Schumann Resonances, a plausible biophysical mechanism for the human health effects of Solar/Geomagnetic Activity

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Abstract

A large number of studies have identified significant physical, biological and health effects associated with changes in Solar and Geomagnetic Activity (S-GMA). Variations in solar activity, geomagnetic activity and ionospheric ion/electron concentrations are all mutually highly correlated and strongly linked by geophysical processes. A key scientific question is, what factor is it in the natural environment that causes the observed biological and physical effects? The effects include altered blood pressure and melatonin, increased cancer, reproductive, cardiac and neurological disease and death. Many occupational studies have found that exposure to ELF fields between 16.7 Hz and 50/60 Hz significantly reduces melatonin levels. They are also associated with the same and very similar health effects as the S-GMA effects. The cell membrane has an electric field of the order of 10^5 V/cm. The ELF brain waves operate at about 10^{-1} V/cm. Fish, birds, animals and people have been shown to respond to ELF signals that produce tissue electric gradients of ULF/ELF oscillating signals at a threshold of 10^{-7} to 10^{-8} V/cm. This involves non-linear resonant absorption of ULF/ELF oscillating signals into systems that use natural ion oscillation signals in the same frequency range. A long-lived, globally available natural ULF/ELF signal, the Schumann Resonance signal, was investigated as the possible plausible biophysical mechanism for the observed S-GMA effects. It is found that the Schumann Resonance signal is extremely highly correlated with S-GMA indices of sunspot number and the Kp index. The physical mechanism is the ionospheric D-region ion/electron density that varies with S-GMA and forms the upper boundary of the resonant cavity in which the Schumann Resonance signal is formed. This provides strong support for identifying the Schumann Resonance signals as the S-GMA biophysical mechanism, primarily through a melatonin mechanism. It strongly supports the classification of S-GMA as a natural hazard.

Introduction:

The idea that spots on the sun or solar flares might influence human health on earth at first appears to lack scientific credibility. However, when significant correlations between hospital admissions and health registers and Solar-Geomagnetic Activity (S-GMA) are found, then the challenge is to conceive of and to document a scientifically plausible and observationally supported mechanism and model. There is a large body of research correlating S-GMA with biological effects and human health effects. There is currently an absence of a known and credible biophysical mechanism to link the S-GMA with these effects. The hypothesis promoted here is that the Schumann Resonance (SR) signal is the plausible biophysical mechanism to link the S-GMA levels to biological and human health effects. This operates by being resonantly absorbed by brain systems and altering the serotonin/melatonin balance. Confirmation of this hypothesis will strengthen the proposal the S-GMA is a natural hazard for humans, animals and other species.

This study is in a context of fundamental biological concepts relating to homeostasis and adaptation. On one hand the survival of organisms in changing environments requires adaptation. On the other hand mammals have very advanced neurological and physiological systems that must be maintained within narrow activity ranges because of homeostatic requirements. Homeostasis is partly maintained in variable environments, such as daily climate cycles, through the use of external reference signals called Zeitgebers (time givers). The daily solar cycle is detected by mammal's eyes and brains. This induces a diurnal cycle of endocrine hormones that regulate a whole body system of diurnal changes. Isolating people or birds from the daily solar/climate signals leads to a significant lengthening of the circadian period, Wever (1973, 1974). Wever also showed that there is a natural ULF/ELF electromagnetic signal that also acts as a circadian Zeitgeber. The characteristics of this signal are contained in the Schumann Resonance signal and there is no other known natural signal with the appropriate characteristics.

Schumann Resonance Signal:

The SR phenomenon was first conceived and proposed by German physicist Dr W.O. Schumann, Schumann (1952). The existence of the signals was confirmed by measurements in the mid-1950's, Schumann and König (1954), Polk (1982). The SR signal is a globally available ULF/ELF signal that has been generated since the ionosphere was formed and thunderstorms have existed. Hence they pre-date animal evolution on earth. The SR signal was investigated for this purpose because of its strong similarity to the human EEG spectrum and evidence that environmental signals of the same frequency range do interact with brains, Figure 1.

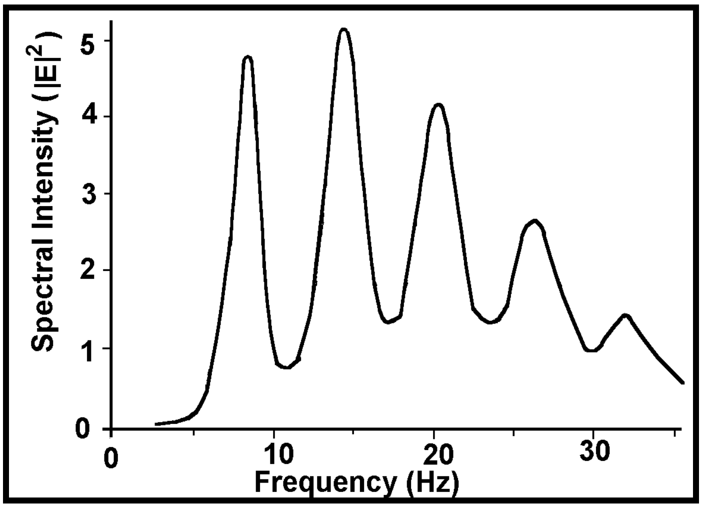

Figure 1: A typical daytime spectrum for the vertical electric field measured near Kingston, Rhode Island, showing the first five Schumann Resonances modes, Polk (1982).

The first five SR modes (0-35 Hz) coincide with the frequency range of the first four EEG bands. The primary EEG frequency bands are: Delta, 0.5 to 4 Hz, Theta, 4-8 Hz, Alpha, 8-13 Hz and 13 to 30 Hz, Malmivuo and Plonsey (1995). Hence resonant absorption and reaction is biophysically plausible.

Resonant absorption of an oscillating signal is a classical physics phenomena used to detect extremely weak signals with particular frequency matching characteristics, even in the presence strong static fields and other oscillating fields. This is used in the telecommunication systems. It is also used for vital biological telecommunication in brain-to-cell and cell-to-cell communication that is necessary to maintain healthy homeostatic relationships. The SR signal also has diurnal and seasonal variations in parallel with the local sunlight Zeitgeber. It persists through cloudy periods and during Arctic and Antarctic dark winters.

SR Signal Frequency:

The Schumann Resonance signal is generated by tropical thunderstorms and is a set of resonant modes within the resonant cavity formed between the earth's surface and the D-Region of the ionosphere. It consists of a spectrum of ULF/ELF resonant peaks with a fundamental frequency of about 7.8 Hz and broad resonant peaks typically at 14, 20, 26, 33, 39, 45 and 51 Hz. An example of the measured daytime spectrum of the first five modes is given in Figure 1. The frequencies vary systematically diurnally primarily with the local D-region height, but also with the tropical thunderstorm activity.

SR Signal Strength:

Balser and Wagner (1960) recorded the SR signal over several days in June 1960 in Boston, USA. They measured a mean RMS vertical electric field strength of this ELF signal of 0.6 mV/m. Polk (1982) summarized several measurement programmes, covering the first three resonant peaks. He gives the vertical electric field range as 0.22-1.12 mV/m (0.013-0.33 pW/cm^2). König (1974a) gives the typical electric field strength as 1 mV/m (0.27 pW/cm^2) and the magnetic field as 10^{-5} A/m (12.6 pT). Williams (1992) reports 5 years of SR magnetic field intensity measurements from Rhode Island with monthly mean 8Hz mode intensities in the range 1.3 to 6.3 pT.

Diurnal and D-Region effects:

Readings from M.I.T. in Boston were the first to show the frequency spectrum of the SR signal, Balser and Wagner (1960). They found that there was a frequency and intensity shift between day and night. The first five modes dominated the daytime. At night their intensity and frequency decreased and a large proportion of signals were less than 4 Hz. This frequency and intensity shift is the result from the increasing the depth of the resonant cavity in the nocturnal hemisphere. The ion/electron density in the D-Region decreases rapidly after sunset as the solar production of ions ceases and recombination dominates. The dependence of the SR signal on the D-Region was established by initial theoretical models, Tran and Polk (1979). They showed that the Q-value of the resonant cavity depended on the conductivity of the atmosphere between 40 and 100 km, most strongly between 40 and 60 km altitude. Sentman and Fraser (1991) confirmed the sensitivity of the SR signal to the local height of the D-Region. The D-Region correction increases the correlation coefficient from r=0.39 to r=0.82, a highly significant improvement.

Role of Tropical Thunderstorms:

The dominant diurnal pattern in the SR signal frequency and intensity are primarily the result of the D-Region diurnal electron density variation. It is also modulated by the diurnal incidence of tropical thunderstorms, Polk (1982). These produce peaks of intensity as the peak of daily solar heating passes progressively around the world from east to west, Nickolaenko, Hayakawa and Hobara (1996). This produces a single peak in January (southern summer) and three peaks at 0800, 1400 and 2200 UST in August (northern summer), Sentman and Fraser (1991). The close correlation between the monthly tropical temperature anomaly and 8Hz SR signal intensity was shown by Williams (1992). His data also reveals the strong influence of the El Nino/La Nina events. El Nino produces hotter mean conditions and La Nina cooler conditions. There are corresponding increases and decreases in SR signal intensity.

D-Region Characteristics:

The D-Region of the ionosphere has electron density profiles that vary significantly with diurnal, 27-day, seasonal and sunspot cycles, and with solar flares and storms, Nicolet and Aikin (1960), King and Lawden (1962), Titheridge (1962), Craig (1965), Matsushita and Campbell (1967), Akasofu and Chapman (1972), Coyne and Belrose (1972), Mitre (1974), Rawer (1984). Craven and Essex (1986), and Hargreaves (1992).

Following a solar flare there is a prompt enhancement of the D-Region through the enhanced ionization from the arrival of cosmic rays. These events are called Sudden Ionospheric Disturbances (SID). A SID increases the ion density of the D-Region by a factor of 10 compared with quiet solar days, Belrose and Cetiner (1962). SID monthly incidence is very closely correlated with Solar Flares and the Solar X-Ray flux, Davies (1996).

Prolonged enhancement of the D-Region electron density was observed for at least 5 days, Craven and Essex (1987) and Balon and Rao (1990), and for at least 6 days, Belrose (1968). The enhancement was particularly strong at night. This effect has been called the post storm effect (PSE). The most probable explanation is the induced precipitation of electrons from the Van Allen Radiation Belt, Hargreaves (1992).

The dependency of the SR signal on the D-Region and the sensitivity of the D-Region to the S-GMA strongly indicates that the SR signal should be closely following the changes in solar and geomagnetic activity. This predicts that the SR signal will be highly correlated with the solar cycles and the S-GMA events. The solar cycles include the diurnal, 3.5 day, weekly, 13.5 day, 27-28 day solar rotation, semiannual, annual, 11 year and 22 year cycles, and a number of harmonics, Chapman (1936), Cliver, Boriakoff and Bounar (1996) and Cornelissen et al. (1998). During solar flares the electron pattern in the D-Region predicts that there will be a prompt enhancement for a day of 2 and then a prolonged enhancement for 6 to 7 days and then falling off quickly. If a second or subsequent S-GMA events occur within this period the effects should be cumulative.

ULF/ELF Resonant Absorption:

It is noted above that the brain waves and SR signal share a ULF/ELF frequency range making resonant absorption possible. Extensive research shows that it is highly likely. Adey (1990) summarized observations of cellular level electric field strengths. The cell membrane potential, a static DC field across the cell membrane, is of the order of 10^5 V/cm. The brain waves have a typical amplitude of 10^{-1} V/cm. The brain successfully operates using oscillating signals a million times smaller than the membrane potential. Fish, birds, primates and humans have been shown to detect and react to ULF/ELF signals in the range 10^{-7} to 10^{-8} V/cm, more than a million times less than the EEG electric field. A recent study involving flat worms (*Planarian Dugesia tigrina*) identified a threshold for 60 Hz electric fields of 5 x 10^{-8} V/cm for induced reproductive anomalies, Jenrow, Smith and Liboff (1996).

The biophysical mechanism for these effects was found when seeking to understand why ULF/ELF signals alter primate and human reactions times and their brain wave signals, Adey (1981). It was shown that environmental electromagnetic fields in this frequency range significantly altered the cellular calcium ion fluxes and EMR waves in brain tissue, Bawin, Gavalas-Medici and Adey (1973), Bawin and Adey (1976) and Adey (1980). The field strength involved was 10^{-7} V/cm. Since that time the calcium ion efflux/influx effect has been observed in many independent laboratories. The effect is taken as established by overwhelming evidence in a review, Blackman (1990). The effect is a function of the modulation frequency more than the signal intensity since it is a resonant phenomenon involving non-linear, non-equilibrium reactions, Adey (1993).

Thus the evidence trail goes from environmental ULF/ELF signals altering cellular calcium ion homeostasis and altering the EEG which alters reaction times. The modulation frequencies involved are in the ULF/ELF range and these are the frequencies of the EEG, ECG and cell-to-cell communication oscillating ion systems. All of these systems primarily use oscillating calcium ion currents, Alberts et al. (1995). Kandel, Schwartz and Jessell (2000). In order to react to a very low intensity entrained signal a "receiver" must be able to resonantly absorb the signal and adjust by tuning into it. The tuning aspects of brains and cells involve cortical hormone related phase-locked loop circuits, Ahissar et al. (1997). A phase-locked loop circuit produces a feed-back signal in proportion to the phase difference between the entrained signal and the reference signal. This shows that brains absorb, detect and respond to extremely low intensity ULF/ELF environmental electromagnetic signals. The evidence shows that it is possible for the brain to detect, tune into, and respond to the SR signal.

König, a student of Dr Schumann, took readings of the SR signal. He observed the close similarity of the SR signal with the EEG alpha rhythm, both of which dominate the daytime, and the local sferics 3 Hz signal with the EEG delta rhythm, that dominate the night, König (1974a). The close similarity, including the diurnal pattern and extensive laboratory experiments, prompted König to postulate that the ELF brain waves had evolved to use these natural signals, König (1974). König's research supports the hypothesis of this study. The SR signal has a reliable, long-lived and globally available diurnal pattern, with ULF/ELF frequency ranges that match natural biological frequency ranges. It is plausible and reasonable that if the SR signal is detected by mammal brains then this detection has a purpose. The SR signal could be used to help to synchronize ULF/ELF biological oscillators as a Zeitgeber (time giver). Without an external reference signal biological systems tend to drift into longer period cycles as part of their adaptive flexibility. It is the role of the circadian Zeitgeber to synchronize the biological cycles with the daily cycles. A daily Zeitgeber is not appropriately precise to synchronize ULF/ELF oscillations. A ULF/ELF environmental signal is necessary for this ULF/ELF Zeitgeber function.

The Schumann Resonance is proposed for this role. It then makes logical sense to extend it to be the biophysical mechanism for the biological and health effects of S-GMA. It is postulated that when the SR signal is in its normal range, associated with normal levels of S-GMA, the synchronization process is healthy. When extreme levels of S-GMA carry the intensity and frequency of the SR signal to extreme values, then this is proposed as the mechanism for altering the brain waves, altering the melatonin/serotonin balance, primarily through melatonin reduction during enhanced activity such as solar maximum and solar storms. This provides a logical and testable model to evaluate the hypothesis.

The Circadian Cycle:

The body has a highly regulated and strongly integrated system that has developed to produce healthy living in the face of diurnal and seasonal climatic variations. Melatonin plays a central role. Environmental factors that alter the melatonin/serotonin balance have the ability to influence all of the functions and organs that the circadian melatonin/serotonin cycle uses for thermal homeostasis. This includes blood pressure, breathing, altering the immune system, cardiac, neurological and reproductive processes.

A primary endocrine process involved in the diurnal (circadian) cycle is the Melatonin/Serotonin system. It initially operates between the pineal gland and the hypothalamus. A particular part of the hypothalamus is the suprachiamatic nucleus (SCN). It contains the "biological clock". In order to mediate the daily cycle there are high affinity melatonin and serotonin receptors in the brain and throughout the central nervous system (CNS). This includes the autonomic and sympathetic nervous systems, Chabot et al. (1998), Beresford et al. (1998), Naitoh et al. (1998), Andrade (1998), Al-Ghoul et al. (1998), Verge and Calas (2000) and Hunt et al. (2001). Melatonin modulates the functional sensitivity of the serotonin receptors, Dugovic, Leyson and Wauquier (1991).

The cardiovascular system is daily mediated with melatonin through receptors in the heart, arteries and lungs, Pang et al. (1993), Viswanathan et al. (1993) and Guardiola-Lemaitre (1997). Heart rate variability (HRV) is used to monitor the autonomic nervous system, Salo et al. (2000), and reduced HRV is a risk factor for heart disease, Carney et al. (2000). Savitz et al. (1999a) quote a conclusion from a recent National Heart, Lung and Blood Institute workshop that "epidemiological evidence strongly implicates activation of the autonomic nervous system as a causal link in the onset of cardiovascular disease".

There are also melatonin receptors in the vital organs throughout the body that are part of the diurnal cycle system. This includes the pituitary gland which regulates the production of Growth Hormone and Thyroid Stimulating Hormone, Vriend, Borer and Thliveris (1987).

Melatonin has direct action in the immune system through the T-Lymphocytes (T-Helper Cells), interleukin-2 and -6 (IL-2. IL-6) and natural killer cells (NK-cells) through melatonin receptors on the T-Cells. This enhances the natural and acquired immunity, Poon et al. (1994), Maestroni (1995), Garcia-Maurino et al. (1999) and Currier, Sun and Miller (2000). Melatonin receptors have been identified in a number of peripheral organs and tissues. For example, melatonin receptors maintain intraocular pressure (IOP) in the eye, Osborne (1994). The reproductive organs also have melatonin receptors in the testes, prostate, ovary, mammary gland and other reproductive organs, Pang et al. (1998). The fetus has many melatonin receptors so that the maternal melatonin can communicate daily and seasonal cycles *in utero*, Naitoh et al. (1998) and Thomas et al. (1998).

Through receptors melatonin regulates the diurnal and seasonal activity. This involves metabolism, body temperature, blood pressure, heart beat, peripheral blood flow, respiratory activity, sleep-wake cycle, reaction times, hormone levels and immune system blood cells. It also involves the humoral organs of the lung, heart, kidney, spleen, liver and lymphocytes of the immune system, Wever (1974) and Ishida, Kaneko and Allada (1999).

Melatonin is also a highly potent antioxidant that scavenges free radicals from cells, Reiter (1994). This implicates that reduced melatonin is associated with neurological, cardiac, reproductive and carcinogenic illness and death, Reiter and Robinson (1995).

The Schumann Resonance Hypothesis:

The hypothesis of this study is that:

"The Schumann Resonance signal is the biophysical mechanism for the health effects of S-GMA because it is detected by the brain where it interacts with the ELF brain waves by resonant interaction with neurons calcium ions and it alters the melatonin/serotonin balance."

As a corollary, the SR provides an ULF/ELF, diurnal and seasonal synchronization reference signal, a Zeitgeber (time giver).

A systematic evaluation of the SR Hypothesis and the GMA Melatonin mechanism will be carried out in the context of a model. The Model outlines all of the linking elements, from the solar, geomagnetic and ionospheric activity to the biological and health effects associated with S-GMA, with the SR signal and induced melatonin reduction at its core.

The Model:

This model was conceived with the Schumann Resonance Hypothesis at its core, assisted by the Melatonin Mechanism. It involves the following elements:

a. Solar activity is highly variable. The level of activity is transferred to the earth promptly through cosmic radiation and over several days through large clouds of ionized plasma transported in the solar wind. These produce significant characteristic changes to the earth's magnetosphere and ionosphere, including the lowest layer, the D-Region.

b. The Schumann Resonances are a spectrum of ULF/ELF radio signals generated by tropical thunderstorms, radiating around the world at the speed of light, ducted within the resonant cavity formed between the lowest layers of the ionosphere (D-Region) and the earth's surface.

c. A combination of seasonal and diurnal changes in the D-Region and in tropical thunderstorm activity, induces strong diurnal and seasonal changes in the SR signal. Solar sunspot cycles, solar rotation and solar flares and storms produce characteristic changes in the D-Region which cause characteristic changes in the SR signal. This leads to highly significant correlations between S-GMA indices and SR signals.

d. Human and animal brains naturally use highly reactive, non-linear alterations of ULF/ELF oscillating calcium ions in neurons and other cells to regulate the basic cell functions, such as neurotransmitter release and cell-to-cell communication.

e. Environmental electromagnetic fields in the ULF/ELF frequency range, including the SR signal, resonantly interact with the natural signals, inducing changes in the cellular calcium ion signals, brain waves patterns and reaction times. This produces altered melatonin/serotonin production.

f. By altering the neurohormone regulation of the natural cycles, as demonstrated by the circadian cycle, a wide range of body organs and processes are altered. Melatonin reduction alters blood pressure and heart rate with cardiovascular and cardiopulmonary consequences. It also produces neurological, reproductive and carcinogenic effects and impairment of the immune system. The vast majority of people cope with these induced changes but the exacerbation of effects in the weak and vulnerable causes detectable increases in illness and death rates.

g. Significant alterations in S-GMA cause significant changes in the intensity of the SR signal. This takes the SR signal strength and frequency outside the normal range, inducing alteration of brain and heart synchronization and changes the melatonin levels. Many of the biological and health effects of altered melatonin are produced by these extreme changes, showing that S-GMA is a natural hazard.

If all the above can be demonstrated, justified and confirmed then there is strong evidence that the SR signal is the plausible biophysical mechanism for the biological and health effects of S-GMA, mainly through altered melatonin. This would confirm that S-GMA is a natural hazard for human beings. The Model Elements (a) to (d) are established by published research cited above.

Two corollaries arise from the hypothesis and model. The first relates to the public health implications of residential, occupational and military exposures to ELF and ELF modulated signals. If extreme variations of natural extremely low intensity ELF signals causes human health effects, then it is highly probable that humanly produced ELF fields that are many orders of magnitude higher than the naturally occurring signals, are also causing significant similar health effects. Since residential and occupational studies are available, this evidence is used to independently test the hypotheses.

The second corollary arises because of the strong dependence of the SR intensity on the tropical temperature anomaly, Williams (1992). This means that the more extreme weather associated with Global Warming, including extremes of El Nino/La Nina events, will cause stronger extremes of SR signals. This occurs especially around sunspot maximum and during periods of strong solar storms, this is predicted to accentuate the adverse health effects associated with S-GMA.

Methods:

The steps taken to evaluate the hypothesis and the model are:

1. Seek correlation between S-GMA indices Ns and Kp and the SR signal.

2. Review of the studies relating ULF/ELF signals, including SR signals and human reaction times and circadian rhythms.

3. Review of the evidence that ULF/ELF electromagnetic fields reduce melatonin.

4. Summarize the biological and clinical studies relating reduced melatonin to health effects.

5. Give an example of sunspot data relationship to human health effects to illustrate the principles and problems of environmental epidemiological studies in an EMR polluted world.

6. Summarize the studies relating S-GMA to biological and health effects under the headings of reproductive, cardiac, neurological and cancer effects in order to evaluate the role of melatonin and homeostatic patterns.

7. The prediction from the hypothesis that similar effects should occur in residential and occupational studies is evaluated to determine conflict or confirmation of the hypothesis.

8. Conclusions are drawn and further clarifying research is suggested.

Correlation to Causation:

If variable A is correlated with variable B, and variable B is correlated with variable C, then variable A is correlated with variable C. However, none of these relationships necessarily imply a causal relationship. The S-GMA indices are highly correlated with biological and health effects. The observed and established characteristics of the atmosphere predict that through the S-GMA effects on the D-Region, the SR signal should be closely correlated with the S-GMA indices. Hence if this correlation is confirmed then the SR signal will also be correlated with the biological and health effects.

A plausible and supported mechanism that explains the connective processes is crucial in moving towards establishing a causal link. The Schumann Resonance signal is favoured for this purpose because of the matched frequency range allowing resonant absorption in the brain. This involves the alteration of calcium ions in neurons, Adey (1981), Blackman (1990). It is supported by the existence of a natural ULF/ELF Zeitgeber, Wever (1974), for which the SR signal characteristics comply. The close dependence of the SR signal on the D-Region implies that there should be a correlation with the biological and health effects correlated with S-GMA.

Statistical Methods:

Sunspot Number (Ns) and GMA indices Ap and Kp, and the Schumann Resonance frequency and intensity data for two US sites, were downloaded from publicly accessible web sites in the United States. Statistical analysis involves several standard methods. Time series cycle frequency analysis uses the Maximum Entropy Spectrum method. Trend analysis uses the least squares fit (LSF), linear correlation coefficient, and the Mantel-Haenszel t-test using a two-tail method to estimate the probability, p-value. For a sample size = N there are N-2 degrees of freedom. The t-value is calculated from the correlation coefficient (r) and the degrees of freedom, $t = r\,[(N-2)/(1-r^2)]^{0.5}$.

For large samples of N>120 elements, using the Student t-distribution, the threshold for significance is p=0.05 and t=1.96. When p=0.01 it is highly significant and has t=2.576. The very highly significant, p=0.005 has t=2.795 and the extremely significant, p=0.001 has t=3.291, Robson (1967), Chou (1972) and Sprott (1990). A sample with 1002 data points, N=1000, and if r = 0.4 then t = 13.8 and $p<10^{-12}$.

For some samples in this analysis the t-value exceeds 5 and occasionally even >10. A log/linear graphic method was used to estimate the p-values for large samples with higher t-values. For t=4.85, $p=10^{-6}$; for t=6.3, $p=10^{-9}$; and for t=7.8, $p=10^{-12}$. Any value more significant than this is referred to as $p<10^{-12}$.

Data-sets used for this analysis:

The geomagnetic field strength is measured at a large number of stations. A global network of 12 stations are integrated to produce 3-hour averaged indices. One is a linear index, Ap or a_p, and another is a pseudo-logarithmic index, Kp. The subscript "p" refers to a planetary index. A common index of solar activity is the sunspot number, N_s. Sunspots are indicative of long-term changes in the solar activity and the A_p and Kp indices of the short-term activity experiences at the surface of the earth, such as the effects of solar flares or solar storms, Campbell (1997).

Solar and Geomagnetic Indexes were down-loaded from the U.S. NGDC-NOAA web-site [ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES]. The 3-hourly global index Kp, a semi-logarithmic measure of GMA was used for most calculations. Daily sunspot number was also used.

The SR data for two sites in California was downloaded from the University of California, Berkeley web-site [ftp://quake.geo.berkeley.edu/pub/em/]. A three-year data-set was assembled covering the period 13th January 1997 to 31 December 1999.

The two SR recording sites were Parkfield (PKB) (lat. 35.8892; long. -120.4249) and Hollister (SAO) (lat. 36.765, long. -121.445). Two sets of data files were available. The first contained 15-minute measurements of the east-west and north-south components of the 0-20 Hz field intensity in pT and the center frequency of the 8Hz peak. The intensity data was vectorially added and the frequency was averaged.

The PKB and SAO hourly data were extremely strongly correlated, $p<10^{-12}$. Hence missing data was replaced through a linear least squares fit relationship. Some signal instability was detected with large changes in single 15-minute data points. These were removed using a linear interpolation filter. Smoothing using 1/4-1/2-1/4 was applied prior to averaging to a form an hourly mean data set for PKB for the period 1997-1999. The first 12 days of 1997 were rejected because of clear data errors.

The second SR set of data involved three orthogonal components with the signals analysed into 13 frequency ranges. This data was used to characterize the ways in which diurnal frequency changes occurred. The 11th column contained the 1-2 Hz SR intensity. The three components were combined vectorially. The unit of $pT/Hz^{1/2}$ was converted to pT by multiplying by $\sqrt{2}$. This data was compiled to form a 3-year data set of hourly mean observations to carry out correlations with Kp and Sunspot numbers.

Figure 2 shows the 20-day mean values of the measured 0-20 Hz SR intensity from the PKB site for the three years of the study period.

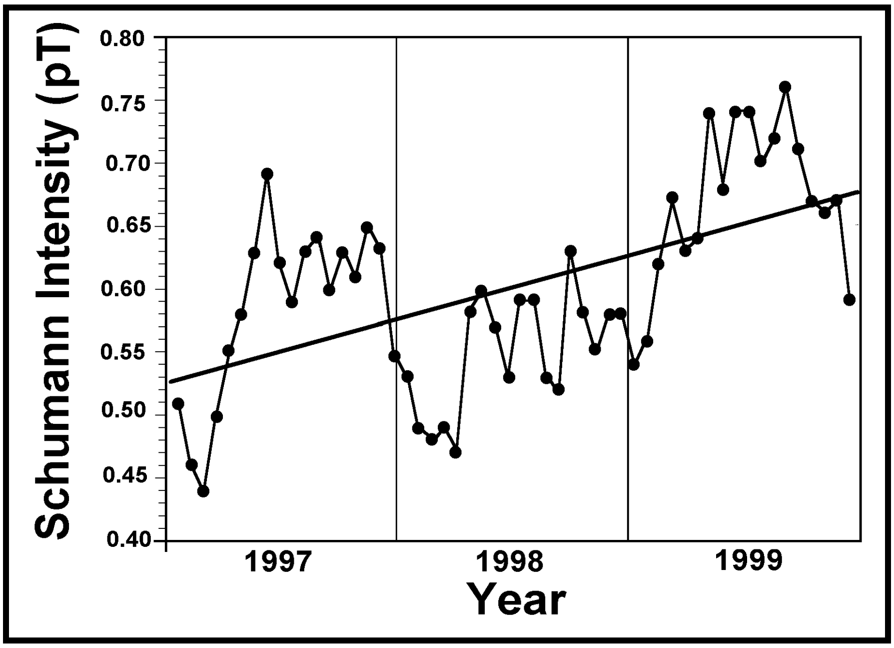

Figure 2: The time sequence of 20-day averaged Schumann Resonance signal intensity in the 0-20 Hz range. From the UC Berkeley dataset, for the three years used in this study. The trend is highly significant, $p<0.0001$.

The SR 20-day mean signal is very highly correlated with the 20-day mean sunspot number, $r=0.881$ N = 54, $t=13.4$, $p<0.00001$. When the daily mean sunspot numbers and SR intensity and frequency are compared, very significant correlations are found. For the SR intensity $r = 0.376$, $t = 13.33$, $p<0.000001$, for the SR frequency $r = 0.436$, $t = 15.91$, $p<0.000001$.

The trend in Figure 2 is primarily due to the mean rise in sunspots over this period toward the sunspot maximum in the 2000 year. The seasonal pattern is related to tropical thunderstorm activity. It is lower during the southern summer and higher during the northern summer.

Annual variations relate to the El Nino/La Nina oscillation. The year 1997 was an El Nino year with higher than average tropical temperatures. By May 1998 it had switched to a La Nina event with lower than average tropical mean temperatures. The La Nina was weak during 1999. Hence the temperature effect raised the 1997 SR intensity and lowered the 1998 SR intensity. Adjusting for this would increase the significant correlation with the sunspot number. Figure 2 reveals the prime of factors, sunspot activity and tropical temperature, that change the long-term mean SR signal intensity.

Graphical and statistical comparison between Kp and SR:

A GMA storm was shown to significantly increase the frequency of the primary SR models, Cannon and Rycroft (1982). Consistent with the effect of the D-Region, this also implies that the SR intensity was significantly increased. This is evaluated with the data set available comparing the Kp index with the SR 0-20 Hz intensity. An initial relationship between the 3-hour Kp GMA index and the 0-20Hz SR intensity from the PKB site shows some vital features and confirms the earlier observations. Figure 3 shows the 0-20Hz SR signal and the Kp Index for March 1999.

The SR signal, Figure 3, shows the distinctive regular diurnal oscillation. Kp shows strong GMA in the first half of the month, weak GMA from the 15th to 27th and then a GMA event starting on the 28th. The overall SR signal reflects these broad changes. The first 10 days show an upward trend suggesting a cumulative effect. Individual GMA events, e.g. on the 4th, 10th, 14th appear to show a time delay. A lagged linear correlation analysis of the 3-hourly mean data, reveals the highest correlation with a 6-hour lag, r=0.312, t=5.123, p<0.00001.

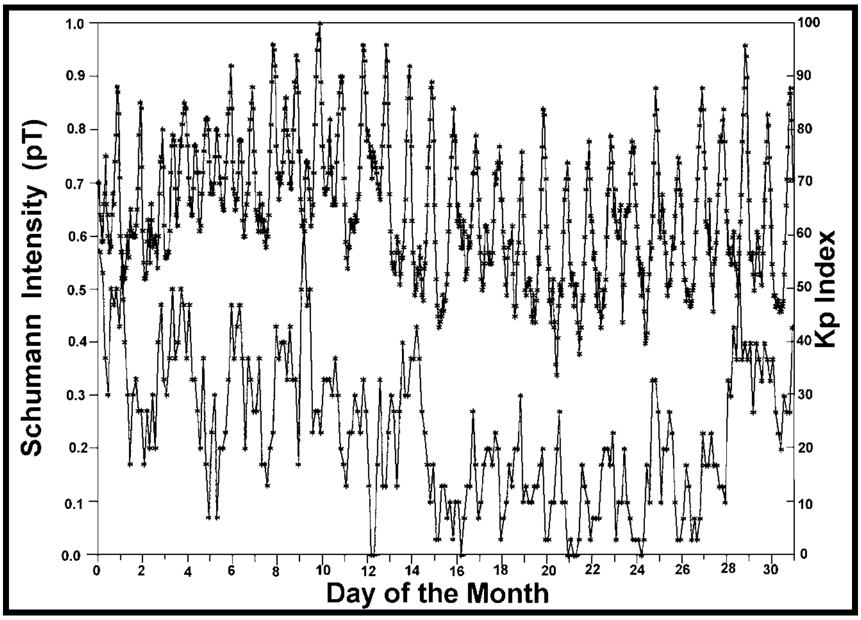

Figure 3: Schumann Intensity (0-20Hz) from the UC Berkeley PKB site (upper graph) and Kp Index (lower graph) for March 1999.

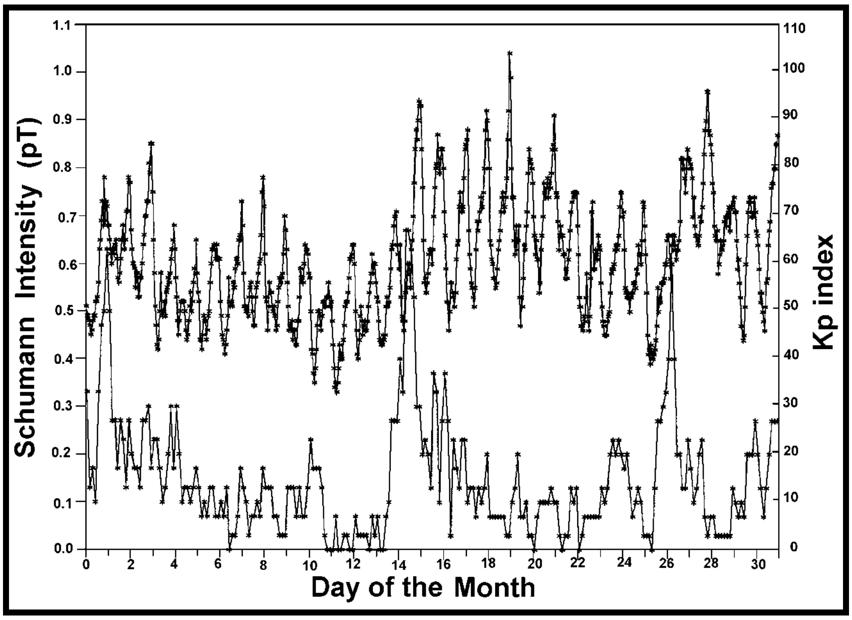

Figure 4: Schumann Intensity (0-20Hz) from the UC Berkeley PKB site (upper graph) and Kp Index (lower graph) for May 1997.

Figure 4 shows an example of a more periodic variation of GMA, from May 1997. The periodic Kp variation is clearly reflected in periodic changes in SR intensity with a small time lag. Lagged correlation analysis shows a significant correlation of with a 24hr time lag, r=0.290, t=4.66, p<0.0001.

Both of these patterns are consistent with the characteristics of the D-Region during and following GMA events. There is strong support for the process suggested that prolonged leakage of ions and the cumulative effect of repeated events builds up the ion density and elevates the SR signal following GMA events. The whole 3-year data set was used in two analyses to see if a lagged correlation analysis and a superimposed epoch analysis would confirm or contradict the patterns seen in Figures 3 and 4.

Lagged correlation between Kp index and SR signal:

The Kp index is a reliable measure of diurnal GMA activity. Since it is available as a 3-hour mean value, the SR signal was averaged over 3-hours to form a comparable data set. The lagged correlation analysis was carried out using a statistical packaged that had a limited memory allocation restricting the analysis to a maximum of 28 months of 3 hourly data. The period September 1997 to December 1999 was chosen because it contained the most reliable SR data. Lagged correlation analysis for the total period of 2.33 years, 3406 data points, shows extremely significant correlations for the 0-20Hz SR intensity dataset, Figure 5, and significant correlations with the 1-2 Hz dataset, Figure 6.

The Student t-value was used for the y-axis in Figures 5 because it is directly related to the significance of the correlation coefficient. This has also been converted to the statistical probability, p-value for a data set for which N = 6575.

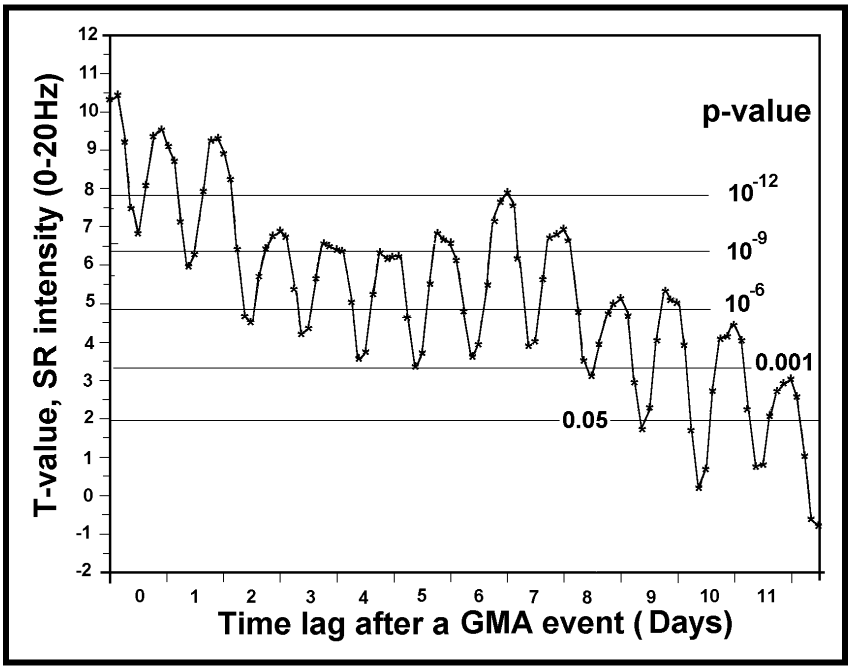

Figure 5: The statistical Student T-value of the time lagged correlation between the 3-hour Kp index and the 3-hr mean Schumann Resonance Intensity for the 0-20Hz band, for the period September 1996 to December 1999.

A similar analysis for the 0-2 Hz signal was carried out and showed very similar results. This analysis shows extremely significant correlations between the Kp index and the SR signal intensity. The pattern in Figures 5 confirms the influence of electron densities in the D-Region with highly extremely significant correlations. They both show a strong and extremely significant initial increase, a prompt response for the first night and day and a persistent relationship that extends out for 6 to 7 days after the day of the event (Day 0) and then it drops off significantly. The correlation also shows a 24-hour diurnal oscillation.

These analyses give strong confirmation of the part of the model proposing that the SR intensity is strongly dependent on the D-Region electron density. It shows that through slow electron leakage, the solar storm events last for about 7 days and this is shown by the SR signal.

Superimposed Epoch Analysis:

The above analysis uses the continuous time series of data over 28 months. An alternative approach is to identify isolated GMA events and to carry out a Super Imposed Epoch Analysis to produce the average signal during before, during and after the moderate to strong GMA events. In the 3-year period being studied 69 relatively isolated GMA events were identified. The intensity of the 0-20 Hz SR signal and the frequency of the 8 Hz signal were averaged over the 3 days prior to and the 6 days following each event, Figure 6. The overall variance of the hourly data over this period was 0.017pT for the SR intensity and 0.0026 Hz for the SR frequency.

Figure 6 shows prompt response of an elevated 0-20Hz SR intensity, especially over the first two days. The SR signal is still elevated at nighttime for at least 6 days after the GMA event. The SR 8 Hz band frequency shows a similar, but slightly smaller response. Both the signal intensity and frequency are consistent with the lagged correlation analysis above showing a prompt response and a prolonged recovery period of 6 to 7 days.

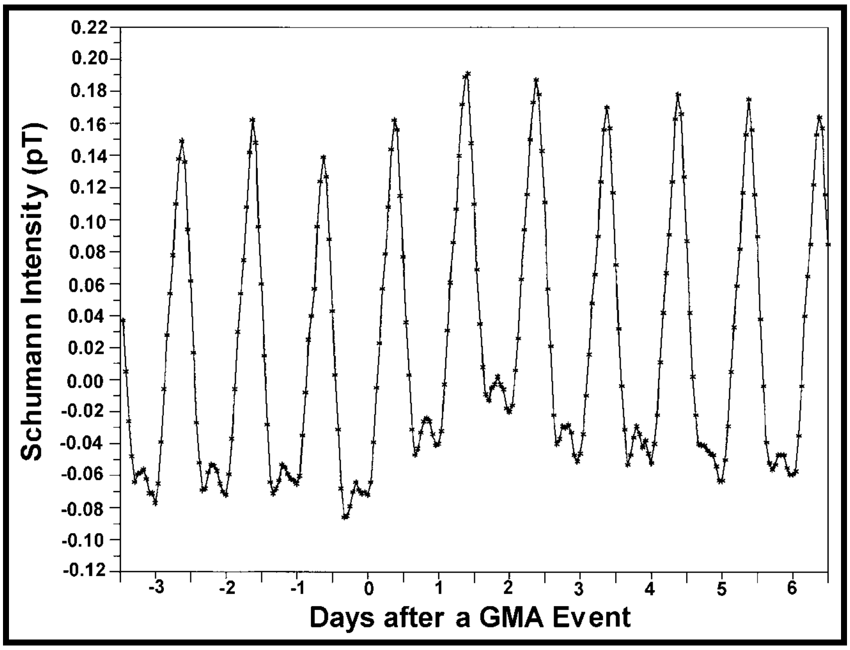

Figure 6: Superimposed epoch analysis of the impact of a Geomagnetic events, as defined by the Kp Index, for the mean anomaly in the Schumann Resonance 0-20 Hz intensity for 69 events in 1997 to 1999. GMA events occurred on day zero.

Thus the individual months, the lagged correlation and superimposed epoch analyses confirm that the SR intensity reliably, consistently and extremely significantly varies with the GMA as indicated by the Kp index. The results are fully consistent with a prompt and a prolonged D-Region electron density effect. Hence the biological and health effects that are correlated with GMA indices are also correlated with the GMA related changes in the SR signal.

Correlations with Sunspot Cycles:

Sunspot number (Ns) is a direct indicator of solar activity. On a monthly basis Ns is highly correlated with GMA over a 100 year period from 1830 to 1930, Chapman (1936). Chapman also shows that sunspot activity peaks at about 3.5 days prior to a magnetic disturbance and that there is a 27 to 28 day cycle in the GMA index, and that there is a semi-annual cycle in the GMA.

A cyclic analysis has been used in other studies to identify causative relationships through closely matched cyclic factors, Komarov et al. (1998). The sun's mean rotation period of about 27-28 days has a series of recognised sub-harmonics of about 18, 14, 9, 7, 5.5 and 3.5 days. Hence a Maximum Entropy Power Spectrum analysis was carried out on the 35 good data months of the SR intensity record, Figure 7.

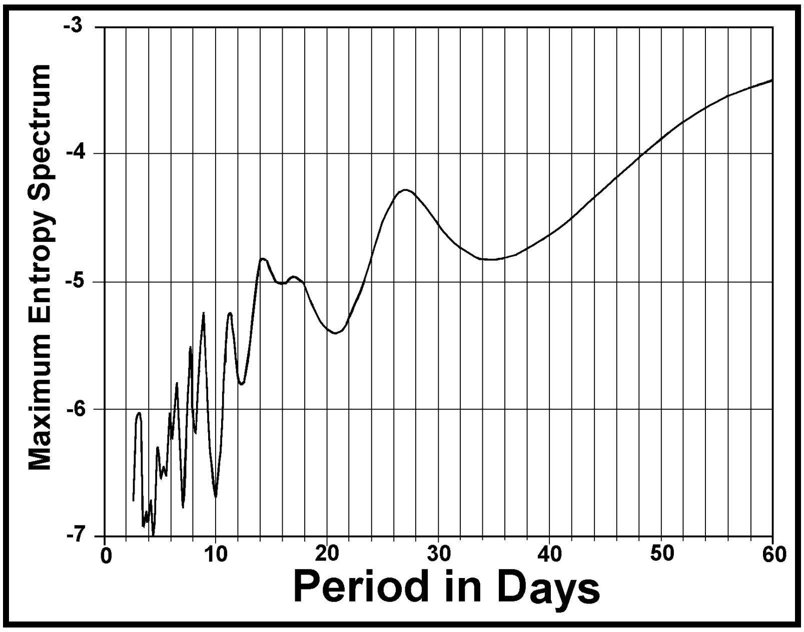

Figure 7: Maximum entropy spectrum for the 2-day average 0-20Hz Schumann Resonance Intensity for the period February 1997 to December 1999.

Figure 7 shows a distinct peak at 27 days and weak peaks at 9 and 14 days corresponding to solar cycles. This confirms that the SR intensity varies in a cyclic manner with a dominant 27 day period that coincides with the solar and GMA primary sub-seasonal period. This shows that the S-GMA modulates the SR intensity and reinforces the extremely strong correlations already identified. There is also weak evidence of a cycle with a period between 3.2 and 3.5 days in the SR intensity. This is near the circasemiseptan cycle identified above that has important biological consequences. Using the 20-day averaged data for the 3-year period shows a strong semi annual, 185day peak in the SR intensity signal.

SR Signal and S-GMA relationships:

The first test of whether the SR signal is the plausible biophysical mechanism for the biological and health effects of S-GMA was to see if the SR signal is correlated with sunspot number and the Kp GMA index. This analysis shows that all correlations are very highly significant and are supported by superimposed epoch and cyclic analyses. Hence it is confirmed that the SR signal has all of the necessary and appropriate characteristics to link S-GMA cycles and events with biological and health effects. This supports and confirms the Model Element (c).

Biophysical Mechanisms:

ULF/ELF Reaction Time experiments:

The original work of Dr Ross Adey's laboratory on calcium ion efflux, was stimulated by observations of ULF/ELF environmental fields altering monkey reaction times in a field strength dose-response manner with a 7 Hz signal, Gavalas-Medici and Day-Magdaleno (1976), and human reaction times, Hamer (1965, 1969) and König (1974). They were also aware of Wever's circadian rhythm experiments. Dr Adey's research showed that the altered reaction times were associated with altered EEG patterns and altered calcium ion efflux from neurons, Adey (1981). Calcium ion efflux was significantly altered between 0.5 and 30 Hz, Adey (1980), and in windows of frequency up to 510 Hz, Blackman et al. (1988). Hence there is an established biophysical pathway between the resonant absorption of very weak ULF/ELF environmental fields in the brain, altered cellular calcium ion homeostasis, altered EEG pattern and altered reaction times.

The frequency range involved in the reaction time, brain waves and calcium ion alterations include those of the primary SR signal, 0-32 Hz. Thus it is biophysically plausible that the SR signal could be associated with altered brain activity and reaction times through resonant interactions with neurons involving changed calcium ion signals.

Human reaction time experiments in association with ULF frequencies, primarily 3 Hz and 8 to 10 Hz, were carried out in Germany and the United States in the 1950s and 1960s. This was stimulated by observations of a large experiment involving nearly 50,000 members of the public. This showed that human reaction time were significantly correlated with the intensity of the 8-10 Hz SR signal, König (1974b), Figure 8.

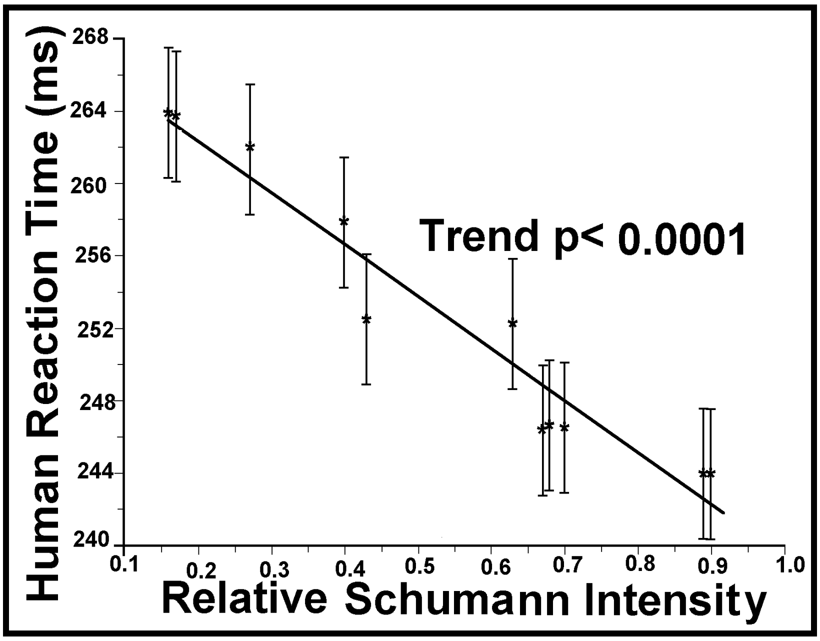

Figure 8: Human reaction times as a function of Schumann Resonance 8-10 Hz relative intensity. Reaction times measured using a light flash and a Morse key, tested during 18 days in September 1953, at the German Traffic exhibition in Munich.

Each point in Figure 8 represents 4500 subjects, with the mean variance of 3.6 ms shown as error bars. Trend: t = 10414, 2-tailed $p<0.0001$. Data is derived from Figure 3 of König (1974b). The relative intensity is estimated to be in the range 0.6 to 1 pT for the 0-20 Hz band.

The first identified power spectrum analysis of the SR signal was Balser and Wagner (1960). König and his colleagues had recorded the SR signal on chart recorders. They characterized the signal as a "10 Hz" oscillation. This is likely to be because the two dominant frequency peaks are near 8 Hz and 14 Hz. As a consequence in German laboratory experiments a 10Hz signal was used to approximate the SR signal. Both König and Hamer confirmed that the "10 Hz" signal sped up reaction times. Hamer showed that moving the frequency from 7.5 to 8.5 Hz and 8.5 to 9.5 Hz significantly altered reaction times with an RMS electric field intensity of 3.8 mV/m. Konig (1974) notes that this level is close to the natural SR signal strength (about 1 mV/m).

König also found that a superimposed epoch analysis related to the arrival of 3Hz signals locally generated thunderstorms, significantly slowed reaction times. This was tested and confirmed in a series of laboratory experiments using human volunteers. König found that with a range of field strengths, 1 to 5V/m, the "3Hz" signal consistently slowed people's reactions and a "10Hz" signal consistently accelerated people's reaction times. Reactions were also correlated with the more objective test for galvanic skin response (GSR), using a 5 V/m 3Hz signal, König (1974b).

Circadian ELF Zeitgeber experiments:

Support for the role of the SR signal as a diurnal Zeitgeber came from the Max Planck Institute's long-term isolation experiments, Wever (1974). The Max Planck Institute set up an elaborate, large and careful experiment to investigate the hypothesis that there was a natural electromagnetic field, such as the Schumann Resonance, that acted as a circadian Zeitgeber. This was promoted because of König's experiments. Because the daily sunlight cycle is a very dominant Zeitgeber, the hypothesis was tested by constructing two identical rooms in which all signs of the usual daily variation, sunlight, temperature, humidity etc, were removed. The second room (Room 2) was also shielded to significantly reduce all external oscillating electromagnetic fields by over 40 db.

From introductory experiments, rectal temperature was identified as a reliable objective measure of the daily circadian rhythm. In the isolation rooms the free running day length was significantly lengthened in Room 1 from 24 to 24.87 hr. In Room 2 it was significantly longer than Room 1, 25.26 hr, $p<0.01$. The standard deviation of the variation of day lengths was also significantly higher in Room 2 compared with Room 1, $p<0.01$. An additional feature was a phenomenon termed internal desynchronization. In this case individuals showed much longer and highly erratic daylengths. While 15 of 50 subjects in the shielded Room 2 internally desynchronized, none of the 34 subjects did in Room 1, $p<0.001$. The desynchronized subjects were followed up because of their evident sensitivity.

König had characterized the primary mode of the SR signal as a "10 Hz" signal. Hence Wever's team used a square-wave 10 Hz, 2.5 V/m signal in Room 2 to see what would happen if a Schumann-like signal was introduced. Without the subjects knowledge, a 10 Hz signal was turned on and off at varying intervals. This signal consistently removed the desynchronization and reduced the mean daylength for those subjects, Wever (1967, 1968). The longer the circadian cycle in the absence of the field, the greater was the shortening by the 10 Hz signal, r = 0.928, n=10, p<0.001. This showed that not only was a highly significant phenomenon occurring, but it also varied in an very significant and reasonable manner.

Wever (1974) concludes that his team found "significant proof that electromagnetic fields in the ELF range influence human circadian rhythms, and therefore, human beings". They proved that there is a ULF/ELF electromagnetic signal that is a circadian Zeitgeber. By design the corrective signal mimics an aspect of the SR signal. While it could be another signal but there is no other known signal has the appropriate characteristics. Hence it is highly likely that the ULF/ELF circadian Zeitgeber is the SR signal.

Taken together, the experiments of König, Hamer and Wever give very strong support for the hypothesis that the SR signal is involved as a diurnal Zeitgeber, that it is detectable by the human brain and that it causes induced alterations in reaction times. This is highly consistent and gives considerable support for the SR hypothesis.

Laboratory evidence that ULF/ELF signals alter reaction times, animal and human brain waves, neuron cell calcium ions and neurotransmitters gives further support. This makes the hypothesis biophysically plausible and observationally supported. It is therefore, largely but not finally confirmed.

Evidence of ULF/ELF induced Melatonin Reduction:

The SR signal has ULF/ELF frequencies. Hence evidence that ULF/ELF electromagnetic fields reduce melatonin or increase serotonin in animals and people is relevant to the Hypothesis and its GMA Melatonin Mechanism.

There is extensive evidence that ELF signals increase serotonin and reduce melatonin in animals and in people. Rosen, Barber and Lyle (1998) state that seven different laboratories have reported suppression of nighttime rise in pineal melatonin production in laboratory animals. They show that a 50 μT, 60 Hz field with a 0.06μT DC field, over 10 experiments, averages a significant 46% reduction in melatonin production from pinealocytes. Yaga et al. (1993) showed that rat pineal response to pulsed ELF magnetic fields varied significantly during the light- dark-cycle. They showed that magnetic field exposure significantly suppressed the rate-limiting enzyme in melatonin synthesis, N-acetyltransferase (NAT) activity, during the mid- to late-dark phase.

Suppression of melatonin in rodents is frequently observed when they are exposed to weak electromagnetic fields. A question has been raised as to whether the pineal gland or the eyes are the sensors of the fields. Brendel, Niehaus and Lerchl (2000) carried out an experiment to resolve this question using hamsters. They concluded that there was significant suppression of melatonin with 16.7 Hz, p<0.01, and with 50 Hz, p<0.001 as a result of primarily mechanisms in the pineal gland.

Stark et al. (1997) observed a significant increase in salival melatonin in a group of 5 cows when the short-wave radio transmitter at Schwarzenberg, Switzerland, was turned off for three days, compared to 5 cows that had much lower RF exposure. Hence, despite the high natural levels of variability of melatonin, there are now at least ten independent observations of significant melatonin reduction in animals from ULF/ELF and RF exposure.

Many human studies that show significant alteration of the melatonin/serotonin balance by electromagnetic fields. Wang (1989) observed a dose-response increase in serotonin in workers exposed to ELF fields and Davis (1997) a dose-response decrease in melatonin in workers. Human melatonin reduction studies from ULF/ELF electromagnetic fields include: Wilson et al. (1990), Graham et al. (1994, 2000), Pfluger and Minder (1996), Arnetz et al. (1996), Davis (1997), Wood et al. (1998), Karasek et al. (1998), Burch et al. (1998, 1999a, 2000) and Juutilainen et al. (2000). For a residential population exposed to a SW radio signal in Switzerland the melatonin rose significantly after the tower signal was turned off, Abelin (1999). Two studies directly involve correlation of melatonin reduction with GMA variation, Burch et al. (1999b) and Rapoport et al. (1998).

Thus there is very strong evidence that ULF/ELF electromagnetic fields reduce melatonin in people and in animals. This occurs down to very low mean intensity levels, with dose-response relationships, and in association with GMA. Under normal criteria this level of evidence would be assessed as a causal biological effect.

S-GMA and melatonin reduction:

In addition to Burch et al. and Rapoport et al, additional direct evidence that reduced melatonin is significantly correlated with S-GMA is available. Bardasano et al. (1989) observed an extremely significant reduction ($p<0.001$) in synaptic ribbons of pinealocytes of rats during geomagnetic storms compared with quiet solar days. Thyroxine levels in a single limbic epileptic patient were highly correlated ($r = 0.66$) in a dose-response manner, with daily GMA, O'Connor and Persinger (1996). The strongest association ($r = 0.76$) was found between thyroxine levels and the Kp index during the previous night (2 am to 5 am). These analyses were carried out specifically to test the GMA Melatonin mechanism and they support it.

Seasonal melatonin variation in rats was correlated with the seasonal variation in the earth's geomagnetic field, Bartsch et al. (1994). A group of hospital patients with cardiovascular pathology and a control group of healthy people were both monitored during magnetic storms. In both groups magnetic storms increased the cortisone, activated the sympathoadrehenal system and reduced the melatonin, Rapoport et al. (1998).

Burch et al. (1999a,b) measured urinary melatonin metabolite in 149 workers exposed to 60 Hz magnetic fields. Reduced melatonin was correlated with 3-phase conductors exposure, cellphone use and overall magnetic fields, with a dose-response decrease in workers exposed to low light levels. When all of these effects were removed from the data, it also showed a highly significant reduction of melatonin for GMA fields above 35 nT, $p<0.01$. When the data was stratified over 6 GMA levels a very highly significant ($p<0.005$) dose-response decrease in melatonin from people was found using a Global 36 hr aa-index, Figure 9.

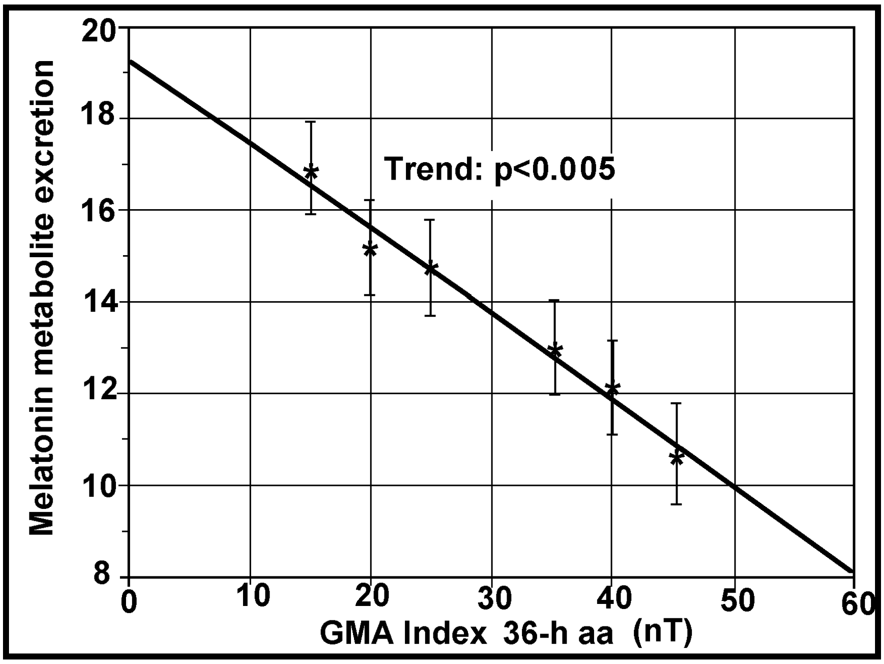

Figure 9: Reduction in the melatonin metabolite 6-OHMS in μg in urine from U.S. electric utility workers, as a function of the 36 hr global GMA aa-index, Burch et al. (1999b).

This gives very strong support to Model Element (e), the GMA Melatonin Mechanism and the Schumann Resonance Hypothesis through the widespread involvement of ULF/ELF signals in laboratory, occupational studies and involving GMA.

Biological implications of reduced melatonin:

Melatonin is a ubiquitous neurohormone whose production is low during the day and high at night. It passes through cell membranes and acts as a highly potent antioxidant to scavenge free radicals that cause damage to DNA, Reiter (1995). Hence melatonin reduction is involved with diseases produced by free radicals, including cancer, aging, neurological diseases, acute heart disease and heart attack, Reiter and Robinson (1995).

The circadian cycle involvement of melatonin shows that reduced melatonin will alter blood pressure and heart rate, neurological cardiopulmonary and reproductive functions. It suggests that reduced melatonin will also reduce immune system competence and enhances the risk of cardiac, neurological and carcinogenic disease and death through reducing its antioxidant activity. These predictions are checked against clinical studies.

Melatonin reduction and health effects:

Reiter and Robinson (1995) and Brzezinski (1997) reviewed the clinical studies involved with reduced melatonin. Dr Brzezinski identifies roles for melatonin in sleep and circadian rhythm, mood, sexual maturation, reproduction, cancer, immune system response and aging. Dr Russell Reiter, an eminent melatonin researcher, is the founder and editor-in-chief of the Journal of Pineal Research. Reiter and Robinson confirm all of the effects identified by Brzezinski, and add arthritis, asthma, diabetes, hypertension, blood clotting and stroke, cardiac arrhythmia, ischemic heart disease, heart attack, epilepsy, manic depression, suicide, sudden infant death syndrome (SIDS), Alzheimer's and Parkinson's Diseases. Published papers are cited to justify each of these health effects. Most of the associated conditions relate to the oxidative damage by free radicals and melatonin's multiple roles as a potent antioxidant, sleep enhancer and immune system booster. Melatonin also acts as a neurohormone and a cellular messenger with receptors in the nuclei of many cells.

In his conclusion Brzezinski favours high clinical doses for melatonin-related therapy. However he cites three trials where 0.1 to 0.3 mg/day was effective at enhancing sleep. Reiter also cites the M.I.T. study of Dollins et al. (1994). He uses it to confirm the long known effect of melatonin on sleep. In the M.I.T. study, the biggest incremental effect of melatonin on sleep onset latency and sleep duration was the first 0.1 mg dose. With at least two other studies confirming the M.I.T. study this confirms that very low daily doses of melatonin have very significant clinical effects.

Since S-GMA significantly reduces melatonin in a dose-response manner, all of these health effects have the potential to be associated with S-GMA. There are several primary effects that are of particular interest in S-GMA related studies. They are cancer, SIDS, cardiac, neurological disease and death, including heart attack and suicide. These are all related to reduced melatonin in clinical studies and through the diurnal regulatory mechanisms.

S-GMA related health effects:

Principles and problems with environmental epidemiology studies:

In seeking to identify and confirm environmental disease agents human populations are studied in attempts to correlate health effects with exposures to agents. Often other factors produce complex variations in the health effects. These are called confounders. Methods have been developed to deal with complex situations and to identify individual agents where possible. Time series analysis where cyclic frequencies can identify common features can be helpful. Multiple regression analysis can also assist. When erratic events are involved the problem can be reduced significantly.

In seeking to identify the effects of natural electromagnetic fields generated by Solar activity through the Geomagnetic System, the "disease agent". Extremely low intensity electromagnetic fields, are being masked and interfered with in developed societies with power supply systems, telecommunications, appliances, computers, etc. This means that earlier records and records from less developed populations could well have "cleaner" relationships with S-GMA indices. This effect is referred to by Villoresi et al. (1998) who found significant correlations between heart attack incidence rate and GMA storm events in the data from 14 large hospitals in St Petersburg for 1989-1990. Weekly analysis showed a rather constant rate during Monday to Friday and sharp decrease in rates over the weekend and during mid-week festivities. They associated this with different EMR exposures during work days and holidays, mainly due to the electrified public transport. This is confirmed by studies showing significantly higher hypertension and coronary heart disease in electric train drivers, Ptitsyna et al. (1996).

To illustrate the principles and problems, an analysis of annual time series data for suicide in Southeast Asia was carried out for the period 1974-1992. The data was extracted from Table II-3-24-1 from a report of the Southeast Asian Medical Information Centre, SEAMIC (1997). Suicide is a good bio-indicator for this purpose because of its clear diagnosis and its direct connection to clinical depression and altered melatonin homeostasis. Data is given for the Philippines, Thailand, Singapore, and Japan. The period and the range of countries, give a range of development, stress levels, health recording systems and EMR exposures. The order of the countries reflects increasing development, health recording systems and exposures to artificial EMR. The data shows an increase in the recorded annual mean male suicide rate from 0.66 in the Philippines, 6.9 in Thailand, 12.4 in Singapore, and 23.1 in Japan (per 100,000 population).

The period covers just less than two solar cycles with two sunspot maximums in 1979/80 and 1989/90 and sunspot minimum in 1986. The suicide rates are generally higher in the later half of the period than the earlier years. When linear trends are removed it is found that Thailand and the Philippines are positively correlated with the sunspot cycle. In the highly developed Singapore and Japan it is weakly negatively correlated. The principle of signal noise level associated with more EMR exposures in developed societies, and the more complete and better accurate data recording, promotes Thailand as the most likely country to detect a sunspot cycle in the annual suicide data. This relationship has been expressed as annual sunspot number vs the annual male suicide rate in Figure 10.

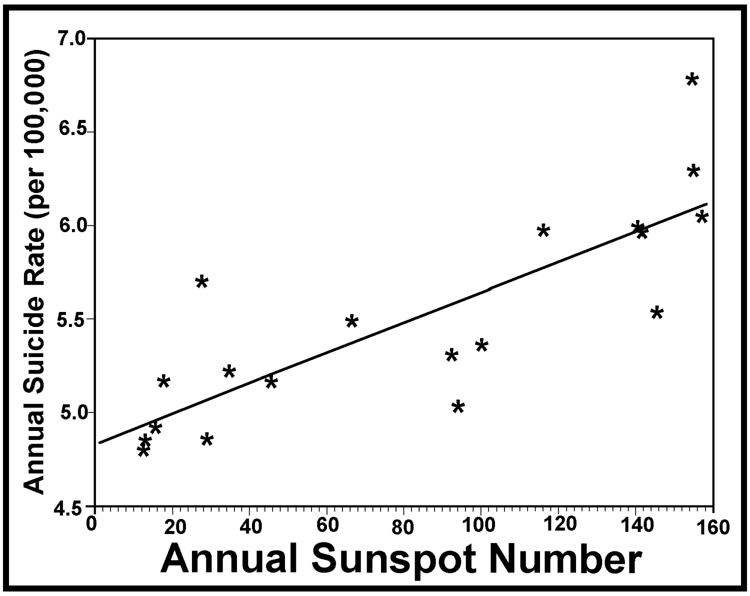

Figure 10: Annual male suicide rate per 100,000 for Thailand from 1974 to 1992, in relation to the annual sunspot number. The correlation coefficient is r = 0.817, $p<0.0001$.

Figure 10 shows an extremely significant correlation between annual sunspot number and annual male suicide rate in Thailand over the period 1974-1992. This is consistent with the S-GMA melatonin link.

Risk of cancer, especially leukaemia and breast cancer, is associated with melatonin reduction. In this data-set the four countries cancer rates are ranked similarly, except Thailand has lower rates than the Philippines. Thailand's annual male leukaemia rate is correlated with sunspot number, r = 0.473, $p<0.05$. So is the female Breast Cancer rate, r = 0.687, $p<0.005$ and the male Cerebrovascular Disease mortality, r = 0.696, $p<0.002$.

This data is consistent with the SR hypothesis in that it significantly correlates human health effects with a S-GMA index (Ns), and Ns is highly correlated with the SR signal. Secondly, it is consistent with the GMA Melatonin Mechanism as it also involves increases health effects that are associated with reduced melatonin. The failure for the sunspot activity to be seen in the Singapore and Japan data is probably being masked by increased nighttime light levels and elevation of exposures to artificial electromagnetic fields, Reiter (1994).

These analyses show how it is becoming more difficult to detect sunspot cycles in human health records. The erratic nature of GMA events still allows the detection of their effects despite the increasing UHF/ELF noise which is reducing the signal to noise ratio. Of particular concern is the use of technologies, such as the GSM mobile phone, that uses a 217 Hz pulse rate with an 8.34 Hz modulation, Stewart (2000). This is in the range of the primary mode SR spectrum signal and the EEG Alpha-Rhythm.

S-GMA related reproductive effects:

The fetus has melatonin receptors to detect its mother's diurnal cycle. Sparks and Hunsaker (1988) reported the results of necropsy samples of infants who died of Sudden Infant Death Syndrome (SIDS). They found that their pineal gland was significantly smaller than aged-matched controls, $p<0.005$. In follow up measurements of 111 SIDS infant's showed smaller pineal glands in 106 infants, raising the significant to $p<0.0001$. This strongly implied that reduced melatonin was associated with SIDS. This suggests that since GMA is strongly correlated with reduced melatonin then it could well enhance the rate of SIDS.

O'Connor and Persinger (1997) showed the GMA is correlated with SIDS. They used monthly SIDS statistics from 1960-1961 in Ontario, Canada. They compared the monthly SIDS rate with the monthly average aa GMA index. The data was stratified within the levels of aa in 10 nT intervals. This showed that there was a highly significant increase in SIDS for the number of days with aa in the 11 to 20 nT range, $r=0.91$, $p<0.001$, and in the 31 to 40 nT range, $r = 0.65$, $p<0.01$. For the intermediate range, 21 to 30 nT there was a highly significant reduction of SIDS, $r = -0.79$, $p<0.001$. Their strongest correlation occurred for a reduction of SIDS between days with 21 to 25 nT, $r = -0.96$, $p<0.0001$. This shows a homeostatic relationship between the GMA level and the rates of SIDS with far lower SIDS rates near the mean GMA level 21-30 nT and significantly higher rates for lower and higher GMA levels.

The possible role of micropulsations (PC1: 0.2-5 Hz) on SIDS rates during periods of very low GMA was then studied, O'Connor and Persinger (1999). Using a similar method they found that stratifying the data into 11, 5 nT interval levels, there was a marginally significant correlation with increased micropulsations levels, $r = 0.63$, $p<0.05$. Consistent with O'Connor and Persinger (1997), they also found a negative correlation $r = -0.79$) at an intermediate level of PC1, 15 to 20 nT, suggesting a homeostatic effect. They noted that the PC1's usually occur in 1 to 4 hour periods over 5 to 7 quiet days following an isolated geomagnetic storm. This shows that the effects would also be correlated with the SR signal that has the same pattern of lasting up to 7 days after a solar storm, Figure 5.

S-GMA related Cardiac effects:

A 35-year old cardiologist, with a family history of hypertension and stroke, used an electronic blood pressure monitor to record his blood pressure every 15 minutes for 3 years. This revealed a significant periodicity of 27.7 days in systolic and diastolic blood pressure and heart rate, which was coherent with the GMA Kp-index, Watanabe et al. (1994).

An Italian study of 447 patients with hypertension also found very significant correlations between systolic and diastolic blood pressure and GMA indices over a 5-year period, Ghione et al. (1998). A multiple correlation with potential confounding factors, such as age and date, confirmed the significant correlation with GMA. Stratifying the days into quiet, disturbed and highly disturbed GMA days consistently showed significantly higher values in the highly disturbed days for all blood pressure parameters, except for systolic night-time pressure. The difference between quiet and highly disturbed GMA days was 6 to 8 mm for the 24 hour systolic and diastolic blood pressure. The GMA indices and the blood pressure measurements contain the 27-day period. The authors concluded that these results seem to reflect a real relation between geomagnetic disturbances and blood pressure.

Two independent studies show that human blood pressure is significantly correlated with GMA. Melatonin is a diurnal blood pressure regulator and S-GMA modulates human melatonin levels, therefore these studies confirm that blood pressure change is a melatonin-related biological effect of S-GMA. Hence it is biologically plausible that extreme levels of S-GMA will cause a wide range of cardiac health effects and death.

Reduced melatonin produces arrhythmic cardiac activity. The cardiac activity of rabbits was monitored during two GMA storms, Chibisov et al. (1995). At the initial and main phase of the storm the normal circadian structure of the cardiovascular parameter was lost. Desynchronization grew during the storm, leading to an abrupt drop of cardiac activity during the main phase of the storm. This was followed by the destruction and degradation of cardiomyocytes. The parameters of cardiac activity became significantly synchronized and the circadian rhythm restored during the storm's recovery period.

Human patients with ischemic heart disease (47-men and 33-women) were monitored for cardiac parameters daily over for 2-3 weeks, Gurfinkel et al. (1995). Changes in their microcirculations were related to GMA and to changes of atmospheric pressure. In the first day of a GMA storm pathological changes of capillary flow were detected in 71.5% of patients with acute myocardial infarction (men: 73.7%, women: 69.2%). They also observed perivascular edema, red blood aggregation, delay and slowing down of capillary flow. Similar changes were detected in 64.8% of patients with angina pectoris, (men: 73.3%, women: 56.3%). The reactions of these patients to GMA disturbances were over 2.5-times higher than the effects of atmospheric pressure changes.

GMA events are significantly correlated with increased blood coagulation and platelet aggregation, Pikin, Gurfinkel and Oraevskii (1998). Blood pressure, capillary flow, blood coagulation and aggregation changes are observed during GMA events, consistent with the effect expected with reduced melatonin in people with heart disease. Therefore, it is reasonably predicted that GMA will be associated with observable changes in cardiac disease and death when large human populations are studied.

GMA related Human Cardiac Disease and Death:

Early correlations between S-GMA and heart attacks were assumed by some authors to be spurious, inaccurate and inconsistent, Malin and Srivastava (1979, 1980) and Knox et al. (1979). Results found in India were not confirmed in populations in the U.S.. These were seen as inconsistent. The lack of a plausible mechanism also made these results not credible to some researchers. Artificial EMR exposures in developed countries masking the natural signals effects is a plausible explanation of the results. In the 1990's many other studies identified relationships that are highly significant and consistent with the original results.

With clinical measurement being able to identify highly significant changes in blood pressure, blood flow, aggregation and coagulation during GMA events, these results are highly plausible. They are mediated by melatonin in the normal diurnal and seasonal cycles. Since melatonin is also significantly correlated with levels of GMA during solar storms this will also have cardiac effects. Reduced melatonin is associated with cardiac arrhythmia and heart rate variability in clinical studies cited above.

De Bruyne et al. (1999) studied older heart patients (>55 years) and compared their heart rate variability (HRV) with their increased risk or mortality from myocardial infarction. They found that both decreased and increased HRV were significant risk factors, with increased HRV being the greater risk factor. This shows a timing related homeostatic relationship and GMA events are related to desynchronization of cardiac rhythms. Measured HRV also demonstrates anomalies in myocardial infarction, sudden death, heart failure, autonomic neuropathy and hypertension, Kerut, McKinnie and Giles (1999).

The EEG pattern, pulse rate, blood pressure and rate of sensomotor reaction was measured in a group of people. The parameters significantly correlated these physiological variables with the Kp-index, Doronin et al. (1998). They noted that the oscillations in the Kp-index had identical periods in the monitored EEG Alpha-Rhythm. This confirms the whole-body changes that occur in conjunction with GMA alteration by changing the brain and heart patterns. This supports the Model that suggests that the brain wave pattern is changed, involving alteration of ELF brain signals, and this is transferred through melatonin receptors and the autonomic nervous system to the cardiovascular system.

Cardiac Effects of High GMA:

During periods of Active Sun and increased GMA the following statistically significant effects have been observed:

- Cardiac Arrhythmia in children, Markarov (1998).

- Novikova and Ryvkin (1977) observed a consistent and significant increase in heart attack incidence and death between active and quiet GMA conditions for 1961-66 at Sverdlovsk, USSR.

- GMA is highly correlated with daily myocardial infarction incidence rates during big GMA storms, Villoresi et. al. (1998).

- GMA activity is also correlated with sudden cardiovascular death, Sitar (1990), and Ischaemic Heart Disease mortality, Otto et al. (1982).

- Monthly solar activity was highly significantly correlated with monthly hospital admissions for cardiovascular disease, Stoupel and Shimshoni (1991). Solar activity is highly correlated with GMA and SR intensity.

- Stoupel et al. (1997) observed that during periods of low solar and geomagnetic activity, solar proton fluxes were correlated with cardiovascular deaths.

- Oraevskii et al. (1998a) found that 75 % of GMA storms caused an increased of the hospitalization of patients with myocardial infarction by 30 to 80%.

- Oraevskii et al. (1998b) report that MIR space orbital station staff experienced a significantly increased heart rate, reduced heart rate variability and decreased respiratory waves, corresponding with a specific adaptation of stress-reaction. At the same time hospital patients with ischemic heart disease had a similar reaction including deterioration of the physiological status, rheologic blood characteristics and heart rate disturbances, associated with GMA disturbances.

- Breus et al. (1998) report disturbance of cardiovascular activity among MIR astronauts during the main phase of solar storms compared to the recovery phase. Similar effects were observed in rabbits.

Cardiac Effects of Low GMA;

Periods of Quiet Sun activity are significantly associated with:

- Stoupel et al. (1990) found a highly significant correlation (p=0.01) for higher pregnancy induced hypertension for monthly periods of low GMA.

- Sudden death from cardiac arrhythmia, especially paroxymal atrial fibrillation, and stroke, Stoupel (1993) and Stoupel et al. (1995a). Stoupel, Martfel and Rotenberg (1994). Stoupel, Martfel and Rotenberg conclude that their results are consistent with previous studies showing increased heart electrical instability during periods of lowest geomagnetic activity.

- Ischaemic Heart Disease for ages >70 years. Stoupel et al. (1995b).

- Stoupel et al. (1999) found an very highly significant inverse correlation (r= -0.64, p=0.0001) for a 72 month period between solar activity and stroke/ischemic heart disease death. They concluded that monthly ratio of deaths from stroke/ischemic heart disease is related to environmental physical activity.

The cardiac studies are consistent with the Schumann Resonance Hypothesis and add considerable weight to the melatonin, homeostatic and arrhythmic factors in the Hypothesis. Blood pressure, blood coagulation, heart attack, cardiac arrhythmia and sudden cardiac death are highly correlated with GMA in a homeostatic (U shaped) manner. This data is consistent with the involvement of melatonin. Being directly supported by clinical cardiovascular monitored changes of blood pressure, capillary flow and blood aggregation, multiple studies and very highly significant correlations with solar activity and GMA. This gives robust evidence supporting a causal relationship between GMA and Ischemic and arrhythmic cardiovascular disease, heart attack and death. The highly significant correlation between S-GMA and the SR signal intensity gives additional support for the SR Hypothesis through a Melatonin Mechanism.

Neurological Effects:

The brain is a very sensitive electromagnetic organ. The model and hypothesis proposes a direct mechanism for SR signals to interact with the brain, altering the brain waves and neurohormone responses. Altered reaction time is a prompt and acute indication of this interaction. It has been shown that exogenous ELF signals affect melatonin/serotonin, dopamine and opiate systems, Frey (1995). This effect is plausible through interference with endogenous ELF systems and the vital role of calcium ion signalling. Melatonin reduction is directly correlated with S-GMA levels that are highly correlated with a natural exogenous ELF field, the SR signal. Given the biological effects of reduced melatonin, this predicts that there could well be a wide range of melatonin related neurological effects correlated with solar cycles and GMA events. A large number of studies have been carried out and are summarized below.

People with Epilepsy are primary subjects for the detection of acute effects of GMA on human neurological functions because of the frequency-based dysfunction that they suffer from. Karlov, Selitskii and Sorokina (1996) compared the reactions of 18 healthy individuals and 20 epileptic patients to magnetic fields modulated in the EEG frequency range. They showed that alteration of the magnetic field elevated the functional activity of the brain synchronizing structures and increased either the epileptic activity or activation of the epileptic focus. Sandyk and Anninos (1992a and b) report success in reducing epileptic seizures with picoTesla ULF magnetic fields with SR-like frequencies. Sandyk (1992) relates these results to the alteration of the EEG alpha rhythm (8-13 Hz), pineal melatonin and magnetic field altered circadian seizure incidences.

Belisheva et al. (1995) concluded that their observations showed that local GMA variations can be a principle reason for modulation of the brain's functional state. They also conclude that this means that an optimal level of GMA, manifested in periodic oscillations in certain amplitude frequency range is demanded for steady brain's function state. The decrease of optimal GMA activity level and the appearance of aperiodic disturbances of GMA are associated with the unsteady brain state. This gives strong support for the role of the SR spectrum in the homeostasis of brain activity.

The EEG rhythms, pulse rate, blood pressure and rate of sensomotor reaction on a group of people were significantly correlated with the Kp index, Doronin et al. (1998). They noted that the oscillations in the Kp index had identical periods to the monitored EEG alpha-rhythm. This confirms a GMA-related modulation of the EEG alpha rhythm, which could well be the SR signal. This was independently confirmed by Belov, Kanunikov and Kiselev (1998), who monitored the EEG rhythms in 26 human subjects.

A positive correlation between the EEG data and GMA was revealed. It was most obvious in the frontal and central lobes of the brain. A negative correlation between some local EEG synchronization and indices of solar activity was also observed. Belov et al. concluded that the degree of synchronization of the spontaneous EEG pattern seemed to reflect sensitivity of the human nervous system to the earth's magnetic field. This confirms a role for a S-GMA-related mechanism, most likely involving the SR signal. They observed a stressor response to strong GMA events and a sedative effect from low frequency magnetic oscillations. These results are consistent with the experiments of König and Hamer who showed that the alpha-rhythm related 10 Hz signal stimulated people and the 3 Hz delta-rhythm related signal slows people.

Neurological Effects of High GMA:

- Tambiev, Medvedev and Egorova (1995) found a significant correlation between GMA and memory and attention. Aviation accidents are positively correlated with solar storms, Komarov et al. (1998). Through cyclic analysis the authors concluded that there was a causal relationship because of strong frequency matching between aviation accidents and GMA event cycles.

- This was confirmed by Selitskii, Karlov and Sorokina (1999) who, by artificially reducing GMA, were able to increase the synchronization of alpha-rhythm EEG and generalized slow-wave discharges in people with epilepsy. This shows that increased GMA produces de-synchronization of the EEG alpha-rhythm and results in significantly more frequent convulsive seizures.

- GMA disturbances suppress the cortical reactivity to external receptive stimuli and raise the functional activity of the cerebral inhibitory components, such as the caudate nucleus in awake cats, Makarova (2000).

- A total of 40 men and women were tested for the effects on their writing of pleasant and unpleasant stories and changes in the local geomagnetic field, Persinger, Richards and Koren (1994). A double-blind method was used in the application of 10 mG fields over the right and left temporal lobes both separately and together. Men and women receiving the stimulation showed significantly more pleasantness when to the right hemisphere was exposed than the left hemisphere. Covariance with changes in the natural geomagnetic field was negatively correlated with pleasantness, increasing the significance of the experimental treatment.

- A group of 127 human volunteers were studied over a 4-year period and were observed to show a step-like increase in partial sensory deprivation (mainly hearing and seeing) for GMA levels above 15 nT, r = 0.33. The strongest correlation was found for the GMA during the 3-hr period at the beginning of the previous nights sleep, Persinger and Richards (1995).

- Rats being studied for chronic limbic epileptic effects showed significantly more aggression (r = 0.5) during GMA events, Persinger (1997). Intense aggression was observed for aa> 40 nT.

- St Pierre and Persinger (1998) found that aggressive biting in rats was positively correlated with GMA. Persinger (1999) identified a moderate association between annual GMA and the probability of war in the same year.

- Avdonina EN, Samovichev EG (1995) evaluated relationships between S-GMA and the days that serial crimes were committed during 1980-1990 in USSR. The analysis of 150 episodes (ten separate series) shows that the crimes are most probable immediately or 1-3 days after sharp decrease of solar activity (Wolf Numbers), geomagnetic activity (A3 and K indices) and of the lowest daily surface and air temperature.

- Bureau and Persinger (1995) investigated the time taken to initiate an epileptic seizure as a function of the level of GMA. They found that the latency decreased in a dose-response manner with GMA level. A 20-25 nT level reduced the latency by 12%.

Bureau, Persinger and Parker (1996) were studying rats with induced limbic seizure hypothermia. During high GMA, >35nT, depth of hypothermia was significantly reduced ($p<0.001$). In the subsequent 5 days mortality was increased when GMA >20 nT.

- In three separate experiments, Michon, Koren and Persinger (1996) tried to clarify the means by which GMA levels affected spontaneous epileptic seizures in rats. A 700 nT constant intensity signal inhibited the seizures. At lower levels, in the range of natural GMA a 7 Hz signal, exposure for 5 mins, once per hour, in the period midnight to 8 am, increased the incidence of seizures the following morning during the presentation of food. This appears to explain persistent effects of GMA on epileptic seizures.

- Rajaram and Mitra (1981) found a very significant, $p<0.01$, correlation between annual percentage of patients with convulsive seizures in Calcutta and annual mean GMA over the period 1955-1971.

- Epileptic seizures and dizziness are correlated with monthly and annual solar activity. This revealed significant differences between males and females, Stoupel, Martfel and Rotenberg (1991), Epileptic attacks were highly correlated jointly with GMA and lunisolar tides, Mikulecky, Moravcikova and Czanner (1996).

- Persinger (1995) identified a significant correlation between sudden epileptic death following periods high daily average GMA, >50 nT. Monthly incidence of sudden unexplained death was correlated with the monthly incidence of GMA events over 50 nT. They concluded that these results supported the role of the "anticonvulsant" melatonin.

- Persinger (1995a) observed a 35 % variance (multiple $r = 0.59$) for the portion of seizures related to increased GMA at the same time as the seizure and during the previous overnight period.

- Renton and Persinger (1998) monitored the partial epileptic-like experiences of 12 women over two months. Five of the women displayed significant increases when the daily GMA level exceeded 40 nT.

- Nikolaev et al. (1976) compared a daily variation of a psychopathological index for a group in a Moscow mental hospital with the Ap index over a period of 9 months. There was a very high correlation.

- Urgent hospitalization for mental disorders and suicide rise significantly with solar activity, Oraevskii et al. (1998a). Psychiatric admissions increase with solar radio flux activity ($p<0.05$) and sudden magnetic storms ($p<0.01$) and decrease with GMA ($p<0.05$), Raps, Stoupel and Shimshoni (1991). Admission for depression increases significantly after solar storms, Kay (1994).

- GMA can be considered as a trigger of migraine attacks, De Matteis et al. (1994). They confirmed this by finding a significant correlation between migraine attack and GMA in a small geographic area chosen to minimize the climatic differences.

- Conesa (1995, 1997) associated high GMA with isolated sleep paralysis.

- The geographic incidence of Multiple Sclerosis is strongly correlated with the Geomagnetic field rather than latitude, Resch (1995).

Neurological effects of Low GMA:

- Highly anxious pilots have greater anxiety on days of quiet sun, Usenko (1992).

- Conesa (1995, 1997) associated low GMA with vivid dreaming.

- Serial crime in Moscow increased 3 days after a low solar activity period. Avdonina and Samovichev (1995).

- Tunyi and Tesarova (1991) found that suicide, sports injuries, fatal work injuries, alcoholism are more prevalent during periods of low solar activity.

- Stoupel et al. (1995a) found that suicide in those older than 70 years was greater during periods of low solar activity. Stoupel et al. (1995b) found on a monthly mean basis that suicide was negatively correlated ($r = -0.22$, $p=0.03$) with GMA levels.

- Raps, Stoupel and Shimshoni (1992) found negative correlations for psychiatric admissions involving 1829 patients between 1977 and 1987, against sudden ionospheric disturbances ($r = -0.274$), GMA index ($r = -0.216$) and hours of positive ionization in the ionosphere ($r = -0.262$). All of these indices are positively correlated with the SR signal strength.

Neurological Summary:

Acute clinical effects of altered EEG rhythms have been observed in several studies. Geomagnetic Storms are strongly related to human health effects and death. Increased GMA, consistent with reduced melatonin, causes arrhythmic brain activity in the form of epilepsy. The occurrence of epilepsy and sudden unexpected death is highly correlated with increased solar activity and GMA storm events in many studies involving rats and people. Suicide is also strongly correlated with enhanced GMA and solar cycles.

There is weak evidence of effects for low GMA activity. For the elderly, >70 years, the risk is increased for low levels of S-GMA. Low S-GMA has also been associated with anxiety, vivid dreaming, injuries and alcoholism.

This adds very strong support for the SR hypothesis that elevated S-GMA alters brain waves and induces reduced melatonin. Weak support is given for the "U shaped" homeostatic relationship.

S-GMA related Mortality and Birth Rate:

If the above arguments are true then GMA would be correlated with mortality amongst the very old and very young.

- Zaitseva and Pudovkin (1995) used a multiple regression analysis involving the annual sunspot number (Ns) and deviation of the Kp index from average with a 30-year mortality and birth rate record, 1867-1897 from Russia. They determined that mortality rate rose significantly (r=0.78) and birth rate dropped significantly (r=-0.67) with changes in the S-GMA indices Ns and ΔKp.

- Shumilov et al. (1998) observed high correlations between traumas, deaths and sudden diseases with both enhanced and very low S-GMA levels, for miners working at high latitudes in the Spitsbergen mines.

- Kopanev, Efimenka and Shakula (1979) experimented with rabbits to test the effect of shielding from the geomagnetic field. They found significantly higher mortality in the animals shielded from GMF, compared to unshielded controls, supporting a homeostatic factor.

- A 100-fold shielding of guinea-pigs from the earth's GM field produced a reduction in ferment antioxidizing activity and non-ferment mechanisms in the heart, along with reduced carbohydrate metabolism for lipid metabolism, Babych (1995). A similar field reduction caused an inhibitory effect, down to complete stoppage, of the ciliate neuronal development of new-born rats, Svanidze et al. (1994) and Sandodze, Svanidze and Didimova (1995).

Cancer Incidence with Sunspot Cycles:

SR signals and S-GMA vary significantly with sunspot activity, and S-GMA is highly correlated with reduced melatonin. Melatonin is a highly potent antioxidant and therefore reduced melatonin causes enhanced DNA damage that can initiate, promote and progress towards cancer. Childhood cancer develops very quickly. Most adult cancer has long latencies. Hence a sunspot cycle related cancer could cluster increased childhood cancer and cancer initiation around sunspot maximum. Solar cycles could plausibly influence long-term cancer cycles. In a similar manner to acute air pollution events in relation to cardiovascular death, sunspot maximum, a period of years with reduced melatonin, could cluster and "harvest" those with terminal cancer, accelerating their death. The following studies report some results.

- Riabykh and Bodrova (1992) found a significant correlation between Wolf Sunspot Numbers and benign breast cancer for women in the middle and late menarche.

- Dimitrov (1993) found some significant lagged-correlations with malignant melanoma in Czechoslovakia and solar 7.5 and 11 year cycles.

- Dimitrov (1999) identified significant solar cycle related Malignant Melanoma and Non-Hodgkin's Lymphoma (NHL) in adult U.S. populations, and Dimitrov (1999a) correlated childhood NHL in the U.S. with solar cycles, $p<0.05$.

This study above found significant correlation with male leukaemia and female breast cancer in Thailand with annual sunspot numbers. There is consistent but limited data to correlate cancer with sunspot activity. The possibility that this related to UV radiation was considered. Malignant Melanoma (MM) is linked to UV radiation, which varies very slightly with sunspot activity, 0.16%, Haigh (1996). MM is also significantly elevated in telecommunications industry in Sweden, Vagero et al. (1985). MM is also associated with the review of ELF exposures in electrical occupations, Hardell et al. (1995) and with the highest ELF exposures in Tynes, Reitan and Andersen (1994). Hence it is highly probable that the relationships found by Dimitrov (1993, 1999) can be related to the SR signal and are unlikely to be caused by sunspot cycle related UV changes.

Other effects:

- Reproductive capacity and survival rates of micro-organisms, Escherichia (E Coli), Shigella and Salmonella, were highly correlated with GMA events. The experiments that started 2-4 days prior to a GM storm showed suppression of reproductive capacity followed by its stimulation. If the storm started on the first day of the experiment then there was a sharp drop in reproductive capacity and population death occurred within 1 to 5 days. In periods of low GMA the suppression of reproductive capacity was commonly recorded, Chernoshchekov (1989).

- Petrichuk et al. (1992) present results of a study of 35 premature and 35 healthy children over a period of 11 years. GMA was correlated with a range of significant factors, including a progressive increase in lymphocytes. If intrauterine development took place during a period of high solar activity, then early development resulted. For both groups the energetic age-dependent factors vary with the GMA. Lymphocytes that are associated with fetal and newborn hypoxia are perturbed by a combination of high atmospheric pressure and GMA, Petrichuk et al. (1998).

- Stoupel et al. (1993) found that intra-ocular pressure in relation to four levels of daily GMA was lowest on stormy days and highest on quiet solar days. This is a melatonin-related effect.

- A range of mouse, hamster and pisces cell lines were studied in situations of changing GMA, Belisheva and Popov (1995). Morpho-functional characteristics, including the percentage of polynuclear cells, were estimated. GMA causes an abrupt, step-wise change in the state of the cell cultures. Changes in properties of the cell surface related to cell fusion, the appearance of heterokaryons, enlargement of cellular adhesion and aggregation.

- Polikarpov (1996) studied the biological activity in soil, including DNA synthesis. The study found that during periods of increased solar and GMA the cell culture S.aureus 209 showed significantly greater biological activity.

Summary about S-GMA biological and health effects:

The above studies consistently show that GMA events produce significant biological changes in micro-organisms (E.Coli and Salmonella) as well as effects on soil organisms, animal cell-lines, human lymphocytes and eyes. This is in addition to the above studies showing cancer, reproductive factors, cardiac events and extensive neurological effects in people that are largely consistent with melatonin reduction by S-GMA.

There is very firm evidence for extreme variations of S-GMA to be classified as a Natural Hazard for all forms of life on earth. There is strong evidence for the GMA Melatonin Mechanism and robust evidence for the Schumann Resonance Hypothesis. The hypothesis and mechanism are supported by ULF/ELF studies showing reduced melatonin in animals and people.

Residential and Occupational exposures prediction:

Evaluation of the SR Hypothesis is advanced by evaluating its prediction that residential ELF and RF/MW fields should significantly increase in cancer, reproductive, cardiac and neurological effects in human populations. Typically these fields are about a thousand times higher in terms of the electric field and a million times higher in terms of exposure intensity and the magnetic field. For example a 1 mV/m SR signal converts to 0.27 pW/cm^2. A survey of 15 U.S. cities in 1979/80, Tell and Mantiply (1980), found the median exposure level was 5 nW/cm^2. Around 1 % of the population was exposed to more than 1 $\mu W/cm^2$. This is over 1 million times higher than the SR intensity. Living near high voltage powerlines chronically exposes people to ELF magnetic fields in the range 0.1 to 0.5 μT, about a million times higher than the 0-20 Hz SR signal at 0.5 pT. If these health effects are found then this strengthens both the SR Hypothesis and the GMA Melatonin Mechanism.

Electrical occupation and residential health studies:

Cancer Studies:

Hardell et al. (1995) reviewed almost 100 studies carried out up to 1994 and described significant increases in cancer as possible associations with ELF fields. They concluded that there were associations many cancer types. These included an increased risk of leukaemia in children and the existence of, or distance to, powerlines in the vicinity of their residence. Occupation exposure to ELF electromagnetic fields showed an increased risk of chronic lymphatic leukaemia, breast cancer, malignant melanoma of the skin, nervous system tumours, non-Hodgkin lymphoma, acute lymphatic leukaemia or acute myeloid leukaemia. Since 1995 many other studies have confirmed, extended and strengthened these conclusions.

For example, Cantor et al. (1995) found that occupational exposure to RF fields significantly increased female breast cancer. In a very large study, Szmigielski (1996), showed that RF/MW exposure from radar and radio in Polish military personnel caused significant increases in cancer mortality across many organs in the body, including brain tumours ($p<0.05$) and leukaemia ($p<0.001$). When the leukaemia cases were divided into various types, Lymphoma, Chronic Myelocytic and Acute myeloblastic Leukaemia were all individually very highly significant, $p<0.001$. Feychting et al. (1995) found a dose response increase in childhood leukaemia with exposure to high voltage powerlines, $\geq 0.5 \mu T$ RR= 5.1 (95%CI: 2.1-12.6) and Savitz et al. (2000) found a dose-response increase in brain cancer in electrical workers with the highest exposure giving RR = 2.5 (95% CI = 1.0-6.3).

Reproductive Studies:

Pregnant physiotherapists experience a dose-response increase in early pregnancy miscarriage having used microwaves for diathermy, Ouellet-Hellstrom and Stewart (1993). Later pregnancy miscarriage was found in physiotherapists using shortwave diathermy, Kallen et al. (1982), Larsen et al. (1991) and Taskinen et al. (1990). Kallen et al. and Larsen et al. also showed significant congenital malformation. Miscarriage is also associated with exposed electronic technicians, Vaughan et al. (1990), as well as electric blanket use, Wertheimer and Leeper (1986) and Belanger et al. (1998). It is also associated with powerline exposure, Juutilainen et al. (1993).

Electrical workers also pass on higher cancer risks to their children, Hicks et al. (1984), Spitz and Johnson (1985), Johnson and Spitz (1989), Wilkins and Hundley (1990), Bunin et al. (1990), Wilkins and Wellage (1996), Olshan et al. (1999), Smulevich et al. (1999) and Feychting, Floderus and Ahlbom (2000). This is likely to be from genetic damage of DNA in the sperm that could be direct, Lai and Singh (1996, 1997), or associated with reduced melatonin.

Cardiac Studies:

Cardiac effects include reduced Heart Rate Variability with 60 Hz fields from RF exposure in TV transmission stations, Sastre, Cook and Graham (1998) and Bortkiewicz et al. (1995, 1996, 1997). Male physiotherapists had significant dose-response increases in Ischemic heart disease from both short-wave and microwave exposure, Hamburger et al. (1983). Naval technicians exposed to radar during the Korean War were diagnosed with significantly higher cardiovascular disease, $p<0.001$, Robinette et al. (1980). Savitz et al. (1999) carried out the most extensive exposure related study and identified significantly increased and significant dose-response increases in cardiovascular disease mortality in electric utility workers. This was particularly related to cases of Arrhythmia and Acute Myocardial Infarction. Significantly elevated risk occurred for all cumulative exposures above 0.6 μT-years. The consistent elevation and exposure gradient effects were found for Arrhythmia and heart attack but not for atherosclerosis and chronic coronary heart disease. The latter two were elevated inconsistently. In contrast, Ptitsyna et al. (1996) found a doubling of chronic heart diseases in train drivers chronically exposed to ULF fields (0.001-10 Hz), consistent with SR frequencies.

Neurological Studies:

Children chronically exposed to a radar pulsed at 24.4 Hz showed significant impairment of learning and physical performance, Kolodynski and Kolodynska (1996). ELF exposed people show significantly more Clinical Depression, Verkasalo et al. (1997); Amyotropic lateral sclerosis, Deapen and Henderson (1986), Davanipour et al. (1997) and Savitz et al. (1998), Johansen et al. (1999); Alzheimer's Disease, Sobel et al. (1995, 1996); and Senile Dementia, Epilepsy, and Motor Neuron Disease, Johansen (2000). Significant increases in suicide from ELF exposures was reported by Perry et al. (1981) and Baris and Armstrong (1990). This was confirmed by Van Wijngaarden et al. (2000). They found a significant dose-response increase relative to recent ELF exposures with a zero exposure threshold. They relate this to melatonin reduction.

Public Health Conclusions:

Multiple published studies show that residential and occupational exposures to electromagnetic fields and radiation results in significant increases, including dose-response increases in cancer, reproductive, cardiac and neurological health effects and mortality. The prediction from the SR Hypothesis is very well confirmed. There is considerable consistency between the S-GMA studies and the residential and occupational ELF/RF/MW exposures. The very recent dose-response studies of ELF exposure and heart disease death, suicide and brain cancer all point towards a near zero threshold of ELF exposure for the level of no effect.

Recommended research to test the Hypothesis:

At the core of the Hypothesis is the postulate that human brains detect and respond to the SR signal. The response involves altered EEG rhythms, reaction times, melatonin production, blood pressure and heart rate. These need to be tested directly in relation to actual or experimental SR signals. Experimental design must deal with possible confounders. The physiological parameters could be monitored during isolated GMA events using local measurements of the SR signal. Tests need to be developed to detect whether the physiological parameters are more closely related to Kp or the SR signal. Isolation experiments, as used by Wever (1974), may be necessary. Correlation of SR signals with acute health effects, such as SIDS, cardiac arrhythmia, heart attack and suicide could also be evaluated for indirect but supportive or challenging evidence.

Summary and Conclusions:

S-GMA indices are significantly correlated with the biological and health effects. Confirmation of the Schumann Resonance Hypothesis first required that the SR Signal be highly correlated with the S-GMA indices. This would show that the SR signal was also correlated with the observed effects. The SR signal is shown to be very highly correlated with sunspot number and the GMA Kp-index. The GMA event analysis confirms that the characteristics of the SR signal closely follow the Kp-index and the electrons and ions density patterns in the D-Region. Hence this aspect of the hypothesis is confirmed.

The second aspect was the biological plausibility of the SR signal interacting with the brain and altering the melatonin production. This is theoretically predicted and plausible through resonant absorption that is made possible through frequency matching and tuned circuits. It is shown conclusively that environmental ULF/ELF electromagnetic fields at extremely low intensity do interact with brain tissue, changing the calcium ion fluxes, the EEG rhythms and reaction times. Brains and cells use phase-locked loop circuits to detect and respond to natural ULF/ELF electric signals. Laboratory experiments show that "Schumann-like" signals do change human and monkey reaction times using ULF to ELF electric field levels that approach the SR intensity. Human reaction times are also highly correlated, in a dose-response manner, with SR intensity, confirming this interaction.

The Melatonin Mechanism is strongly supported by multiple independent studies showing that ULF/ELF fields reduce melatonin in animals and people. The S-GMA connection is confirmed directly and with significant dose-response relationships. The S-GMA health studies and the occupational and residential health studies are almost all associated with reduced melatonin. This strongly supports The SR Hypothesis and the Melatonin Mechanism.

Mammals have advanced physiological systems to deal with diurnal and seasonal climate variations. This involves the melatonin/serotonin system communicating with all the vital organs in the body in order to maintain thermal homeostasis. External ULF/ELF signals help to regulate this through providing a Zeitgeber signal. It is highly probable that the Schumann Resonances provide this signal. It is thus plausible that alteration of the SR signal by S-GMA is transferred to mammal pineal glands and can affect their vital organs, especially their brains, CNS, hearts, reproduction and immune systems.

Taken together, the large body of research and the SR/S-GMA correlations shown in this paper, provides robust support for the hypothesis that the Schumann Resonance signal provides a Zeitgeber for human brains and acts as the plausible biological mechanism, including a melatonin mechanism, for the observed health effects caused by Solar/Geomagnetic Activity, including cancer, reproductive, neurological and cardiac health effects and mortality. This gives strong support for the hypothesis that S-GMA is a natural hazard.

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