

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

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- **Thanks for arranging this workshop in Stuttgart!**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **Christina M. Krause**
- **Research interests**
- **Memory and human cognitive processes**
- **The many factors which influence this**
- **Interindividual variation**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- This is a review of five EEG studies from the years 2000-2007 by the Turku research group
- The research group is:
  - Christian Haarala-Björnberg
  - Heikki Hämäläinen
  - Christina M. Krause
  - Mika Koivisto
  - Matti Laine
  - Antti Revonsuo
  - Lauri Sillanmäki
- Anna Häggqvist
- Carina Saarela
- Katarina Alanko
- Annika Hultén
- Tiia Liesivuori
- Mirka Pesonen,

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

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- University of Helsinki (own research funds)

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- Krause, C.M., Sillanmäki, L., Koivisto, M., Häggqvist, A., Saarela, C., Revonsuo, A., Laine, M., Hämäläinen, H. Effects of electromagnetic field emitted by cellular phones on the EEG during a memory task. *NeuroReport*. 2000, 11: 761-764.
- Krause, C.M., Sillanmäki, L., Koivisto, M., Häggqvist, A., Saarela, C., Revonsuo, A., Laine, M., Hämäläinen, H. Effects of electromagnetic field emitted by cellular phones on the electroencephalogram during a visual working memory task. *International Journal of Radiation Biology*. 2000, 76: 1659-1667.
- Krause, C.M., Haarala, C., Sillanmäki, L., Koivisto, M., Alanko, K., Revonsuo, A., Laine, M., Hämäläinen, H. Effects of Electromagnetic Field Emitted by Cellular Phones on the EEG During an Auditory Memory Task: A Double Blind Replication Study. *Bioelectromagnetics*, 2004, 25:33-40.
- Krause, CM., Haarala, C., Pesonen, M., Hulten, A., Liesvuori, T., Koivisto, M., Revonsuo, A., Laine, M., Hämäläinen, H. Mobile phone effects on children's event-related oscillatory EEG during an auditory memory task. *International Journal of Radiation Biology*, 2006, 82: 443-450.
- Krause CM., Pesonen, M., Haarala, C., Björnberg, C., Hämäläinen, H. Effects of pulsed and continuous wave 902 MHz mobile phone exposure on brain oscillatory activity during cognitive processing. *Bioelectromagnetics*. 2007, 28: 296-308.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- Technical details (engineers answer the questions ☺ )
  - 902 MHz EMF
  - pulse frequency 217 Hz
  - pulse width 577 us
  - mean net forward power 0.25 W
  - Specific absorption rate (SAR) values were assessed with a SPEAG Dosimetric Assessment System 3 (DASY3). The spatial peak SAR value averaged over 1g and 10 g of tissue were 0.878 mW/g and 0.648 mW/g, respectively.



# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **First the results on effects of EMF on brain electric oscillations (EEG) and simultaneously measured behaviour**
  - **Reaction times**
  - **Response accuracy**
- **Finally, conclusions, confusion and discussion about the observations**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **There exist many ways to assess brain activity**
  - EEG, PET, fMRI, MEG
- **These reflect different aspects of neural activity**
- **There are some differences between the different methods**
  - Temporal and spatial resolution

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **Alive active brains generate electricity which can be measured from the scalp by means of the EEG (electroencephalogram) or the MEG (magnetoencephalogram)**
- **This electric activity reflects the activity of the brain**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

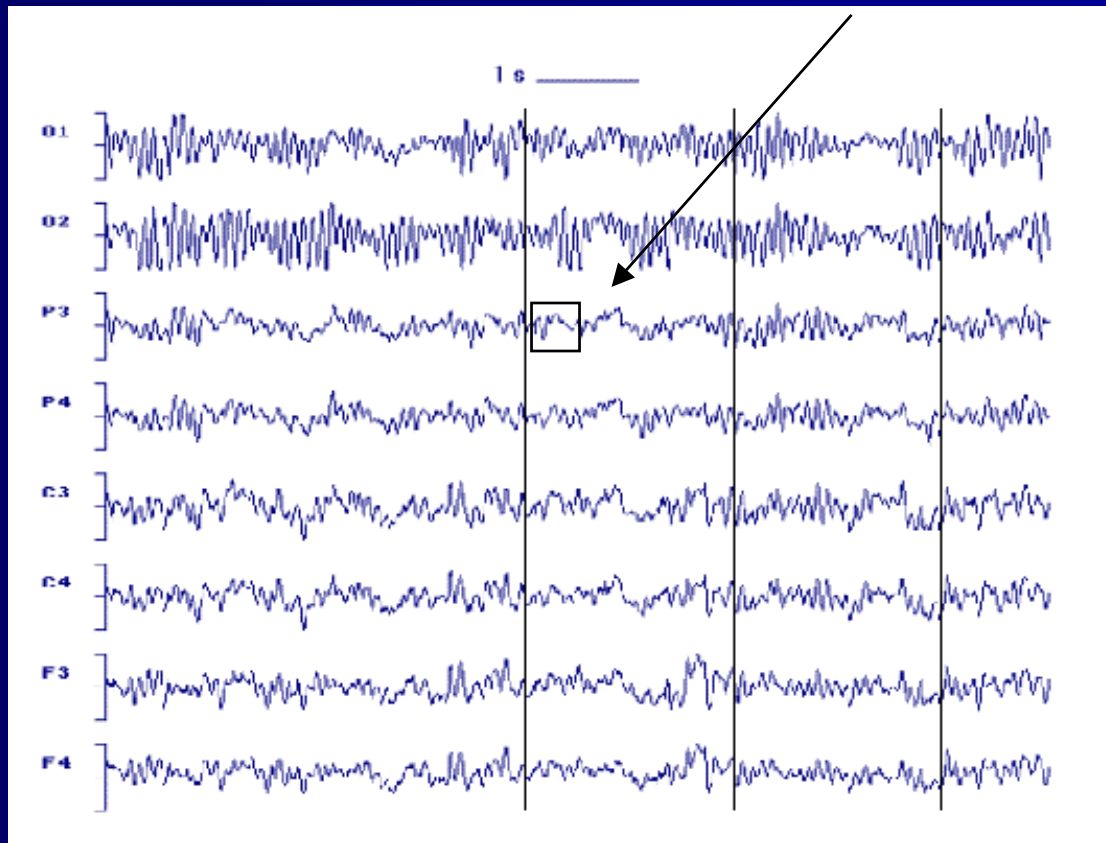
- **The EEG is noninvasive, cheap, easy to use and is also characterized by a good temporal resolution**



# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- An example of the output:

*WHAT HAPPENS HERE?*



# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- With new signal analysis methods the chaotic EEG/MEG signal can be "cracked"
- The chaotic EEG/MEG signal consists of several separate simultaneous oscillations at different frequencies (Hz)

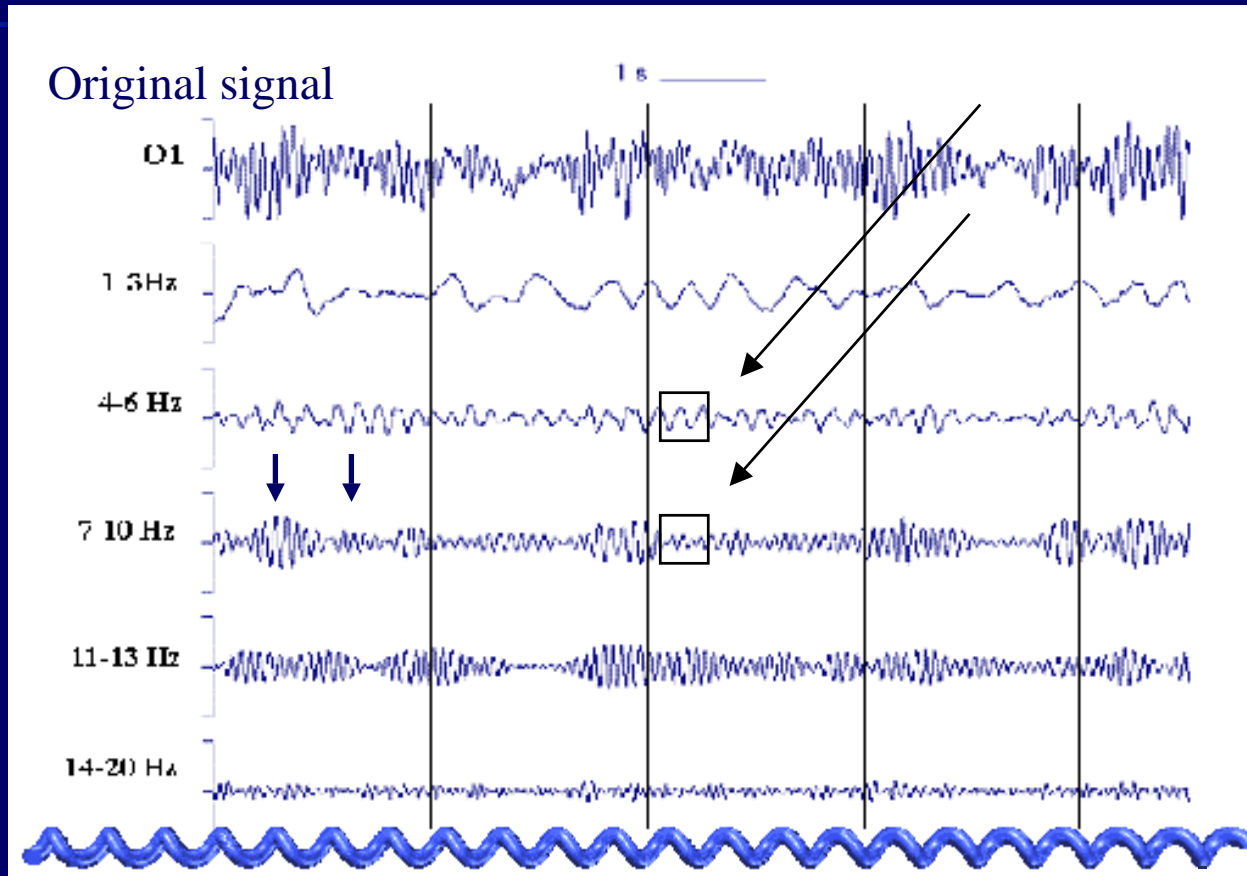


- Oscillatory = rotating around zero
- The responses and reactivity of the different frequencies differ, are not random and reflect different cognitive processes

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

*WHAT HAPPENS HERE?*

Frequency (Hz)



”Delta”

”Theta”

”Alfa-1”

”Alfa-2”

”Beta”

Time (s)

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

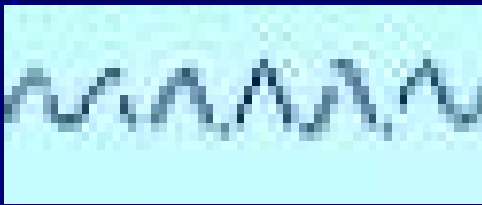
ERD = Event-Related Desynchronization

ERS = Event-Related Synchronization

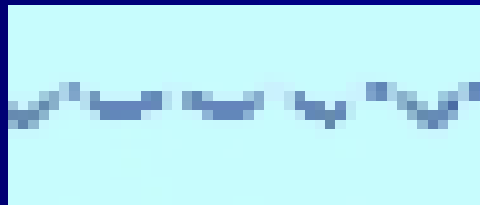
Relative power/amplitude decrease/increase in  
percentage

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

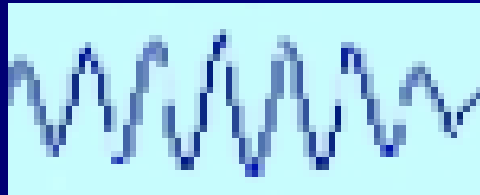
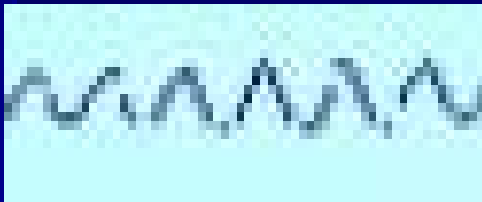
Resting



Cognitive task



**ERD**



**ERS**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

Different frequencies respond systematically differently to different cognitive processes



~20 Hz (beta) motor cortex –  
movements, imaging movements,  
viewing movements

~7-15 Hz (alfa) thalamocortical –  
attention, semantic memory,  
emotions

~1-6 Hz (delta and theta) hippocampus –  
encoding of new information

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- By means of measuring brain oscillatory responses during cognitive processing we try to gain insights into “how” the brain enables higher-level information processing
- Oscillations might be the communication/storage method

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- Today of interest is if, and then how EMF affects brain oscillatory systems and human cognitive performance

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- The first report in the year 2000:
- Krause, C.M., Sillanmäki, L., Koivisto, M., Häggqvist, A., Saarela, C., Revonsuo, A., Laine, M., Hämäläinen, H. *Effects of electromagnetic field emitted by cellular phones on the EEG during a memory task.* NeuroReport. 2000, 11: 761-764.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- The memory search paradigm:



1

2

3

4

5



# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **GSM phone on the right side (N= 16), single-blind**
- EMF increased the relative power in the 8-10 Hz frequency band.
- EMF increased the initial ERS responses and decreased the later ERD responses in the 6-8 and 8-10 Hz frequency bands, only during retrieval from memory
- No effects on performance

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- The replication report in the year 2004:
- Krause, C.M., Haarala, C., Sillanmäki, L., Koivisto, M., Alanko, K., Revonsuo, A., Laine, M., Hämäläinen, H. *Effects of Electromagnetic Field Emitted by Cellular Phones on the EEG During an Auditory Memory Task: A Double Blind Replication Study*. *Bioelectromagnetics*, 2004, 25:33-40.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **GSM phone on the left side (N=24), double blind**
- EMF decreased the relative power in the 4-6 Hz frequency band.
- ERD/ERS responses were statistically significantly modulated by the exposure to EMF in the 4-6 Hz and 6-8 Hz frequency bands.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **Behavioral results**
- The mean percentage of incorrect answers:
  - EMF on                      19.1 (SD = 4.2)
  - EMF off                      6.3 (SD = 3.1)
- $p < .001$

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- Visual working memory task in the year 2000
- Krause, C.M., Sillanmäki, L., Koivisto, M., Häggqvist, A., Saarela, C., Revonsuo, A., Laine, M., Hämäläinen, H. *Effects of electromagnetic field emitted by cellular phones on the electroencephalogram during a visual working memory task*. International Journal of Radiation Biology. 2000, 76: 1659-1667.

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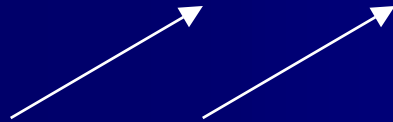
n 0-back a C f c X n N x I s i i

n 1-back a C f c X n N x I s i i

n 2-back a C f c X n N x I s i i

Target

Non-target



# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **GSM phone on the right side (N=24), single-blind**
- In the 6-8 Hz frequency band, EMF decreased the differences in ERD/ERS between targets and non-targets
- In the 8-10 Hz frequency band, EMF enhanced the initial ERS in 2-back, for non-targets
- In the 8-10 Hz frequency band, EMF increased and delayed the later emerging ERD, in 0-back and 1-back, especially during the presentation of targets
- No effects on reaction times or response accuracy

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- The study on children in the year 2006
- Krause, CM., Haarala, C., Pesonen, M., Hulten, A., Liesvuori, T., Koivisto, M., Revonsuo, A., Laine, M., Hämäläinen, H. *Mobile phone effects on children's event-related oscillatory EEG during an auditory memory task*. International Journal of Radiation Biology, 2006, 82: 443-450.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **GSM phone on the right side (N=15), 10-14 year old children, double-blind**
- **During encoding, EMF modulated/increased the ERS responses of the ~4-8 Hz EEG frequencies**
- **During recognition, EMF altered/increased the ~4-8 Hz ERS and increased the ~15 Hz ERD responses**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- The year 2007 study
- Krause CM., Pesonen, M., Haarala, C., Björnberg, C., Hämäläinen, H. *Effects of pulsed and continuous wave 902 MHz mobile phone exposure on brain oscillatory activity during cognitive processing*. Bioelectromagnetics. 2007, 28: 296-308.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **Left and right side exposure**
- **Three exposure conditions, SHAM, PM (pulse modulated), CW (continuous wave)**
- **N=2 \* 36 male adults**
- **Auditory and visual memory tasks**
- **Double-blind**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- **PM:** During encoding, greater ~8 Hz ERS responses were elicited during PM and during recognition, smaller ~8 Hz ERD responses were witnessed during PM exposure, as compared to the CW exposure condition
- **SHAM:** during encoding, greater ~8–10 Hz ERS values were observed during left-side exposure than during right-side exposure.
- **CW:** During encoding, greater ~10–15 Hz ERS responses during right-side exposure and during recognition, greater ~10 Hz ERD responses during left-side exposure
- No effects in the visual working memory task
- No behavioral effects

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

## **Summary of the findings:**

**Only systematic observation is that EMF seems to affect ~8 Hz EEG activity during cognitive processing. However, the size and direction of effects vary from one study to another**

**No systematic effects on behavior**

**Replication studies were not successful**

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

Very small EMF effects cause only subtle EEG and behavioral differences which are susceptible to subtle "random" factors

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

Interindividual variation in EEG and responses to EMF (and also to cognitive tasks):

Differences in skull and tissue?

Differences in cognitive strategies?

Differences in personality?

Cognitive state, choice of subjects etc.

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

Considerations:

What is an "effect big enough"?

ERD/ERS 5-10 %

RTs 10-40 ms

Errors 6.3 - > 19.1 %

What do such changes mean in reality and everyday life?

What are the psychological implications of such effects?

Other studies by Krause et al (2001, 2002)

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

## Conclusion

EMF seems to have effects on the EEG especially in the ~8 Hz frequency range during cognitive processing

The causes (mechanisms) and consequences (psychological) remain a mystery

# EFFECTS OF EMF ON BRAIN ELECTRIC OSCILLATIONS AND COGNITIVE PROCESSES

- Thanks for your attention!
- Christina M. Krause
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