RADIOFREQUENCY EFFECTS ON THE HUMAN ELECTROENCEPHALOGRAM:

ITS RELEVANCE FOR HEALTH AND HOW DO WE EXPLAIN THIS PHENOMENON

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Bundesamt für Strahlenschutz

OUTLINE

- History
- Cognition
- Evoked and event related potentials
- Spontaneous waking EEG
- Sleep EEG
- Exposure and dosimetry
- Possible mechanisms
- Health relevance

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HISTORY

Low Energy Emission Therapy

27.12 MHz modulated at 42.7

Sleep inducing and promoting effect

(Reite et al., Bioelectromagnetics, 1994)

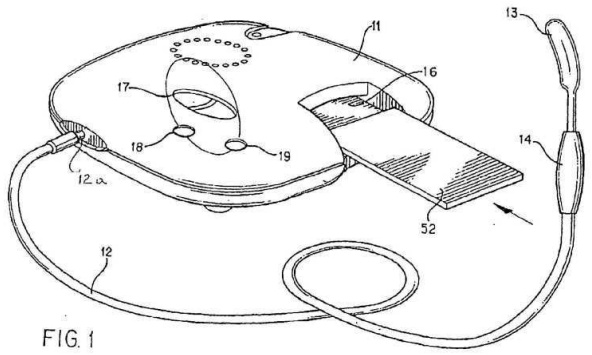


FIG. 1

Effect of EMF on human brain activity

Mega-Wave 150 (150 MHz)

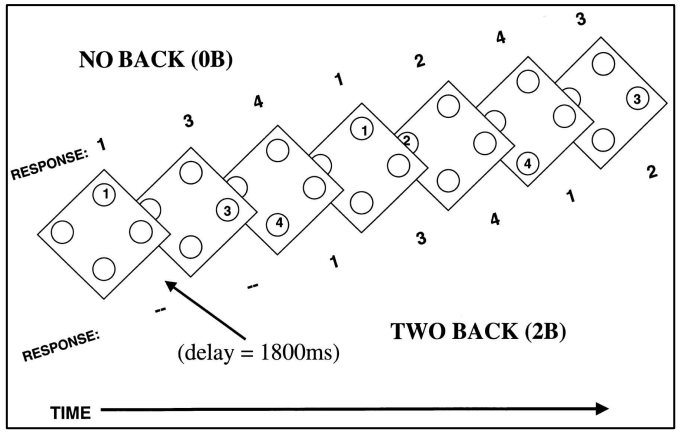
D1 Mobile phone 324, GSM

Increase of EEG power in Alpha and Beta Band

(Reiser, Eur. J. Med. Res., 1995)

COGNITION

- reaction time
- auditory and visual discrimination
- short and long term memory



Callicot et al. 1999

Stroop Effect

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLUE
BLUE RED PURPLE
YELLOW RED GREEN

Small, single blind, older studies: Effects in both directions, often improvement

Large, double blind recent studies, correction for multiple testing: no or very small effects, failed replications.

TETRA: 400 MHz, up to 10 W/kg, very few studies. Some minor effects on memory cannot be excluded, replication needed, ongoing study in Germany.

COGNITION

Barth et al., Occup. Environ. Med. 2008: *Results of the meta-analysis suggest that EMFs may have a small impact on human attention and working memory.*

van Rongen et al., J. Toxicol. Environ. Health. 2009: *No consistent significant effects on cognitive performance in adults have been observed. If anything, any effect is small and exposure seems to improve performance. Effects in children did not differ from those in healthy adults.*

Valentini et al., Occup. Environ. Med. 2010: *Mobile phone-like EMF do not seem to induce cognitive and psychomotor effects.*

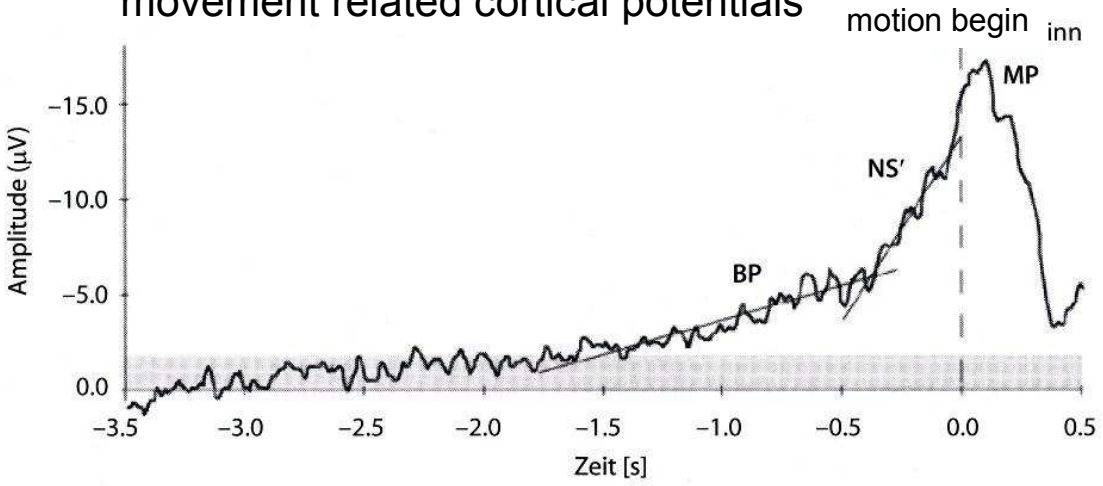
Kwon and Hämäläinen, Bioelectromagnetics 2011: *Behavioral studies previously reported improved cognitive performance under exposure, but it was likely to have occurred by chance due to multiple comparisons. Recent behavioral studies and replication studies with more conservative statistics found no significant effects compared with original studies.*

Recent German study (Sauter et al. 2011) – no effect of EMF on cognition, but significant influence of time of day.

EVOKED AND EVENT RELATED POTENTIALS

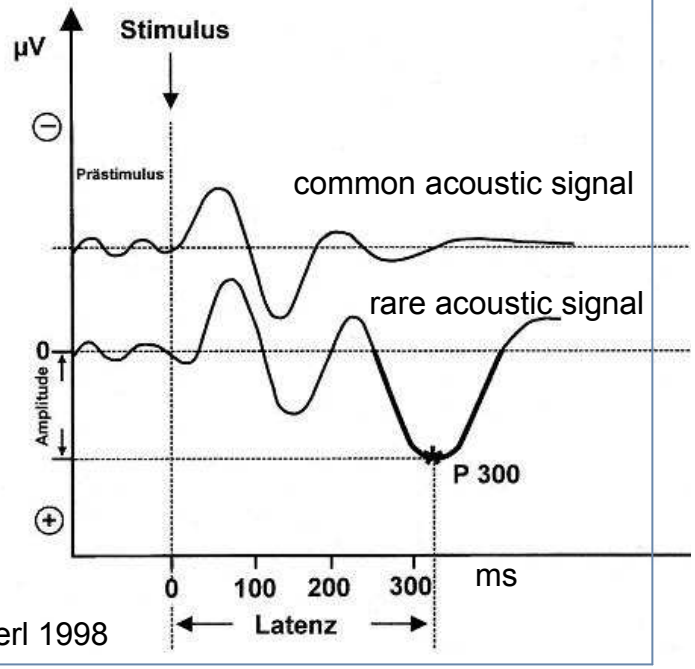
- brain signals recorded by EEG
- sensory perception – auditory, visual
- intention, awaiting and performing a task
- many parameters: amplitude, latency, frequency, power

movement related cortical potentials



Stöhr et al. 2005

acoustically evoked potential



Hegerl 1998

EVOKED AND EVENT RELATED POTENTIALS: Australia

Changes in spectral power of EEG during an auditory task (Croft et al. 2002) and in amplitude and latency of auditory evoked potentials (Hamblin et al. 2004). Weak methodology – dosimetry, single blind, small sample size.

Larger, double blind replication study, with a power of 80% to detect a difference of 0.25 SD failed (Hamblin et al. 2006): *There was no significant difference between exposure conditions for any auditory or visual event related potential (ERP) component or RT. As previous positive findings were not replicated, it was concluded that there is currently no evidence that acute MP exposure affects these indices of brain activity.*

Large study including adolescents, adults and elderly has shown effects on auditory evoked potentials (all age groups, 2G only) and event related desynchronization/ synchronization (all age groups, 2G and 3G) during an auditory task which was specially adjusted to individual abilities (Leung et al. 2011): *The subtlety of mobile phone effect on cognition in our study suggests that it is important to account for individual differences in future mobile phone research.*

EVOKED AND EVENT RELATED POTENTIALS: Finland

Effects on brain oscillatory activity in the frequency range of 8-12 Hz during auditory and visual memory tasks (Krause et al. 2000) unable to replicate (Krause et al. 2004), but found again later (Krause at. al. 2007).

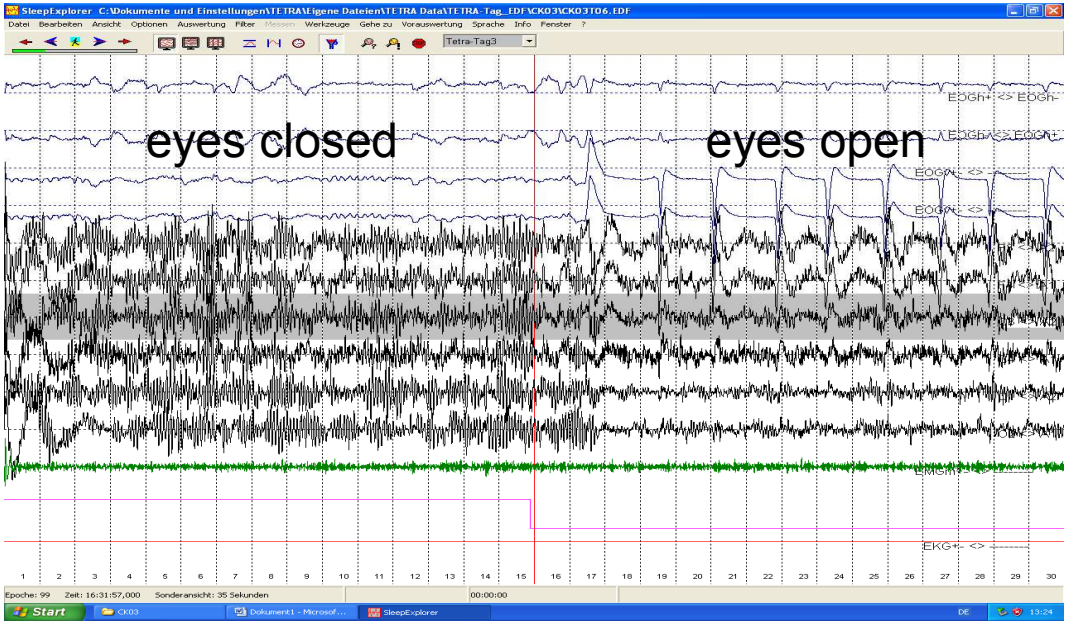
The effects on the EEG were, however, varying, unsystematic and inconsistent with previous reports. We conclude that the effects of EMF on brain oscillatory responses may be subtle, variable and difficult to replicate for unknown reasons.

Slight effects on event related desynchronisation/synchronisation during an auditory memory task in children (Krause et al. 2006), but no effect on auditory evoked potentials neither in adults (Kwon et al.2009) nor in children (Kwon et al. 2010).

Kwon and Hämäläinen, Bioelectromagnetics 2011: *Neurophysiological studies found no significant effects on cochlear and brainstem auditory processing, but only inconsistent results on spontaneous and evoked brain electrical activity. The inconsistent findings suggest possible false positives due to multiple comparisons and thus replication is needed.*

SPONTANEOUS WAKING EEG

Registration of brain electrical activity
Frequency bands: δ (0.5 – 3.5 Hz)
θ (3.5 – 7.5 Hz)
α (7.5 – 12.5 Hz)
β (12.5 - 30 Hz)



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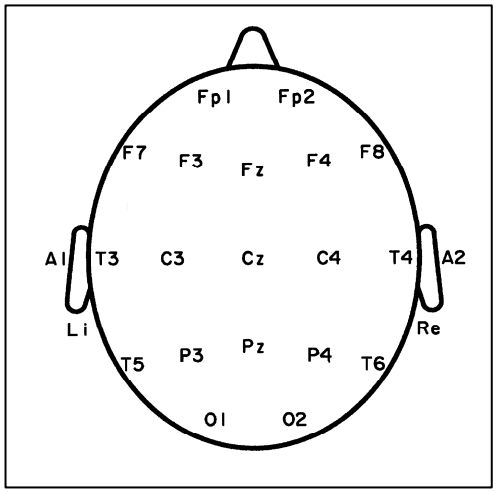


SPONTANEOUS WAKING EEG

significant changes with exposure	year	N	Authors
No effect	1997	34	Rösche and Mann
No effect	2000	19	Hietanen et al.
Increased α-power, decreased δ-power	2002	24	Croft et al.
Increased α-power, decreased δ-power	2005	20	Curcio et al.
No effect	2007	12	Perentos et al.
Increased α-power	2007	24	Regel et al.
Interhemispheric synchronization in α-band	2007	10	Vecchio et al.
No effect	2008	15	Kleinogel et al
Increased α-power	2008	120	Croft et al.
Increased α-power (young adults, 2G)	2010	41,42,20	Croft et al.
Interhemispheric synchronization in α-band	2010	16	Vecchio et al.
Interhemispheric synchronization in α-band	2012	11	Vecchio et al.

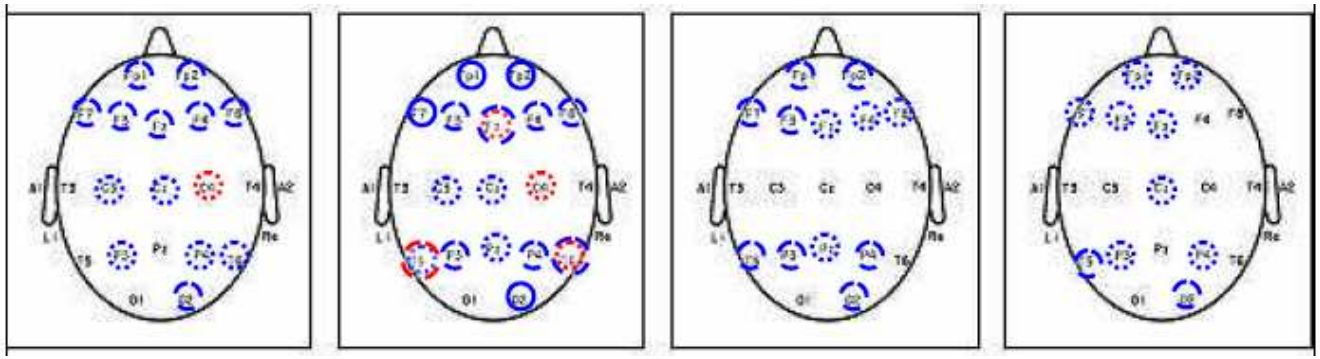
SPONTANEOUS WAKING EEG

Recent German study (Charité Berlin):

No effect of GSM and UMTS on waking EEG (power, α-attenuation) after correcting for multiple testing

Significant influence of time of day.

10.0 Hz | 10.25 Hz | 10.5 Hz | 10.75 Hz

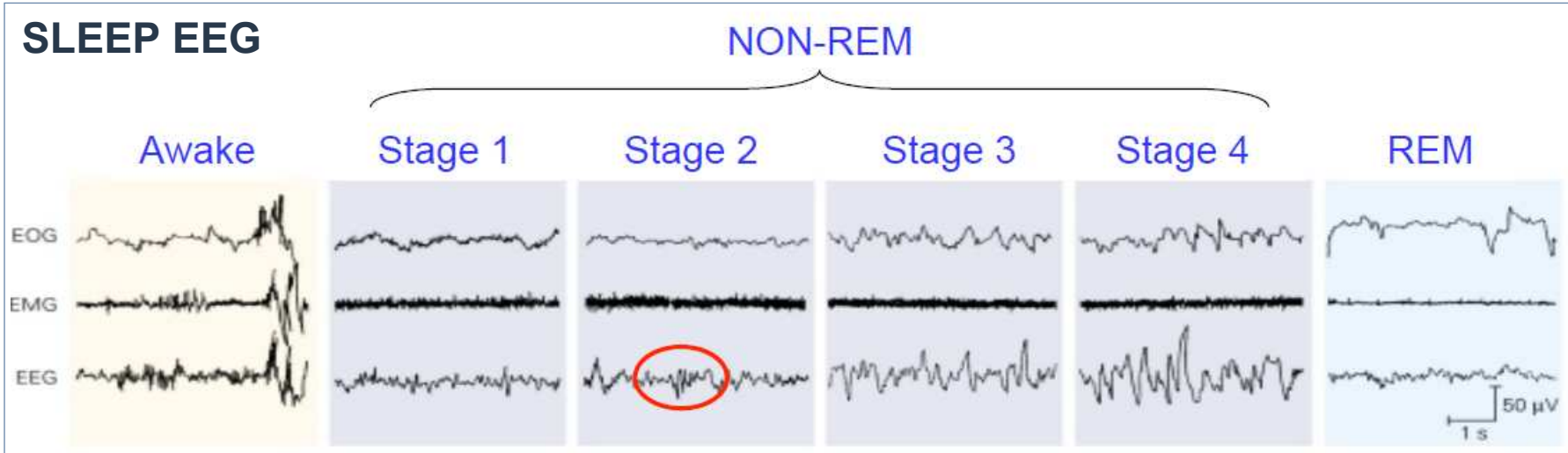


0.05; 0.01; 0.001

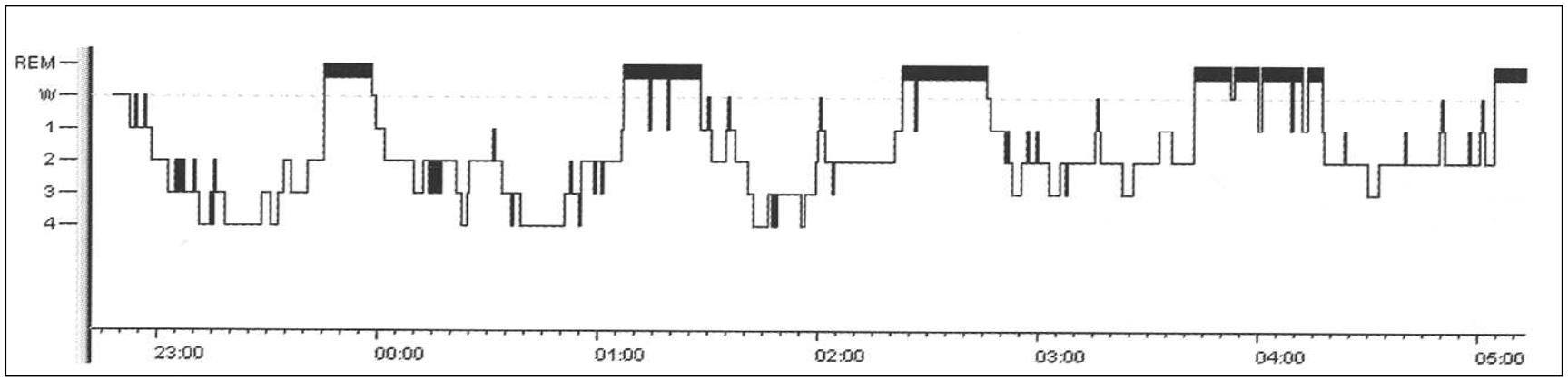
blue: time of day

red: GSM

SLEEP EEG



Appleton & Lange
Kandel/Schwartz/Jessell
Principles of Neural Science
Fig. 47.01



SLEEP EEG

Laboratory studies: Sleep macrostructure

significant changes with exposure	year	N	Authors
Reduced sleep latency	1996	12	Mann and Röschke
Reduced REM-sleep (% SPT)	1996	34	Mann and Röschke
No effect	1998	22	Wagner et al.
No effect	2000	20	Wagner et al.
Reduced wake after sleep onset	1999	24	Borbély et al.
No effect	2000,2003	16	Huber et al.
No effect	2002	16	Huber et al.
No effect	2005	13	Hinrichs et al.
reduced REM-sleep latency	2005	50	Loughran et al.
Prolonged sleep latency	2007	10	Hung et al.
No effect	2007	10	Fritzer et al.
No effect	2007	15	Regel et al
Reduced duration and prolonged latency of SWS	2011	48	Lowden et al.

SLEEP EEG

German Study: GSM (Danker-Hopfe et al. 2011)

NREM1-sleep whole night [min]	**reduced**
REM-sleep whole night [min]	**increased**
REM-sleep whole night [% TST]	**increased**
Mean duration of REM-cycles	**increased**
REM-sleep middle sleep cycles [min]	**increased**
REM-sleep 3rd quarter of the night [min]	**increased**
REM-sleep 3rd quarter of the night [%]	**increased**
NREM2-sleep whole night [min]	**reduced**
NREM2-sleep whole night [% TST]	**reduced**
NREM2-sleep 3rd quarter of the night [min]	**reduced**
NREM2-sleep 3rd quarter of the night [% TST]	**reduced**
Stage shifts from SWS to NREM1	**reduced**
Movement time 1st sleep cycles [min]	**increased**
Movement time 1st quarter of the night [min]	**increased**

14 observed, 12 expected by chance

SLEEP EEG

German Study: UMTS (Danker-Hopfe et al. 2011)

NREM1-sleep whole night [min]	**reduced**
NREM1-sleep whole night [% TIB]	**reduced**
NREM1-sleep during sleep period time [min]	**reduced**
NREM1-sleep [% SPT]	**reduced**
NREM1-sleep 2nd third of the night [min]	**reduced**
NREM1-sleep 2nd third of the night [% TIB]	**reduced**
Mean duration NREM cycles [min TIB]	**reduced**
Mean duration REM cycles [min TIB]	**increased**
NREM2-sleep middle cycles [min]	**reduced**

Less observed that expected by chance

No effect of GSM and UMTS on sleep macrostructure

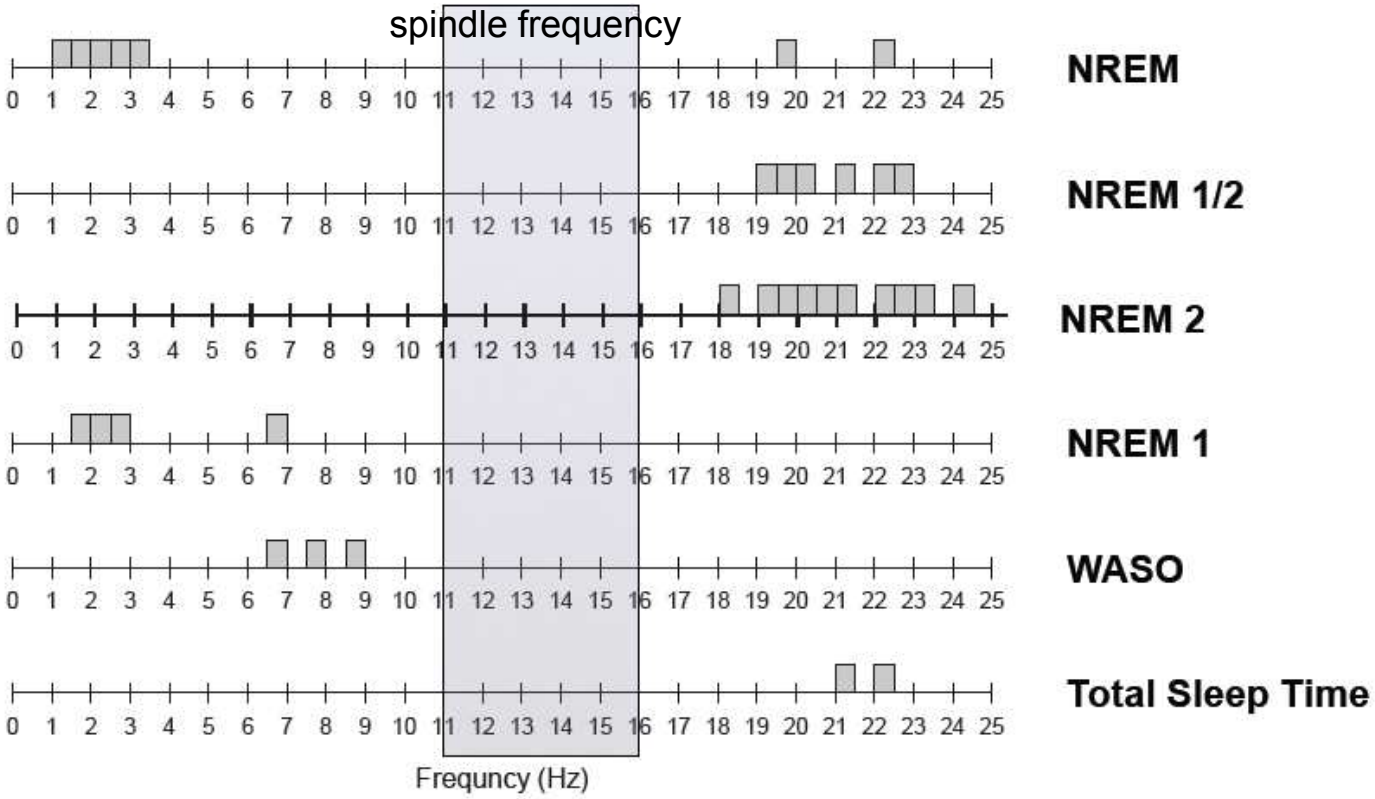
SLEEP EEG

Laboratory studies: Power spectral analysis

significant changes with exposure	year	N	Authors	
Increased mean power during REM sleep	1996	12	Mann and Röschke	
No effect	1998	22	Wagner et al.	
No effect	2000	20	Wagner et al.	
Increased mean power during NREM sleep	1999	24	Borbély et al.	spindle frequency range
Increased mean power during NREM sleep	2000,2003	16	Huber et al.	
Increased mean power during NREM sleep	2002	16	Huber et al.	
Increased mean power during NREM sleep	2007	15	Regel et al.	
Increased mean power during NREM sleep	2005	50	Loughran et al.	
No effect	2005	13	Hinrichs et al.	
Increased mean power during NREM sleep	2007	10	Hung et al.	1 - 4 Hz
Increased mean power during NREM sleep	2012	20	Loughran et al.	spindle frequency range
Increased mean power during NREM sleep	2011	48	Lowden et al.	
Increased mean power during NREM sleep	2012	30	Schmid et al.	

SLEEP EEG

German Study: Spectral power, GSM (Somnolyzer, 400 variables)



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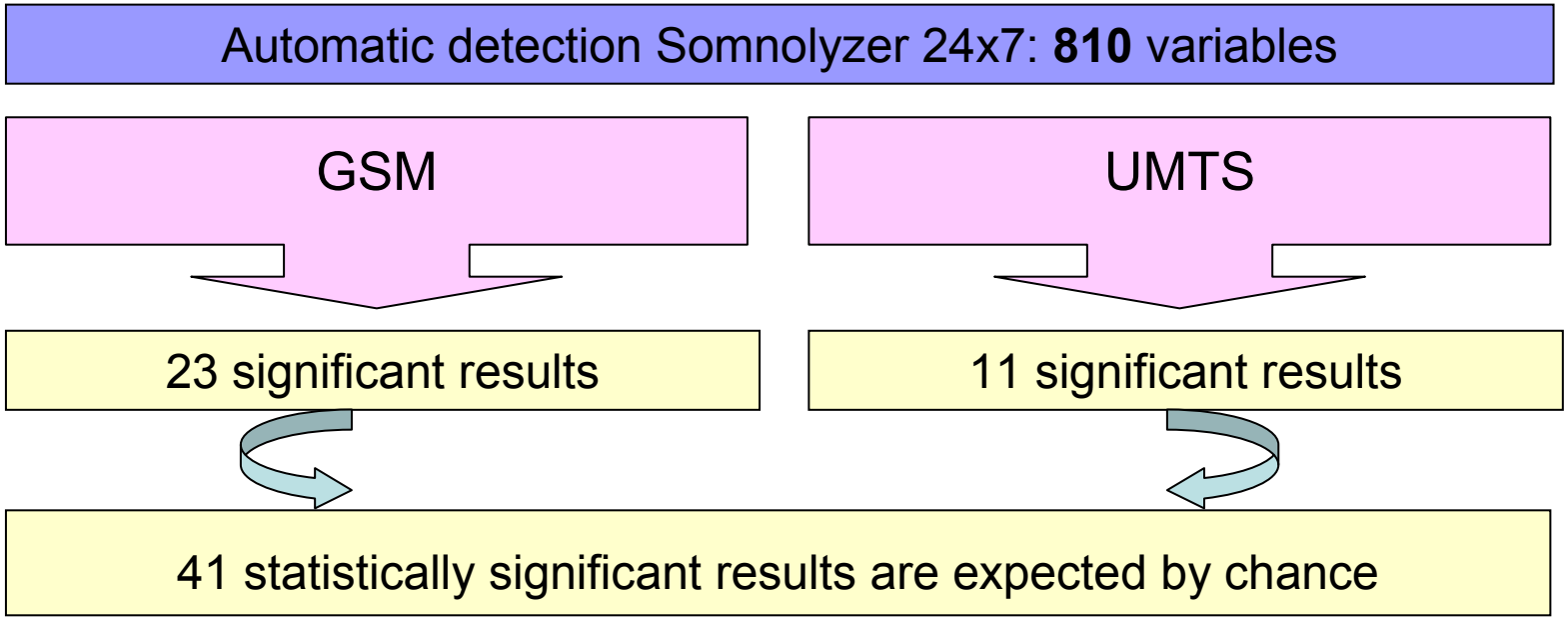
No changes of power in SWS and REM sleep; No changes under UMTS

SLEEP EEG

German Study: spindle detection



No systematic changes in frequency, density, amplitude and duration of spindles

Young healthy men – no information about female, elderly…

Individual variability?

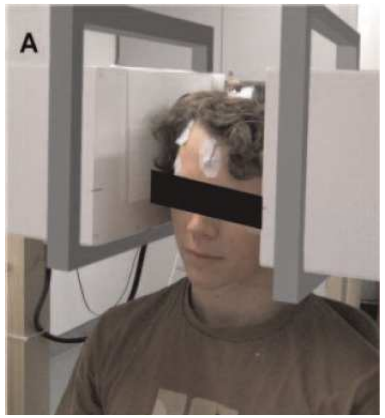
Exposure and dosimetry

- exposure intensity
- exposure duration
- pulsed – continuous wave
- near field – far field
- sleep: prior to sleep – during sleep
- waking: tests during or before and after exposure
- mobile phone, simulated mobile phone, homogeneous exposure of a hemispehre
- left – right side

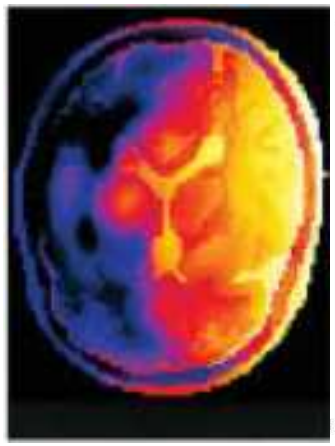
Exposure and Dosimetry

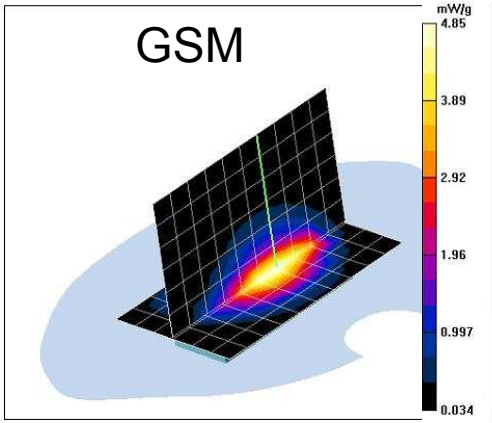
Nokia 6110

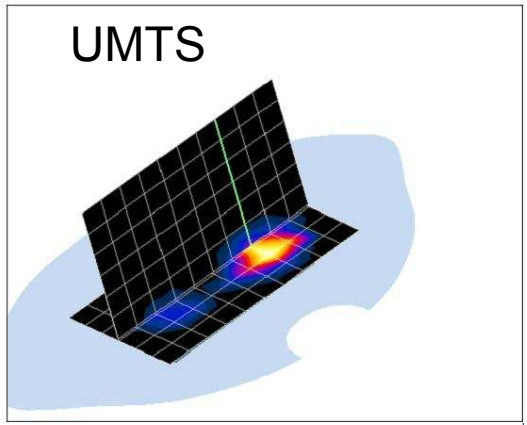
Patch antenna



Planar antenna







Boutry et al. 2007, Murbach et al. 2012, Bahr et al. 2007

Possible mechanisms

Thalamus: - central role in spindle generation
- sensory and motor signals to the cerebral cortex, regulation of consciousness, sleep, and alertness

Hypothalamus: thermoregulation, circadian rhythm, sleep

Influence of EMF: direct, or via cortical stimulation

Thermal or non-thermal?

Sensitivity of neurons: ~ 0.1°C; neuronal Networks: 0.03°C

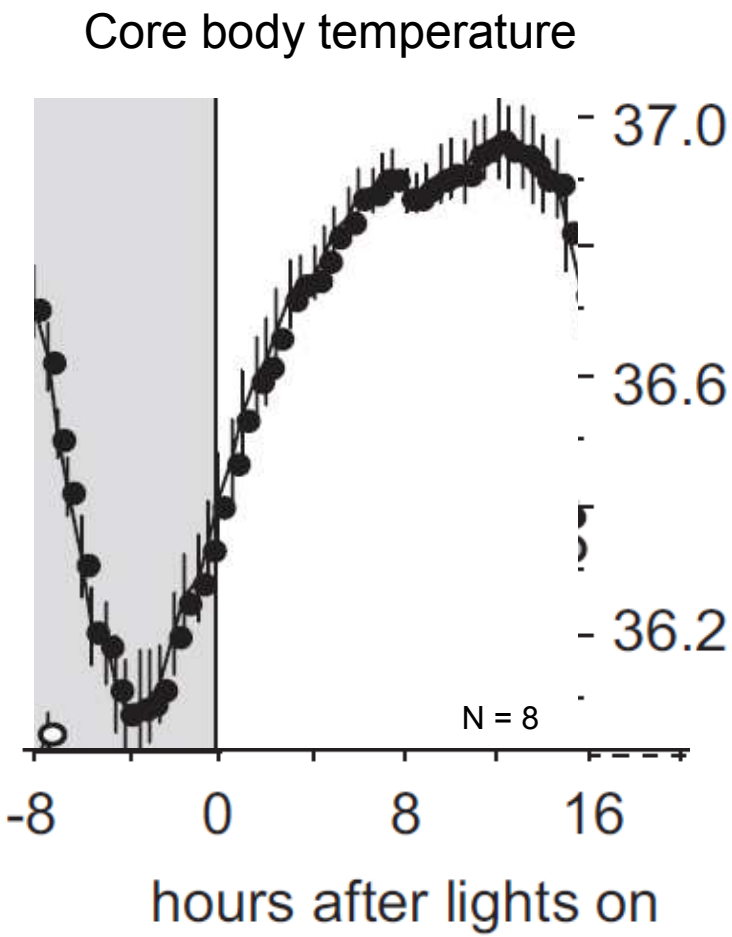
Peak **exposure** of thalamus:
Nokia 6110: Turku: 0.024 W/kg; Swinburne: 0.011 W/kg
Patch antenna: 0.16 W/kg (Boutry et al. 2007)
Planar antenna (TETRA, 6 W/kg) – 0.08 W/g (Schmid et al. 2012)

Temperature increase at 2 W/kg (simulated mobile phone):
cortex < 0.1°C, thalamus < 0.01°C (Schmid et al. 2007)

Possible mechanisms

- Circadian rhythm
- Thermoregulation
- Sleep regulation
- Warming: sleep induction

Activation of warm-sensitive neurons of Hypothalamus triggers NREM-sleep onset. These neurons are activated by direct warming as well as by peripheral thermo sensory input.



Kräuchi et al. 2007

Health relevance

- No effect on cognition
- No effect on evoked and event related potential
- No effect on waking EEG
- No effect on sleep macrostructure and sleep quality
- Possible effect on sleep EEG
- Probably sleep inducing and promoting effects, no sleep disturbance
- Apparently dose dependent
- Role of pulse modulation not clarified
- Possibly thermal
- Physiologically interesting, differences between laboratories should be clarified
- Age, gender and individual variability insufficiently investigated
- Probably no adverse health relevant effects