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# Hypothesis on how to measure electromagnetic hypersensitivity

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Electromagnetic hypersensitivity (EHS) is an ill-defined term to describe the fact that people who experience health symptoms in the vicinity of electromagnetic fields (EMFs) regard them as causal for their complaints. Up to now most scientists assume a psychological cause for the suffering of electromagnetic hypersensitive individuals. This paper addresses reasons why most provocation studies could not find any association between EMF exposure and EHS and presents a hypothesis on diagnosis and differentiation of this condition. Simultaneous recordings of heart rate variability, microcirculation and electric skin potentials are used for classification of EHS. Thus, it could be possible to distinguish “genuine” electromagnetic hypersensitive individuals from those who suffer from other conditions.

**Keywords:** athermal effects, heart rate variability, hypersensitivity to electromagnetic fields, radiofrequency, time series analysis

## Introduction

Electromagnetic hypersensitivity (EHS) is a term used to describe individuals who consider themselves suffering from the effects of electromagnetic radiation. Their estimated percentage varies according to country and year of inquiry and is dependent on the classification used. No objective criteria for EHS exist. According to Hallberg and Oberfeld the number of electromagnetic hypersensitive individuals in Sweden rose from 0.06% in 1985 to 9% in 2003, while in 2003 their number was 5% in Switzerland, and in 2004 they numbered 9% in Germany and 11% in England (Hallberg & Oberfeld, 2006). Johansson gives a number of 230 000–290 000 people (2.6–3.2% of the population) in Sweden who report symptoms when in contact with electromagnetic fields (EMFs) (Johansson, 2006). The prevalence in Austria increased from 2% in 1994 to 3.5% in 2008 (Schroettner & Leitgeb, 2008). For California the proportion of individuals with EHS symptoms is estimated to be around 3% of the population (Levallois, Neutra, Lee, & Hristova, 2002).

The symptoms described by people suffering from EHS are non-specific and range from headache, skin symptoms to sleeping problems, heart problems and

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**nervous symptoms** (Irvine, 2005; Johansson, 2009). Bergqvist and Vogel describe three stages in the development of EHS: temporary symptoms in the first stage, persisting symptoms with increasing intensity, duration or number of symptoms in the second stage and frequent neurovegetative symptoms triggered by EMFs in the third stage (Bergqvist & Vogel, 1997). Accordingly, impacts of complaints range from mild impairment to withdrawal from work and society. Scientists and sufferers disagree about aetiology and significance of this illness (Moore & Stilgoe, 2009).

Some scientists believe that EHS is caused by so-called “athermal” or “non-thermal” effects, i.e. electromagnetic radiation effects that do not result in detectable heating of exposed tissue (Johansson, 2006). As such they are likely to occur well below the current limit values and seem to be the “long-term effects” of EMF exposure in contrast to the short-term thermal effects.

The probability of adverse effects in relation to EMF exposure depends on the individual constitution, pre-existing disease, duration of exposure, type of electromagnetic radiation (continuous wave or modulated), how sensitized the individual is by prior exposures and intensity, among others. There is no specific set of symptoms that would clearly distinguish an electromagnetic hypersensitive individual from someone with other hypersensitivity syndromes. Until now, no model for the biological effect could be established. Therefore it is not possible to define the influencing factor of an athermal effect, which is a prerequisite for any statistical testing. EHS may be a multi-causal event, complicating the identification of one or more contributory mechanisms.

In double-blind provocation studies with regard to EHS, people are classified as sensitive or not according to their own assessment (e.g. self-reported EHS; Eltiti et al., 2007; Hillert et al., 2008; Kim et al., 2008; Landgrebe et al., 2008; Wilén, Johansson, Kalezic, Lyskov, & Sandström, 2006). Huss and others, in an innovative environmental medicine counselling project, came to the conclusion that in 32% of cases there was a plausible relationship between EMF exposure and reported symptoms (Huss et al., 2005). This means that 68% of those who claim to be electromagnetic hypersensitive could, in fact, suffer from other conditions or even have a psychological condition causing their symptoms. With this in mind, it is no surprise that provocation studies with self-reported electromagnetic hypersensitive individuals could not find any association between symptoms and exposure. What is needed is a method to measure “genuine” EHS in order to differentiate this kind of hypersensitivity from other kinds of conditions.

### Proposal on how to measure EHS

There are possible parameters that could be used to measure EHS. Thus, “genuine” electromagnetic hypersensitive individuals could be distinguished from those who suffer from other conditions. A prerequisite for possible parameters to measure EHS would be: they must be beyond voluntary control and they must be measurable.

EHS has been tested mostly on the level of one or more effects such as changing skin temperature, bodily sensations or cognitive efficiency and other psychological events immediately on exposure. As such, only short-term thermal effects are taken into account as possible outcomes of exposure to EMFs. Obviously, the athermal reaction of biological systems is initiated on the vegetative level, as this is where biological functions are fundamentally regulated, e.g. oxygen supply through respiration and blood flow. Following with a considerable time delay, there might be a change of skin temperature or in behaviour on any cognitive or mental level. Additionally, it is of importance that the test parameter is not influenced by autogenous activity, for instance changing breathing frequency. Suitable are the

following non-invasive methods: heart rate variability (HRV), microcirculation (capillary blood flow) and electric skin potentials.

The determination of HRV is a well-established method to evaluate the activity of bioregulation: the time variances of succeeding heartbeats are within an individual time frame. A limited variance points to a disturbance in bioregulation. A constant succession of the single events is not consistent with life. The methods used are a time-series analysis (Figure 1) and the frequency analysis (Fast Fourier Transformation, FFT) of the subsequent ECG R-waves (Figures 2 and 3). In the time series analysis (Figure 1), the ECG signal is recorded over a time frame of 1.1 s (triggered by the R-waves) and displayed in an overlapping manner over a period of 3 min. A shortened bandwidth of the actions represents a limited bioregulation as it is seen in electromagnetic hypersensitive individuals under or shortly after EMF exposure from mobile phones. The narrower the basic frequency of the ECG in the FFT (limited bioregulation), the more marked the harmonics (Figure 3).

Wilén et al. could not find significant differences in their power spectral analysis of HRV recordings between self-declared electromagnetic hypersensitive individuals and matched controls (Wilén et al., 2006). But they did not investigate and compare the dynamics of changes in HRV during and after exposure. In our experience, the dynamics of changes in HRV are of vital importance. After recording and analysing them and comparing them with simultaneously recorded measurements of capillary blood flow and electric potential difference of the skin (as described further below),

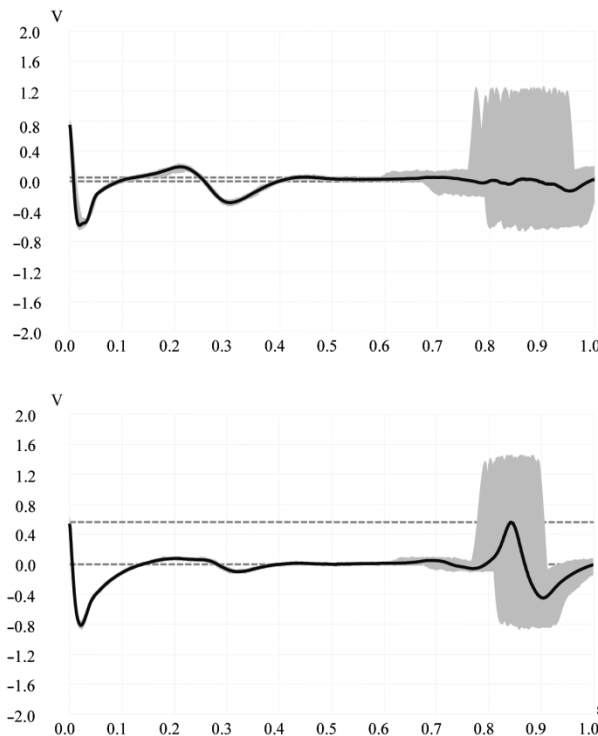


Figure 1. HRV in a time series analysis showing active bioregulation (above) and limited bioregulation (below). The shaded area (light grey) represents all the single events. The continuous line (dark grey) represents the arithmetic mean of the succeeding heartbeats. The maximum of the continuous line represents the core area of the successive R-waves following the trigger: the higher this mean maximal value in relation to the individual event, the narrower is the bandwidth of the HRV.

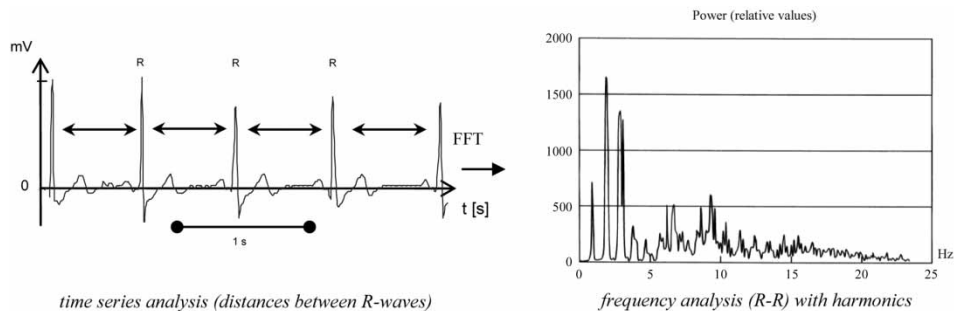


Figure 2. Determination of the HRV using FFT. The variability of the heart rate is determined via frequency analysis (FFT) of the basic signal (distance of individual R-waves in the ECG) and its harmonics.

a consistent pattern of changes can be found in “genuine” electromagnetic hypersensitive individuals.

Yilmaz investigated the effects of EMF from mobile phones on the HRV using nonlinear analysis methods (Yilmaz & Yildiz, 2010). He found significant changes in healthy young volunteers and concluded that EMF significantly influenced the cardiac system in its complexity. We hypothesize that changes would be more pronounced in “genuine” electromagnetic hypersensitive individuals.

The continuous detection of **capillary blood flow (microcirculation)** is **an important tool for analysing the capacity of autonomous nervous activity (Figure 4)**. The **substantial intestinal motility is particularly reflected in this dynamic of regulation**. In EHS patients this regulation shows no activity at all for some time after exposure (Figure 5). The method used is the measurement of peripheral blood flow by Doppler meter at the lobe of the ear. Changes in capillary blood (microcirculation) flow are analysed as a function of time (Figures 4 and 5). The microcirculation is controlled by the vegetative nervous system. Recorded before, during and after exposure, these data thus provide insights into the activity of bioregulation. **The basic frequency** is the typical periodical biological regulation of approximately 0.15 Hz (one period of about 7 s), which **correlates with the intestinal motility and gallbladder motility**. Superimposed on those signals are high-frequency signals that correlate with the individual heartbeats (R-waves) (Figure 4). **Under stress, i.e. during and after EMF exposure, the basic frequency of the microcirculation is diminished as is the high-frequency signal (Figure 5)**.

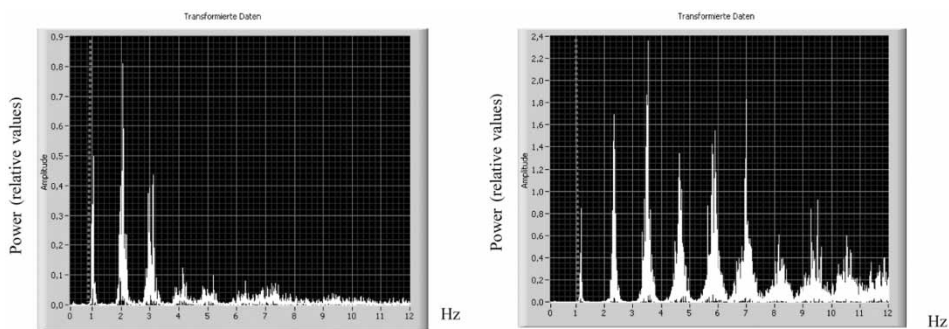
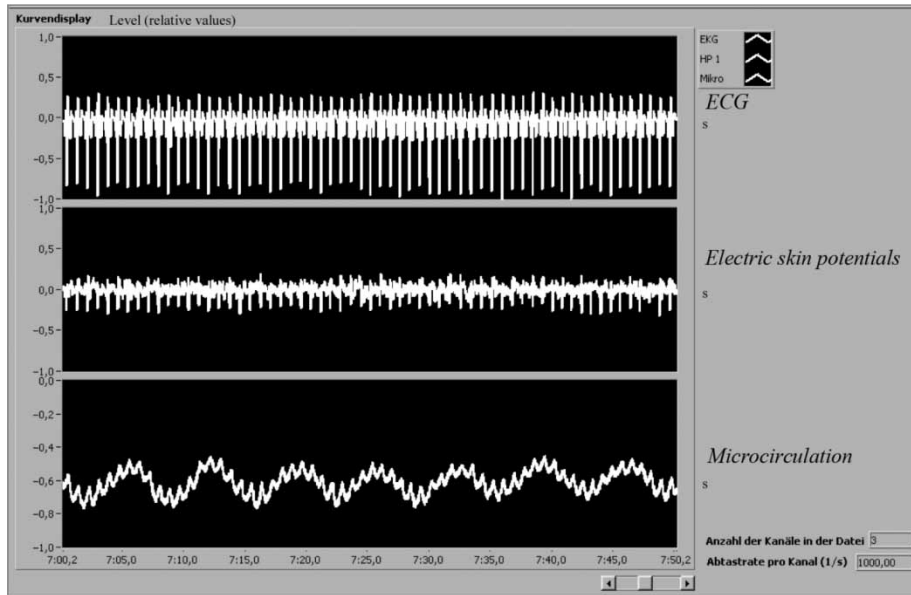
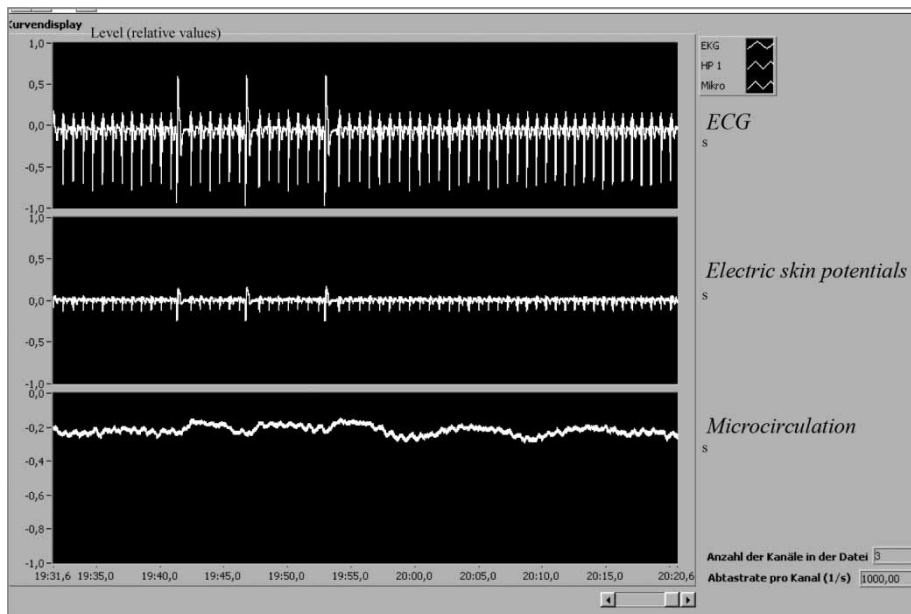


Figure 3. Results of the FFT with power spectrums of ECG, basic frequency of ECG (-) and harmonics. The left picture with almost no distinct harmonics is typical for an active bioregulation, the right picture due to the increased amount of harmonics is typical for a limited bioregulation.



**Figure 4.** Simultaneous display of temporal ECG changes (on top), electric skin potentials (middle) and microcirculation (bottom) typical for **a normal (healthy) bioregulation.**

The electric potential difference on the skin is measured by an electrode matrix over some millimetres on the skin surface of the forearm (Figure 6). The measured potentials are displayed as temporal sequence of the recorded signals during the different experimental settings (before, during and after exposure). Under normal conditions (stress-free situation), the electric skin potentials reflect low-amplitude signals like the ECG (Figure 4, middle).



**Figure 5.** Simultaneous display of temporal ECG changes (on top), electric skin potentials (middle) and microcirculation (bottom) typical for **a pathological bioregulation.**





Figure 6. Measurement device for the determination of the electric potential difference. Four times four electrodes serve as sensors and are placed in a distance of 2.4 mm from each other onto the skin surface.

With increasing stress, i.e. under EMF exposure, the electric skin potential difference shows less and less amplitude (Figure 5, middle) until there is no more oscillation. Under extreme stress there is a zero line only.

While healthy individuals show no changes in HRV, electric skin potentials and microcirculation under exposure compared with the unexposed state, “genuine” electromagnetic hypersensitive individuals exhibit typical changes in those parameters over time of exposure and thereafter (Table 1). With no exposure both groups are not distinguishable from each other. In contrast to that, individuals hypersensitive to other substances/agents exhibit the same changes or parts of them already in an unexposed state. Under exposure those parameters do not change substantially. Another group of individuals cannot be classified and thus cannot be evaluated.

All these three parameters (HRV, electric skin potentials and microcirculation) are influenced in EHS patients under exposure within some minutes and remain so after exposure for some minutes up to 1 h. The all-in-all matrix with these data can be used for EHS classification (Figures 1 and 3-5), as shown in Table 1, and should allow to distinguish “genuine” EHS from other types of conditions (Table 1). The proposed method to measure EHS using simultaneous recordings of HRV, microcirculation and electric skin potentials is the result of extensive measurements by one of the authors (von Klitzing) in this area.

## Discussion

EHS has been attributed by most researchers to psychological processes or has been described as somatization/psychiatric disorder so far (Landgrebe et al., 2008;

Table 1. A hypothetical overview of changes in electrophysiological parameters in healthy individuals, in electromagnetic hypersensitive individuals, in individuals with other conditions and in individuals that cannot be classified.

	Healthy individuals	“Genuine” electromagnetic hypersensitive individuals	Individuals hypersensitive to other substances/agents etc.	Individuals that cannot be classified
Without EMF exposure				
Time series analysis of heart rate	Normal bandwidth of HRV	Normal bandwidth of HRV	Narrow bandwidth of HRV	Narrow bandwidth of HRV or normal bandwidth of HRV
FFT	Almost no distinct harmonics	Almost no distinct harmonics	Increased amount of harmonics	Increased amount of harmonics or almost no distinct harmonics
Electric skin potentials	Correlation with ECG-waves	Correlation with ECG-waves	Less amplitude	Less amplitude
Microcirculation	Basic frequency of approximately 0.15 Hz High-frequency signal correlating with the R-waves of the ECG	Basic frequency of approximately 0.15 Hz High-frequency signal correlating with the R-waves of the ECG	Basic frequency of approximately 0.15 Hz High-frequency signal correlating with the R-waves of the ECG or Basic frequency diminished, High-frequency signal diminished	Basic frequency of approximately 0.15 Hz High-frequency signal correlating with the R-waves of the ECG or Basic frequency diminished High-frequency signal diminished
During and after EMF exposure				
Time series analysis of heart rate	Normal bandwidth of HRV	Narrow bandwidth of HRV	Narrow bandwidth of HRV	No changes or Unspecific changes
FFT	Almost no distinct harmonics	Increased amount of harmonics	Increased amount of harmonics	No changes or Unspecific changes
Electric skin potentials	Correlation with ECG-waves	Less amplitude	Less amplitude or Unspecific changes	No changes or Unspecific changes
Microcirculation	Basic frequency of approximately 0.15 Hz high-frequency signal correlating with the R-waves of the ECG	Basic frequency diminished, high-frequency signal diminished or still present	Basic frequency diminished, high-frequency signal diminished or still present	No changes or Unspecific changes



Leitgeb, 2009; Rubin, Munshi, & Wessely, 2005; Rubin, Nieto-Hernandez, & Wessely, 2010). It had been widely assumed that with repeated provocations, symptoms in the self-reported electromagnetic hypersensitive individuals would be similar and could be provoked in the short term. Thus a lot of provocation tests have been conducted (Eltiti et al., 2007; Nam et al., 2009; Oftedal, Straume, Johnsson, & Stovner, 2007; Regel et al., 2006; Rubin, Hahn, Everitt, Cleare, & Wessely, 2006; Rubin et al., 2010). Almost all of them could not demonstrate any real EMF effect and they seem to confirm that EHS is only “psychological”. McCarty et al. questioned this assumption of similar symptoms and referred to the considerable variability of reported effects in previous surveys. They could demonstrate that EMF effects could lead to somatic reactions in a sensitive individual (McCarty et al., 2011).

Based on previous unpublished research we present our hypothesis on how to measure EHS assuming like McCarty et al. that subjective symptoms vary considerably inter-individually and across subjects. **In our hypothesis, the tested parameters are on the vegetative level. They are relatively free from voluntary control.** Nevertheless they still vary considerably. Moreover based on our measurements, we are convinced that within the group of self-reported electromagnetic hypersensitive individuals there are “true” cases of hypersensitivity and “false” ones. The latter could comprise what others subsume as “psychological” effects of EMF.

In this paper, we propose a method that would enable researchers to distinguish “true” electromagnetic hypersensitive individuals from other kinds of conditions. We assume that somatic reactions could be provoked by EMF effects in sensitive individuals. According to our hypothesis, a classification of EHS should be possible with data based on simultaneously measured HRV, electric skin potentials and microcirculation during and after exposure to EMFs.

Our hypothesis is a hypothesis that eludes conventional statistical testing methods, because the parameter to be tested would be the vegetative system. But the vegetative system cannot be regarded as constant. It is constantly changing over time, which means that the tested effect will be influenced by intra- and inter-subject variability. In other words, the connecting parameter between groups is not distinct.

The simultaneous measurement of HRV, capillary blood flow and electric skin potentials over time in electromagnetic hypersensitive individuals under or shortly after exposure in time-slot EMF does not allow for statements about a certain harmful effect of EMFs on humans. **We are only measuring a phenomenon,** but this demonstrates **that the biological system of electromagnetic hypersensitive individuals responds to EMF exposure. Probably in those people EMFs are perceived by the vegetative nervous system as a kind of disturbance.** The extent to which this is related to other possible measurements, such as immune function tests, remains to be elucidated. Johansson et al. could demonstrate *in vivo* that cutaneous mast cells increase in number and migrate towards the uppermost dermis after EMF exposure (Johansson, 2007; Johansson et al., 2001). Interestingly, this effect was found 2–4 h after exposure, which is later than what we saw by our tested parameters. But again, there is a considerable time delay.

## Conclusion

We hypothesize that the group of self-reported electromagnetic hypersensitive individuals comprises a heterogeneous group of people who “truly” experience symptoms after being exposed to EMFs and people with other conditions. This, in combination with variability of symptoms, absence of model of effect, small number

of cases and focus on short-term effects, might be the reason why most provocation studies could not find any significant association between EMF exposure and bodily symptoms in the self-declared EHS patients.

The proposed method of simultaneously measuring HRV, capillary blood flow and electric skin potentials over time could allow to distinguish “genuine” electromagnetic hypersensitive individuals from individuals who suffer from other conditions. EHS is still a “*terra incognita*” in science, and the variability of the vegetative system makes it difficult or even impossible to investigate this phenomenon using conventional statistical methods.

### Declaration of interest

This study was supported by the excellence initiative of the German federal and state government. The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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