Cellular Basis of EMF Sensitivity

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A fundamental issue regarding

EMF Sensitivity

is

How is the EMF detected by the body?

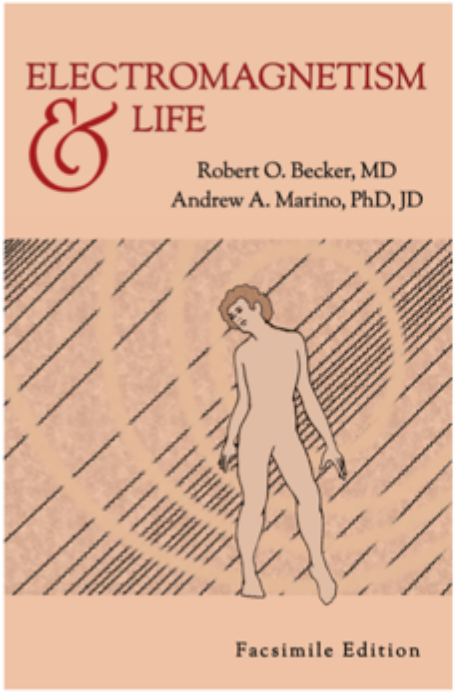
Our concern is with the cellular and molecular processes by means of which the body becomes aware of the presence of an EMF.

Summary

- **Background: Origin of sensory-transduction hypothesis**
- **Human and Animal Studies: 2000–2010**
- **Conclusion: Sensory transduction mediated by a force-sensitive receptor protein can explain how EMFs are detected by the body**
- **Can antibodies block EMF effects**

I conclude that the detection process is a form of sensory transduction. Antibodies may be useful for blocking EMF transduction.

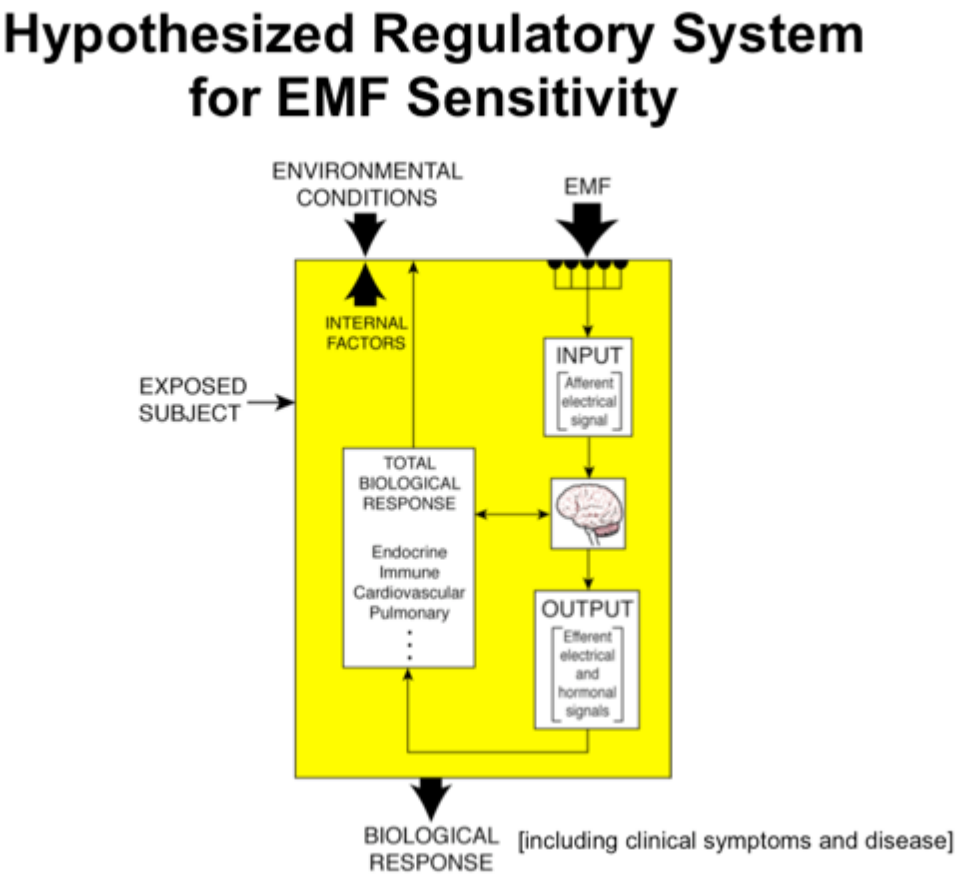
Origin of Sensory-Transduction Hypothesis



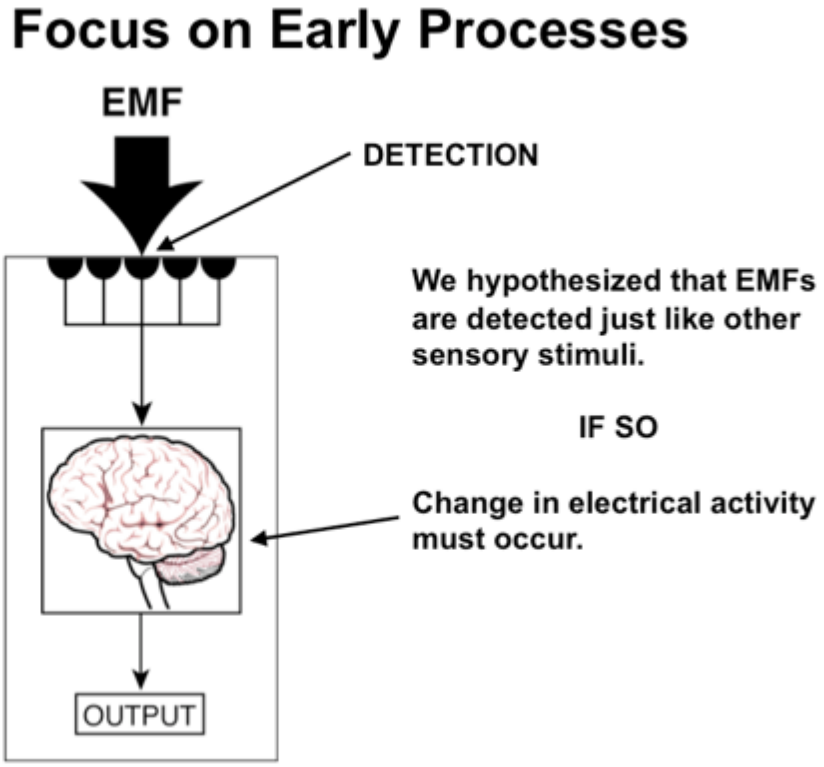
Original Publication 1982

Facsimile Edition 2010

Sensory transduction is the most parsimonious explanation for the extraordinarily diverse range of bioeffects attributed to EMFs.



Generalized causal framework for explaining the link between EMF exposure and its biological consequences.



My focus is on the immediate and early processes (initial 500 ms).

Main Types of Sensory Stimuli

Mechanical Stimuli	*Location of *Receptor Cell*
Balance	Vestibular organ
Sound	Cochlea
Pressure	Tissue
Vascular pressure	Blood vessels
Muscle stretch	Muscle spindle
Muscle tension	Tendons
Joint position	Ligaments
Osmotic pressure	Hypothalamus
Pain	Many organs

Energetic Stimuli	*Location of *Receptor Cell*
Light	Retina
Heat	Tissue
EMFs	Unknown

Chemical Stimuli	*Location of *Receptor Cell*
Arterial oxygen	Carotid body
Glucose	Hypothalamus
pH (spinal fluid)	Medulla
Taste	Tongue
Smell	Nose
Pain	Many organs

*A specialized neuron or a neuroepithelial cell

With few exceptions (see the glass catfish model) the anatomy of EMF sensitive cells is unknown.

Central Questions

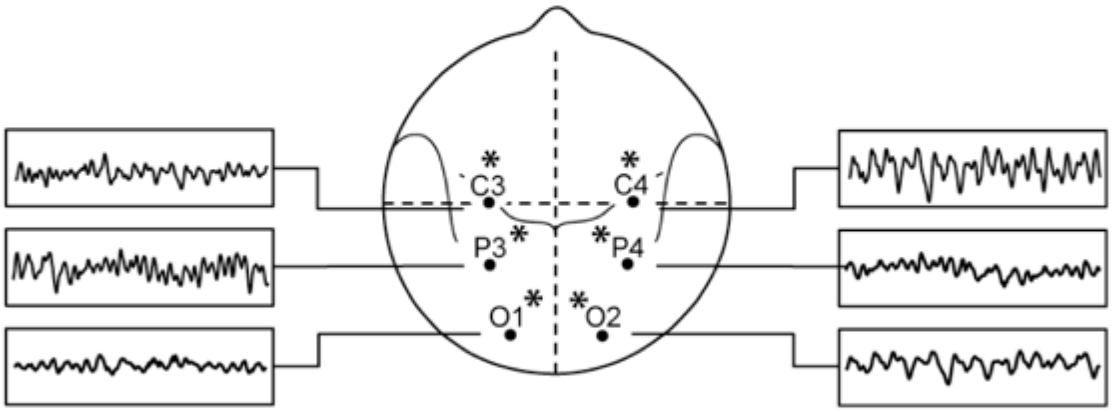
1. Do electromagnetic fields commonly present in the general and workplace environment alter brain electrical activity?

IF SO

2. How and where are the fields detected by the body?

An observation that EMFs affect brain electrical activity within milliseconds after presentation of the field will be interpreted to indicate that the EMF was detected by means of sensory transduction.

Measurement of the Electroencephalogram (EEG)

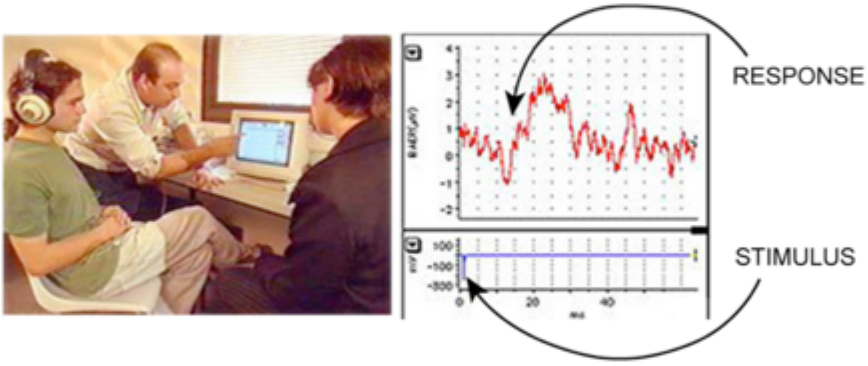


*Standardized scalp locations (10/20 convention)

The EEG is measured from standardized locations on the scalp. We used 6 such locations.

Experimental Approach: Evoked Potentials

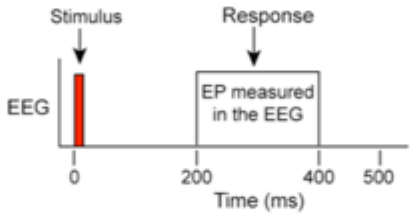
The onset and/or offset of any stimulus triggers an evoked potential (EP) in the brain.



Conversely, if an EP is triggered by an agent, it is a sensory stimulus.

The evoked potential is a weak signal superimposed on the EEG and detected by means of time averaging (averaging of numerous stimulus–response trials).

How and Why EPs Are Used Clinically



- **Stimulus is chosen based on sensory modality under study**
- **EP is detected by time averaging the EEG over many stimulus-response cycles because, by assumption the response is time-locked to the stimulus**
- **Altered latency or amplitude of EP indicates a change in the nervous system**

Alterations in visual, auditory, or somatosensory evoked potentials may indicate neurological pathology.

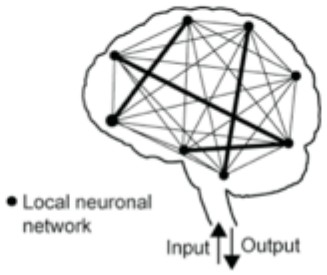
A Fundamental Distinction

Linear Systems

- A given input always produces the same output
- Time averaging leads to an INCREASE in S/N $\propto \sqrt{n}$

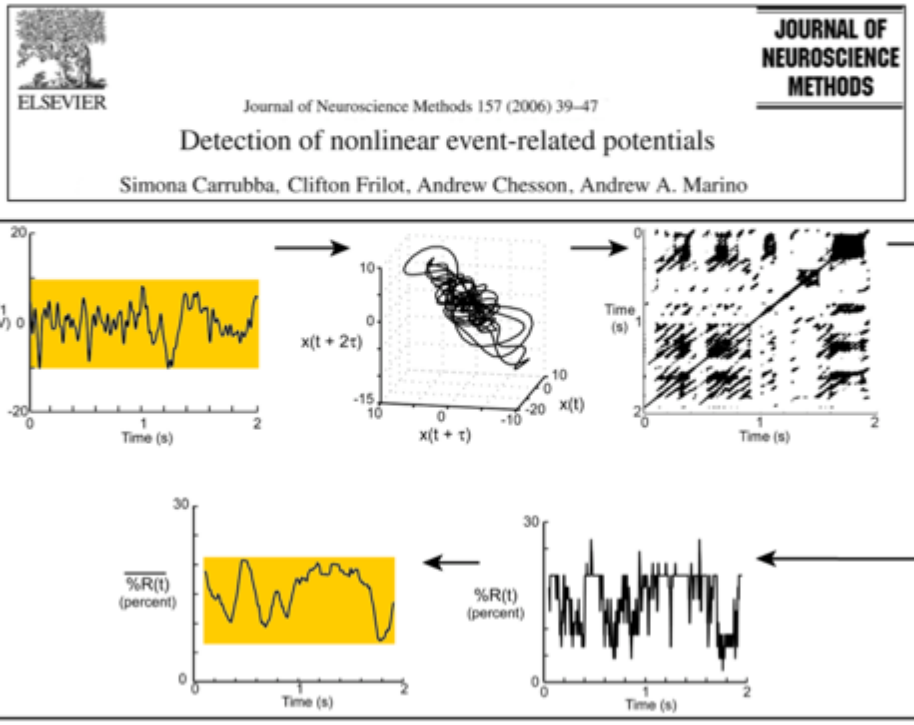
Nonlinear Systems

- A given input can produce an infinite number of different outputs
- Time averaging leads to a DECREASE in S/N $\propto \sqrt{n}$



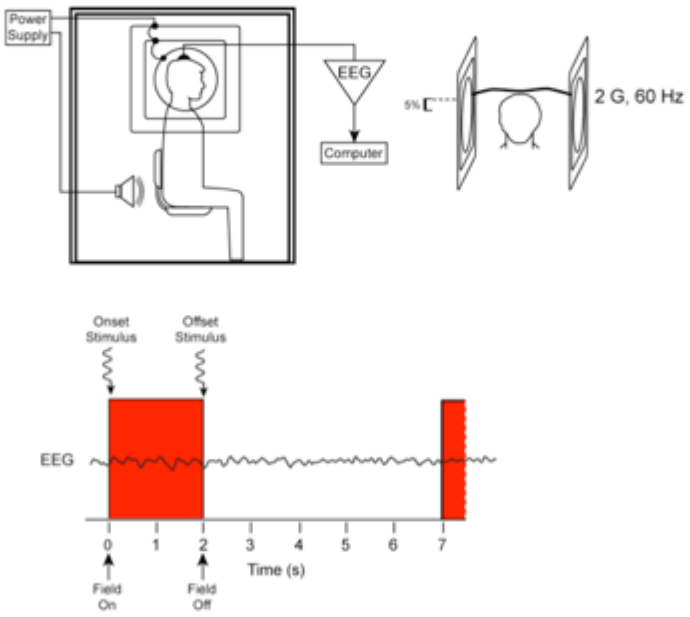
Recognizing the distinction between linear and nonlinear systems is critical to understanding the basis of human sensitivity to EMFs.

New Method for Measuring Nonlinear EPs



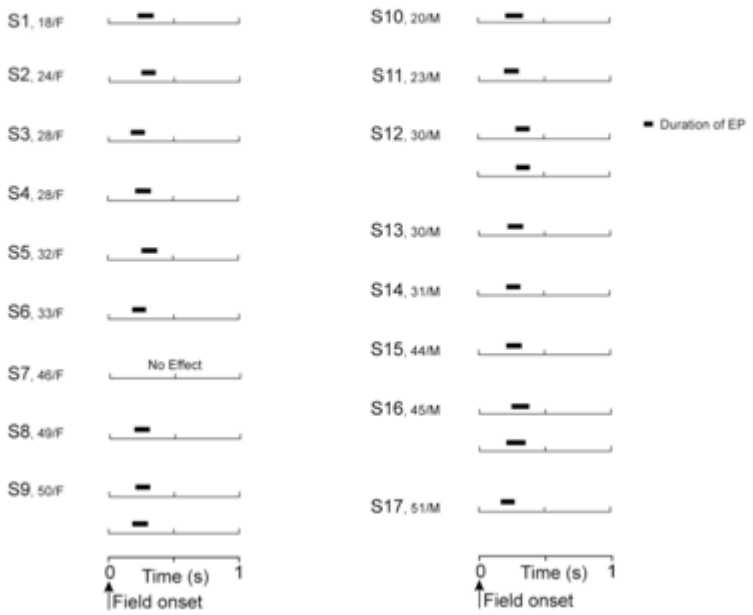
Nonlinearity is the general functional relationship in nature. Linearity (a huge conceptual, mathematical, and practical simplification) is a special case. We developed a method for analyzing EEGs that allows detection of linear effects (as do many other methods) and nonlinear effects (not presently possible with any other method).

Detecting Nonlinear EMF-Induced Evoked Potentials



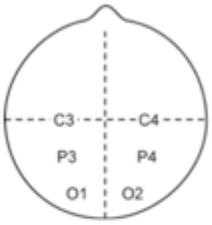
Evoked potentials are triggered by the onset and offset of stimuli, with latencies of 10–500 ms depending on the stimulus.

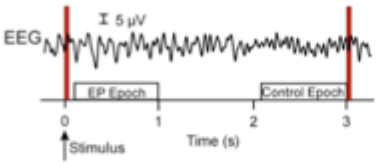
Onset Evoked Potentials Consistently Detected in Volunteers Exposed to 2 G, 60 Hz



Original data showing the existence of onset evoked potentials triggered by a magnetic field.

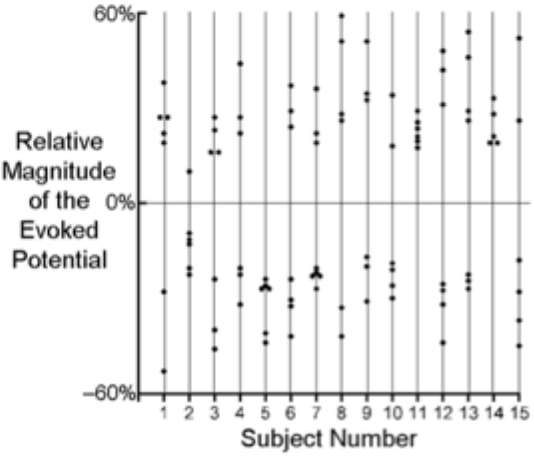
EMF-Induced Evoked Potentials: Consistent Nonlinear Phenomena





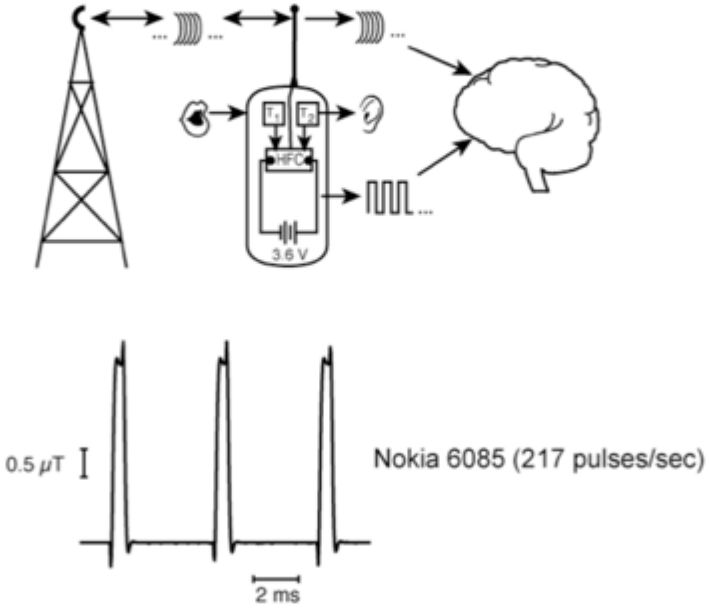
	Gender		Electrode	
	Male	Female	Occipital	Non-Occipital
Latency (ms)	311±55	309±58	304±56	322±55
Duration (ms)	263±31	264±30	265±33	262±28

Subject	All Effects	Family-Wise Error
S1 (30F)	O1, C4, P4	0.001
S3 (23M)	**O1**, **C4**, **P3**	0.047
S4 (22M)	O1, **O1**, C4	0.009
S5 (51F)	O1, **O1**, C3	0.042
S6 (23M)	C4, **C4**, P4	0.14
S7 (29F)	O1,O2,C4,P3,P4	0.001
S8 (45F)	**O1**, O2, **O2**	0.003
S9 (25M)	O1, **O1**, C4	0.028
S10 (21M)	O2, C4, **P3**	0.025
S11 (31F)	C3, C4, P4	0.002
S12 (51F)	C4, **P4**, P4	No Effect
S13 (31F)	O1,O2,**O2**,**C3**	0.003
S14 (24F)	O2, P3	0.286
S15 (36M)	O2, **O2**, **C3**	0.004



EMFs applied according to clinical procedures (essentially superimposed onset and offset) also produced evoked potentials.

Mobile-Phone EMFs in the Brain



Hypothesis: Human brain can detect every pulse

Mobile phones produce two kinds of EMFs, each of which consists of multiple pulses.

Evoked Potentials in Subjects (N=50) Exposed to a Single Mobile-Phone Pulse

Subject	All Effects	Family-Wise Error
S1 (24/M)	O1 **O1** O2 P4	0.010
S2 (53/F)	C3 C4 **C4** P3	0.002
S3 (22/F)	C3 **C3** P3 **P3**	0.001
S4 (22/M)	C3 C4 P3	0.001
S5 (22/F)	O1 **O1 O2**	0.081
S6 (43/F)	O1 C4 **C4**	0.006
S7 (22/F)	O2 **O2 P4**	0.031
S8 (50/F)	**O2** P3 P4	0.062
S9 62/M)	C4	No Effect
S10 (18/F)	**O2** C3 **C3**	0.078
S11 (36/F)	O2 **O2** C3	0.043
S12 (47/F)	**C3** P3 **P4**	0.085
S13 (32/F)	O1 **O1 P3**	0.006
S14 (24/F)	O1 O2 **O2**	0.038
S15 (52/M)	C3 P3 **P3**	0.015
S16 (22/F)	C3 **C3** C4 **C4**	0.021
S17 (23/F)	C3 **C3**	No Effect
S18 (29/M)	C4 **C4** P3	0.043
S19 (23/M)	C3 **C3** P3 **P3**	0.023
S20 (26/M)	P3 P4 **P4**	0.015

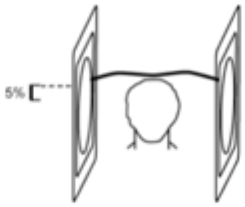
Significance: Cell phones generate 217 evoked potentials each second of phone use.

Each pulse from a mobile phone produces an evoked potential.

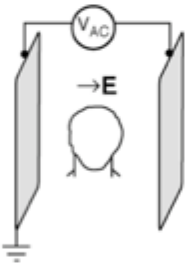
(for our purposes)

What is an Electromagnetic Field?

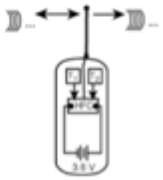
Applied magnetic field that necessarily induces an electric field



Applied electric field, but no magnetic field

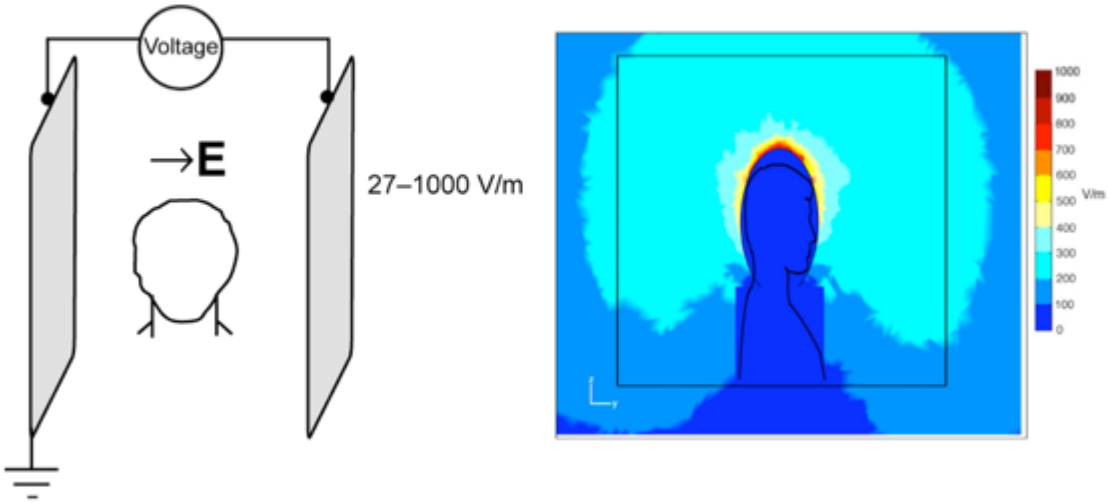


A propagating combined electric and magnetic field



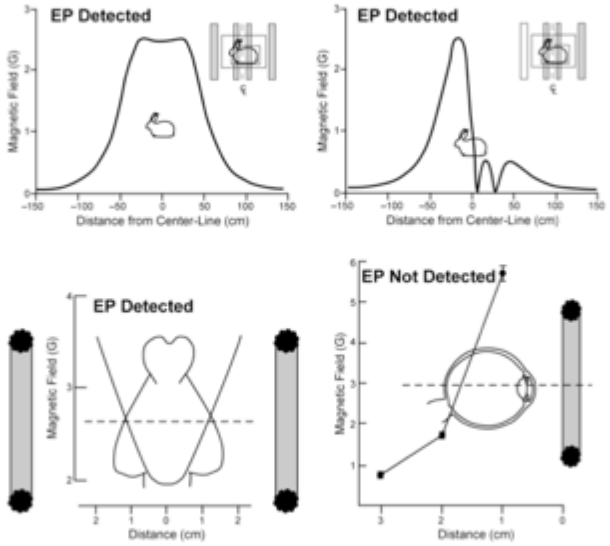
There are different kinds of EMFs, and different ways of characterizing a given EMF. What exactly does the body detect?

The Electric Field is Sufficient to Trigger EMF-Induced Evoked Potentials



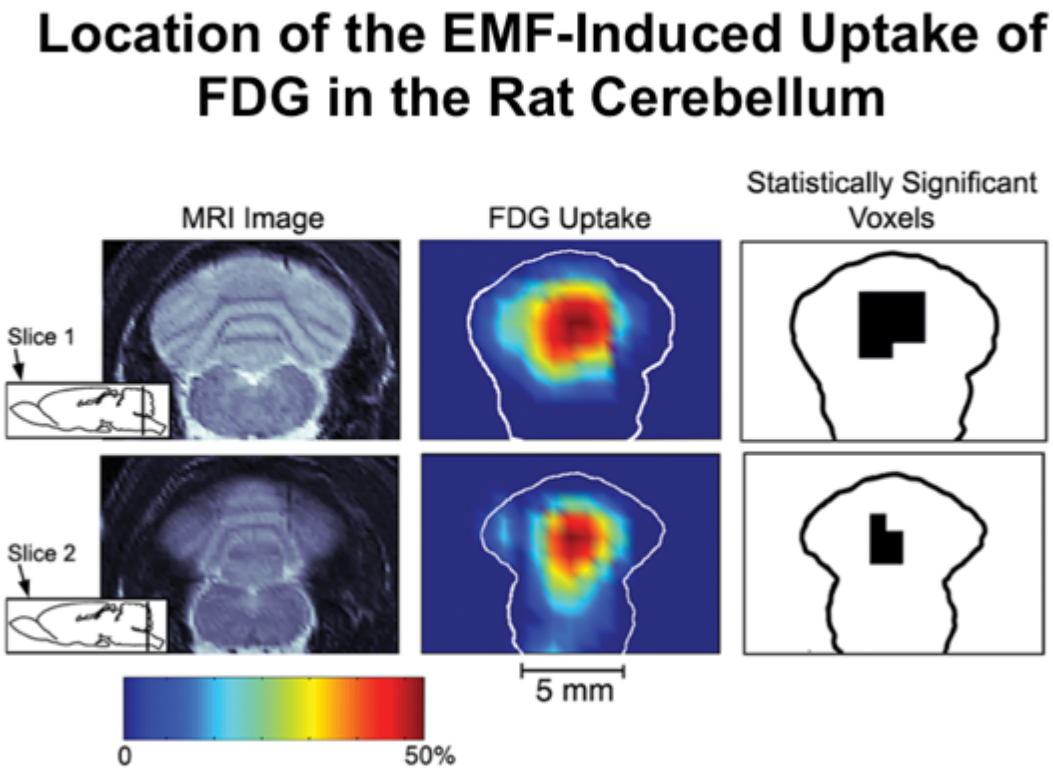
The body detects the electric field.

Location of Receptor Cells



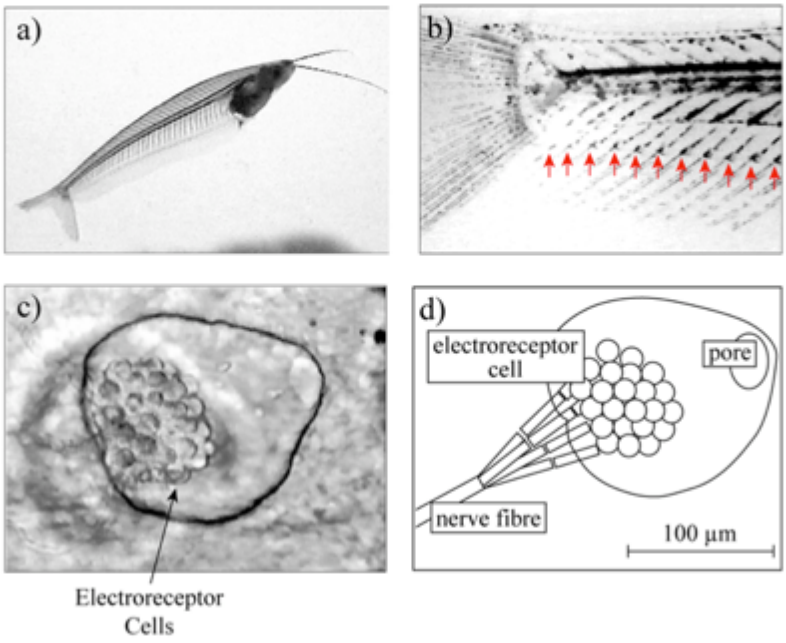
Conclusion: Electroreceptor cells are located in the head, probably the brain.

The receptor cells that detect the electric field are located in the head, probably the brain.



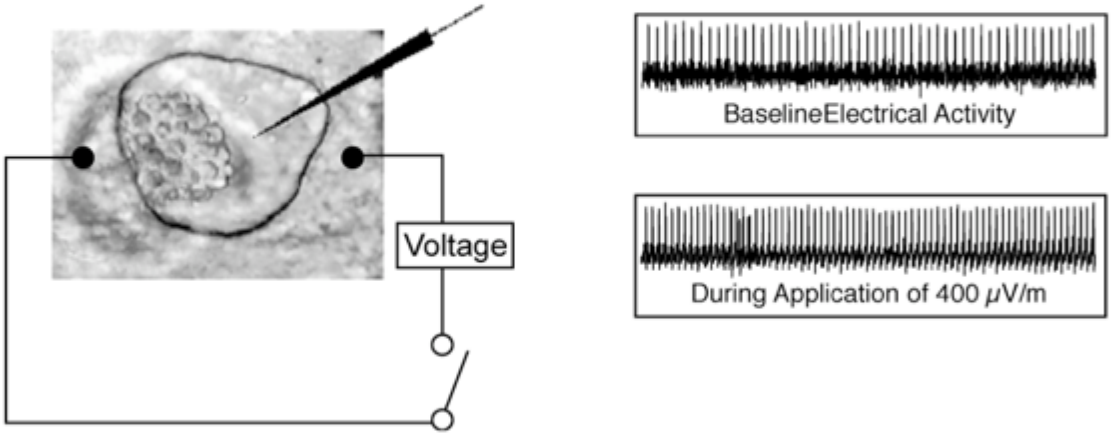
The electroreceptor cells are probably located in the cerebellum.

How is the EMF Transduced: The Glass Catfish Model



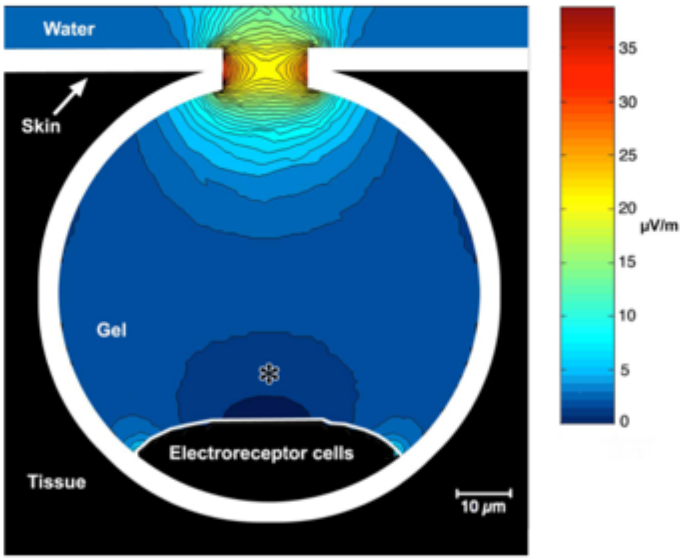
The glass catfish has many thousands of electric field receptor organs located in invaginations in the skin. Each organ contains 5–30 electroreceptor cells.

Detection of Ultra-Weak Electric Field



The afferent nerve from each electroreceptor organ fires at a fixed rate in the absence of stimulation. When a weak field occurs in the animal's environment the frequency of the signal carried by the afferent nerve is altered.

Calculation of Electric Field at Surface of Electroreceptor Cells

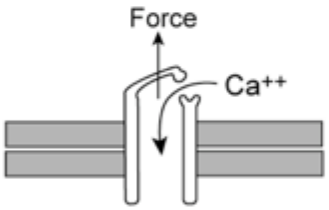


Conclusion: The electroreceptor cell (∗) can detect about 1 μV/m.

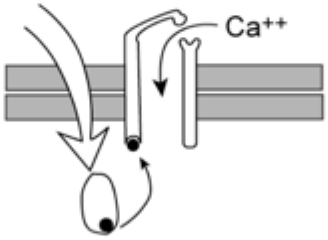
The electroreceptor cell can detect an extraordinarily weak electric field at its surface.

Signal Transduction in Sensory Receptors

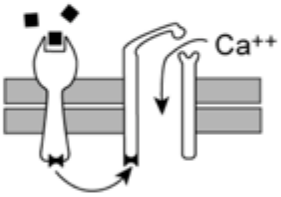
*Force receptor



Light receptor

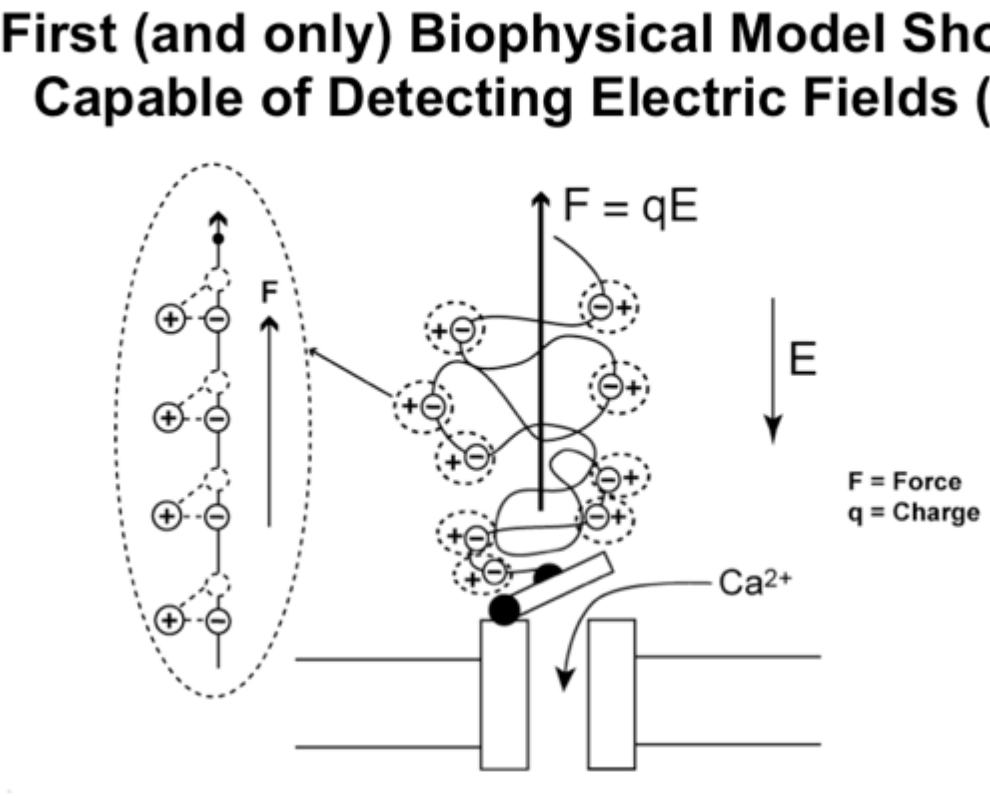


Chemical receptor



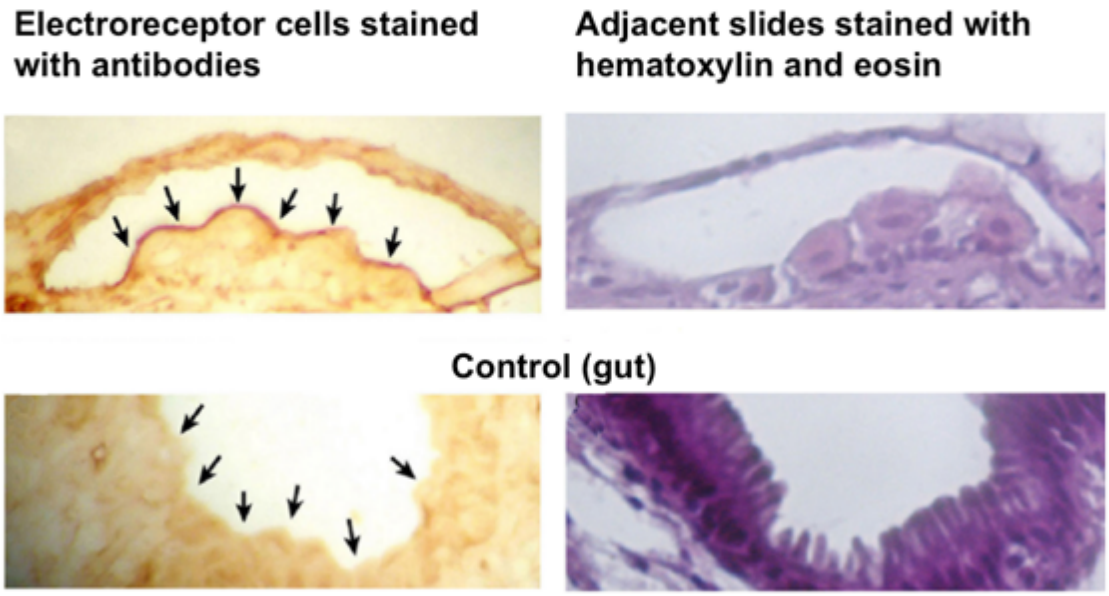
*The likely candidate

Only three kinds of sensory receptors are known in nature. The electroreceptor is a force transducer.



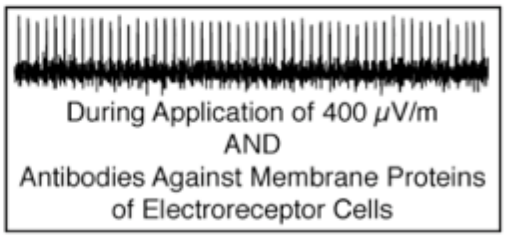
A realistic biophysical model capable of detecting an electric field of 1 μm.

Antibody Staining of Electroreceptor Cells



The membrane proteins of electroreceptor cells can be extracted and used to create antibodies (in mice).

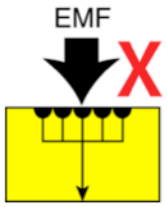
Antibodies Can Block EMF Transduction



The antibodies can block the interaction of the electric field with the membrane ion channel (see the biophysical model on a previous slide) thereby preventing the subsequent afferent signal.

Conclusion

- Cellular basis of EMF sensitivity is sensory transduction by a force-sensitive protein, probably a calcium-ion channel
- It may be possible to prevent EMF transduction by means of blocking antibodies



It should be possible to block EMF sensitivity using antibodies against the EMF interaction site on the electroreceptor cell.