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Biological Effects of Very Low Frequency (VLF) Atmospherics in Humans: A Review

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Abstract — The living organism is constantly affected by natural electromagnetic influences covering a wide range of frequencies and amplitudes. One of these influences, with frequencies in the very low frequency (VLF) range, (1-100 kHz) is represented by a phenomenon called VLF-*atmospherics* or VLF-*sferics.* Sferics are very short, weak, and dampened electromagnetic impulses generated by atmospheric discharges (lightning). Due to this fact, they can be used to study the characteristics of lightning, as well as the lower ionosphere. Besides their significance as indicators of thunderstorm activity, it has been hypothesized that sferics are able to affect the functioning of living organisms and physico-chemical systems. More specifically, this atmospheric parameter has been considered a possible trigger for changes in the somatic and emotional well-being of humans, sometimes referred to as weather sensitivity symptoms or meteoropathy. The following review attempts to summarize present knowledge of biological significance of VLF-sferics in humans.

Keywords: sferics — pulsed electromagnetic signals — biological effects

1. What are VLF-Sferics?

The living organism is constantly affected by natural electromagnetic influences covering a wide range of frequencies and amplitudes. One of these influences with frequencies in the very low frequency (VLF) range (1-100 kHz) is represented by a phenomenon called *VLF-atmospherics or VLF-sferics.* Sferics are electromagnetic impulses that are emitted during thunderstorms. Generated by lightning discharges, they propagate with approximately the speed of light through the atmospheric waveguide which is formed by the earth's surface and the lower ionosphere. During their propagation, sferics undergo pronounced changes with regard to their amplitude and frequency composition, due to dispersion and dampening effects. With increasing distance from their place of origin, both the higher and the lower frequency components decrease. Since the atmospheric waveguide functions similar to that of a band pass filter for frequencies around 10 kHz, this component undergoes minimal attenuation during the signal's propagation. For distances beyond 1000 km, mainly frequencies around 10 kHz can be observed (Betz, *et al.,* 1996).

Atmospherics are characterized by very low amplitudes and short durations. Their electric and their magnetic field strength does not exceed values of a few volts per meter and some microTesla, respectively (Reiter, 1995). Common signal intensities are in the nanoTesla range. The duration of a VLF-sferics impulse is on average 0.5 ms (Betz *et al.,* 1996). The signal features such as amplitude, frequency composition, waveform and duration primarily depend upon the kind of discharge, the distance between source and detector, and the conditions of transmission within the atmosphere.

Due to their origin in atmospheric discharges, sferics can be used for detection of lightning and localization of thunderstorm areas. The number of recorded impulses per time unit is an indicator of thunderstorm activity, which shows typical daily as well as seasonal variations. The highest pulse frequencies in mid-European countries can be registered during summer afternoons. A second peak occurs around midnight, which is present for most of the year (see Figure 1).

2. Biological Effects of VLF-Sferics in Humans

Besides their significance as indicators of thunderstorm activity, biological effects of VLF-atmospherics in humans have been reported. In general, these studies were characterized by two different approaches. The majority of studies was based on a descriptive-correlational approach, where attributes of the natural sferics activity were correlated with physiological parameters, indices of somatic and emotional well-being or behavioral measures. Here, sferics ac-

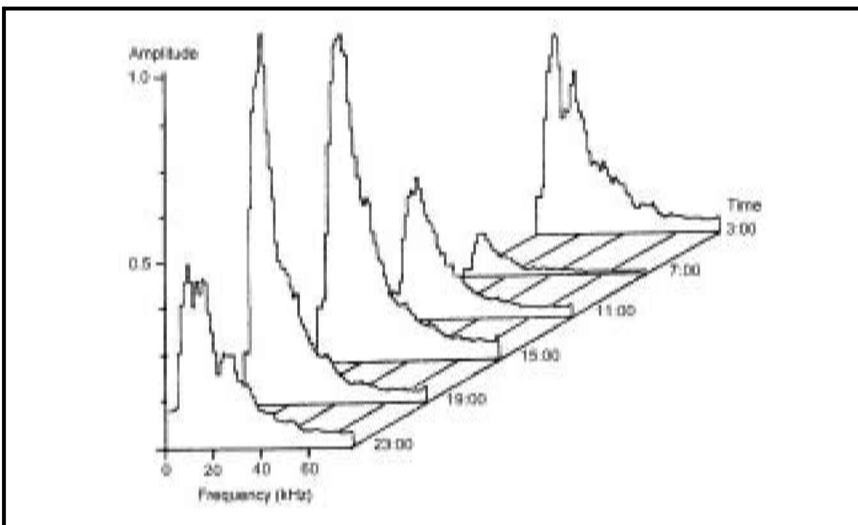

Fig. 1. Time dynamics of natural sferics activity for a day. Amplitude spectra of single sferics signals were combined for a duration of four hours each. The spectral maximum of the single spectra was standardized to 1.

tivity was usually described by impulse rates (number of sferics per time unit), which were registered within different frequency bands and intensity ranges. Only rarely were simulation studies performed in order to investigate sferics effects on humans under controlled experimental conditions.

2.1 Correlational Studies

One of the first observations of an association between biological processes in humans and natural sferics activity was mentioned by Dorno (1934), who described the case of Major Holtzei. The Major suffered from tinnitus after having been wounded in the First World War. In order to identify the triggers for his unbearable ear noises, he started to record the intensity of his symptoms every day, which showed a noticeable covariation with the impulse rate of sferics.

It was Reiter (1960) who did the first specific investigations concerning the biological effects of atmospherics in humans. Between 1948 and 1954 he assessed variations in pain perception within various patient groups over periods of several months. At the same time he registered sferics rates within two frequency bands (4-12 kHz and 10-50 kHz) and correlated both the atmospheric and biological parameters with one another. By using this method, he found significantly positive correlations between the impulse rate of atmospherics and the pain intensity reported by patients suffering from brain injuries, damaged tissue (operation wounds, scars), or internal illnesses (asthma, angina pectoris, migraine). Besides that, he observed higher rates of criminal offenses, suicides, car accidents, and prolonged reaction times during enhanced natural sferics activity (Reiter, 1950; 1951; 1960).

Investigations by Ruhenstroth-Bauer *et al.* (1984; 1985; 1987) revealed connections between different pathological symptoms and the impulse rate of VLF-atmospherics. This research group used a registration method developed by Baumer and Eichmeier (1980), who describe atmospherics as having clearly separated spectral maxima at 6, 8, 10, 12, and 28 kHz. The impulse rates at these frequencies were associated with the occurrence of epileptic seizures, sudden deafness, and myocardial infarctions. In the group of patients suffering from epilepsy ($n = 6$), who had been monitored over a period of 7 months, the onset of seizures was positively correlated ($r_s = .30$) with the 28 kHz sferics rate and negatively correlated ($r_s = -20$) with the 10 kHz rate (Ruhenstroth-Bauer *et al.,* 1984). In instances of sudden deafness, which had been analyzed for a sample of 203 patients over a period of one year, an elevated incidence of the illness showed up for a specific day, when the impulse rate in the 8 kHz range was low, and the 12 kHz sferics rate of the day before had been high. The correlation with this combined sferics measure was $R = .23$ (Ruhenstroth-Bauer *et al.,* 1987). Furthermore, a positive association ($r = .15$) between the number of patients admitted to hospitals because of myocardial infarctions and sferics activity in the 28 kHz band was observed by studying 162 clinic admissions due to this diagnosis (Ruhenstroth-Bauer *et al.,* 1985). A connection between atmospherics and the occurrence of heart attacks had been noticed before by Brezowsky and Rantscht-Froemsdorff (1966), and by Klein (1968). However, in these studies low impulse rates (amplitude $\geq$ 0.02 V/m) were coupled with an enhanced incidence of myocardial infarctions.

An investigation by Sulman, Levy and Lunkan (1976) showed that during enhanced sferics rates in the 10 kHz range subjects experienced symptoms such as migraine, sleep disorders or tension more often. Pelz and Swantes (1986) collected daily pain reports from patients with amputated legs ($n = 178$) over a period of four years and put them into relation with the 5 kHz-sferics activity (amplitude > 14 μV/[Hz $\times$ m]). Both parameters were positively associated with each other ($r = .68$). In addition, the number of thunderstorms registered within the residential areas of the patients was also correlated with the number of phantom limb complaints ($r = .47$). A relationship between VLF-atmospherics and pain symptoms had also been detected by Ludwig (1973). Here, patients suffering from rheumatism indicated feeling more pain during nights which had been characterized by a marked increase in sferics activity (amplitude $\geq$ 0.02 V/m). Finally, Laaber (1987) observed that pupils ($n = 23$) made more mistakes on a concentration task when sferics rates in the 10 kHz range had increased on the night before the test ($r = .35$).

Negative results were obtained in the studies by Ungeheuer (1952), Ließ (1959), and Harlfinger (1991). Stimulated by the work of Reiter (1950), Ließ (1959) had analyzed the relationship between the somatic and psychical condition of hospitalized patients (n = 30) and the sferics activity in the range between 3 and 50 kHz. None of the three analyzed symptom groups (cardiac/circulatory, scar/fracture and psychical complaints) was connected to the atmospherics rate, which had been recorded daily over a period of 6 months. In the same vein, Ungeheuer (1952) observed no increase of pathological incidences in 64 Bavarian clinics during a night (2.7. – 3.7. 1952) with markedly enhanced sferics activity in the 28 kHz band. Finally, Harlfinger (1991) monitored 8 subjects over a period of 4 weeks. On a daily basis, the beta-endorphin concentration in the venous blood as well as natural sferics rates (< 100 kHz) had been determined and put into relation with each other. No correlation could be revealed.

Looking at the amount of data gathered in these correlational studies, the predominance of positive results seems to support the assumption that sferics are biologically effective. However, correlational studies cannot detect causal connections and the possibility that other environmental parameters associated with sferics activity are responsible for the observed biological changes cannot be excluded.

Besides that, another problem present through the whole history of sferics research relates to the registration and analysis methods used to assess atmospherics. The applied signal descriptors are heterogeneous between different research groups and vary with regard to the applied amplitude and frequency ranges. Therefore, results are difficult to compare. Furthermore, critics of the

Baumer-Eichmeier-System (Baumer & Eichmeier, 1980) interpret the distinct sferics frequency maxima reported by the authors as artifacts due to errors within the analysis method. Thus, the dominating sferics frequencies which were found by Baumer and colleagues only partially reflect the natural sferics characteristics. Consequently, the outcomes of their biological studies, which make up a big part of recent sferics research concerning humans, have to be viewed with skepticism (for details concerning this problem see König *et al.,* 1990).

2.2 Sferics Simulation Studies

In order to detect biological effects of sferics, simulation studies have to be conducted where the signals can be presented under controlled experimental conditions. A first attempt to demonstrate such an effect in humans was executed by Ludwig and Mecke (1968). In their pilot study, the authors exposed subjects to various “sferics programs” characterized by different electric and magnetic field amplitudes (1 V/m, 10 mV/m; 26.5 μA/m, 2.65 mA/m). The square impulses with frequencies of 10 and 100 kHz were presented with pulse repetition frequencies of 2.5, 5, 10 or 20 Hz. The simulation provoked complaints of dizziness in some of the subjects who had been diagnosed as “labile vagotonics,” which implies an overresponsivity of the parasympathetic nervous system.

Ranscht-Froemsdorff and Rink (1972) investigated the influence of sferics on blood coagulation. Within a shielded climate chamber, subjects were exposed for several weeks to either a narrow banded 10 kHz-impulse with an amplitude of 10 mV/m and a repetition frequency varying between 3 and 10 Hz, or to a broad-banded (10-100 kHz) signal with an amplitude of 100 mV/m and an impulse rate ranging between 30 and 100 Hz. Both sferics programs aiming at simulating “good” and “bad” weather provoked a slowing in blood coagulation when the room temperature was between 17-22 ^{0}C.

Jacobi *et al.* (1981) also demonstrated an effect of VLF-sferics on blood composition. After a 3 hour-exposure to a 10 kHz-sferics impulse with an amplitude of 0.4 V/m, which was repeated with a frequency of 10 Hz, the platelet adhesiveness significantly increased. This response was most pronounced in anxious and depressed subjects, who had attained high scores on the psychasthenia scale of the MMPI (Minnesota Multiphasic Personality Inventory; Hathaway & McKinley, 1963).

Electrocortical effects were observed in a pilot study executed by Tirsch *et al.* (1994). The application of 10 kHz sferics with a magnetic field strength of 50 nT for only ten minutes led to a peak frequency shift within the EEG alpha band (8-13 Hz) in occipital regions by increasing the power of faster oscillations within this frequency range.

Similar to the correlational studies, the simulation experiments were also affected by different methodological problems. The artificially produced sferics signals varied greatly with regard to their amplitude and stimulus shape. Often square or sinusoidal impulses were used which are very different from the shape of natural sferics (see Figure 2). For the majority of experiments, only electric fields were applied, which cannot be considered to accurately represent the natural environment in which sferics are experienced, as most people spend the majority of time indoors, where the electrical component cannot penetrate. Therefore, it seems more likely that the magnetic field of atmospherics is biologically effective, which has hardly been studied.

Therefore, our research group conducted a series of experiments to examine whether the magnetic component of a sferics impulse is able to affect the human organism (Schienle *et al.,* 1996; Schienle *et al.,* 1997; Schienle *et al.,* 1998). For the simulation, a 10 kHz sferics signal with a duration of 500 μs was chosen (see Figure 2) and applied with a newly constructed atmospherics impulse generator with which previously recorded natural sferics can be precisely reproduced (Kulzer, 1994). The magnetic component of the applied signal had an amplitude of 50 nT (peak value), which is typical for a thunderstorm in close vicinity (< 100 km). The stimulus was applied with a pulse repetition frequency varying randomly between 7 and 20 Hz, representing intense thunderstorm activity. The electrical component of the sferics impulse was shielded, and therefore had no effect on the subjects.

As a dependent physiological variable to examine the biological effectiveness of VLF-atmospherics, the EEG was selected because in other investigations sferics activity had been associated with changes in complex behavior (Laaber, 1987), pain perception (Ludwig, 1973; Pelz & Swantes, 1986; Reiter, 1960), and the arousal level of organisms (Ludwig & Mecke, 1968), which would indicate that this signal possibly acts upon the central nervous system,

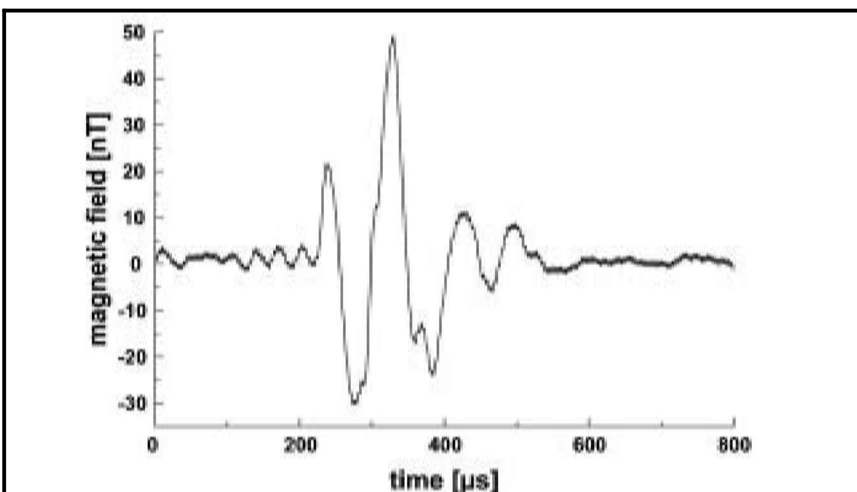

Fig. 2. Simulated 10 kHz-sferics impulse with a duration of 500 μs and a magnetic flux density of 50 nT (peak value).

on cortical or subcortical structures. Furthermore, brain electrical processes had been influenced by the application of 10 kHz sferics impulses as in the study by Tirsch *et al.* (1994).

In our first study (Schienle *et al.,* 1996), 52 subjects were exposed to the described 10 kHz-sferics signal for 10 minutes. Their electrocortical background activity within this time interval was compared to a 10-minute control period without sferics simulation. This was done at six electrode sites in right and left frontal, parietal and occipital regions (F3/F4; P3/P4; O1/O2). The exposure provoked a significant decrease in EEG alpha power (8-13 Hz) in parietal and occipital regions compared with the control condition. However, response differences were found between subjects who underwent the sferics condition first in comparison to subjects who had started the experiment with the control condition. Whereas the first group displayed a decrease in alpha power under treatment, the second group showed a tendency in the opposite direction. As a possible explanation for this sequence effect, it was hypothesized that a delayed or prolonged sferics effect could have caused the different response patterns. Assuming that after the termination of the treatment, sferics influence continued to be present in the form of a further power increase, this response would have been incorrectly interpreted as a sferics-induced power reduction.

This hypothesis was examined in a second experiment (Schienle *et al.,* 1997). Here, the EEG registration was continued after the end of exposure in order to detect possible prolonged effects. The 40 subjects participating in the experiment had been divided into two groups. The experimental group underwent a 10-minute baseline period, followed by 10 minutes of sferics stimulation, and subsequently, 20 minutes without sferics application. The control group underwent 40 minutes without sferics stimulation. As in the first experiment, groups were compared with regard to their spectral power in the different frequency bands of the EEG at six electrode sites (F3/F4; P3/P4; O1/O2).

The results showed that sferics exposure provoked increases in alpha power at all registered electrode sites with the exception of the left parietal region. Furthermore, an enhancement in beta power (14-30 Hz) was demonstrated, which was restricted to the right hemisphere. The effect was present during simulation and continued to be present until 10 minutes after the end of treatment.

In order to replicate this finding, a third experiment was conducted (Schienle *et al.,* 1998). Thirty-two women suffering from migraine attacks or tension-type headaches, who characterized themselves as weather-sensitive, underwent the same procedure as the subjects in the previous study. Half of the females were exposed to sferics, whereas the other half formed the control group. Again, the exposure provoked increases in alpha power at all electrodes (F3/F4; P3/P4; O1/O2) as well as enhancements in beta power, which were restricted to parietal and occipital regions. Once more, a prolonged sferics effect could be identified. Subjects of the experimental group were still on an increased alpha power level at parietal regions 20 minutes after the end of exposure. However, the stimulation did not induce headache symptoms, which is in line with previous results (Schienle *et al.,* 1996), demonstrating that the short-term sferics exposure was not consciously perceivable or able to elicit changes in the emotional and somatic well-being of the subjects.

2.3 Individual Differences in Sferics Responsivity

In addition to the concern within sferics research to describe biological effects induced by this stimulus, a further approach aimed at demonstrating individual differences in sferics responsivity. This differential approach was based on the hypothesis that certain constitutional factors are connected with an increased or decreased sensitivity towards sferics and therefore can act as mediators of sferics effectiveness. A concept often referred to in this context but hardly investigated is weather sensitivity. It is defined as the enhanced reactivity toward variations in atmospheric parameters such as humidity, pressure, temperature, *etc.* (Pschyrembel, 1990). Common symptoms are fatigue, negative mood, decreased work motivation and headaches. The high prevalence of weather sensitivity, which has been estimated at 30 per cent in mid-European countries (Faust, 1973), underlines the importance of studying the still unknown origin of this syndrome.

It was Reiter (1960) who hypothesized that the organisms' sensitivity to sferics could be the basis for weather sensitivity. He had observed that different patient groups displayed pain symptoms one or two days *before* an upcoming weather change when there were no visible signs for this change but sferics activity had already increased. In accordance with this hypothesis are the observations by Sulman *et al.* (1976), who noticed an increased occurrence of weather sensitivity symptoms during enhanced sferics activity in the 10 kHz band (unfortunately no statistical analyses are reported). Besides that, a further indication for a differential sferics effectiveness can be deduced from the results of Jacobi *et al.* (1981), and Ludwig and Mecke (1968), who discovered that subjects responded more strongly to the simulation of sferics-similar signals when they were emotionally or vegetatively labile.

Since these results are not sufficient to judge the significance of the weather sensitivity concept for sferics reactivity, this aspect was also covered within our series of experiments. In all studies, subjects filled in a weather symptom list (WSL). This measure was formed by data reported by Faust (1973), who had asked 778 adults for common emotional and somatic weather reactivity symptoms. The most frequently named 25 complaints were included in the WSL.

It could be shown (Schienle *et al.,* 1997), that subjects' electrocortical response towards sferics was dependent upon their degree of weather sensitivity. High scorers on the WSL displayed an alpha power increase that exceeded the stimulation period by 20 minutes until the end of registration, whereas low scorers displayed only minor power changes throughout the experiment (Figure 3). This process was most pronounced in a specific sub-band of the alpha

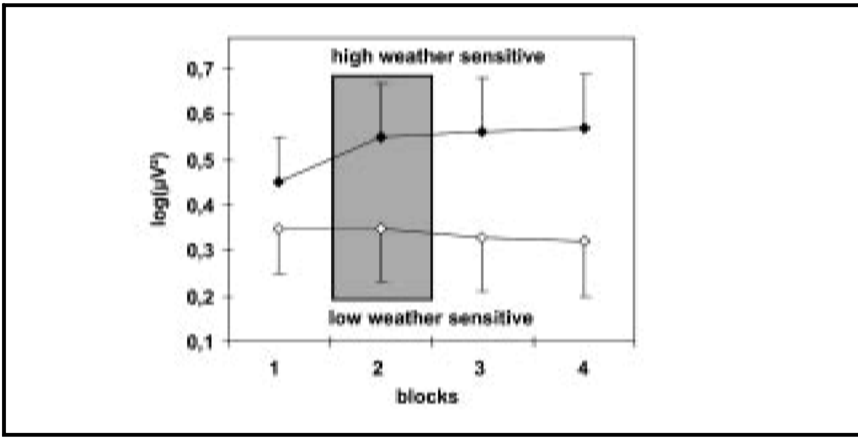

Fig. 3. Means and standard errors for log-transformed alpha power (11-13 Hz) in the four 10-minute blocks of the experiment comparing high and low scorers on the weather sensitivity questionnaire (upper and lower third) at electrode O2 (note : the gray block indicates sferics exposure).

band with frequencies between 11 and 13 Hz. Similar sferics-induced changes in alpha power were displayed by subjects with a high degree of neuroticism and somatic complaints. These traits showed highly positive corrrelations ($r \approx .70$) with the weather sensitivity dimension.

Comparable responses to the sferics simulation were displayed by women suffering from migraine attacks and tension-type headaches, who had characterized themselves as being weather sensitive (Schienle *et al.,* 1998). This group which reported that specific weather conditions (*e.g.* sudden temperature changes, upcoming thunderstorms) act as triggers for their pain also showed a prolonged alpha power enhancement to the exposure, which was present in parietal regions.

3. Explanatory Approaches and Future Research

In the majority of studies analyzing the biological effectiveness of VLF-atmospherics in humans, positive results have been obtained. Although some of the investigations were not free of methodological flaws, the amount of data gathered within this area strongly supports the idea that sferics indeed can influence the human body. The repeated demonstration of electrocortical effects induced by an accurately reproduced magnetic component of a 10 kHz-sferics impulse further underlines the physiological significance of this atmospheric parameter.

Considering the extremely low amplitude and short duration of sferics impulses, the ability of this signal to evoke changes in living organisms is surprising and remarkable at the same time, as we are exposed to electromagnetic fields of much higher intensities on a daily basis, *e.g.* from technological sources. Electric appliances and tools such as computers and TV-screens, heating blankets, or soldering irons produce magnetic field strengths of some microTeslas when we touch them or are in proximity. In comparison, the amplitudes of typical VLF-atmospherics are in the nanoTesla range and thus, only a fraction of the described technically generated fields which are considered to have no significant bioeffects (Polk & Postow, 1995).

Thus, questions are provoked as to why sferics could be biologically effective despite their low amplitude and how this influence could be transmitted to the organism. A possible explanation is provided by the concept of "biological windows," which states that organisms are characterized by different sensitivities to specific frequencies as well amplitudes within the electromagnetic spectrum. With regard to frequency windows, it could be shown that organisms are susceptible to ELF-fields or ELF-pulsed fields (1-300 Hz), especially when the signal frequencies correspond to brain wave frequencies (Postow & Swicord, 1995).

With regard to investigations on humans, it was demonstrated that these types of stimuli were able to change the electrocortical activity in a way very similar to the effects observed in the sferics simulation studies. In an experiment by von Klitzing (1993), subjects were exposed to a 150 MHz signal of low amplitude (1 $\mu W/cm^2$) which was pulsed with a frequency varying between 8 and 10 Hz. A stimulation for 15 minutes provoked an increase in EEG alpha activity. By using a 150 MHz signal with an intensity of 100 nT and a pulse frequency of 217 Hz, 10 Hz oscillations were also enhanced (von Klitzing, 1995). In both cases, the effect extended the stimulation period for some minutes. Increases in alpha activity were also observed in a study by Caccia and Castelpietra (1985), who applied a 2.2 mT field for 20 minutes. The signal repetition frequency was variable with an average at 50 Hz. Lyskov *et al.* (1993) revealed a significant increase in alpha as well as beta power by exposing subjects to an intermittent (1s on/off) sinusoidal 45 Hz signal with an amplitude of 1.26 mT for 15 minutes. A single case study by Sandyk and Derpapas (1993) showed that minimal field intensities can be sufficient to induce changes in electrocortical activity. A patient suffering from Parkinson's disease was exposed to a 7.5 picoTesla-field pulsed with 5 Hz. The repeated stimulation for 10 minutes led to an increase in alpha and beta power.

As these investigations illustrate, humans are able to respond to weak ELF- and ELF-pulsed magnetic fields with changes in brain electrical activity. The exposure provoked temporary alpha and beta power enhancements, a result that is in line with the observed electrocortical effects induced by VLF-sferics, which also can be viewed as ELF-pulsed signals.

But why should living organisms including humans display an increased sensitivity towards signals within the ELF-frequency range? König *et al.* (1981) take an evolutionary approach in their review of biological effects of environmental electromagnetism. The authors point out that organisms have been exposed to a variety of electromagnetic energies during evolution. The period when life began to evolve on earth was characterized by severe thunderstorm activity, when atmospherics occurred in great frequency and with great intensity. Consequently, the organism may have adapted to this type of electromagnetic phenomenon as it did to other electromagnetic energies such as visible light.

An indication for such an adaptation could be seen in the existence of brain-electrical activity. As König *et al.* (1981) point out, ELF-sferics such as the 10 Hz-Schumann oscillations are phenotypically very similar to the spontaneous alpha rhythm within the EEG of humans. The authors even go further in stating that the conditions under which both signals typically occur are also alike. Schumann resonances are observed primarily during fair weather conditions, a state that corresponds to the relaxed mental state associated with the presence of alpha waves in the EEG. Although this comparison seems to be oversimplified, there are other findings which could support the idea that Schumann resonances act as internal rhythm generators. Wever (1968) exposed subjects who stayed in a shielded underground bunker for at least one week to 10 Hz square impulses with an electric field intensity of 2.5 V/m, which should resemble ELF-sferics. In comparison to a control period without stimulation, the circadian body temperature rhythm was significantly shorter under the field condition (25.1 vs. 26.4 h). Wever (1968) concluded that ELF-sferics could act as a pacemaker that stabilizes circadian physiological rhythms.

VLF-sferics on the other hand could have a different biological meaning since their occurrence is more irregular and indicates thunderstorm activity at a closer distance. An increased rate of this signal type supplies information that within the next day or within the next hours the weather will change. By taking up an evolutionary point of view again, it can be speculated that in earlier times, this information was of critical importance for survival. The recognition of sferics as a warning stimulus for storms could have made it possible to foresee, and subsequently seek shelter from dangerous weather conditions.

Following this hypothesis, sferics could have a twofold biological significance. ELF-sferics, which indicate global thunderstorm activity, have a stabilizing influence on physiological rhythms, whereas VLF-sferics provoke startle or preparatory responses. It is not clear yet if the observed electrocortical changes under the influence of VLF-sferics can be considered as such a response. However, temporary alpha power enhancements have been found to be associated with states of emotional distress (Andresen, 1993) and preparation for motor actions (Shaw, 1996).

Although the described models and approaches trying to explain the biological changes induced by sferics are plausible, they are too non-specific regarding the underlying mechanisms for such an influence. In order to obtain more information concerning this point it is interesting to look at results obtained through *in vitro* studies analyzing the bioeffects of ELF and ELF-pulsed fields. The findings of these investigations point to the cell membrane and ionic control mechanisms as interfaces for the transmission of electromagnetic signals.

Here, it was demonstrated that such fields are able to affect calcium-ion fluxes across cell membranes (*e.g.* Bawin & Adey, 1976). Again, the observed changes were most pronounced when the applied frequencies were in the EEG range (5-20 Hz).

In order to explain the induced ion movements under the influence of weak magnetic fields in the low frequency range, which cannot be traced back to thermal effects or the induction of biologically effective currents, a model such as the cyclotron resonance model (Liboff, 1985) can help us to understand the observed effects. This approach states that an ELF magnetic field can provoke an ion movement when its frequency corresponds to the resonance frequency of the ion. Under the presence of a static magnetic field with an amplitude similar to that of the geomagnetic field ($\approx 50\ \mu T$), the resonance frequencies of physiologically important ions such as Na^+, K^+, Mg^{++} and Ca^{++} are in the ELF-frequency range. Since ion exchange processes through cell membranes play a crucial role for the signal transmission in the central nervous system, these observations could be also useful for the understanding of the observed electrocortical sferics effects.

Nonetheless, many questions still remain unanswered, *e.g.* the question concerning the signal components of sferics which hold the biological information. Besides the pulse repetition rate that could affect physiological processes, other signal characteristics such as waveform, amplitude, frequency, and duration of exposure are possible mediators of bioeffects. Further, models need to be developed that can explain why some subjects are more sensitive to VLF-sferics than others. Up until now, we cannot say if the prolonged alpha power increase displayed by emotionally and somatically labile individuals is a component or an initial phase leading to weather sensitivity complaints, since the stimulation did not induce immediate changes in the subjects' well-being. Nevertheless, the results imply a possible somatic basis for weather sensitivity, which should no longer be subsumed under the heading hypochondria.

In summary, the findings of biologically oriented sferics investigations imply that the human organism is more sensitive toward weak magnetic influences in the low frequency range than was previously assumed. This encourages further research within the field in order to identify the extent of inducible bioeffects as well as their underlying mechanisms.

References

Andresen, B. (1993). Multivariate statistical methods and their capability to demarcate psychophysiologically and neurophysiologically sound frequency components of human scalp EEG. In: Zschocke, S. & Speckmann, E.J. (Eds.). *Basic Mechanisms of the EEG.* Boston: Birkhäuser.

Baumer, H. & Eichmeier, J. (1980). Eine Anlage zur Registrierung der Atmospherics bei 10 und 27 kHz. (A system for registering atmospherics at 10 and 27 kHz). *Archiv für Meteorologie, Geophysik und Bioklimatologie,* 29, 143.

Bawin, S.M. & Adey, W.R. (1976). Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequencies. *Proceedings of the National Academy of Sciences,* 73, 1999.

Betz, H.D., Kulzer, R., Gerl, A., Oettinger, W.P., Eisert, B. and Jacubassa, D. (1996). On the Correlation Between VLF-Atmospherics and Meteorological Data. Paper presented at the *23rd International Conference of Lightning,* Florence, Italy.

Brezowsky, H. & Ranscht-Froemsdorff, W.R. (1966). Herzinfarkt und Atmospherics. (Cardiac infarction and atmospherics). *Zeitschrift für angewandte Bäder- and Klimaheilkunde,* 13, 679.

Caccia, M.R. & Castelpietra, R. (1985). Electroencephalogram synchronization induced by electromagnetic low frequency field administration in normal humans (preliminary observations). *Bioelectrochemistry and Bioenergetics,* 14, 215.

Dorno, C. (1934). Ein kleiner Beitrag zum Kapitel "Physiologische Wirkungen der Luftelektrizität." (A small contribution to the chapter "physiological effects of air electricity"). *Strahlentherapie,* 42, 87-95.

Faust, V. (1973). Zur symptomatik der wetterfühligkeit. (on symtoms of weather sensitivity). *Münchener Medizinische Wochenschrift,* 115, 441.

Harlfinger, O. (1991). Wetterbedingte einflüsse auf die schmerzempfindung. (Weather-related influences on pain perception). *Fortschritte in der Medizen,* 109, 647.

Hathaway, S. R. & McKinley (1963). *MMPI-Saarbücken.* German version of the Minnestota Multiphasic Persomality Inventory von O. Spreen. Bern: Verlag Hans Huber.

Jacobi, E., Richter, O. and Krüskemper, G. (1981). Simulated VLF-fields as a risk factor of thrombosis. *International Journal of Biometeorology,* 25, 133.

Klein, E. (1968). Über den möglichen Einfluß atmosphärischer Impulsstrahlung (Atmospherics) auf den Herzinfarkt. (On the possible influence of atmospherics on cardiac infarction). *Äztliche Forschung,* 22, 240.

König, H.L., Betz, H.-D. and Kulzer, R. (1990). Development and construction of a registration and analysis system for natural electromagnetic low frequency radiation (VLF-atmospherics). *Unpublished manuscript,* Technical University of Munich, Germany.

König, H.L., Krueger, A.P., Lang, S. and Sönning, W. (1981). *Biological Effects of Environmental Electromagnetism.* New York: Springer-Verlag.

Kulzer, R. (1994). Atmospherics-Impulse-Generator. *Unpublished manuscript,* Technical University of Munich, Germany.

Laaber, M. (1987). *Einfluß verschiedener Umweltparameter auf das Aufmerksamkeits-Konzentrationsverhalten von Schulkindern unter besonderer Beachtung der "SPHERICS."* (*Influence of Different Environmental Parameters on Attention/ Concentration of Pupils Focusing on Sferics*). Doctoral thesis, University of Vienna, Austria.

Liboff, A.R. (1985). Cyclotron resonance in membrane transport. In: Chiabrera, C., Nicolini, C., and Schwan, H.P. (Eds.). *Interactions Between Electromagnetic Fields and Cells.* New York: Plenum Press.

Ließ, I. (1959). *Untersuchungen über die Korrelation zwischen der atmosphärischen Impulsstrahlung als meteorotropen Faktor und Befindensstörungen von chirurgisch Kranken in Berlin.* (*Investigations on the Correlation Between Atmospherics as a Meteorotropic Factor and the Well-Being of Surgery Patients in Berlin*). Doctoral thesis, University of Berlin, Germany.

Ludwig, H.W. (1973). Wirkungen einer nächtlichen Abschirmung der elektrischen Feldstärke bei Rheumatikern. (Effects of nightly shielding of electric field strength on rheumatic patients). *Archiv für Meteorologie, Geophysik and Bioklimatologie,* 21, 305.

Ludwig, W. & Mecke, R. (1968). Wirkung künstlicher Atmospherics auf Säuger. (Effects of artificial atmospherics on mammals). *Archiv für Meteorologie, Geophysik und Bioklimatologie,* 16, 251.

Lyskov, E., Juutilainen, J., Jousmaki, V., Hänninen, O., Medvedev, S., and Partanen, J. (1993). Influence of short-term exposure of magnetic field on the bioelectric processes of the brain and performance. *International Journal of Psychophysiology,* 14, 227.

Pelz, J. & Swantes, H.J. (1986). Statistische Untersuchungen über das Auftreten von Stumpf- und Phantomschmerzen, sowie ihre mögliche Abhängigkeit von luftelektrischen Erscheinungen. (Statistical investigations on the occurrence of stump pain and phantom limb pain and their possible dependence on air-electrical phenomena). *Kleinheubacher Berichte,* 29, 367.

Polk, C. & Postow, E. (1995). *Handbook of Biological Effects of Electromagnetic Fields.* Boca Raton: CRC Press.

Postow, E. & Swicord, M.L. (1995). Modulated fields and window effects. In: Polk, C. & Postow, E. (Eds.). *Handbook of Biological Effects of Electromagnetic Fields.* Boca Raton: CRC Press.

Pschyrembel (1990). *Clinical Dictionary.* Berlin: Walter de Gruyter.

Ranscht-Froemsdorff, W.R. & Rinck, O. (1972). Elektroklimatische Erscheinungen des Föhns. Korrelationen von Blutgerinnung und simulierten Sferics-Programmen. (Correlation between blood coagulation and simulated sferics-programs). *Zeitschrift für angewandte Bäder- und Klimaheilkunde,* 19, 169.

Reiter, R. (1950). Besteht ein Zusammenhang zwischen luftelektrischen Störungen und meteorotropen Erscheinungen? (Is there a connection between air-electric disturbances and meteorotropic incidences?). *Zeitschrift für physikalische Therapie, Bäder- und Klimaheilkunde,* 3, 143.

Reiter, R. (1951). Verkehrsunfallziffern Bayerns und ihre Zusammenhänge mit Infra-Langwellen-Störungen. (Road accidents in Bavaria and their connection to long wave disturbances). *Münchener Medizinische Wochenschrift,* 25, 1.

Reiter, R. (1960). *Meteorobiologie und Elektrizität der Atmosphäre.* (Meteorobiology and atmospheric electricity). Leipzig: Akademische Verlagsgesellschaft Geest & Portig.

Reiter, R. (1995). Biological effects of electromagnetic man-made noise, atmospherics, and small ions. In: Volland, H. (Ed.). *Handbook of Electrodynamics.* Boca Raton: CRC Press.

Ruhenstroth-Bauer, G., Baumer, H., Burkel, E.M., Sönning, W. and Filipiak, B. (1985). Myocardial infarction and the weather: a significant positive correlation between the onset of heart infarction and 28 kHz atmospherics. *Clinical Cardiology,* 8, 149.

Ruhenstroth-Bauer, G., Baumer, H., Kugler, J., Spatz, R., Sönning, W. and Filipiak, B. (1984). Epilepsy and weather: a significant correlation between the onset of epileptic seizures and specific atmospherics. *International Journal of Biometeorology,* 28, 333.

Ruhenstroth-Bauer, G., Mees, K., Sandhagen, R. and Filipiak, B. (1987). Demonstration of statistically significant correlations between 8 and 12 kHz atmospherics and sudden deafness. *Zeitschrift für Naturforschung,* 42, 999.

Sandyk, R. & Derpapas, K. (1993). The effects of external picoTesla range magnetic fields on the EEG in Parkinson's Disease. *International Journal of Neuroscience,* 70, 85.

Schienle, A., Stark, R., Kulzer, R., Klöpper, R. and Vaitl, D. (1996). Atmospheric electromagnetism: individual differences in brain electrical response to simulated sferics. *International Journal of Psychophysiology,* 21, 177.

Schienle, A., Stark, R., Walter, B. and Vaitl, D. (1997). Effects of low-frequency magnetic fields on electrocortical activity in humans: a sferics simulation study. *International Journal of Neuroscience,* 90, 21.

Schienle, A., Stark, R. and Vaitl, D. (1998). Atmospheric influences and headache: Electrocortical responses of weather-sensitive women to the simulation of 10 kHz sferics, submitted for publication.

Shaw, J.C. (1996). Intention as a component of the alpha-rhythm response to mental activity. *International Journal of Psychophysiology,* 24, 7.

Sulman, F.G., Levy, D. and Lunkan, L. (1976). Wetterfühligkeit und ihre Beziehung zu Sferics, Ionen und Elektrofeldern. (Weather sensitivity and its relation to sferics, ions, and electric fields). *Zeitschrift für physikalische Medizin,* 6, 229.

Tirsch, W.S., Zenner, S., Ruhenstroth-Bauer, G. and Weinmann, H.M. (1994). Spektralanalytische Untersuchungen über den Einfluß der atmosphärischen Impulsstrahlung (Atmospherics) auf das menschliche EEG. (Spectroanalytical investigations about the influence of atmospherics on the human EEG). *Abstract, EEG-Symposium Obergurgl,* February, 1994.

Ungeheuer, H. (1952). Ein biometeorologisches Experiment. (A biometeorological experiment). *Berichte des Deutschen Wetterdienstes in der US-Zone,* Bad Kissingen, 42, 125.

von Klitzing, L. (1993). Athermische biologische Effekte durch gepulste elektromagnetische Felder. (Non-thermal biological effects by pulsed electromagetic fields). *Internationales Elektrosmog-Hearing,* Hannover, Germany.

von Klitzing, L. (1995). Low frequency pulsed electromagnetic fields influence EEG of man. *Physica Medica,* 2, 77.

Wever, R. (1968). Einfluß schwacher elektromagnetischer Felder auf die circadiane Periodik des Menschen. (Influence of weak electromagnetic fields on circadian periodicity of humans). *Naturwissenschaften,* 55, 29.