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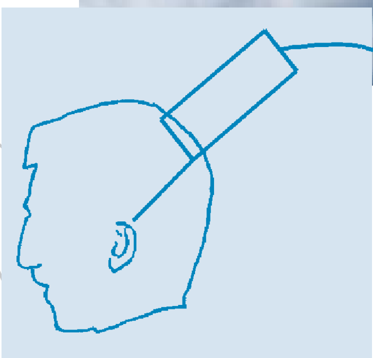

H. Hinrichs, H.J. Heinze

High frequency GSM-1800 fields with various modulations and field strengths: No short term effect on human awake EEG.

Forschungsgemeinschaft Funk

Dear readers,

we are proud to present our 23th issue of our Edition Wissenschaft. This edition is entitled: “High frequency GSM-1800 fields with various modulations and field strengths: No short term effect on human awake EEG”. The authors are Prof Hinrichs and Prof. Heinze of the Department of Neurology II of the Otto-von-Guericke University, Magdeburg, Germany.
Since our foundation as research organization in the year 1992 the Forschungsgemeinschaft Funk (FGF) had followed with great interest the public discussions about the suspected influence of low-energetic electromagnetic fields in the information processing of the human brain. In the most cases the international research community has approached these potential interactions of EMF with the application of electronic devices to measure the electroencephalogram (EEG).

The observation of the brain activity with EEG has a long tradition. In the past we have often reported about this study issue under different aspects. You can find more than 40 different reports only in the two periodically publications of the FGF as there are “Newsletter of the FGF” and “Edition Wissenschaft”. The reports encompass from some basic explanations about what a EEG is and where it can deliver reliable results for the estimation of the influence of EMF in the human central nervous system. The aim of the new study was to illuminate on potential EEG alternations according to the GSM 1800 standard.
We hope that this study will bring a further module to understand the EME issue.

Kind regards
Gerd Friedrich

Contents

H. Hinrichs, H.J. Heinze

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Introduction

Since the advent of mobile phone networks concerns have been raised regarding possible health risks caused by both the active mobile phone and the base stations. Human central nervous system (CNS) is one of the most sensible organs controlling both vital physiological functions and consciousness. It is therefore since long one of the favourite targets of research activities focusing on possible biological interference of high frequency weak electromagnetic fields (EMF) according to the Global System for Mobile communication (GSM)-standard for current mobile phone networks.
The electroencephalogram (EEG) recorded continuously from the scalp has been established as a global measure of brain function since its first observation by Berger et al. (1929). Taking into account suggestions of Adey (1992) and others GSM-like EMF might well be a candidate of interference with the EEG because its amplitudes are pulsed at frequencies not far away from the typical EEG frequency-range (0...30 Hz). Interference may occur either directly, for instance with low frequency components generated by infrequently transmitted frames for channel organisation, or by cross modulation with the regular 217 Hz pulse frequency of the active phone.
In the past a couple of papers have reported from studies on possible EEG-variations during exposition of human subjects to weak electromagnetic fields (EMF) emitted by GSM-based devices. In an early study Reiser et al. (1995) observed an increase of Alpha- and also Beta- (frequencies > 12 Hz) activity only 15 minutes after, but not during a 15 minute exposition to GSM-EMF. In a similar experiment, Thuroczy et al. (1996) recorded the EEG of subjects before, during and after two consecutive periods of exposition to radio frequency EMF. He also found significant variations of the EEG, including Alpha-power. However, a clear tendency towards either decrease or increase in the different frequency bands cannot be derived from the published results because the EEG-changes are inconsistent between different phases of his experiment.
Mann and Röschke (1996), Wagner et al (1998) and Wagner et al. (2000) looked for possible alterations of sleep profiles due to athermic EMF-effects caused by continuously applied GSM 900 fields. EEG was included as one of the parameters. In the first study they found indeed significant effects on sleep profile including EEG fluctuations within the alpha frequency band. However, in their two follow up studies these findings could not be validated. In contrast, in two recent studies Huber et al. (2000) and Huber et al. (2002) showed EEG variations in the alpha frequency range during night-time after exposure of the subjects to pulse modulated electromagnetic fileds (EMF) of 900 MHz frequency but not after application of EMF without modulation. In yet another trial Röschke and Mann (1997) focused on variations of the awake human EEG under GSM 900 exposure. No short term EEG effects were found. In a similar experimental setup Spittler et al. (1997) also failed to find any significant EEG alterations. Krafczyk et al. (1998) included both GSM 900 and GSM 1800 in their experiment looking for potential EMF induced EEG-effects. Again, no EMF-related EEG-modulations were observed. The same holds for a similar study of Hietanen et al. (2000) who looked for possible EEG changes while subjects where exposed to 900 MHz and 1800 MHz radiofrequencies of five different standards, among them a GSM. The observed differences in Delta power was most likely attributed to statisti-

cal chance.
Contradictory results were furthermore reported both from behavioural experiments (Preece et al., 1999; Koivisto et al., 2000; Koivisto et al., 2001; Russo et al., 2005; Besset et al., 2005; Preece et al., 2005; Eliyahu et al., 2006) and from studies applying event related techniques based on the electroencephalogram (EEG) (Freude et al., 1998; Freude et al., 2000; Krause et al., 2000 a; Krause et al., 2000b; Krause et al., 2004;Maby et al., 2005) or the Magnetoencephalogram (MEG) (Eulitz et al., 1998; Hinrichs and Heinze, 2004).
Comparing these different findings and their underlying experimental parameters, one of the reasons for the inconsistencies might be the different field strengths and/or different kinds of modulations applied in the experiments. Based on this hypothesis, the aim of the current study was to evaluate whether short term EEG-effects, if any, are in any way dependent on variations in field power or modulation of a GSM 1800-like EMF. Therefore, we evaluated short EEG epochs recorded from humans during exposition to EMF with four different modulation schemes and also four different field powers. The experiment was designed as a cross over double blind placebo controlled trial.

Material and Methods

27 healthy drug free subjects were included in the study. 9 of them were discarded due to either vigilance fluctuations or too many artefacts during EEG recording. Thus data from 18 subjects (11 female), average age 29.7 years (18 … 58 years) were evaluated. They were recruited from the local student population and from university employees. Neurological and psychological state was normal in all cases. Written informed consent was obtained from all subjects. The study was approved by the local ethic committee.
EEG recordings were performed in a separate room which of the walls were coated with foam elements designed to absorb EMF at 1-2 GHz with at least 20 dB attenuation (RANTEC FL 2250). The bioamplifier was positioned outside this room. During recording subjects were seated in a wooden desk chair in a relaxed wakefulness with eyes closed. For exposition a modified commercial mobile phone (Nokia PT11) was used, with the antenna directly coupled to a test transmission amplifier (Rohde &Schwarz SME23) generating GSM-1800-fields with different characteristics as described in Table 1. The phone was attached to the chair-frame and individually positioned with its antenna close to the ear (distance from subjects' heads about 10 mm).The orientation and position of the antenna (see Figure 1) approximately matched the '30°-position' as specified in the measurement standard formulated by the Comité Européen de Normalisation Electro-

Label	Pp[W]	Fmod [Hz]	Pavg [W]	SAR (10g) [W/kg]	SAR (1g) [W/kg]
A	1/4	CW/no modul.	1/4	1.22	2.28
B	2	217	1/4	1.22	2.28
C	1	217	1/8	0.61	1.14
D	2	108	1/8	0.61	1.14
E	8	27	1/8	0.61	1.14
F	Field switched off ('Placebo')				

Table 1: Description of GSM-field characteristics applied
Pp = Peak-power of carrier
fmod = Modulation-frequency
Pavg = Average power of the modulated carrier
SAR = Specific absorption rate

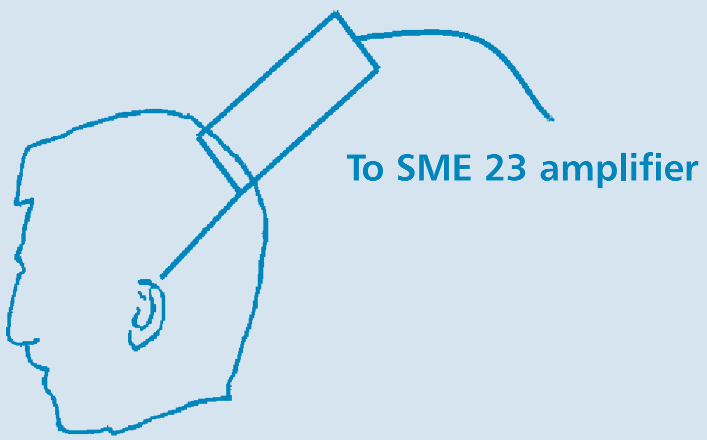

Figure 1
Experimental setup of exposition apparatus. The rectangle represents the phone's body. It was fixed to a wooden frame with its position individually adjusted to the subjects head.

technique, SC211/B, WGMTE (1997). The corresponding SAR values were assessed in a separate study (IMST, 1998) with an anatomically realistic full scale head phantom.
EEGs were recorded referentially with Ag/AgCl-electrodes from all 19 sites of the international 10-20-electrode system (Jasper, 1958) plus the two mastoid (A1, A2) electrodes. An electrocardiogram (ECG) and two electrooculograms (EOG) were also included summing up to a 24 channel setting. After passing an anti-aliasing low pass filter (Cauer type, 64 Hz cutoff-frequency, 49 dB attenuation at 100 Hz) the signals were digitised with a sampling rate of 153.6 Hz/channel.
Each subject underwent an EEG recording of 4 min for each field condition as specified in table 1, including a sham exposition were no field was present (placebo condition). The six recording periods were separated by breaks of 3,5 min each in order to keep a sufficiently high level of vigilance. The sequence was randomised over subjects with respect to the exposition conditions. Both the subject and the EEG technician were not aware of the actual field conditions (double blind condition). A preceding 6 minute recording with EMF switched off served as an adaptation session and was not analysed. Signal characteristic was continuously controlled with the aid of an output signal monitor included in the SME23 signal-generator.
After rereferencing the signals to the average mastoid-EEG the data were subjected to a power spectral analysis using the fast Fourier Transform (FFT) algorithm. According to Welch (1967) short term periodograms were calculated for consecutive epochs of 512 samples each (3.33 sec) and averaged over the full 4 min interval. Epochs containing artefacts were rejected applying an amplitude and gradient threshold criterion (Hinrichs et al. 1996). In order to reduce the number of parameters entering the subsequent statistical evaluation (see Herrmann et al. (1979)) band power values were computed for six frequency bands: Delta [1.5-3.5 Hz], Theta [3.5-7.5 Hz], Alpha [7.5-12.5 Hz], Beta1 [12.5-18.0 Hz], Beta2 [18.0-30.0 Hz] and Total [1.5-30.0 Hz]. In addition, median frequencies, i.e. the median of the spectral distribution within a certain frequency band, were derived for all frequency bands. Delta- and Total-band parameters were discarded for 7 frontal channels (Fp1, Fp2, F3, F4, Fz, F7, F8 of the 10-20-scheme) in order to prevent potential residual weak low frequency EOG-artefacts from corrupting the result. Thus a set of 200 parameters were subjected to the subsequent statistical evaluation.
A Shapiro and Wilk (1965) analysis indicated serious deviations from a normal distribution for many of the spectral parameters. Therefore they were logarithmically transformed before further evaluation. Taking into account the pronounced correlations between power- and frequency values of the various EEG channels, a multivariate analysis of variance (MANOVA) with 'subject', 'field condition' and 'measurement period' as factors was applied to detect possible differences between the EEG recorded under the six different exposure conditions. Each frequency band was analysed separately. Both the global significance measure (Pillai's trace) as well as the univariate test results were considered for detecting possible differences between the EEG-parameters. Differences were considered significant at a level of $p<.05$. Statistical analyses were performed with the SAS PC 6.03 package.

Results

The power-spectral values for the electrode being located closest to the tip of the antenna are depicted in Figure 2 as an example. In general, only minor differences are found between the results observed under different field conditions. The same holds for the median frequencies. These observations are confirmed by the statistical evaluation as specified in Table 2.
The MANOVA clearly failed to detect any significant differences among the spectral parameters derived under the various field conditions. Also, the individual univariate test yielded statistically significant condition-related differences in only a few parameters in three frequency bands. Taking into account the large number of 200 simultaneously tested variables, up to 10 statistically significantly differences are to be expected by mere chance at a significance level of $p< .05$ (see Abt 1983, Ferber et al., 1999). As listed in Table 2, overall five significantly differing variables were encountered which, in addition, are not systematically clustered either in a certain frequency band or in a distinct topographical area. This leads to the summarising conclusion of no systematic differences between EEG-spectra derived under various modulations and field strengths of GSM-EMF.
Following their self-ratings none of the subjects experienced any sensations during field exposition.

Frequency band	Number of variables included	MANOVA: p-values for hypothesis of no differences	ANOVA: Variables with significant (p<.05) differences in univariate tests	
			Variable	p-value
Total	24	.4934	—	
Delta	24	.1934	—	
Theta	38	.4542	—	
Alpha	38	.7161	MED_17	.0489
Beta1	38	.3732	MED_1	.0438
			MED_3	.0178
			MED_15	.0382
Beta2	38	.2051	POW_9	.0473

Table 2: Results of statistical analyses.
Significance levels of multivariate analysis of variance (MANOVA) are specified in terms of Pillai's Trace.
MED_xx : Median-frequency in channel xx
POW_xx: Band power in channel xx

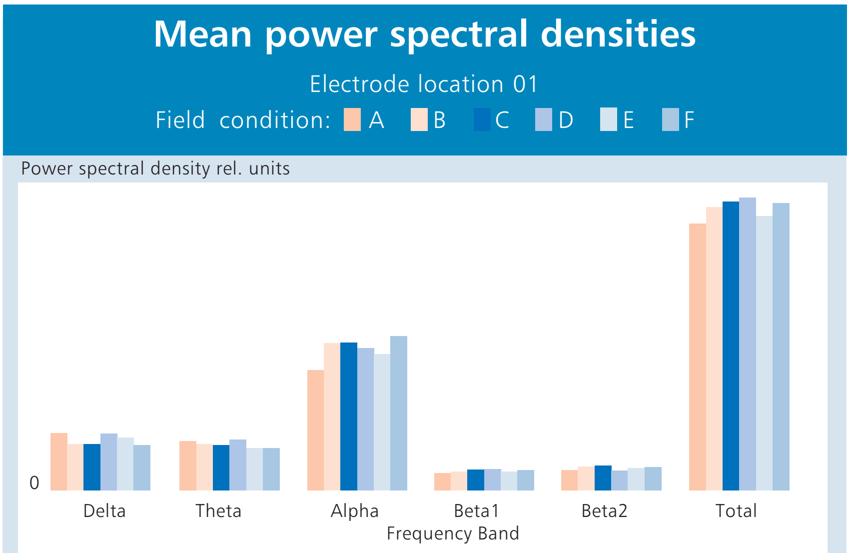

Figure 2
Spectral band powers at electrode position O1 (localized near to the end of the antenna) for the different exposure conditions. Exposure conditions are marked by the corresponding labels as specified in table 1.

Discussion

The aim of the investigation was (i) to replicate results from earlier studies for GSM 1800-like EMF and (ii) to look for a potential dose-response function in terms of an amplitude or frequency window as claimed for instance by Adey (1992).

Unlike Reiser et al. (1995), von Klitzing (1995) and Thuroczy et al (1996) we did not find any evidence for an athermic biological effect of GSM-like fields on the awake EEG. However, this negative outcome is in line with the results of Spittler et al. (1997), Röschke et al. (1997) and Hietanen et al. (2000) (focusing on GSM 900 fields) and Krafczyk et al. (1998) looked at both GSM 900 and GSM 1800 fields.
However, taking into account the different experimental settings, the results are not fully comparable. In our study duration of exposition per recording and field condition was only 4 minutes with a 3.5 minute break as opposed to an exposition interval of 20 minutes (Hietanen et al., 2000), 10 minutes (Spittler et al., 1997), 3.33 minutes (Röschke and Mann, 1997), and 15 minutes (Reiser et al. 1997). Reiser et al. observed GSM-related EEG-power increases in just one out of 19 channels only 15 min after end of exposure. This kind of slightly delayed response after a longer expostion period presumably would not have been detected by our measurements which aimed at tracing immediate short term effects without coping with possible overlap effects within a sequence of EEGs recorded under different conditions. Longer periods between successive exposition and successive recordings clearly decreases the risk of overlap effects, however, at the expense of an increased variability due to chronobiological fluctuations, which have been described many times for EEG-parameters (see e.g. Shannahoff-Khasa, 1993; Cajochen et al., 1999). Also, longer exposition periods might enhance the chance of provoking CNS-effects, but at the same time increase the liklehood of vigilance induced EEG variations which might mask mild GSM induced modulations.
A comparison of our study to those of v. Klitzing (1992, 1995) is not feasible because v.Klitzing did not fully specify the details of his experimental setting and the post-processing procedures including the

statistical methods applied. Thuroczy (1996) reported an increase of EEG-alpha-power induced by radiofrequency EMF. However, looking into the figures of the corresponding paper also the inverse alterations occurred in the sequence of field exposition he applied. The question is, whether additional uncontrolled factors, for instance vigilance, might have influenced the experiment.
The EEG findings reported from some of the various sleep studiies conducted so far (Mann and Röschke, 1996; Wagner et al., 1998; Wagner et al., 2000; Borbèly et al., 1998; Huber et al., 2000; Huber et al., 2002) could not be checked in the current experiments because these groups not only applied a much longer exposition phase but analysed the EEG during all night sleep, i.e. under physiologically different conditions. In addition, the group of Huber et al. applied a different (mixed) modeulation scheme not covered by the pulse frequencies appleid in the present study.
Several groups have looked for EMF induced variations of the event-related EEG potentials (ERP) or event related magnetic fields (ERF) during the performance of cognitive tasks (Freude et al. (1998) ; Freude et al. (2000) ; Eulitz et al. (1998); Krause et al., 2000a; Krause et al., 2000b; Krause et al., 2004; Krafzcyk et al.,1998 ; Hinrichs and Heinze, 2004; Maby et al., 2005). Some effects (though inconsistent) were indeed observed under exposition to GSM-fields. However, the effects reported from some of these studies can hardly be compared to our results because the psychophysiological status of the subjects during the performance of a cognitive task interferes with the ongoing EEG thus making these signals uncomparable to those EEG recorded under standard conditions. According to the experimental setup the ERP reflect specific sensory or cognitive brain functions as opposed to the EEG serving as an integrative measure of global brain function. In this sense the EEG is generally limited to conclusions referring to this more general CNS status.
In our study both the modulation. i.e. the pulse frequency , and the field strength were varied over a large range within the limits specified by the recent ICNIRP recommendations (ICNIRP, 1998). The aim of this setup was to detect a potential amplitude or frequency windows acting on EEG interference process. Such a non-linear mechanism would not be too surprising taking into account former findings of, for instance, Dutta et al. (1989) who observed an enhanced Ca++-efflux in human neuroblastoma cells under the influence of a 147 MHz EMF most effectively occurring at 16 Hz and 50 Hz modulation frequency. From these observations a frequency-dependent susceptibility of EEG to EMF cannot be excluded because Ca++ plays an important role in inter-neural communication (see for instance Dudel (1995)). However, the lack of any EEG-variation at four different field strengths and pulse frequencies in the present study, although restricted to short term exposition, discourages the acceptance of any window-related mechanism. This interpretation is supported by a recent study conducted by Meyer et al. (1998) who was unable to replicate the findings of Dutta et al. (1989) in the case of GSM 900-fields.
Our findings may also contribute to the interpretation of some inconsistent results arising from three recent sleep studies of Mann and Röschke(1996), Wagner et al (1998) and Wagner et al. (2000). In their first experiment they applied a power density of approximately 0.5 W/m**2 (estimated afterwards from the experimental setup (Wagner et al., 2000) and observed some statistically significant variations of sleep structure which, however, were no longer present in their follow-up study at 0.2 W/m**2, although a tendency similar to the previous findings remained (Wagner et al (1998)). Suspecting a dose response effect, they conducted a third study, this time applying an increased field strength of 5 W/m**2 (Wagner et al., 2000). Surprisingly, no effects at all were observed this time. Summarising these results one might conclude that in fact a window mechanism is acting on this level of interference. However with our findings in mind this way of explanation is discouraged.

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Abstract

Several studies recently reported partly contradictory results regarding potential effects of electromagnetic fields (EMF) of digital mobile phone on human awake electroencephalogram (EEG) and on sleep profile. The reason for these inconsistencies may be the different characteristics of the EMF applied in the experiments. The aim of the present study was to illuminate the influence of modulation frequency and field strength on potential EEG alterations induced by EMF according to the GSM 1800 standard. For this purpose we conducted a double blind placebo controlled study with 18 healthy human subjects. They were exposed to EMF emitted by a GSM mobile phone at 1/4, 1, 2 and 8 W peak power being pulse modulated at either 217, 108, 27 or 0 Hz (i.e. CW). The corresponding specific absorption rate (SAR (10g)) was approximately 0.61 W/kg or 1.25 W/kg respectively. During exposition of four minutes no immediate alterations of the EEG in terms of spectral components were detected.

Key Words
electroencephalogram; GSM;
electromagnetic field

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