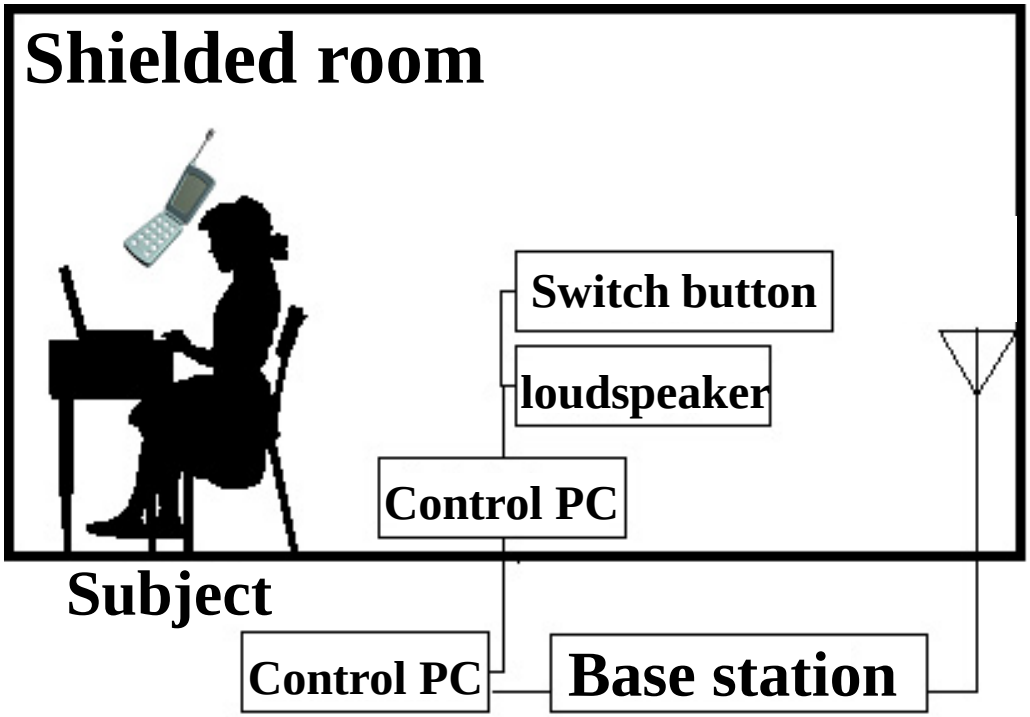
資料2-5

EMFのヒトへの影響
（EMFの脳への影響）

- 認知機能への影響
- 被験者の主観的評価
- 覚醒時の脳波に対する影響
- 睡眠（脳波）に対する影響
- 誘発電位に対する影響
- 脳血流に対する影響

暴露環境



EMF暴露

例）1.95-GHz wide-band code division multiple access (W-CDMA) signal

電磁波の暴露と認知機能(記憶、注意、集中)

認知機能は電磁波の影響をみるのに鋭敏ではない。

authors	electromagnetic field	Task performed	findings
Preece et al. (1999)	915-MHz GSM, mobile telecommnunication	short- and long-term memory, simple and choice reaction time, and sustained attention	significant shortening of reaction time in choice reaction time, no change in simple reaction time
Koivisto et al. (2000a)	900-MHz GSM, mobile phone	Simple and choice reation time tasks, vigilance task	no significant reaction time in choice reaction time, reduction in simple reaction and vigilance task
Koivisto et al. (2000b)	900-MHz GSM, mobile phone	12 cognitive tasks including simple reaction time and vigilance tasks, mental arithmetics task	speeding up of response times in simple reaction time and vigilance tasks, the cognitive time needed in a mental arithmetics task was decreased
Haarala et al. (2003b,2004)	902-MHz GSM pulsed EM field	short term memory task	Failure to confirm above results, no effects on adults' and children's cognitive function
Lass et al. (2002)	450-MHz RF modulated at 7 Hz	3 cognitive tasks including memory recognition task	no significant effects in exposed group, showing worse performance and greater intersubject variability. Fewer errors on the memory recognition task in exposed subjects.
Edelstyn & Oldershaw (2002)	900-MHz GSM mobile phone	6 widely used cognitive tasks	exposure facilitated cognitive tasks involving attentional capacity and one task that involved processing speed
Zwamborn et al. (2003)	UMTS-like signal at 10 V/m.	reaction time, memory comparison, dual-tasking, selective visual attention, and filtering irrelevant information	No significant effects on the cognitive functions
Smythe & Costall (2003)	900-MHz GSM mobile phone	short- and long-term memory tasks	males exposed to an active phone made fewer spatial errors than those exposed to an active phone condition, while females were largely unaffected
Maier et al. (2004)	900-MHz GSM-type RF	Discrimination of auditory stimuli	Exposure significantly reduced the subsequent performance of the task
Curcio et al. (2004)	900MHz GSM	acoustic simple reaction time task, visual search task, arithmetic descending subtraction task, acoustic choice reaction time task	Significant reduction of both simple and choice reaction times, subjects exposed before testing performed more rapidly than those exposed during testing
Besset et al. (2005)	900-MHz GSM	europsychological battery of 22 tasks screened information processing, attention, memory, and executive function	no significant effect of RF exposure on task performance
Russo et al. (2006)	888-MHz continuous-wave (CW) or GSM RF	reaction-time task, 10-choice serial reaction time task, subtraction task, and vigilance task,	no significant effects of RF exposure on task performance
Keetley et al. (2006)	GSM RF radiation	Rey's audiovisual learning test, digital span test, digital symbol substitution test, speed of comprehension test, trail making task, reaction time task, choice reaction time task, and inspection time task	simple and choice reaction times showed significant impairment
Eliyahu et al. (2006)	GSM mobile phone RF radiation	spatial item recognition task, spatial item recognition task, spatial compatibility tasks	exposure of the left hemisphere of the brain resulted in slower left-hand responses in the second session compared to the first, for the spatial item recognition task and one spatial compatibility task
Terao et al (2006)	800-MHz mobile phone	Precued choice reaction time task	Exposure did not have any significant effect on reaction time or accuracy
Eliyahu et al. (2006)	GSM mobile phone RF radiation	spatial item recognition task, spatial item recognition task, spatial compatibility tasks	exposure of the left **hemisphere of** the brain resulted in slower left-hand responses in the second session compared to the first, for the spatial item recognition task **and** one spatial compatibility task
Wilén et al. (2006)	mobile phone radiation	tests of arousal and vigilance, short-term memory, and reaction times	No significant effects of RF radiation on any cognitive variable
Haarala et al. (2007)	continuous or GSM signal operating at 0.25 W	simple reaction time, 10-choice reaction time, subtraction, verification, vigilance, and memory (n-back test).task	No significant difference on response between exposure to either the left or right hemisphere and sham exposure
Regel et al. (2007)	900-MHz GSM	Simple reaction time task, 2-choice reaction time task, n-back task, visual selective attention task	reduction of reaction time with increasing field strength for the 1-back task, and similar relations at trend level for the 2-back task and the choice reaction time task, but no significant effect on the simple reaction time or 3-back task.
Cinel et al. (2007)	900MHz GSM-like and continuous wave signals	auditory order threshold task	Replication of the Maier et al (2004) study on a larger number of subjects, no significant effect of exposure to RF EMF
Terao et al. (2007)	Mobile phone (1.95 GHz EMF at 0.27W net antenna input power, 250 mW)	visually guided saccade (VGS), gap saccade (GAP), and memory guided saccade (MGS) task	no significant effect on saccade tasks
Riddervold et al. (2008)	2140-MHz base station-like signal modulated as UMTS, or a 2140-MHz continuous-wave signal	reaction time (RTI) Rapid Visual Information Processing (RVP), Paired Associated Learning (PAL)	no significant effect on cognitive functions
Furubayashi et al. (2009)	2.14 GHz, 10 V/m (W-CDMA)	Precued choice reaction time task	no significant effect on cognitive functions
Okano et al. (2010)	Mobile phone (1.95 GHz EMF at 0.27W net antenna input power, 250 mW)	antisaccade task, overlap saccade task, memory guided saccade task	no significant effect on inhitibion of saccades
Curcio et al. (2012)	902.40 MHz GSM-EMF	somatosensory task	RTs in a somatosensory task resulted unaffected.
Vecchio et al (2012)	902.40 MHz GSM-EMF	visual go/no-go task	faster reaction time to go stimuli in the post- than pre-exposure

Provocation study

authors	electromagnetic field	Symptoms assessed	findings
Koivisto et al. (2001)	pulsed 902-MHz field, 30min, 1hr	rate subjective symptoms and sensations	No significant differences were found between exposure conditions, although fatigue and headaches increased toward the end of sessions.
Hietanen et al. (2002)	RF EMFs	Blood pressure, heart rate, and breathing rate, report any abnormal feelings.	more symptoms were reported during sham exposure than during real exposure, subjects could not indate sham exposure from real exposure
Rubin et al. (2006)	900-MHz GSM mobile phone radiation, 50min	Subjective scoring of the severity of headaches and various other symptoms such as nausea, fatigue, and dizziness	Prevalence of various symptoms experienced was higher in sensitive than non-sensitive subjects. No difference in detecting real/sham exposure between sensitive and non-sensitive subjects.
Wilén et al. (2006)	900-MHz (GSM) RF radiation, 30min	Physiological parameters such as heart-rate variability, electrodermal activity, and respiration rate, cognitive function tests	No significant effects of RF radiation on any physiological parameter were found. “Sensitive” subjects showed differences in heart-rate variability compared to controls
Oftedal et al. (2007)	450-MHz RF modulated at 7 Hz	headache, discomfort, and various physiological parameters	increase in headache and discomfort was found after sham but not after real exposure; subjects could not perceive being exposed .no effects on heart rate and blood pressure..
Zwamborn et al. (2003)	UMTS-like signal at 10 V/m., GMS signal at 0.7V/m	cognitive functions and self-reported well-being	A significant decrease in well-being after UMTS exposure, No significant effects were seen using GSM signals either at 900 or 1800 MHz
Regel et al. (2006)	2140-MHz UMTS base-station-like RF signal	self-reported well-being	Subjects were also not able to discriminate between exposure levels, but they reported more health complaints when they suspected exposure
Eltiti et al. (2007)	GSM and UMTS fields, 10 mW/m2	Well-being, physiological functions, perception of EMF	well-being of the sensitive but not of the control subjects was decreased after GSM and UMTS exposure, skin conductance and heart rate were higher than in controls, but these parameters were not influenced by exposure. Perception of the on/off status of the field not better than chance in either group
Riddervold et al. (2008)	2140-MHz signal modulated as UMTS, or a 2140-MHz continuous-wave signal, 45 min	self-reported symptoms and perceptions of air temperature, air humidity, and air quality	no significant effect on symptoms and perceptions
Landgrebe et al. (2008)	mobile telephone exposure	fMRI	electrosensitive subjects, the areas of the brain that are activated in anticipation of, and during, sham exposure are the same that are activated in both sensitives and nonsensitives when they are exposed to heat
Rubin et al. (2008)	mobile telephone exposure	occurrence of symptoms	Well-being in those who use the label “electrosensitive” was worse than in the subjects that reported being sensitive to mobile phones but that did not use the label “electrosensitive,” or in controls without symptoms.
Furubayashi et al. (2009)	UMTS-like signal at 10 V/m, 30min	Psychological and cognitive parameters, autonomic functions, perception of EMF and level of discomfort	The subjects with mobile phone-related symptoms did experience a higher level of discomfort than controls, but this was independent of the type of exposure. Perception of the on/off status of the field not better than chance in either group

頭痛、疲労感、自覚的な気分（不快・不安感）、生理的指標などの症状…十分に鋭敏な視標でない可能性

電磁波に過敏な被験者は、そうでない被験者と比較して、必ずしも正確に電磁波の暴露を感知しているわけではない。

Correct-response rate: MPRS group 52±8%, control group 49±5%;
no significant difference between the two groups'

電磁波に過敏な被験者は、そうでない被験者と比較して、暴露に対する症状や自律神経の生理指標の反応の程度が強いわけではない。

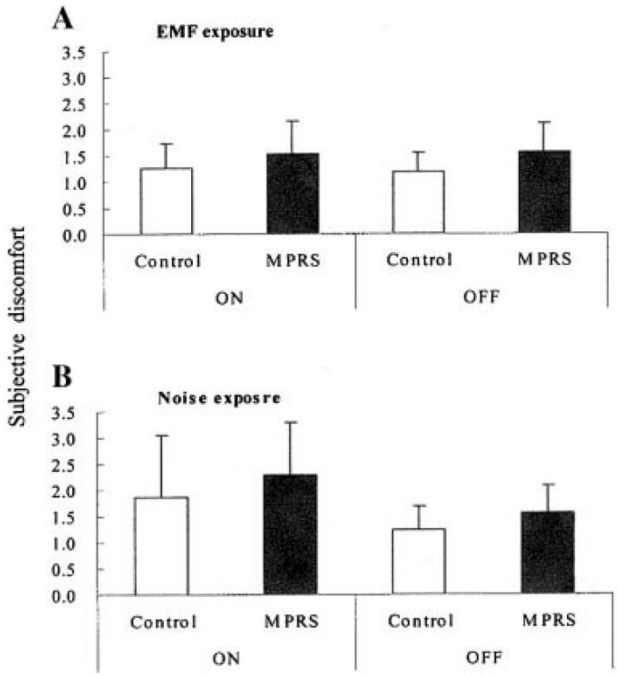


Fig. 3. Effect of EMF or noise exposure on perceived discomfort. Subjective discomfort was assessed on a 5-point scale (1: no discomfort, 5: maximal discomfort imaginable) in each condition. The average discomfort level is shown here, separated according to whether intermittent EMF (**A**) or noise (**B**) was on (left two bars) or off (right two bars). Data are given separately for the control and MPRS groups. Error bars give standard deviation.

(Furubayashi et al., 2009)

覚醒時脳波への影響

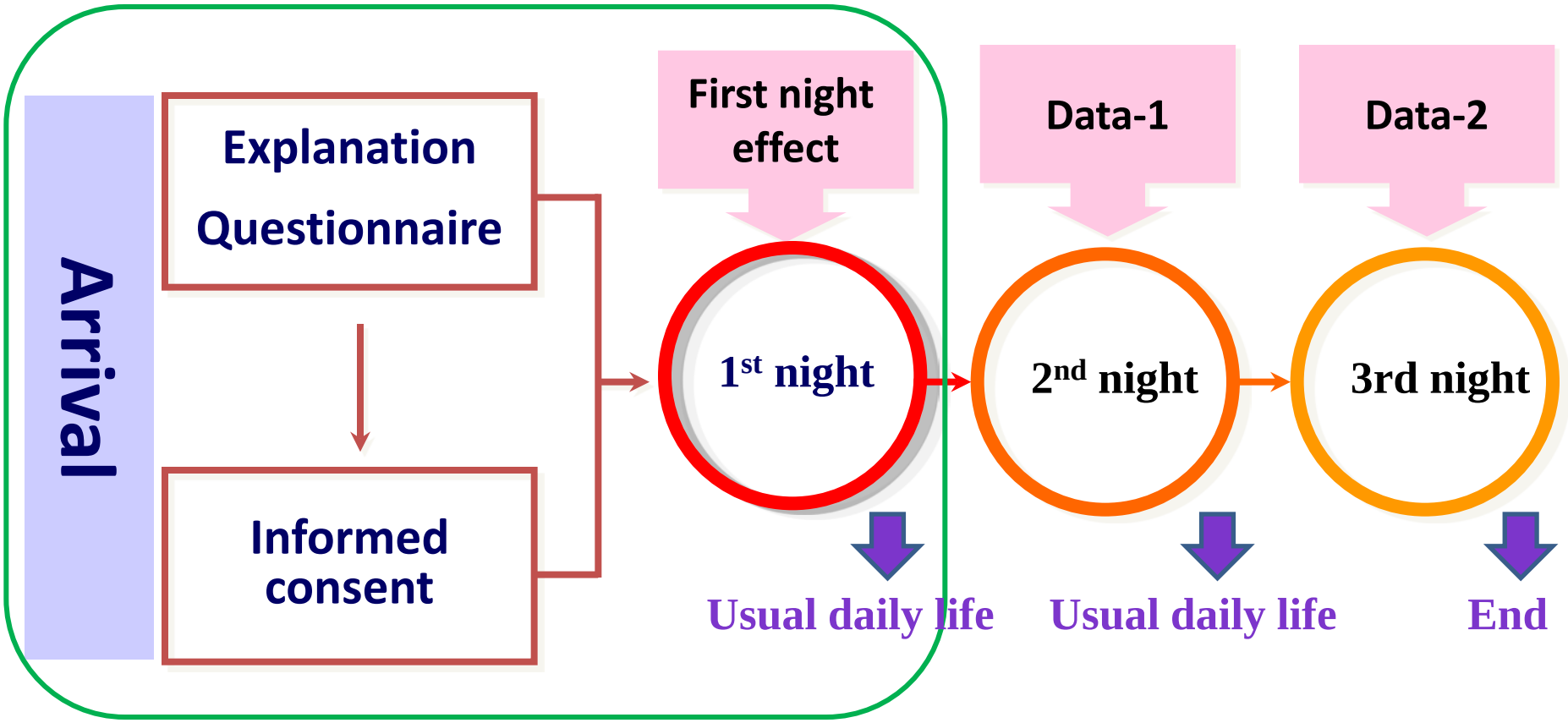
authors	electromagnetic field	Parameters assessed	findings
Reiser et al. (1995)	GSM mobile phone	EEG power	Increased power of EEG frequencies in the 18–35 Hz
Röschke and Mann (1997)	GSM mobile phone positioned at 40cm from vertex	EEG power	No significant effect on the EEG
Borbély et al. (1999)	900-MHz “pseudo GSM signal”	EEG power	Increased resting EEG power in the 11–11.5 Hz bin only
Hietanen et al. (2000)	Analogue and GSM at 900 and 1800 MHz, hand-sets	EEG power	effect in only absolute but not relative power in one frequency band in one of four brain regions
Lebedeva et al. (2000)	900-MHz signal directed at the back of the head	EEG power	“dimensional complexity” was more sensitive to the effects of RF signals than conventional indices.
Freude et al. (2000)	900-MHz GSM phone	EEG power during a visual monitoring task	decrease of EEG power in all regions except frontal
Huber et al. (2000)	900-MHz GSM signal	EEG power before sleep	Resting EEG reduced in the 10.5–11 Hz range
Huber et al. (2002)	900-MHz GSM signal, hand-set continuous-wave 900-MHz signal	Waking EEG	Increased power in the alpha band for pulse-modulated EMF only
D’Costa et al. (2003)	GSM phone positioned behind the head, the antenna pointing toward the head.	EEG power	EEG alpha (8–12 Hz) and beta (13–30 Hz) bands showed significant differences when the full power mode was on
Kramarenko and Tan (2003)	GSM phone on standby	EEG power	A slow-wave delta (2.4–6 Hz) appeared in areas on the side of the phone in adults, the slow waves with lower amplitude (1–2.5 Hz) appeared earlier in children
Hinrikus et al. (2004)	450-MHz microwaves with 7-Hz on–off modulation	EEG power	Changes in the EEG in the frontal region
Papageorgiou et al. (2004)	GSM-like signal	EEG power during a memory test	exposure decreased the power in males and increased it in females , no effect of exposure on performance in the memory test, no details of experimental setup given
Curcio et al. (2005)	900-MHz GSM phone	EEG power	A small increase in some frequencies in the alpha band, stronger under exposure
Maby et al. (2006)	undefined GSM mobile phone	EEG power	decrease in EEG power in the theta, alpha, and beta bands, decrease in the variations in the delta band, in the epileptic patients an increase in power in all EEG bands
Bachmann et al. (2007)	450-MHz signal, pulse modulated at 1000 Hz, 30min	EEG power	Significant changes in the ratio of the EEG power in the beta and theta frequency bands
Vecchio et al. (2007)	GSM phone located at the left side of the head	EEG connectivity	the connectivity between both brain hemispheres in parts of the alpha band (8–12 Hz)
Regel et al. (2007)	GSM-type pulsed or continuous, planar antenna.	EEG power	An increase in frequencies in the alpha band
Perentos et al. (2007)	900-MHz GSM mobile phone or a 900-MHz continuous wave	specified EEG bands	No significant effect of either type of signal on any EEG band
Hinrikus et al. (2008)	7-, 14-, and 21-Hz pulse-modulated 450-MHz microwaves	EEG power	Significant changes in the alpha (8–13 Hz) and beta (15–20 and 22–38 Hz) bands with the 14- and 21-Hz modulations, No effect of the 7-Hz modulation
Croft et al. (2008)	875-MHz GSM phone	EEG power	An increased power in the alpha band, larger on the ipsilateral compared to the contralateral side in posterior regions
Kleinlogel et al. (2008)	1950 MHz UMTS (SAR 0.1 and 1 W/kg), pulsed 900 MHz GSM (1 W/kg)	EEG power	No significant changes in the measured parameters
Croft et al. (2010)	2nd generation (2G) GSM, and 3rd generation (3G) W-CDMA	EEG power (alpha activity)	young adults' alpha was greater in the 2G compared to Sham, no effect was seen in the adolescent or the elderly groups no effect of 3G exposures was found in any group
Vecchio et al. (2010)	GSM-EMF	inter-hemispheric functional coupling of electroencephalographic rhythms delta (about 2-4 Hz), theta (about 4-6 Hz), alpha1 (about 6-8 Hz), alpha2 (about 8-10 Hz), and alpha3 (about 10-12 Hz)	Increased inter-hemispheric synchronization of the dominant (alpha) EEG rhythms in elderly during GSM
Vecchio et al. (2012)	GSM-EMF	inter-hemispheric functional coupling of electroencephalographic rhythms delta (about 2-4 Hz), theta (about 4-6 Hz), alpha1 (about 6-8 Hz), alpha2 (about 8-10 Hz), and alpha3 (about 10-12 Hz)	increases in inter-hemispheric functional coupling of electroencephalographic α rhythms
Trunk et al. (2013)	3rd generation (3G) Universal Mobile Telecommunications SystemUMTS	EEG power (alpha activity)	No measurable effects on the EEG spectral power in delta, theta, alpha, and beta frequency bands

睡眠（脳波）への影響

authors	electromagnetic field	power of exposure	findings
Reite et al. (1994)	27.12MHz modulated at 42.7Hz		decreased sleep latency by 2min, increased deepsleep by 1min
Mann & Röschke (1996)	900MHz GSM		reduced sleep onset latency, reduced percentage REM sleep with increased power density of alpha wave
Wagner et al. (1998)	900-MHz GSM	0.5 and 0.2 W/m2	failed to replicate Mann and Röschke (1996)
Borbély et al. (1999)	"pseudo GSM"900-MHz		reduced number of waking episodes after sleep onset, EEG power spectra during the first of the night's episodes of REM sleep
Wagner et al. (2000)	GSM 900-MHz, 50 W/m2	2 W/m2	no significant effects on sleep architecture or EEG spectral power density
Huber et al. (2000)	900MHz GSM, antenna		increased spectral power in alpha and beta bands (9.75–11.25 Hz and 12.5–13.25 Hz) in the first non-REM sleep phase.
Huber et al. (2002)	900MHz GSM, hand-set		significant rise in the 12.25–13.5 Hz band during sleep
Loughran et al. (2005)	894.6-MHz mobile phone	larger sample (50)	increase in spectral power only in the 11.5–12.25 Hz range
Regel et al. (2007)	900MHz GSM	similar as Huber et al. (2002)	dose-related increase in spectral power in the 10.75–11.25 Hz and 13.5–13.75 Hz bands during non-REM sleep
Fritzer et al. (2007)	"pseudo" GSM900-MHz	similar as Borbély et al.	No significant differences in any parameter
Hung et al. (2007)	900-MHz GSM	different ELF pulse modulations	an increase in sleep latency, no change was seen in 1–4 Hz EEG power
Lowden et al. (2011)	884 MHz GSM, on-DTX and DTX mode	10 g psSAR of 1.4 W/kg	decreased time in Stages 3 and 4 slow-wave sleep, increased alpha range in the sleep EEG
Danker-Hopfe et al. (2011)	900MHz GSM, mobile phones W-CDMA		No evidence indicative of a negative impact on sleep architecture
Enomoto et al. (2013)	1950 MHz, mobile phones W-CDMA	SAR 1.52 and 0.13 W/kg	No significant differences sleep variables and power EEG spectra

Study protocol

Enomoto et al. (2013)



誘発電位への影響

authors	electromagnetic field	ERP modality	findings
Freude et al. (1998)	916.2 MHz EMF pulse modulated at 21.7 Hz	visual ERP	reduction in the amplitude of potentials in the central and temporo-parieto-occipital regions
Freude et al. (2000)	916.2 MHz EMF pulse modulated at 21.7 Hz 900-MHz GSM phone	Bereitschaftspotential, CNV	no marked effect
Urban et al. (1998)	900-MHz GSM mobile phone	visual ERP	No significant effects of exposure
Jech et al. (2001)	900-MHz GSM	visual ERP (visual oddball task)	enhanced amplitude of two components of the brain's response to the oddball stimuli, but only when the stimuli were presented to the right half of the visual field
Arai et al. (2003)	900-MHz GSM pulsed EM field	auditory brainstem response (ABR), the ABR recovery function and middle latency response (MLR)	None of the 3 measures were affected by exposure to pulsed EM field emitted by a mobile phone
Yuasa et al. (2006)	GSM 900-MHz, mobile phone RF	somatosensory ERP	No significant effects on somatosensory ERP or its recovery function,
Ferreri et al. (2006)	GSM mobile phone RF radiation	cortical excitability studied by TMS	transient decrease in intracortical inhibition and a transient increase in intracortical facilitation
Krause et al. (2000a, 2000b)	902MHz GSM	event-related desynchronization/synchronization (ERD/ERS)	increased the ERD/ERS responses in the 8–10 Hz frequency band only, Exposure effects at 6–8 and 8–10 Hz
Krause et al. (2004).	894.6-MHz mobile phone	ERD/ERS	ERD/ERS responses in the 4–8 Hz EEG frequency range, Failed replication of the findings from their earlier study
Krause et al. (2007)	900MHz GSM-like and continuous wave signals	EEG during visual and auditory memory task	No significant effects of exposure to either type of signal on performance
Stefanics et al. (2007)	900MHz GSM Mobile Phone	Auditory Brainstem Response (ABR)	No significant differences in the latency of ABR waves I, III and V before and after genuine/sham EMF exposure
Stefanics et al. (2008)	3G MTS mobile Phone	N100, N200, P200 and P300 in auditory oddball paradigm	No measurable changes in latency or amplitude of ERP components or in oscillatory gamma-band activity
Terada et al. (2007)	PulsedEMF, 800 MHz frequency band	Single and double pulse TMS	no effect on any parameters of MEPs
Kleinlogel et al. (2008)	UMTS RF exposure	N100 and P300 in auditory oddball paradigm	No deleterious effects of UMTS RF exposure
Kwon et al. (2009, 2010)	900MHz GSM, mobile phones W-CDMA	Mismatch negativity (MMN) of Auditory event-related potentials	no statistically significant effects on MMN, either in adults or children
Trunk et al. (2013)	3G MTS mobile Phone	auditory event-related potentials (ERPs) and automatic deviance detection processes reflected by mismatch negativity (MMN)	no measurable effects of a 30 min 3G mobile phone irradiation on the EEG spectral power

脳血流（代謝）への影響

authors	electromagnetic field	imaging modality /task perfomed	findings
Huber et al. (2002)	900-MHz GSM, mobile phone	PET	significant increase in rCBF in the dorsolateral prefrontal cortex of the left (exposed) hemisphere
Huber et al. (2005)	900-MHz GSM, base-station-like and mobile-phonelike exposure	PET	Increased rCBF the dorsolateral prefrontal cortex on the side of exposure only for mobile phone-like exposure
Haarala et al. (2003)	902-MHz GSM-phone signal	PET / visual working memory task	bilateral decrease in rCBF in the auditory cortex, no significant change in the task performance
Aalto et al. (2006)	900-MHz GSM	PET	reduced rCBF close to the antenna, and an elevation at various other locations deeper in the brain
Mizuno et al. (2009)	195MHz, W-CDMA	PET	no significant rCBF changes caused by the EMF
Volkow et al. (2011)	acute cell phone exposure	PET	increased cerebral metabolic rates of glucose in the brain regions closest to the active handset
Kwon et al. (2012)	902.4-MHz GSM, mobile phone	PET	no significant rCBF changes caused by mobile phone

今後の課題

- 被験者の主観的評価、認知機能、生理学的視標、脳波、誘発電位、睡眠や脳血流に対するEMFの影響については否定的な研究も多い（とくに2006年以降の研究）。
- 陽性の結果を出ている研究でも、追試されているものは少ない。同じ研究グループでおこなっている実験でも、結果が食い違っていることがある。
- 電磁波の効果が“ない”と証明することは、“ある”ことを証明するよりはるかに困難である（多数例の検討が必要）。
- 陽性の結果が出た場合には、基盤となる神経生理学的な知見の裏付けが必要。
- さらに、“電磁波に対する過敏性のある人”の存在が状況を複雑にする。
- 携帯電話の脳への影響は、電磁場自体の影響より、それを使うこと自体による認知機能の影響のほうが大きいかもしれない。
- これまでの研究はいずれも主として急性暴露に関するものであり、長期的な影響については十分評価されているとは言えない（脳腫瘍の発生など）。