in that row by the maximum absolute value of all anomalies in that window. The overall mean of the composite matrix is then removed.

Once SEA results are obtained they must be tested using several methods (Haurwitz and Brier 1981; Singh and Badruddin, 2006). Among these is the statistical significance test. The probability that the signal derived from the compositing arose by chance can be calculated using a model of the distribution of a variable about its mean. Another way to validate the results is to subdivide the data set to show consistency in the behavior of the signal within the epochs.

The significance of the final superposed composite response can be established using a Monte Carlo resampling procedure (Adams et al. 2003). Our resampling procedure takes ensembles of 10,000 random surrogates derived from permutation of the original composite matrices and calculates distributions from random reshuffling of anomalies for each event series. Each event receives equal weighting in the distribution calculation. This preserves the statistics of the original SEA matrix but destroys any preferred temporal ordering between the pre- and post-epochal time interval.

Confidence intervals are estimated using a block bootstrap procedure. The block resampling technique allows us to determine significance in order to preserve the data's autocorrelation structure. Block resampling takes the original SEA epoch matrix and shuffles it randomly to have a random composite matrix. The size of the effectively independent blocks is determined after Politis et al. (2009). These distributions provide a way to statistically judge how anomalous the actual composites are. We use these distributions to test the significance of the actual composites at the 90, 95, and 99% confidence levels.

Finally, we check the effect of randomly shuffling the starting points of the epochs. This allows a test that our observations are not an artifact analysis method. Provided that when we do this the SEA results deteriorate significantly, it will provide a further test to suggest the reliability of our results.

Results

In total, SEA was carried out on 27 superstorms for an epoch comprising the storm main phase. The zero epoch time is within 10 min of the start of the main phase. Figure 4 (top panels) shows the normalized SEA results for heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP). Confidence limits (90, 95, 99%) marked by dashed horizontal lines are calculated using the Monte Carlo resampling procedure previously described. The blue and red colors mark the pre- and post-zero crossing epoch near the start of storm main phase.

Because of the potential that gaps in the physiological data can bias the SEA, we performed SEA experiments with different averaging window lengths. For each experiment, the raw physiological data was smoothed with a time window ranging from 30 min to 6 h in length. For comparison, the lower three panels in Fig. 4 show composite results for window lengths of 100 min. We find that for SEA experiments, the gross features present in Fig. 4 remain consistent but became indistinguishable for time averaging windows larger than 6 h.

For HR, we find that SEA showed a lower average value following the start of the storm main phase for the $-720/+825$ -min period (Fig. 4a). This decrease in heart rate following the onset of the storm main phase tends to persist for almost the entire period following the zero epoch and is significant at a 99% confidence interval after about 550 min from the zero epoch. SBP shows a decrease after the zero epoch for the $-300/+300$ -min time window but no clear response to the storm main phase for any wider windows (Fig. 4b). On the other hand, although closely related to the systolic blood pressure which, as we have said, does not show significant response, DBP does show a significant response in terms of a temporary decrease detected at $+500$ min ($>99\%$ confidence interval) (Fig. 4c). Given the potential lags in response, we expect strongest results when the raw physiological data are averaged in larger windows. Thus, whereas no significant post-event changes were found in SBP for the 40-min averages (Fig. 4b), there are temporary significant increases/decreases apparent near $+400$ min and $+800$ min (Fig. 4e) for the 100-min averages (90% confidence interval).

The effect of storms on HR, SBP, and DBP was further tested by comparing the average physiological variables at different times during the storm main phase (SMP) with the corresponding averages at the time of zero crossing (ZC):

$H_0: < Var (SMP) > = < Var (ZC) >$, where Var is HR, SBP, DBP, and $< >$ indicates averaging.

The alternative hypothesis reads

$$H_1: < Var (SMP) > \neq < Var (ZC) >$$

The usual parametric approach to comparing two means, such as at the key event and then following the key event is the Student's t test. In view of the availability of longitudinal control, the paired t test can be used in our case. The null hypothesis, defined above, is then examined with a two-tailed test. However, before performing statistical significance tests pre- and post-key event, defined by the zero crossing into the space storm main phase, it is necessary to examine the type of distributions of data both before and after the key event. To test whether the distributions are normal, we employed the Lilliefors test (Conover 1980; Lilliefors 1969). All the data were significantly different from normal, suggesting that it is unwise to employ parametric tests of statistical significance.

Accordingly, we tested pre- and post-key event periods difference of means using the nonparametric Wilcoxon signed-rank test (Fay and Proschan 2010; Derrac et al. 2011). Unlike the well-known parametric t test, to which it is equivalent for normal distributions, this test does not require the assumption of normal distributions.

We compare the average physiological variable at the zero epoch to the post-epoch mean value in time windows of width 180, 360, 600, and 825 min to decipher the lagged response of the physiological data to the start of the space storm main phase (Table 3).

The response of HR to the start of storm main phase is consistent throughout most of the post-epoch interval. The SEA results showed a significantly decreasing pattern for every time window following the zero epoch ($p < 0.05$) except for the smallest time window of 180-min. SEA results for SBP and DBP on the windows examined show no statistically significant response to the start of the storm main phase and in all cases $p > 0.2$.

We also wish to compare SEA results of physiological behavior pre- and post-zero epoch. No significant response was observed for HR. Both SBP and DBP show significant but temporary increases in narrow time windows around approximately 200 min before the start of the storm main phase (Fig. 4b, c). However, when we compare broader averaged physiological behavior there is no significant response in any of the time windows pre- and post-zero epoch (Table 4).

Discussion

We have investigated a case study of the patterns of blood pressure and heart rate variability in the human organism over a decadal time scale to test the hypothesis that there exists a measurable connection between the sun-modified geophysical environment and metrics in human blood circulation. In a previous study based on 4- up to 3-day records obtained once in each season during which a single double storm occurred (Chibisov et al. 2004), a connection was made between space storms and circulation in rabbits. Our present study is different and unique in that the data cover over 16 years of human physiological measurements of HR, SBP, and DBP during which the effect of 27 major storms could be assessed.

Our results suggest that there is a measurable connection between the sun-modified geophysical environment and metrics in human blood circulation, in particular, HR. The zero event time was chosen as the zero crossing prior to the minimum of the storm main phase. We tested the null hypothesis that the median of the physiological data does not change in a statistically significant manner following the zero epoch and during the storm main phase. We are constrained to conclude that we cannot reject the null hypothesis for SBP and DBP, but that the alternative hypothesis must be adopted for HR.

When we compared the physiological variables before the zero epoch to the main phase, we found no significant response in any of the time windows pre- and post-zero epoch (Table 4). This, together with the results collected in Table 3, suggests that it is the onset of the space storm that is the relevant trigger for the observed statistically significant changes in HR.

While there were significant and temporary increases found in both SBP and DBP pre-zero epoch (Fig. 4b, c), only HR featured significant and sustained significant decreases after the zero epoch. SEA results show that immediately after the zero epoch HR increases, but as the main phase of the storm progresses, and within about 150 min after the zero epoch, HR decreases steadily. This decrease in heart rate becomes statistically significant 500 min after

the zero epoch event and then remains so to the end of the main phase. This is consistent with a study by Otsuka et al. (2003) who found associations between space storms and heart rate variability that persisted up to 2 days following the onset of disturbed geomagnetic conditions.

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Fig. 1. SYM-H index for a sample space storm. The event that we use for SEA is defined as the time for the zero crossing prior to the minimum

Fig. 2.

An example of the physiological data compared with SYM-H (upper panel). The epoch times are shown for the zero crossing (red) and end of main phase (green)

Fig. 3.
Plot of average value of the SYM-H index for all 27 space storms, obtained by SEA. Dashed lines show one standard deviation

Fig. 4.

Upper row shows normalized SEA results for 27 space storm events for heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP). The upper panels show the results with 40-min averages. For comparison, the lower panels show composite results for averaging 100 min. Confidence limits (90, 95, 99%) are marked by horizontal lines. The blue and red colors mark the pre- and post-zero crossing epoch (start of storm main phase)

Table 1

Basic statistics for physiological data

	N	Mean	SD	Median	Mode
SBP	82,950	133.2	22.2	132	128
DBP	82,951	74.1	15.1	74	77
HR	82,962	64.0	15.1	65	66

N number of data, *SD* standard deviation

Table 2

List of storms use in SEA analysis, showing the zero crossing epoch time (T_0) and the time of minimum SYM-H (T_1) and the value of the minimum

Event	T_0	T_1	Minimum (nT)
1	29-Dec-1989 11:30	30-Dec-1989 00:25	-121
2	30-Mar-1990 07:24	30-Mar-1990 11:42	-192
3	17-Apr-1990 08:55	17-Apr-1990 15:44	-128
4	26-May-1990 22:11	27-May-1990 08:31	-120
5	12-Jun-1990 20:36	13-Jun-1990 03:20	-161
6	09-Oct-1990 22:32	10-Oct-1990 08:18	-167
7	07-Jun-1992 20:03	08-Jun-1992 16:09	-107
8	22-Aug-1992 23:53	23-Aug-1992 02:30	-150
9	07-Mar-1994 00:03	07-Mar-1994 22:07	-105
10	27-Sep-1995 00:50	27-Sep-1995 20:17	-114
11	17-Feb-1998 13:34	18-Feb-1998 00:47	-120
12	02-May-1998 09:55	04-May-1998 05:18	-272
13	26-Aug-1998 11:15	27-Aug-1998 08:59	-174
14	12-Feb-2000 00:00	12-Feb-2000 11:34	-165
15	18-Apr-2001 02:03	18-Apr-2001 06:03	-122
16	22-Apr-2001 03:01	22-Apr-2001 15:39	-104
17	17-Apr-2002 11:48	20-Apr-2002 06:01	-185
18	19-Aug-2002 11:54	21-Aug-2002 05:22	-119
19	11-Jul-2003 02:35	12-Jul-2003 05:36	-125
20	13-Oct-2003 1 9:56	14-Oct-2003 23:01	-103
21	09-Mar-2004 12:42	10-Mar-2004 05:30	-101
22	03-Apr-2004 15:09	04-Apr-2004 00:42	-149
23	22-Jul-2004 21:06	23-Jul-2004 02:40	-123
24	26-Jul-2004 23:01	27-Jul-2004 13:35	-208
25	07-Jan-2005 17:54	08-Jan-2005 00:05	-112
26	17-Jan-2005 15:33	18-Jan-2005 08:20	-107
27	21-Jan-2005 19:40	22-Jan-2005 06:04	-101

Table 3

Wilcoxon nonparametric signed-rank test p values and significance levels are given

	<u>[0] vs [0–825]</u>		<u>[0] vs [0–600]</u>		<u>[0] vs [0–360]</u>		<u>[0] vs [0–180]</u>	
	<i>p</i> value	Signif	<i>p</i> value	Signif	<i>p</i> value	Signif	<i>p</i> value	Signif
HR	0.020	*d	0.028	*d	0.050	*d	0.104	
SBP	0.294		0.286		0.286		0.211	
DBP	0.262		0.364		0.457		0.355	

Where there are differences, arrows show the direction of the variation of the physiological variable. Where a meaningful significance level exists, we show the direction of the physiological behavior. In this case, HR tends to decrease (d)

*
 $p < 0.05$

Table 4

Wilcoxon nonparametric signed rank test p values and significance levels are given for different mean values calculated in windows indicated in the top row. There are no significant differences

	<u>[-360-0] vs</u> <u>[0-825]</u>		<u>[-360-0] vs</u> <u>[0-600]</u>		<u>[-360-0] vs</u> <u>[0-360]</u>		<u>[-180-0] vs</u> <u>[0-180]</u>	
	p value	Signif	p value	Signif	p value	Signif	p value	Signif
HR	0.165		0.204		0.391		0.286	
SBP	0.183		0.337		0.270		0.429	
DBP	0.084		0.117		0.171		0.178	