Current State of Knowledge
Where are the Areas of Scientific Consensus
Acute Effects of RF EMF

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• Acute effects of radio frequency electromagnetic fields (RF EMF)

• Human laboratory studies – provocation studies
Aim of Human Laboratory studies

• To clarify whether EMF have a biological effect (below current exposure limits/guidelines)
• To clarify whether EMF affect humans (brain physiology, well being)
• To establish biological mechanisms
• (To assess health risk)
Overview

• RF EMF and the Brain
  – Current state of knowledge
    • Waking EEG
    • Sleep EEG
    • PET (rCBF and brain glucose metabolism)
    • Cognition
• Why the variation
• Overall conclusions
RF EMF and the Brain: Effects on the Waking and Sleep EEG
Why Use the EEG?

- Simple, non-invasive technique that reflects synchronous activity in cortical neurons
- Well-characterised
  - Correlated with vigilance state and cognitive functioning/processing during waking
  - Reflects different stages of sleep

Aeschbach (1995)
High Intra-Individual Stability

Waking

NREM Sleep

Napflin et al. 2007

Buckelmüller et al., 2006

November 16-17, 2011, Brussels, Belgium
Waking EEG
# RF EMF and Waking EEG: Summary of Current Knowledge

<table>
<thead>
<tr>
<th>Author</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reiser 1995</td>
<td>↑ alpha (9.75 – 12.5 Hz)</td>
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<tr>
<td></td>
<td>↑ beta (12.75 – 35 Hz)</td>
</tr>
<tr>
<td>Röschke &amp; Mann 1997</td>
<td>No effect</td>
</tr>
<tr>
<td>Hietanen et al 2000</td>
<td>No effect</td>
</tr>
<tr>
<td>Huber et al 2002</td>
<td>↑ alpha (~10 Hz)</td>
</tr>
<tr>
<td>Croft et al 2002</td>
<td>↑ alpha (8 – 12 Hz)</td>
</tr>
<tr>
<td></td>
<td>↓ delta (1 – 4 Hz)</td>
</tr>
<tr>
<td>D’Costa et al 2003</td>
<td>↓ alpha (8 – 12 Hz)</td>
</tr>
<tr>
<td></td>
<td>↓ beta (13 – 30 Hz)</td>
</tr>
<tr>
<td>Curcio et al 2005</td>
<td>↑ alpha (8 – 12 Hz)</td>
</tr>
<tr>
<td>Regel et al 2007</td>
<td>↑ alpha (10.5 – 11 Hz)</td>
</tr>
<tr>
<td>Perentos et al 2007</td>
<td>No effect</td>
</tr>
<tr>
<td>Hinrikus et al 2008</td>
<td>↑ alpha (8 – 13 Hz)</td>
</tr>
<tr>
<td></td>
<td>↑ beta (15 – 38 Hz)</td>
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<tr>
<td>Croft et al 2008</td>
<td>↑ alpha (8 – 12 Hz)</td>
</tr>
<tr>
<td>Croft et al 2010</td>
<td>↑ alpha (8 – 12 Hz)</td>
</tr>
</tbody>
</table>
RF EMF and Waking EEG: Summary of Current Knowledge

• Exposure to pulse-modulated RF EMF affects Waking EEG
  – Alpha activity
  – Pulse modulation seems important for RF EMF-induced EEG effect
  – Mostly during exposure (but also following, e.g. Huber et al., 2002; Regel et al. 2007)
  – Independently replicated
Sleep EEG
RF EMF and Sleep EEG: Summary of Current Knowledge

Mann & Roschke 1996
Mann et al 1998
Wagner et al 1998
Borbely et al 1999
Wagner et al 2000
Huber et al 2000
Huber et al 2002
Loughran et al 2005
Hinrichs et al 2005
Fritzer et al 2007
Hung et al 2007
Regel et al 2007
Lowden et al 2010
Schmid et al 2011
Loughran et al in press.

Frequency (Hz)

REM sleep
NREM sleep

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RF EMF and Sleep EEG: Summary of Current Knowledge

• Exposure to pulse-modulated RF EMF affects the sleep EEG
  – Spindle and alpha frequency activity
  – Pulse modulation seems important for RF EMF-induced EEG effect
  – Effects outlast exposure
  – Independently replicated
  – Independent of exposure side and may be dose-dependent
  – Sensitive to individual variability
RF EMF and EEG: Consistent exposure-related effects

- Borbely et al. 1999
- Huber et al. 2000
- Huber et al. 2002
- Curcio et al. 2005
- Loughran et al. 2005
- Regel et al. 2007a
- Regel et al. 2007b
- Croft et al. 2008
- Croft et al. 2010
- Schmid et al. 2011
- Loughran et al. in press

Frequency (Hz)

Resting/Waking EEG
Sleep EEG

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RF EMF and the Brain: Effects on Regional Cerebral Blood Flow (rCBF) and Brain Glucose Metabolism
Other techniques support altered neural activity from pulse modulated RF EMF exposure

Regional Cerebral Blood Flow (rCBF)

Brain Glucose Metabolism

Huber et al., 2002; Huber et al., 2005 (not shown)

Volkow et al., 2011

Aalto et al., 2006

Kwon et al., 2011
Regional Cerebral Blood Flow (rCBF) (increase)

Brain Glucose Metabolism (decrease)

Kwon et al., 2011

Huber et al., 2005
RF EMF and PET Studies: Summary of Current Knowledge

• Evidence that exposure to pulse-modulated RF EMF affects:
  – rCBF
  – Brain glucose metabolism
  – Effect mainly in exposed hemisphere
RF EMF and the Brain: Effects on Cognitive Performance
RF EMF and Cognitive Performance

• Numerous studies performed
• Two main endpoints investigated:
  – Accuracy of performance
  – Reaction time (RT/speed of performance)
• Cognitive domains:
  – Verbal memory
  – Visuospatial working memory capacity
  – Retrieval efficiency
# RF EMF and Cognition: Summary of Previous Research

<table>
<thead>
<tr>
<th>Cognitive Performance</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ RT</td>
<td>Koivisto et al., 2000a, b; Preece et al., 1999; Curcio et al., 2004; Jech et al., 2001; Lee et al., 2003</td>
</tr>
<tr>
<td>↓ RT</td>
<td>Regel et al., 2007a, b; Hamblin et al., 2004; Edelstyn et al., 2002; Eliyahu et al., 2006; Keetley et al., 2006; Luria et al., 2009</td>
</tr>
<tr>
<td>↑ Accuracy</td>
<td>Regel et al., 2007a, b; Lass et al., 2002; Smythe et al., 2003</td>
</tr>
<tr>
<td>↓ Accuracy</td>
<td>Krause et al., 2004; Rodina et al., 2005; Leung et al., 2011</td>
</tr>
<tr>
<td>No Change in performance</td>
<td>Fritzer et al., 2007; Bessett et al., 2005; Unterlechner et al., 2007; Terao et al., 2006; Schmid et al., 2005; Russo et al., 2006; Preece et al., 2005; Krause et al., 2007; Krause et al., 2000a, b; Kleinlogel et al., 2008; Hinrichs et al., 2004; Haarala et al., 2003a, b; 2004; 2005; 2007; Freude et al., 2000; Curcio et al., 2008; Croft et al., 2002; Aalto et al., 2006</td>
</tr>
</tbody>
</table>
RF EMF and Cognitive Performance: Summary of Current Knowledge

- Large number of studies performed
- Large variability in results
- More recent studies with improved methodology suggest no effect of RF EMF on cognitive performance
- Several recent reviews conclude that mobile phone-like RF EMFs do not induce cognitive or psychomotor effects
Why the Variation?

• Differences in exposure parameters
  – Exposure conditions often ill-defined
  – Dosimetry not specified
  – Single-blind conditions / no blinding
  – Variable exposure conditions across studies (studies not comparable)

• Differences in study design
  – Cognitive tasks
  – Sleep measurements
  – EEG recordings
  – Between subjects vs. within subjects design

• Magnitude of effect
  – Sample size

• Statistics
  – Multiple comparisons

• Individual Variability
Exposure during sleep
Exposure during waking

Antenna asymmetrical in mobile phones: Left and right hemispheric exposure different
Summary of Current State of Knowledge

• Exposure to pulse-modulated RF EMF affects:
  – Waking EEG (alpha activity)
  – NonREM sleep EEG (spindle and alpha frequency ranges)

• Pulse modulation critical for RF EMF-induced EEG effect
  – Critical field parameters associated with the effects unknown
  – Frequency of pulse modulation appears to be non-specific

• RF EMF effects:
  – Outlast exposure
  – Appear to be non-thermal
  – Independent of exposure side
  – May be dose-dependent
  – Large individual variability

• Other techniques support altered neural activity from RF EMF exposure
  – Regional cerebral blood flow (rCBF) (e.g. Huber et al., 2002, 2005; Aalto et al., 2006)
  – Brain glucose metabolism (Volkow et al., 2011; Kwon et al., 2005)

• Cognitive function:
  – Currently no clear or consistent evidence for an effect; rather no effect
  – Individual variability?
Mechanisms Unknown

• Only known mechanisms for interactions with RF EMF are thermal
  – Mechanisms responsible for the effects on brain physiology are currently unknown
  – Some evidence that the effects are non-thermal
  – Important to know what is behind the effects

• Effects occurring at exposure levels lower than current guidelines!
Overall Conclusions

• Pulse modulated RF EMF, such as emitted by mobile phones, alters brain physiology
  – Numerous studies have shown consistent effects as measured by the EEG
  – Effects occur during different vigilance states (i.e. waking and sleep)
  – Replicated within laboratories and independently
  – Effects evident with both ‘simulated’ and ‘real’ mobile phone exposure
  – Studies not showing effects suffer from several methodological weaknesses

• Potential health consequences unknown

• Priority of future research
  – Mechanisms and site of interaction
  – Function significance
  – Long-term ramifications
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