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ORIGINAL ARTICLE

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Microwaves emitted by cellular telephones affect human slow brain potentials

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Abstract The influence of electromagnetic fields (EMF) emitted by cellular telephones on preparatory slow brain potentials (SP) was studied in two experiments, about 6 months apart. In the first experiment, a significant decrease of SP was found during exposure to EMF in a complex visual monitoring task (VMT). This effect was replicated in the second experiment. In addition to the VMT, EMF effects on SP were analysed in two further, less demanding tasks: in a simple finger movement task to elicit a Bereitschaftspotential (BP) and in a *two-stimulus task* to elicit a contingent negative variation (CNV). In comparison to the VMT, no significant main EMF effects were found in BP and CNV tasks. The results accounted for a selective EMF effect on particular aspects of human information processing, but did not indicate any influence on human performance, well-being and health.

Key words Slow brain potentials · Preparation · Cellular phones · Microwaves

Introduction

The wide and growing use of mobile communication systems has led to wide ranging discussions about possible interactions of electromagnetic radiation with the human body, in particular the brain. One of the most commonly applied electrophysiological methods for investigating different aspects of brain function is the electroencephalogram (EEG). Controversial observations have been made for the spontaneous EEG of waking subjects under the influence of electromagnetic fields (EMF) emitted by cellular telephones. Changes in the α activity have been observed immediately after exposing the head of human subjects for 15 min to a special coil in the neck region (Klitzing 1995). An increase in the $\beta 1$ and δ powers with a delay of approximately 15 min after exposure has been observed by Reiser et al. (1995). Röschke and Mann (1997) have not detected any differences in the awake EEG in terms of spectrum power density measurements during 3.5 min exposure to a 900-MHz EMF pulsed at a frequency of 217 Hz and a pulse width of 580 μs. In line with this finding Gehlen et al. (1992) have not found influences of EMF on spectrum power in the frequency range of 0.5 Hz–30.0 Hz.

Initially reported effects on the spontaneous EEG (Klitzing 1995; Reiser et al. 1995) have been interpreted as a sign of alterations in vigilance and not in support of an interference between the exposure system and the electrophysiological function of the brain (Herrmann and Hossmann 1997).

Controversial observations have also been made about the influence of digital mobile radiotelephones on the EEG of sleeping healthy subjects. Mann and Röschke (1996) have reported alterations in the quantitative sleep profile as an effect of a digital mobile radio telephone. Besides an hypnotic effect with a shortening of sleep-onset latency, a suppressing effect on rapid eye movement (REM) with a reduction in duration and percentage of REM sleep has been described (Wagner et al. 1998). Moreover, spectrum analysis revealed qualitative alterations in the EEG signal during REM sleep with an increased spectrum power density. The same group (Wagner et al. 1998), have however, failed to reproduce these effects in a second study: a suppression of REM sleep as well as a sleep-inducing effect during field exposure did not reach statistical significance, so that previous results indicating alterations of these sleep parameters could not be replicated. Spectrum power analysis also did not reveal any alterations of the EEG rhythms during EMF exposure. The failure to confirm the previous results have been interpreted as a

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sign of dose-dependent effects of EMF on human sleep profile.

At the cellular level, a number of phenomena induced by EMF have been identified which, in principle, could modify the functions of the central nervous system (for review see Adey 1997). Time-locked EEG activity elicited by sensory and motor events and which reflects particular steps of information processing might provide additional insights into a possible influence of EMF on the brain. In the following, we will deal with preparatory slow brain potentials (SP) occurring prior to voluntary initiated movements (Bereitschaftspotential, BP; Kornhuber and Deecke 1964, 1965) or between a warning and an imperative stimulus (contingent negative variation, CNV; Walter et al. 1964). These potentials refer to that stage of information processing related to getting ready or prepared for an activity to reach a particular goal. Preparatory processes are of fundamental importance for effective motor and mental performances in the goal-directed behaviour. They ensure faster and more efficient information processing and motor responses resulting, for instance, in a decrease in reaction time and in a better accuracy of performance (Donchin et al. 1984; Requin et al. 1984; Freude et al. 1989). At a physiological level, SP were interpreted as an index of the allocation of resources to specific networks for the anticipated task performance. Activation of response programmes has been assumed to be more efficient in networks prepared in such a way (for review see Birbaumer et al. 1990).

In the following, we will describe two experiments investigating the possibility of EMF influences on SP elicited in different experimental paradigms. The two experiments were performed about 6 months apart.

Methods

Participants

A group of 20 healthy right-handed male volunteers aged between 21 and 30 years participated in experiment 1 (mean age: 25.3 years). The handedness of the subjects was estimated using a short version of the Edinburgh Inventory (Oldfield 1971). The experiments took place in the morning, between 9 a.m. and 12 a.m. Before starting the experiments, the subjects gave their written informed consent. All subjects declared that they felt healthy, relaxed and able to participate in the experiment. They were paid for participation. Data from 4 subjects had to be discarded because of an excessive number of artefacts (e.g. eye blinks, movements of the body). All the subjects had naturally (12) or corrected to normal vision.

In experiment 2, 19 right-handed male volunteers aged between 21 and 26 years participated (mean age: 25.7 years). Of these subjects 8 had participated in the first experiment. Data from 3 subjects had to be discarded because of an excessive number of artefacts. All the subjects participating in experiments 2 had naturally (15) or corrected to normal vision.

EMF exposure conditions

The 916.2 MHz EMF (pulse frequency 217 Hz, pulse width 577 μs) was emitted by the aerial of a digital mobile telephone. The radiated peak power of the aerial was 2.8 W, resulting in an average power of 350 mW. Power was measured using a power meter (HP 435A) at the telephone connector. To guarantee that the subjects would be unaware of the absence or presence of the EMF (EMF_{off} or EMF_{on}), respectively and a constant EMF intensity, the telephone antenna was fed by an ultra high frequency generator and a power amplifier located in an adjacent room. The telephone was connected to this generator via a coaxial extension cable. The Global System for Mobile Communication electromagnetic standard signal was provided without any acoustic signal transmission.

The digital mobile telephone was positioned in direct contact to the left ear of the subjects. Care was taken that contact between telephone and ear was constant during the experiment. The telephone was typical of other telephones regarding its antenna pattern. During the experiment the subjects sat in an artificially illuminated room in front of a computer monitor (17-inch screen). Each task during each EMF exposure was performed in two blocks. The EMF exposure per block was changed in counterbalanced order, unknown to the subjects. In blocks with EMF exposure, the field was permanently switched on. While performing the tasks, the subjects did not speak via the telephone and no acoustic information was provided.

Task demands and procedure

Task 1 (visual monitoring task)

The subjects performed a complex and demanding visual monitoring task (VMT), shown diagrammatically in Fig. 1. The subjects had to observe the moving pointer of a symbolised clock (diameter: 93 mm), which subtended a 9° visual angle and was presented in the middle of the computer screen. The clock pointer moved counter-clockwise and had to be stopped after three complete revolutions as precisely as possible in the 12 o'clock position. The pointer was stopped by pressing a mouse key with the right index finger. Each single trial comprised three complete pointer revolutions. One complete revolution took 720 ms. The inter-trial interval between pointer stop and the following computer-started pointer movement varied between 2 and 4 s. At the beginning of the experiment, the subjects practised the task for 10 trials. The VMT was performed in both experiments. In experiment 1 tasks were performed in blocks comprising 30 trials (which took about 3 min), in experiment 2 in blocks comprising 50 trials (which took about 4 min).

In experiment 2, two additional tasks were performed.

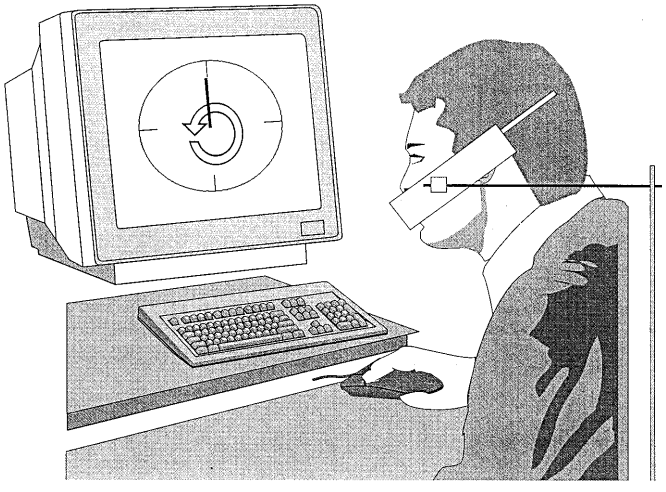

Fig. 1 Sketch of the experimental set up for the visual monitoring task

Task 2 (BP)

The subjects were asked to press a key with their right index finger 30 times at self-paced intervals (simple finger movements). Avoiding eye movements the subjects had to focus in the middle of the screen on a digit increasing with the number of key presses.

Task 3 (CNV)

This task was characterised by the presentation of a warning stimulus (S_1) which was followed by an imperative stimulus (S_2) requiring a motor reaction. The appearance of a pointer of a symbolised clock at the 12 o' clock position represented the S_1 stimulus, the beginning of the pointer movement representing the S_2 stimulus. The interval between S_1 and S_2 was 2160 ms (corresponding to the time of three pointer revolutions in task 1). As soon as the pointer started to move, the subjects had to stop the pointer by pressing a mouse key with their right index fingers. After stopping the moving pointer, it vanished and appeared again after a random time of between 2 s and 4 s. Each block comprised 50 trials.

Performance parameters

Task 1

The subjects' performances were evaluated as to their accuracy. The deviation of angle between the 12 o' clock position and the actual stop position was measured for every trial. Performance data were given as mean absolute values, i.e. independently of whether the pointer was stopped before or after the 12 o' clock position. All hits within the $\pm 90°$ segment (relative to the 12 o' clock position) were included in further analysis.

Task 2 (BP)

The time interval between the subsequent self-paced key presses was estimated to show whether temporal sequence of subsequent finger movements was influenced by EMF.

Task 3 (CNV)

The reaction time (RT) was measured as the difference between the start of pointer movement and the key press for stopping the moving pointer.

EEG recording and data processing

In both experiments, EEG was recorded from 30 electrodes (FP1, FP2, F3, F4, C3, C4, Cz, Oz, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Pz, FT9, FT10, FC5, FC6, CP1, CP2, CP5, CP6, A1, A2) using a commercially available electrode cap (Electro-cap International, USA). Electrodes were positioned according to an extended 10–20 system (Pivik et al. 1993) and amplified in the frequency range from DC to 30 Hz (SynAmps amplifier). Electrode impedances were kept below 5 kΩ. All channels were recorded using the Cz (vertex) electrode as a reference. For detection of eye movement artefacts vertical and horizontal electrooculogram (EOG) were also recorded. The EOG electrodes were attached above the right eye and its outer canthus. An earth electrode was placed on the middle of the forehead. The EEG and EOG were stored continuously together with the key-press related trigger signals. Further signal processing included low-pass filtering (upper frequency cut off: 10 Hz), digital rereferencing to connected ear-electrodes, baseline correction (200-ms baseline from −2500 ms to −2300 ms before key presses) and averaging. Single trial signals exceeding amplitude thresholds (vertical EOG ± 100 μV, horizontal EOG ± 75 μV, all EEG signals ± 75 μV) were considered to be artefacts and were excluded from further processing. Using this procedure on average 28% of trials were rejected. The SP was analysed for the period between −2500 ms before the key press up to 500 ms afterwards. Mean SP amplitude was calculated for the SP interval from −500 ms to 0 (0, moment of the key press). The SP amplitudes were calculated relative to the baseline.

Statistical analysis

For statistical analysis repeated measures ANOVA were used. Effects of the factors *EMF* and *Hemisphere* were computed for six regional groupings of electrodes: the left/right frontal region (F3, F7, FC5 compared to F4, F8, FC6), the left/right central region (C3, CP1, CP5 compared to C4, CP2, CP6) and the left/right temporo-parieto-occipital region (T5, P3, O1 compared to T6, P4, O2). Where necessary, adjustment for nonsphericity was calculated according to the equations of Huynh and Feldt (1970).

Results

Performance parameters

Task 1

In experiment 1, the mean value of angle deviation averaged for all subjects for EMF_{off} was 18.3°, and 17.0° for EMF_{on}. These differences did not reach the level of significance ($P \leq 0.05$).

In experiment 2, the mean absolute angle deviation between the 12 o' clock and the actual stop position was 19.2° for EMF_{off}, and 17.4° for EMF_{on}. As in experiment 1, no significant difference in performance parameters between the two conditions of EMF exposure was found.

Task 2

The mean interval between two successive key presses did not differ significantly between the conditions of EMF exposure (for EMF_{off} 3.0 s, for EMF_{on} 3.2 s), i.e. the self-pacing of movements was not significantly influenced by EMF.

Task 3

In the CNV task, mean RT for both conditions of exposure was calculated. The RT between 150 ms and 500 ms were considered. The RT between the two conditions of EMF exposure did not differ [RT (EMF_{off}) 242.5 ms, RT(EMF_{on}) 243.0 ms].

Slow brain potentials

Task 1

Figure 2 shows SP elicited in experiment 1 in VMT prior to key presses for stopping the moving pointer. The SP

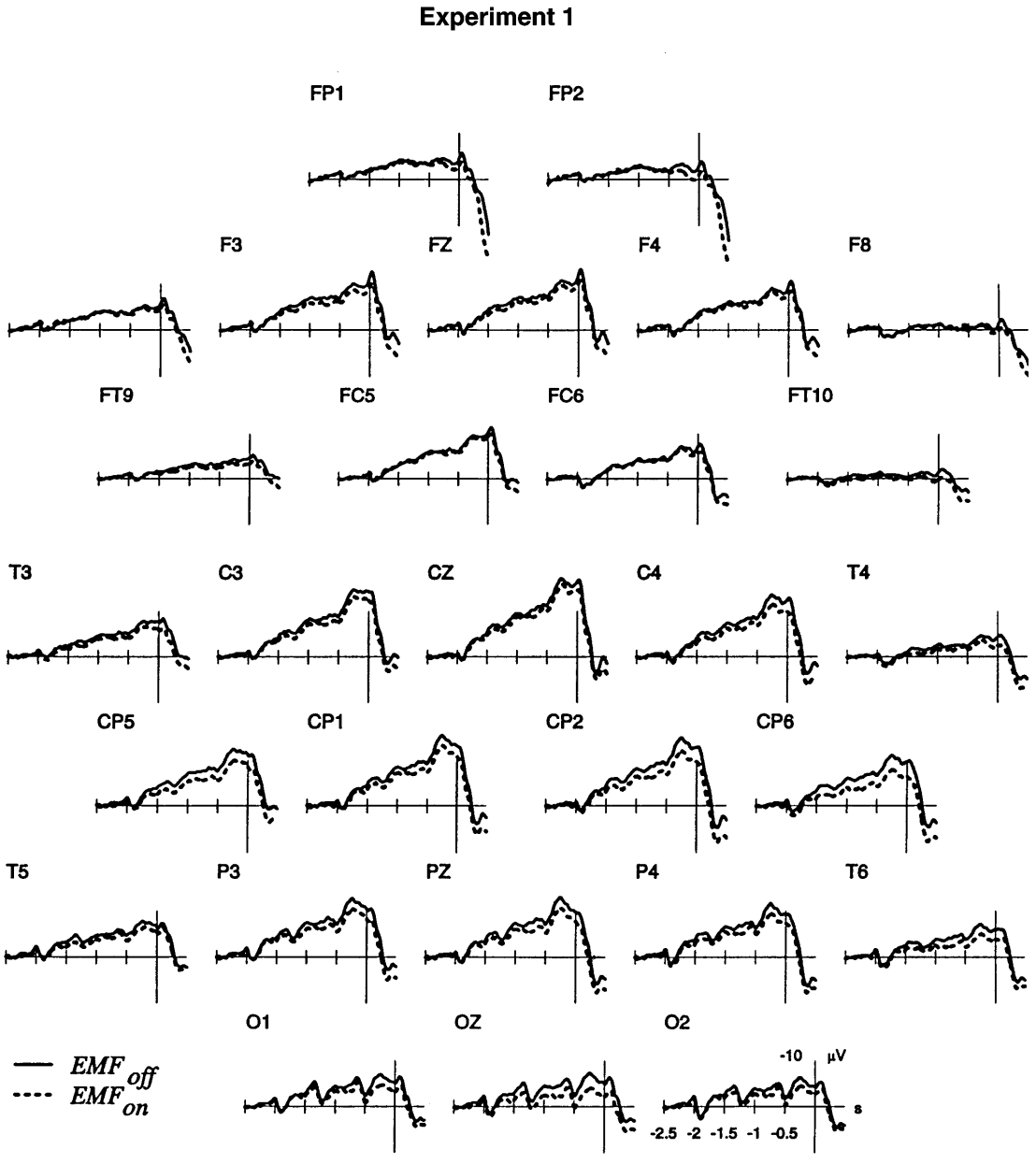

Fig. 2 Grand mean of slow brain potentials (SP) at all electrode positions (see Methods) recorded in the visual monitoring task in *experiment 1* for the two conditions of exposure, electromagnetic field off and on (EMF_{off}, EMF_{on}). The *abscissa* represents the time interval for SP analysis (0 – moment of key press for stopping the moving pointer). Grand mean potentials were obtained by averaging data of all subjects for each of the two conditions of *EMF* exposure

were clearly expressed at all electrode positions. The solid lines represent SP elicited during EMF_{off}, the dotted lines SP during EMF_{on}. In particular at central, parietal and occipital electrode positions, SP amplitudes were diminished during EMF_{on} compared to EMF_{off}. Figure 3 (upper graphs) shows SP shifts for electrode positions, where SP difference between the conditions of EMF exposure are especially pronounced. Statistical analysis considering the six regions of interest confirm a significant EMF influence. The ANOVA including the factors EMF, Hemisphere and Region revealed significant influences of the factor EMF [$F(1, 15) = 15.6$; $P \leq 0.05$], Hemisphere [$F(1, 15) = 23.0$; $P \leq 0.05$] and Region [$F(2, 14) = 24.7$; $\varepsilon = 0.85$; $P \leq 0.05$] and significant interaction effects between EMF × Region [$F(2, 14) = 5.3$; $\varepsilon = 1$; $P \leq 0.05$].

The significant interaction effect was attributed to the fact that EMF is differentially effective at the different brain regions. As shown in Fig. 4 (upper graph), SP elicited at frontal electrode positions seemed not to have been affected by EMF. On the other hand, EMF effects were clearly evident at central [$F(1, 15) = 29.5$; $P \leq 0.05$] and parieto-temporo-occipital electrode [$F(1, 15) = 10.4$; $P \leq 0.05$] positions. In conclusion, results from the first experiment showed that EMF elicited by cellular telephones influenced SP selectively in VMT.

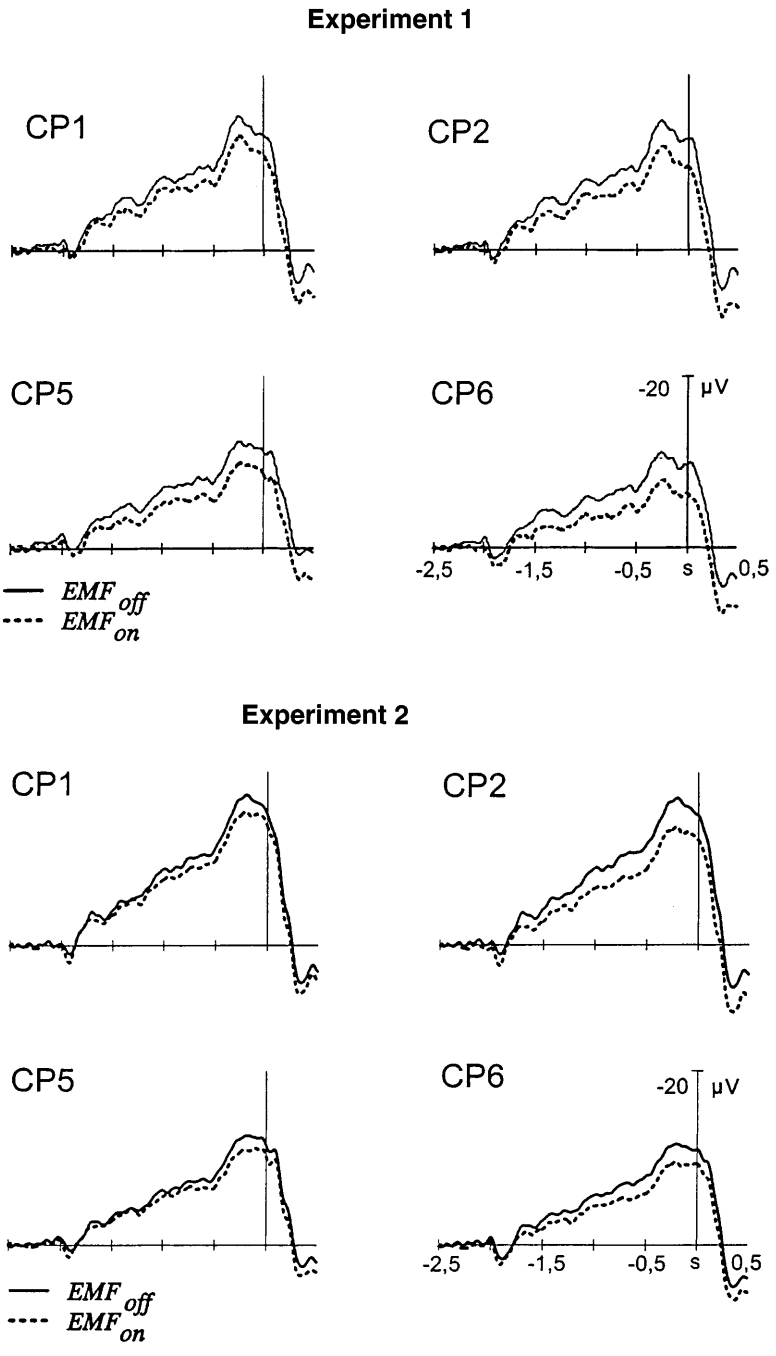

Fig. 3 Grand mean of slow brain potentials recorded in the visual monitoring task in experiments 1 and 2, for electrode positions showing a pronounced significant *EMF* effect. *Left-hand* waveforms (*CP1*, *CP5*) show recordings from the left hemisphere; *right-hand* waveforms (*CP2*, *CP6*) from the right hemisphere. A reduction in slow brain potentials during *EMF* exposure was seen in the two experiments separated by 6 months

This VMT was also performed in experiment 2 to evaluate the replicability of effects found in experiment 1. Some of the results have previously been published in a short communication (Freude et al. 1998). As in experiment 1, SP shifts elicited in VMT were less negative during EMF_{on}. Again, SP parameters were found selectively influenced by EMF at the different brain regions. Figure 3 (lower graphs) shows SP shifts for electrode positions, where SP differences between both conditions of EMF exposure are especially pronounced.

The ANOVA including the factors EMF, Hemisphere and Region revealed significant influences of the factor EMF [$F(1, 15) = 4.7$; $P \leq 0.05$], Hemisphere [$F(1, 15) = 18$; $P \leq 0.05$] and Region [$F(1, 15) = 93.8$; $\varepsilon = 1$; $P \leq 0.05$] and significant interaction effects for EMF × Hemisphere [$F(2, 14) = 10.3$; $\varepsilon = 1$; $P \leq 0.05$] and for EMF × Region [$F(2, 14) = 4.2$; $\varepsilon = 1$; $P \leq 0.05$], i.e. in experiment 2, a significant main EMF effect was found as in experiment 1.

Evaluating the influence of EMF separately for the three different regions the following effects were detected. As in experiment 1, in the frontal regions no significant SP changes due to EMF_{on} were found. A significant decrease of SP was observed at the central and temporo-parieto-occipital regions [central: $F(1,$

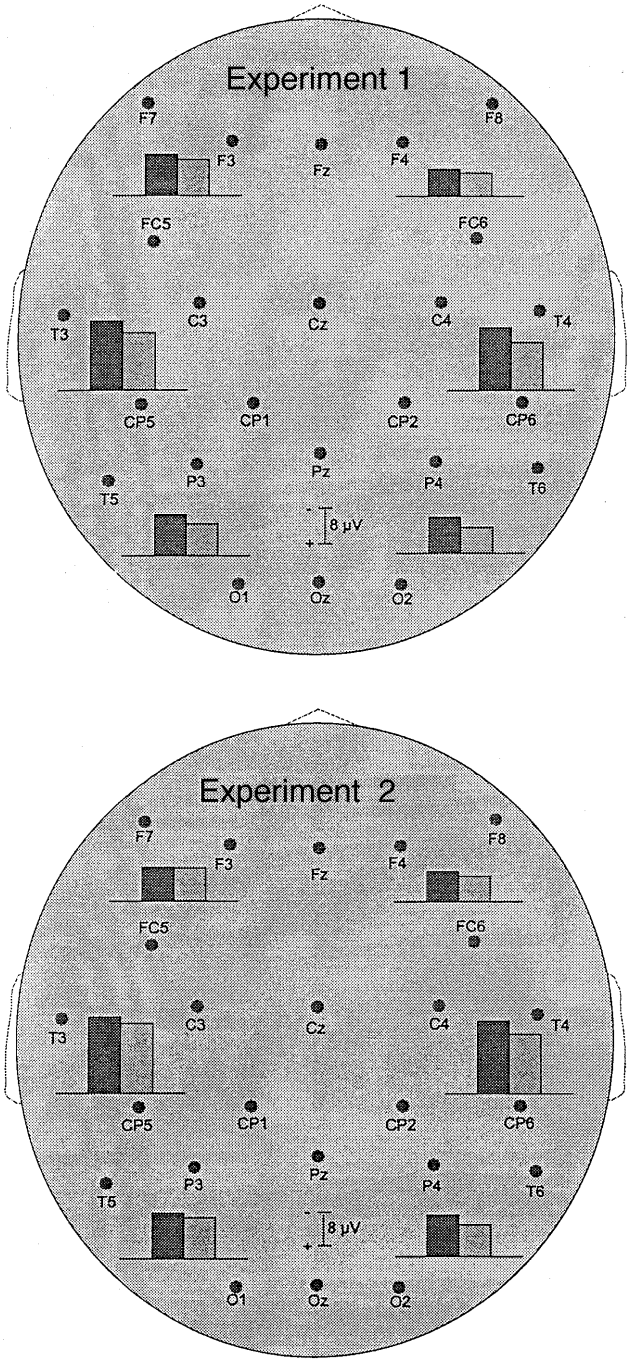

Fig. 4 Mean SP amplitudes (time interval: −500 ms to 0 ms; 0 ms–moment of the key press) for frontal, central and temporo-parieto-occipital electrode positions for both conditions of *EMF* – exposure (EMF_{off} (*black bars*) and EMF_{on} (*grey bars*)) for experiments 1 and 2. In comparison with the frontal electrode positions, SP differences between the two conditions of *EMF* exposure are significant for the central and temporo-parieto-occipital electrode positions

15) = 7.7; temporo-parieto-occipital: $F(1, 15) = 6.2$; $P \leq 0.05$]. Figure 4 (lower graph) illustrates the mean SP amplitudes for the two conditions of EMF exposure separately for the different regions indicates decreased SP amplitudes during EMF_{on}.

Significant interaction effects between EMF × Hemisphere [central: $F(1, 15) = 8.2$; temporo-parieto-occipital: $F(1, 15) = 5.0$; $P \leq 0.05$] account for the more pronounced effects of EMF_{on} over the right hemisphere (Freude et al. 1998). The more pronounced effect is seen over the right central/temporo-parieto-occipital regions. The significant effect on SP differences between the left and right hemisphere would indicate a selective EMF influence on SP lateralization.

Task 2

The BP which were recorded prior to simple finger movements showed typical waveforms with the most pronounced negative shifts over the central electrode regions. As has been found for BP recorded prior to movements with the right index finger, negative shifts are more pronounced over the contralateral hemisphere. Accordingly, the factor Hemisphere had a significant influence on BP amplitudes [$F(1, 11) = 7.37$; $P \leq 0.05$]. Also, the factor Region was significant [$F(2, 22) = 7.2$; $\varepsilon = 0.73$; $P \leq 0.05$] which could be attributed to the pronounced differences in BP amplitude between the frontal and central electrode positions. Significant interaction effects Hemisphere × Region [$F(2, 22) = 5.3$; $\varepsilon = 0.9$; $P \leq 0.05$] accounted for the most pronounced lateralization over the central hemispheres. However, the factor EMF was not significant; BP prior to simple finger movements was not affected by EMF.

Task 3

The CNV waveforms could be recorded between (S_1) and (S_2) signals at all electrode positions as shown in Fig. 5. The most pronounced amplitudes occurred at central and parietal electrode positions. Factors Hemisphere [$F(1, 12) = 8.91$; $P \leq 0.05$] and Region [$F(2, 24) = 39.7$; $\varepsilon = 0.96$; $P \leq 0.05$] had significant influences on CNV amplitudes. Whereas no significant EMF influence could be found, the interaction between EMF × region [$F(2, 24) = 6.12$; $\varepsilon = 1$; $P \leq 0.05$] was significant which could be attributed to the more pronounced CNV amplitudes during EMF_{on} at the frontal electrode positions compared to EMF_{off}. Further investigations are needed to ascertain whether this significant EMF × Region interaction effect can be replicated.

Discussion

The results obtained in both experiments showed that the subjects' performances were not affected by the EMF elicited by the cellular telephone, independently of the requirements of the three tasks applied. On the other hand, SP were influenced by EMF_{on}. SP showed a reduction of negative shifts during EMF_{on} in the complex VMT. This EMF_{on} effect was selective as to the

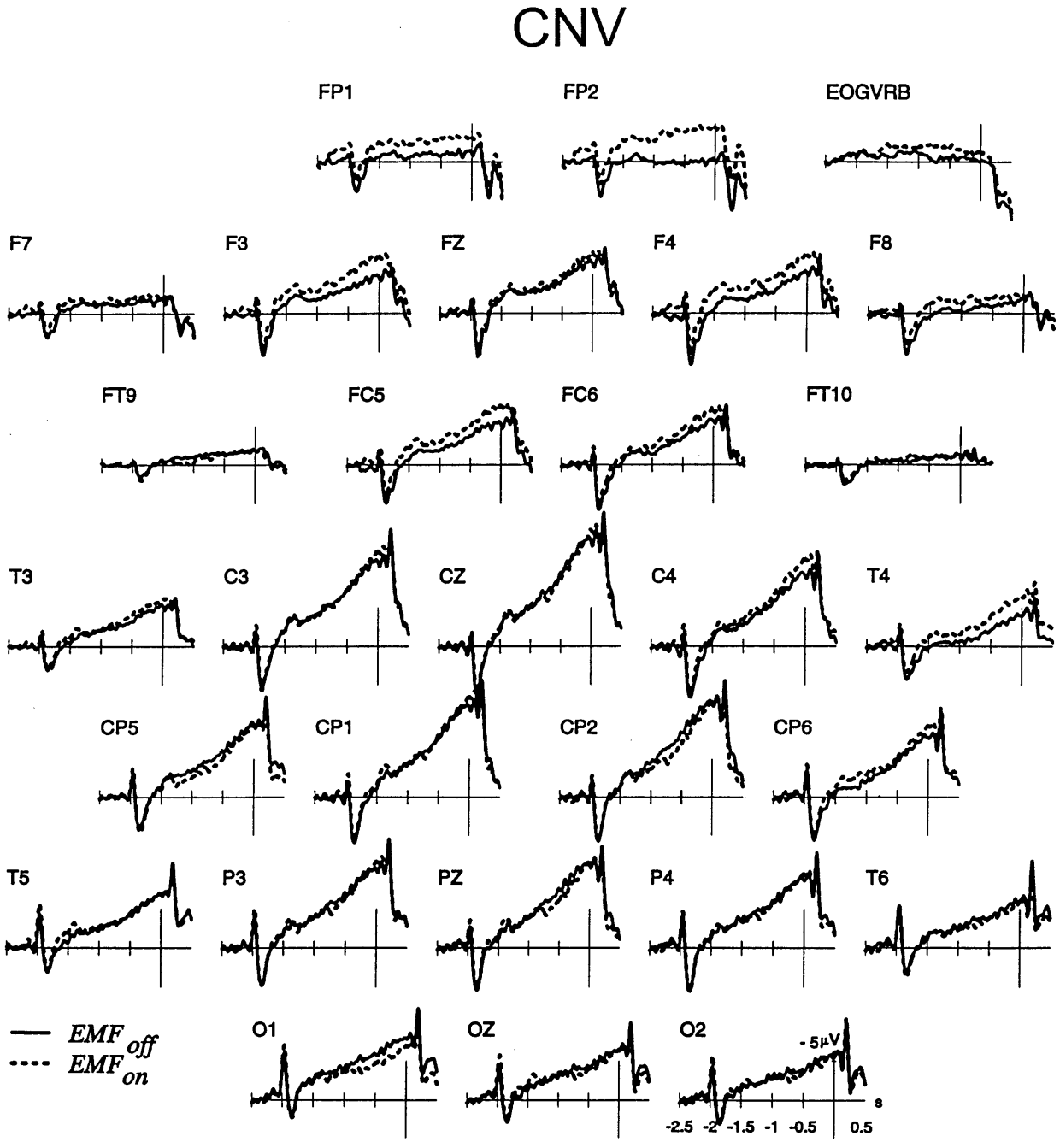

Fig. 5 Grand mean contingent negative variations (*CNV*) at all electrode positions recorded in the S_1-S_2 task in experiment 2 for the two conditions of exposure EMF_{off} and EMF_{on}. The *abscissa* represents the time interval for *CNV* analysis (0 – moment of key press for stopping the pointer immediately after movement onset). Grand mean potentials were obtained by averaging data of all subjects, separately for the two conditions of *EMF* exposure

topographical distribution: SP reduction was found at central and parieto-temporo-occipital electrode positions but not at frontal ones. These EMF_{on} effects on SP were reproduced in a second experiment 6 months later. In the task situation for eliciting a BP by simple finger movements no significant EMF_{on} influence was found. The significant interaction effect between EMF and brain region in the CNV task condition requires further investigation in a replication study.

To discuss possible causes for EMF_{on} effects, one should consider that at the low average power of 350 mW thermal effects at cortical level can probably be excluded. Measurements of the specific absorption rate (SAR), which were performed by the technological centre of the German Telecom, Darmstadt (Marx and Buhl 1996) on behalf of our institute (on the basis of CENELEC-Norm of the European Committee for Electrotechnical Standardization), showed special peak SAR values of 1.42 $mW \cdot g^{-1}$ and 0.882 $mW \cdot g^{-1}$ respectively averaged over 1 g and 10 g of tissue. It was

furthermore shown that SAR decreased in an exponential manner depending on the distance from the cellular telephone.

Considering representative anatomical parameters for tissues of the head [average scalp thickness of 6 mm; bone (skull) thickness of 7 mm; and cerebro-spinal fluid thickness of 1 mm; Berg and Scherg 1994] electromagnetic energy may have a slight effect at the cortical level. At a depth of about 14 mm, SAR amounted to about 25% of the electromagnetic energy at the skin surface. Furthermore, thermoregulatory blood flow responses in the brain, which have been found to be increased during mental work (Ingvar and Lassen 1977), can be assumed to have been effective in maintaining a homeothermic state under the present conditions of EMF exposure.

The biological effects described so far have been categorised as so-called non-thermal effects (Glaser 1992; Michaelson and Elson 1996). It has generally been accepted that fields not exceeding the energy of thermic noise can become effective (Glaser 1992; Herrmann and Hossmann 1997; Adey 1997). However, knowledge of the underlying biophysical mechanisms is lacking. The EMF effects on cell membranes have been discussed as "probably the major primary tissue site of interaction with environmental ELF (extremely low frequency) and ELF modulated RF (radio frequency) microwave fields" (Adey 1997), on the calcium homeostasis of cells (Kaczmarek and Adey 1973, 1974; Bawin et al. 1975; Bawin and Adey 1976; Blackman et al. 1985), on neurotransmitter systems (Dutta et al. 1992; Kolomytkin et al. 1994) or on permeability of the blood-brain barrier (Merritt et al. 1978; Albert and Kerns 1981; Lin and Lin 1982; Neubauer et al. 1990; Persson et al. 1992; Salford et al. 1994).

Considering the theoretical assumptions concerning the genesis of SP based on psychophysiological studies and neurophysiological evidence (Skinner and Yingling 1977; Rockstroh et al. 1989; Birbaumer et al. 1990), interactions between mechanisms underlying SP genesis and pulsed EMF seem to be plausible at least. Different cortical and subcortical structures have been shown to be involved in SP genesis (Skinner and Yingling 1977), vertically arranged pyramidal cells being considered the main structural basis for SP recorded from the cell surface (Caspers et al. 1980; Birbaumer et al. 1990). Simultaneous recordings of membrane potentials, intra- and extracellular recordings at apical dendrites and of field potentials have shown that long-lasting excitatory postsynaptic potentials are mainly responsible for the genesis of the superficially recorded SP (Caspers and Speckmann 1974; Goldring 1974; Caspers et al. 1980; Creutzfeldt 1983). Thus, the cellular processes underlying SP genesis might be influenced by variations in particular membrane properties affected by the EMF.

Furthermore, SP research has provided clear evidence that a great variety of transmitters and neuromodulators in cortical regions and subcortical structures is involved in SP generation (Rebert et al. 1986; Birbaumer et al. 1990). Accordingly, it might be speculated that the interaction between SP genesis and pulsed EMF is mediated via neurotransmitter systems as neurotransmitter binding has been shown to be sensitively modified by microwave fields (Baranski et al. 1972; Dutta et al. 1992; Kolomytkin et al. 1994).

This evidence does not provide a satisfactory explanation for the findings reported in this study but accounts for the principle possibility of an EMF-SP interaction. Whether further factors, such as a contribution of glial cells to SP generation as has been suggested by Caspers and Speckmann (1974), Somjen (1973, 1975, 1978), Bauer (1993), Roitbak (1996), would be influenced by weak EMF would require further clarification.

For a more specific discussion of the findings, i.e. that SP are reduced during EMF_{on}, the following indications should be considered. The pulsed EMF was not applied time-locked to the mental task but continuously during the experimental blocks, i.e. during task preparation/processing as well as during the intertrial intervals. Thus we have to assume a continuous influence of EMF during the whole of EMF_{on}. It might be that the continuously applied EMF affects the DC potential of the brain (not measurable with the electrode and amplification systems used in this study). The DC potentials of the brain have been found to comprise a steady potential difference of several millivolts between the cortical surface (negative) and an extracellular reference point, usually the subcortical white matter (Creutzfeld 1983). As Caspers et al. (1987) have pointed out, the topical application, e.g. of repetitive electrical stimulation to the cerebral cortex, is always associated with characteristic changes of DC potentials.

In general, increased cortical activity is accompanied by increased surface negativity, thereby increasing the DC potential. At relatively high negative DC potentials, the negative components of various types of cortically evoked potentials can be decreased in amplitude and finally reversed in polarity. Within the concept of threshold regulation proposed by Birbaumer et al. (1990) a high negative DC would correspond to a lowering of thresholds for neurone excitation which might affect preparatory SP insofar as the need for a further reduction of neurone thresholds for performing a particular task would be less (when starting from a high level of excitation), resulting in a diminished preparatory shift.

Given that the pulsed EMF exert an excitatory influence and induce an increased negative DC, reduction of the event-related negativity as measured in VMT is a plausible effect. This effect might only be evident in task situations, in which cortical regions are especially involved in task processing. This was not the case in the low demanding simple finger movement task (BP) which it has been shown can even be performed automatically with repetition of movements (Kristeva 1977) and in the lower demanding CNV task.

The influence of EMF not only in the left cortical areas where the cellular telephone was positioned but

also in the contralateral hemisphere also needs further examination. Execution and control of behaviour do not correspond to single cell activity but to neurone networks, assemblies of neurones connected to one another by plastic synaptic junctions that serve to transmit and store information. It has been suggested that the mutually excitatory connections allow for activation of the entire network after one part of it has become activated (for example by EMF) giving rise to reverberatory excitation (Braitenberg 1978).

In conclusion, we should stress that the results presented show an influence of EMF_{on} on event-related SP, reflecting particular stages of information processing. However, they do not allow any conclusions to be drawn concerning human well-being and health.

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