Evidence of a Nonlinear Human Magnetic Sense

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Summary

- Model for detecting EMFs?
- Sensory transduction
- Evoked potentials (EPs)
- Nonlinear magnetosensory EPs

This work addresses the question of how we should think about the process by which EMFs interact with living tissue. I studied the possibility that it is a form of sensory transduction. If so, we would expect to be able to measure evoked potentials. I'll show you data indicating that magnetic fields do in fact produce evoked potentials.

How Should the EMF Interaction Be Modeled?

Proposed theories

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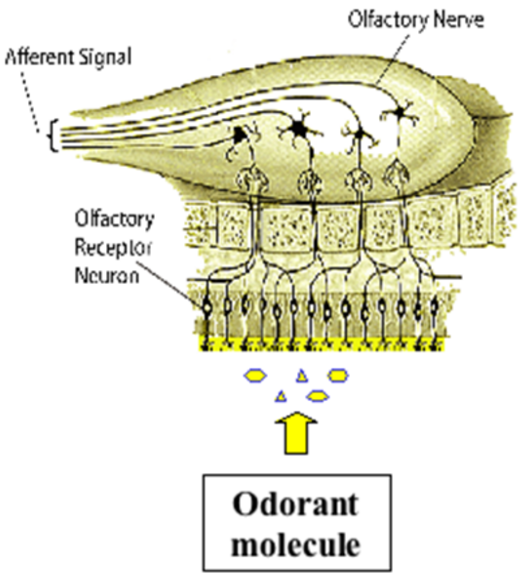
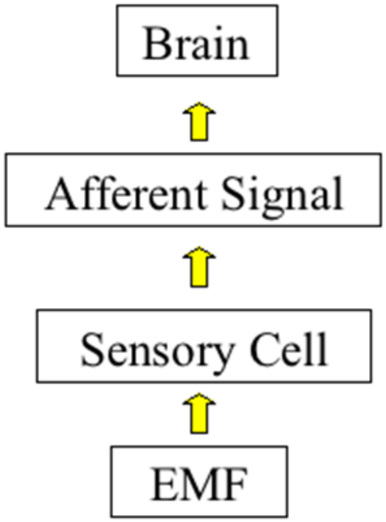
Sensory perception *

* Becker & Marino: Electromagnetism & Life, 1980.
Marino: Bioelectrochem., 1993.
Sonnier & Marino: Electro - & Magnetobiology, 2001.
Marino et al.: Clin. Neurophysiol., 2004.

Many biophysical and physiological theories have been proposed to explain how EMFs interact with the body. Far too many for me to even list, much less describe. Our theory, based on work stretching back more than 25 years is that the detection process is a form of sensory transduction.

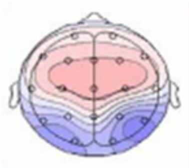
Sensory Transduction Hypothesis





The panel on the left depicts the operation of a typical sensory system. Our hypothesis is that detection of EMFs occurs by means of the same processes. In sensory transduction a stimulus such as light, sound, touch, or as illustrated here odor interacts with a specialized cell (it's either a neuron or a neuroepithelial cell) thereby setting in motion a chain of electrochemical events culminating in an afferent signal to the brain. Our idea is that EMF detection works the same way.

Experimental Rationale

All known sensory stimuli ➡  ➡ Evoked Potentials

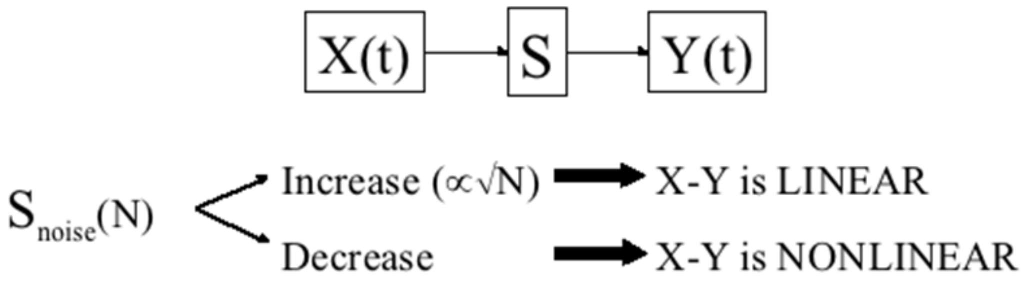
- Onset (Off-On transition)
- Offset (On-Off transition)
- Latency ~ 50-500 ms

If magnetic field is sensed ➡ Evoked potential

This slide depicts the reasoning behind our experiment. Sensory stimuli produce evoked potentials. If a magnetic field is a sensory stimulus, then it ought to produce evoked potentials. What are the characteristics of evoked potentials? That is, how do we know an evoked potential when we see it? Well, they can be triggered by the onset of the stimulus or its offset, and they usually occur with a latency of 50-500 ms. So, if we see electrical changes in brain electrical activity that occur in relationship to the onset and to the offset of a magnetic field and they occur with a latency of up to 500 ms, we planned to conclude we had observed an evoked potential.

Our Definition of Nonlinearity*

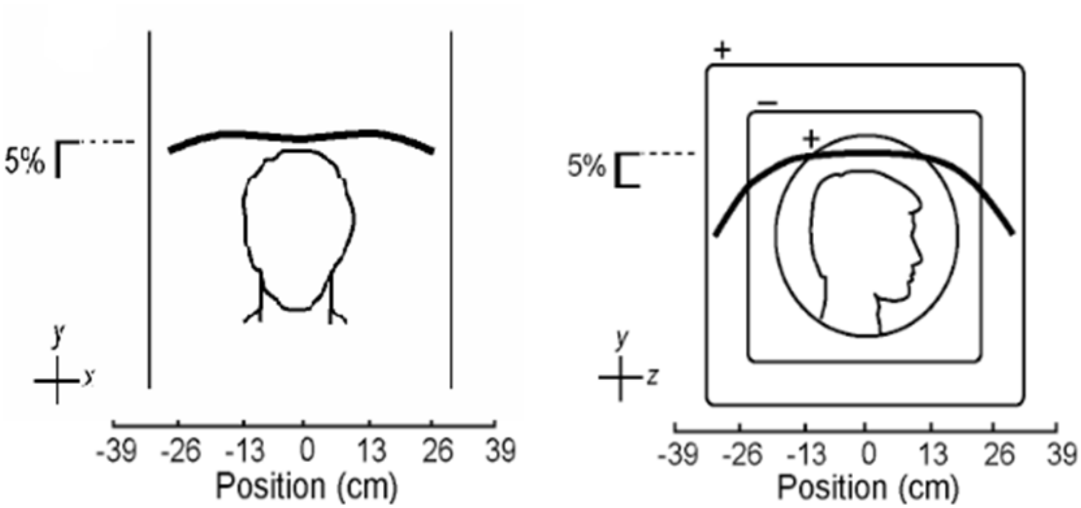
X(t): Sensory stimulus (applied N times)



*Marino et al, BEMS, 2001 - Marino et al, BEMS, 2003

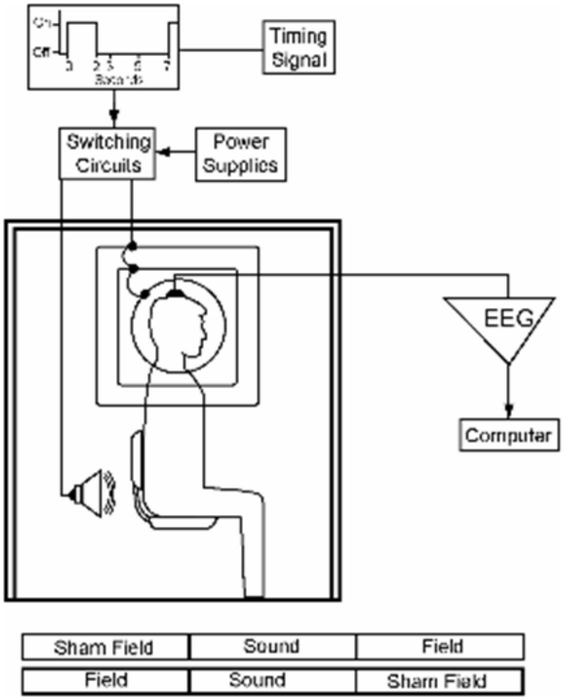
We are going to conclude, ultimately, that evoked potentials induced by magnetic fields are "nonlinear," so I want to make it very clear what I mean by that term. What I have in mind here is that S is the magnetic field, S is the brain, and Y is the electrical activity of the brain. If we repetitively apply X and average Y, then we can think of two possible results of that process. If the signal-to-noise increases with N, then we define the relationship between X and Y to be linear. If it decreases, then the relationship is nonlinear.

Homogeneity of Magnetic Field
(2 gauss RMS, 60 Hz)



A magnetic field that was homogeneous to within 5% was applied using a pair of 3 coils. The coils were designed using a commercial software program, and field uniformity was verified by measurements using a fluxgate magnetometer.

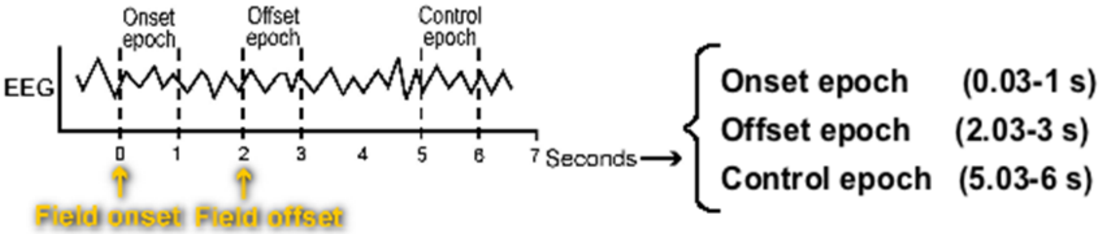
Experimental Procedure



This slide depicts our overall procedure. The subject sat in an isolation chamber that was carefully arranged to avoid all possible sensory cues. The EEG was measured from occipital, central, and parietal electrodes, digitized, and stored for analysis. The field was applied for 2 seconds, followed by a 5-second inter-stimulus period. We call the combination of one exposure epoch and one inter-stimulus period a trial. We used sound as a positive control. The subject underwent 3 blocks of trials. The sound was always applied in the middle block of trials. The order of application of the field or sham-field was varied randomly from patient to patient. I want to note that the subject had no indication whatsoever. That is, there was no sensory difference between application of the field and the sham-field.

Experimental Design

N≥50 7-s trials

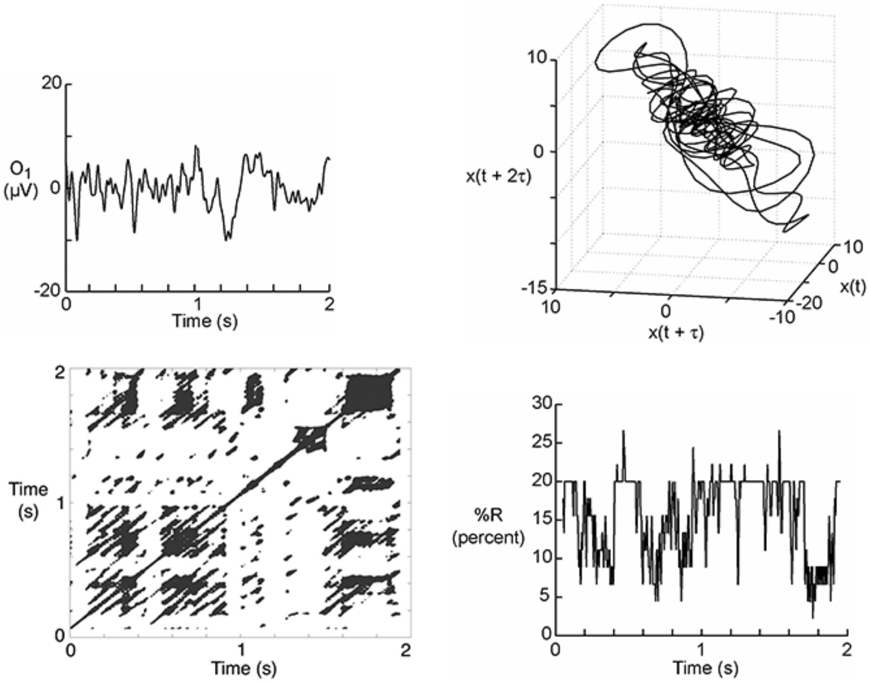


Linear analysis: V(t)

Nonlinear Analysis: V(t) ➡ %R(t)

In order to determine the possible existence of an onset effect we examined the EEG during the first second after application of the field. To detect an offset effect we examined the EEG between 2 and 3 seconds. In both cases the control was the EEG measured between 5-6 seconds in the trial. A Faraday induction effect was triggered in the electrodes due to the rapid field onset and offset. This spike was eliminated from the analysis by deleting the first 30 ms after the stimulus from the EEG record. We performed 2 independent analyses. In one case we used the standard method of time-averaging of the voltage signal recorded from the scalp. This method of analysis detects only linear determinism. We also analyzed the data using a form of a nonlinear analysis called recurrence quantification analysis. The dependent variable in this analysis was percent recurrence.

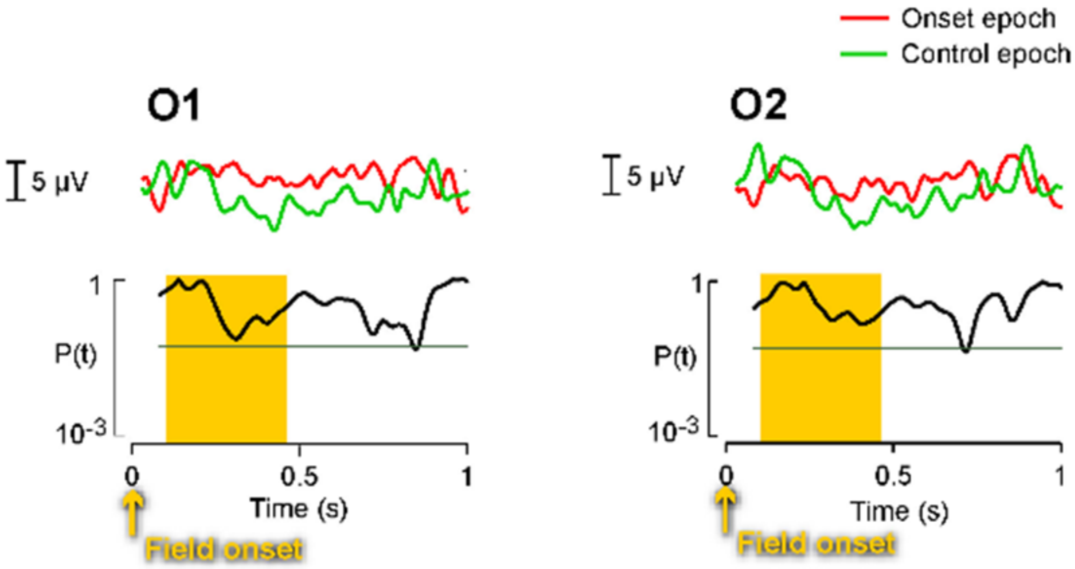
Recurrence Quantification Analysis*



* Carrubba et al.: J. Neurosci. Methods, 2006 (in press)

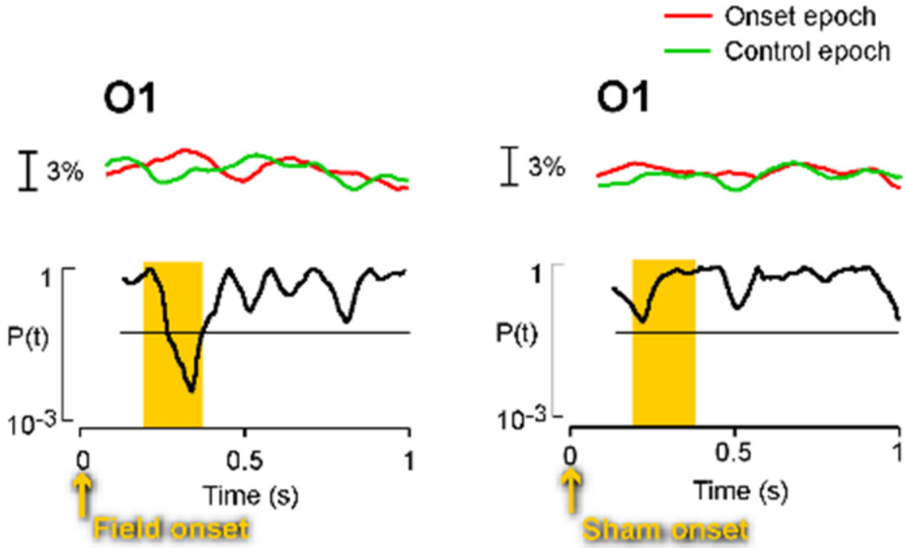
What is recurrence quantification analysis? I simply don’t have time to describe it in detail. A paper describing the method will appear shortly. Briefly, the method consists of taking a portion of the EEG, embedding it in phase space, calculating the corresponding recurrence plot, and then characterizing that plot using any of 6 different parameters that have been described. I chose to use percent recurrence. This process is iterated using a sliding window on the voltage time series, resulting in the production of a %R time series.

Effect of Field-Onset on EEG Time Series



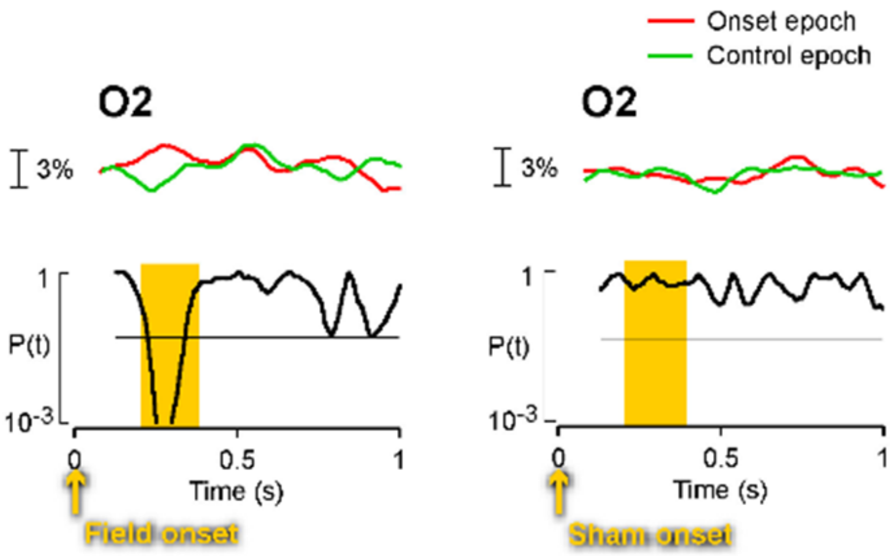
The EEG recorded from the 2 occipital electrodes is shown at the top. Each of the points in the region where the evoked potential was expected was compared with its corresponding control by means of the t test. As you can see, none of the tests were statistically significant, indicating that the presence of an evoked potential was not detected in the method of time-averaging.

Effect of Field-Onset on %R(t) Time Series



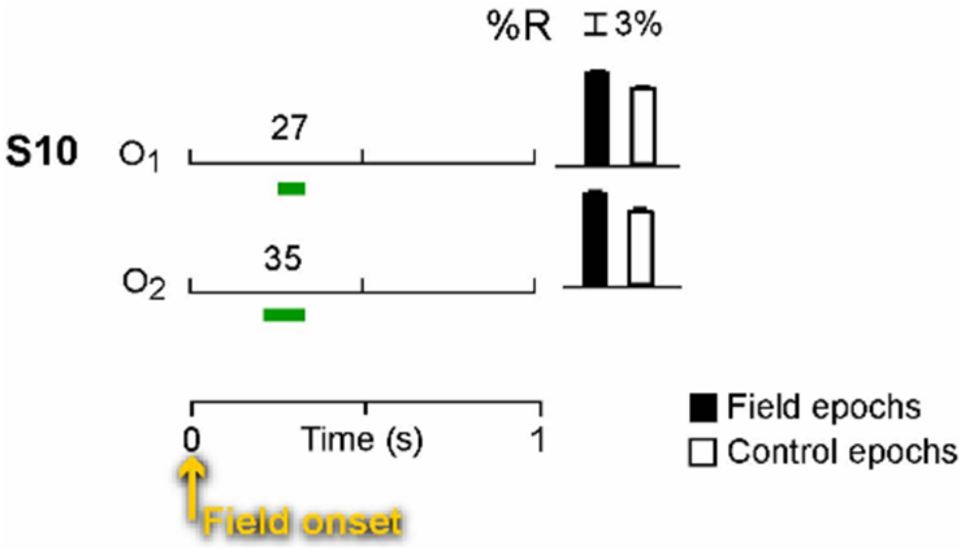
This is the corresponding result using %R. You can see than an evoked potential was detected in the expected time interval when the data was analyzed using an analytical method that allows for the presence of nonlinear determinism. The sham-field analysis was negative, as expected. This result was obtained on a particular patient using the EEG measured at O1.

Effect of Field-Onset on %R(t) Time Series



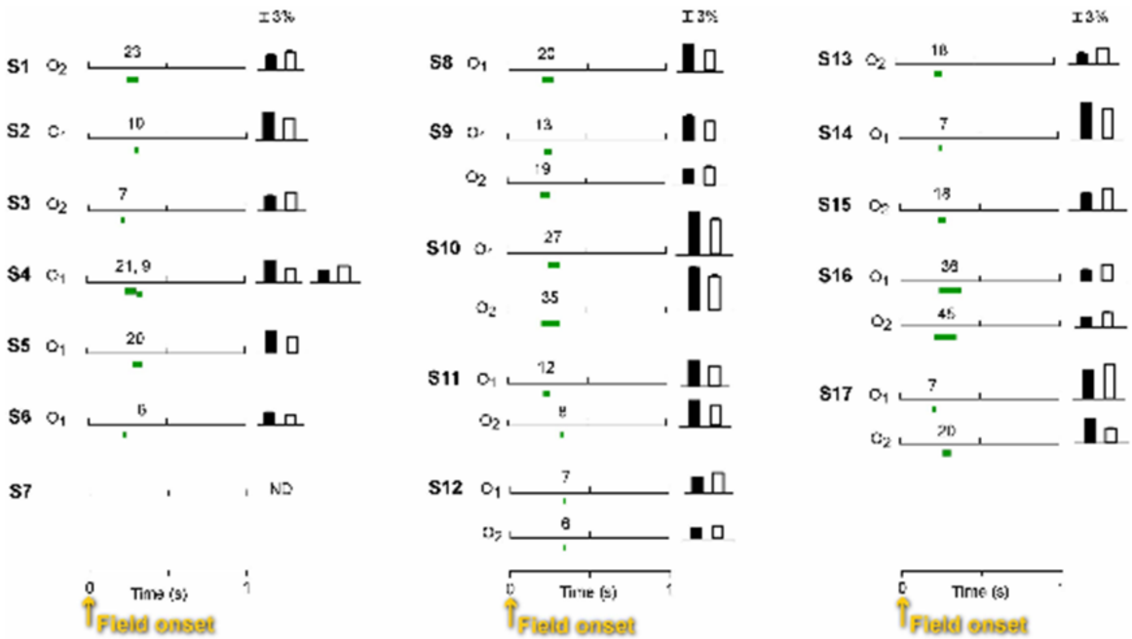
This is the result of the same analysis performed on the signal measured from O2. Again, an evoked potential was detected due to field onset.

Detection of Magnetic Fields



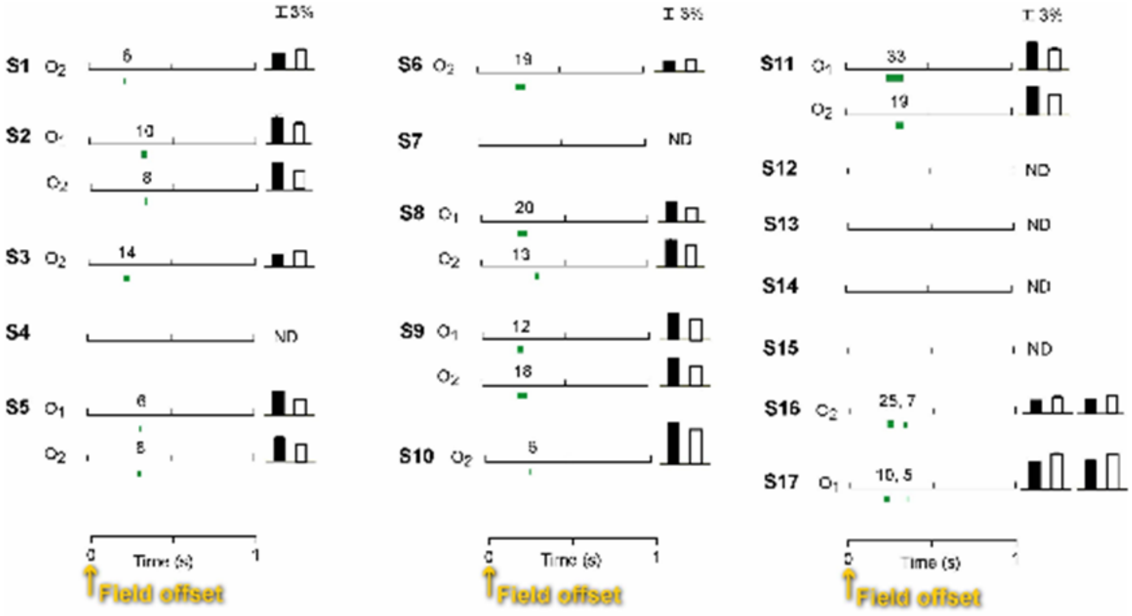
This slide summarizes the data just described from subject S10. The green bars indicate the latency and duration of the observed evoked potential. The numbers above the axis indicate the number of tests out of the 45 that were performed that were statistically significant. The bar graph depicts the mean and standard deviation of the nonlinear quantifier in the exposed and control epochs. You can see that, in this case, in both electrodes, the evoked potentials manifested as an increase in the determinism present in the EEG.

Effect of Field Onset on %R



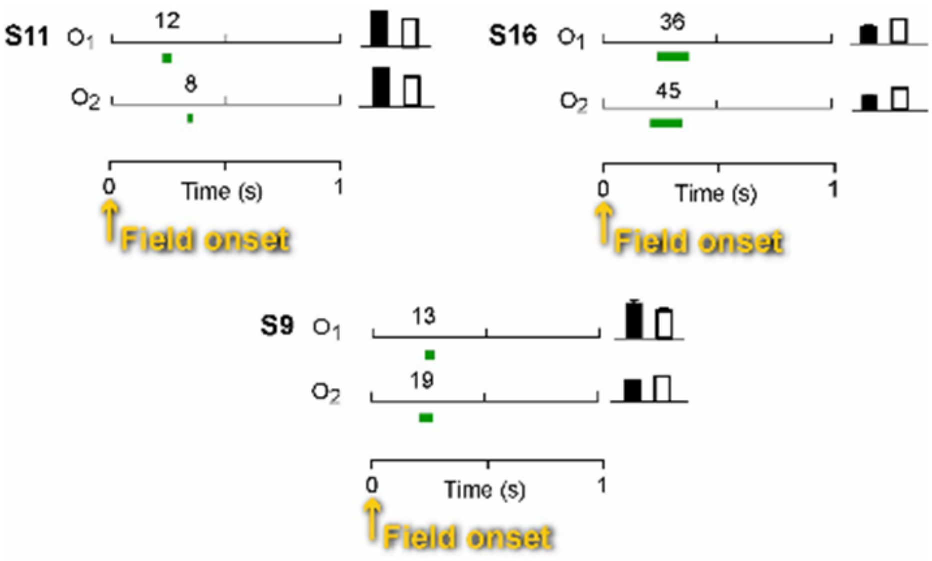
This slide depicts the frequency of occurrence of evoked potentials in the 17 subjects in the study. An onset evoked potential was detected in 16 of the 17 subjects.

Effect of Field Offset on %R



This slide depicts the frequency of occurrence of evoked potentials in the 17 subjects in the study. An onset evoked potential was detected in 11 of the 17 subjects.

Evidence of Nonlinear Characteristics of Magnetosensory Evoked Potentials



We observed 4 kinds of results that, collectively, tell us a lot about the kind of determinism manifested by magnetosensory evoked potentials. In subject 11 in both occipital electrodes, the evoked potential appeared as an increase in the determinism in the EEG. The opposite was true in subject 16, where the existence of the evoked potential was manifested as a decrease in both electrodes. In subject 9 we found mixed results. That is, the evoked potential appeared as an increase in determinism in O1 but a decrease in determinism in O2.

Summary of Results

	RQA	Time Averaging
Magnetosensory Onset Potentials	16/17	0/17
Magnetosensory Offset Potentials	11/17	0/17
False-Positive Results	1/34	0/34

Magnetosensory onset potentials were detected in 16 of the subjects and offset potentials in 11 of the subjects using recurrence quantification analysis. No evoked potentials were detected using the method of time-averaging. We found only one false-positive result in the sham analyses. Offset potentials are normally detected less frequently even with conventional stimuli such as sound and light.

Conclusion

- Human Magnetic Sense
- Nonlinear

The evidence indicated that low-frequency magnetic fields induced evoked potentials in the human subjects, thereby supporting our hypothesis that EMF detection is a form of sensory transduction. Further, as we anticipated, the observed effects were nonlinear in the sense that they were nonlinearly related to the stimulus and could be averaged away if the determinism was not captured prior to the averaging process.