Bioelectromagnetics 27:204–214 (2006)

Psychophysiological Tests and Provocation of Subjects With Mobile Phone Related Symptoms

Jonna Wilén,[1] Amanda Johansson,[1] Nebojsa Kalezic,[2] Eugene Lyskov,[2] and Monica Sandström[1]*

[1]*National Institute for Working Life, Umeå, Sweden*
[2]*Centre for Musculoskeletal Research, University of Gävle, Gävle, Sweden*

The aim of the present study was to investigate the effect of exposure to a mobile phone-like radiofrequency (RF) electromagnetic field on persons experiencing subjective symptoms when using mobile phones (MP). Twenty subjects with MP-related symptoms were recruited and matched with 20 controls without MP-related symptoms. Each subject participated in two experimental sessions, one with true exposure and one with sham exposure, in random order. In the true exposure condition, the test subjects were exposed for 30 min to an RF field generating a maximum SAR_{1g} in the head of 1 W/kg through an indoor base station antenna attached to a 900 MHz GSM MP. The following physiological and cognitive parameters were measured during the experiment: heart rate and heart rate variability (HRV), respiration, local blood flow, electrodermal activity, critical flicker fusion threshold (CFFT), short-term memory, and reaction time. No significant differences related to RF exposure conditions were detected. Also no differences in baseline data were found between subject groups, except for the reaction time, which was significantly longer among the cases than among the controls the first time the test was performed. This difference disappeared when the test was repeated. However, the cases differed significantly from the controls with respect to HRV as measured in the frequency domain. The cases displayed a shift in low/high frequency ratio towards a sympathetic dominance in the autonomous nervous system during the CFFT and memory tests, regardless of exposure condition. This might be interpreted as a sign of differences in the autonomous nervous system regulation between persons with MP related subjective symptoms and persons with no such symptoms. Bioelectromagnetics 27:204–214, 2006.

Key words: cellular phones; radiofrequency exposure; neurophysiological; cognitive; autonomous nervous system

INTRODUCTION

In a previous cross-sectional study among 7800 mobile phone (MP) users in Sweden [Oftedal et al., 2000; Sandström et al., 2001], about 13% of the respondents reported at least one symptom in connection with their MP use. The most commonly reported symptoms were warmth sensations on and around the ear, burning sensations in the skin, and headaches. This group of people (further referred to as the ''MP group'') reported symptoms similar to those of people claiming to be sensitive to electromagnetic fields in general. But the MP group did not in general connect the perceived symptoms with other electrical appliances, and there might be reason to believe that these two groups are not similar with respect to the origin of the symptoms. Sandström et al. [2003] also found that people with perceived electrical hypersensitivity (EHS) showed deviations in the autonomic regulation compared to a control group, as well as in the response to sensory stimuli, such as the perception of flickering light, measured by critical flicker fusion threshold (CFFT) [Lyskov et al., 2001a,b]. This has not yet been investigated among people who experience symptoms only in connection with MPs. A possible effect of RF exposure on cognitive functions has also been studied, but to date the results are inconclusive [Preece et al., 1999; Koivisto et al., 2000; Haarala et al., 2004]. Therefore, it might be of interest to extend the

Grant sponsor: Swedish Council for Working Life and Social Research.

*Correspondence to: Monica Sandström, National Institute for Working Life, Box 7654, SE-907 13 Umeå, Sweden.
E-mail: monsand@arbetslivsinstitutet.se

Received for review 29 March 2005; Final revision received 5 September 2005

DOI 10.1002/bem.20195
Published online 22 November 2005 in Wiley InterScience (www.interscience.wiley.com).

investigation of the possible effect on brain functions not only to cognitive functions, but also to sensory perception.

It has been discussed whether the reported MP-related symptoms are truly a consequence of the RF exposure. The heating of electrical components of an MP in use, due to the heating of electrical components, and the ELF magnetic field arising from the current of the battery have been proposed to be involved [Straume et al., 2005], together with ergonomic and psychological factors. It is therefore of interest to study the RF exposure exclusively.

Laboratory studies [Koivisto et al., 2001; Hietanen et al., 2002] have not been able to demonstrate a connection between RF exposure and self-reported symptoms among MP users. These studies, however, have not distinguished between people claiming to be sensitive to MPs only and people claiming to be sensitive to electromagnetic fields in general. The aim of the present laboratory study is, therefore, to compare the baseline physiological data, such as heart rate (HR), heart rate variability (HRV), respiration rate, local blood flow, electrodermal activity (EDA), and critical flicker fusion threshold (CFFT), together with short-term memory and reaction time, between people with MP-related symptoms and a control group with no symptoms in association to MP or any other electrical appliances. A second aim of the study is to investigate the physiological and cognitive response to RF exposure, in people with and without MP-related symptoms.

MATERIALS AND METHODS

The study is divided into two parts: (1) A comparison of the aforementioned physiological baseline data, short-term memory, reaction time, and various individual characteristics between people with MP-related symptoms and a healthy control group. (2) A provocation study where physiological data, short-term memory, and reaction time were compared before and after exposure to MP-like RF signals.

Subjects

Subjects, who according to their own statement experienced symptoms when using an MP, were recruited through advertisements in four local newspapers. Among the respondents, subjects were selected by means of a questionnaire (see description below). Respondents reporting possible confounding factors, for example, aspects of health status and medication, were excluded. Since the aim of the study was to investigate people with MP-related symptoms specifically, respondents experiencing symptoms when using electrical equipment other than MPs or reporting EHS, were also excluded. After the selection, 20 respondents out of an initial 32 remained: 16 males and 4 females. Control subjects were matched with respect to age, gender, and occupation. The ages of the subjects in the case group (further referred to as ''cases'') ranged from 32 to 64 (average: 45.4, SD: 9.6), and the ages of the subjects in the control group (''controls'') from 29 to 65 (average: 44.9; SD: 10.5). A further description of the subjects is given in Table 1. The study protocols were approved by the Ethical Committee for research at Umeå University.

Questionnaires

A total of four questionnaires were distributed to the subjects. The first questionnaire mainly included questions regarding perceived symptoms and MP use. It was sent to the respondents during the recruitment period and the selection of subjects was made based on their answers. The second questionnaire was handed out to the subjects included in the study after the first experimental session. This questionnaire included separate questions about symptoms experienced in general and symptoms that occurred or were aggravated in connection with the use of an MP, an ordinary phone, in connection with visual display terminal (VDT) work, or when being near other electric equipment (this last question was asked even though subjects reporting EHS had been excluded from the provocation study in the screening process).

An individual was defined as having a symptom if the symptom occurred at least once a week. A list of symptoms was given: dizziness, feelings of discomfort, difficulties concentrating, memory loss, unusual fatigue, headaches, sensations of warmth behind/around the ear, sensations of warmth on the ear, burning sensations in the facial skin, tingling/tightness in the facial skin, and other symptoms, meaning that the respondent could specify any other symptom, which he/she had experienced. Exposure factors related to the use of MPs and possible confounding factors such as gender, age, health status, medication, sleeping habits, occupation, VDT work, and psychosocial factors were registered.

The Swedish AMY classification of occupations [Arbetsmarknadsstyrelsen, 1996], which is based on ISCO-88, was used in order to classify different occupations into four categories; Management—leading position in companies or public administration, politicians; Professional—at least 4 years of university education; Intermediate—shorter university education; Other—no demand for university education, including blue-collar workers, secretaries, and salesmen.

In order to estimate the psychosocial workload of a subject, an index was computed based on four

TABLE 1. Subject Characteristics

	Case ($n = 20$)	Control ($n = 20$)
Gender		
Male	16	16
Female	4	4
Age		
<30 years	0	1
30–39 years	7	7
40–49 years	7	5
≥50 years	6	7
State of health		
Good	9	15
Average	9	4
Not so good	2	1
Exercise activity		
0–2 times/week	8	9
>2 times/week	10	10
Missing	2	1
Occupation		
Management	5	1
Professionals	4	8
Intermediate	7	4
Others	4	7
Psychosocial workload		
Low	8	6
Medium	8	8
High	4	6
VDT work		
No VDT work	5	3
<1 h/day	4	1
1–4 h/day	7	8
>4 h/day	4	7
Missing	0	1
Time with MP		
2–7 years	4	8
8–14 years	9	11
15–22 years	7	1
Calling time (min/day)		
<2 min/day	3	7
2–15 min/day	3	7
15–60 min/day	6	3
>60 min/day	8	3
Number of calls/day		
<2 calls/day	3	7
2–4 calls/day	2	5
5–8 calls/day	3	3
>9 calls/day	12	5
Handsfree/external antenna		
Never	10	13
0–25%	2	2
26–50%	1	0
51–75%	2	0
>75%	2	2
Always	1	0
Missing	2	3

commonly used questions about workload, influence on working conditions, support from colleagues, and whether the work was experienced as stimulating and interesting. Each question was given a score, and the index was the sum of the scores for all four questions. The index was divided into three categories; low, medium, and high, where low means that the person is experiencing the best psychosocial climate and the lowest psychosocial workload. [For further details about the occupation classification and the psychosocial index, see Hansson Mild et al. [1998].]

Following each of the two experimental sessions (real/sham provocation), a follow up-form was handed out in order to record any possible symptoms perceived during or after the tests as well as the subjects' own experience of the experimental situation.

Exposure

In our previous hypothesis-generating study [Wilén et al., 2003], we could not find any clear relation between the localization of the RF exposure on the head and the prevalence of perceived symptoms. We, therefore, decided to expose the whole area where ordinary MPs are likely to deposit the RF energy, using a wall mounted base station antenna with a similar method to the system used by Huber et al. [2003]. Some aspects concerning the exposure set-up are also discussed in detail in Kuster et al. [2004].

To achieve a simulated pattern of SAR distribution in the parietal area of the head, a test GSM 900 MP (Ericsson GH 337, DC power supply Mascot 719) was used as signal generator. The RF signal was power amplified (Ophir 5802064) and fed to a power attenuator unit to adjust the signal level (Radiall attenuators, −30 dB). The signal was further directed to a power divider (MCLI CI-20) allowing the signal to reach a power meter (HP 437B) and the left or right antenna or a dummy load (Thermaline 8080; 25 W, 50 W) via a remotely controlled selector. A schematic circuit diagram is shown in Figure 1.

Two Allgon 7336 antennas were selected, due to their pattern of emission. The SAR distribution from the antenna was measured with a DASY 3 system at AMC Centurion AB (Åkersberga, Sweden) and is shown in Figure 2. The antenna was placed 8.5 cm from the head phantom during measurements. The measured maximum SAR values were: $SAR_{1g} = 1.0$ W/kg and $SAR_{10g} = 0.8$ W/kg.

The provocation experiments were performed in a specially designed exposure chamber where background levels of both power frequency and radio frequency fields were low enough that their contribution to the exposure could be considered as negligible. The subjects were seated in a semi-reclining chair in front of an LCD computer screen. The antennas were mounted on an adjustable wooden framework surrounding the subject's chair. The antennas were placed one on each side of the subject's head at a distance of 8.5 cm. The

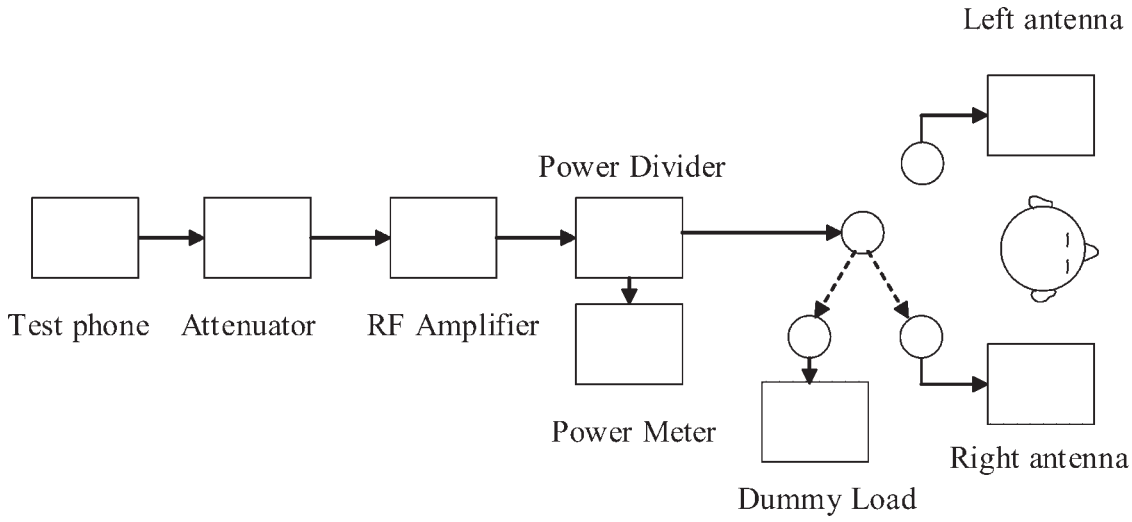

Fig. 1. Circuit diagram of the exposure system. Only the right antenna was used for RF provocation.

head was positioned between two wooden bars in order to ensure a well-defined location during the provocation (exposure/sham).

Only the right antenna was used for the RF exposure; the left antenna served solely as a dummy to blind the subjects to the exposure conditions.

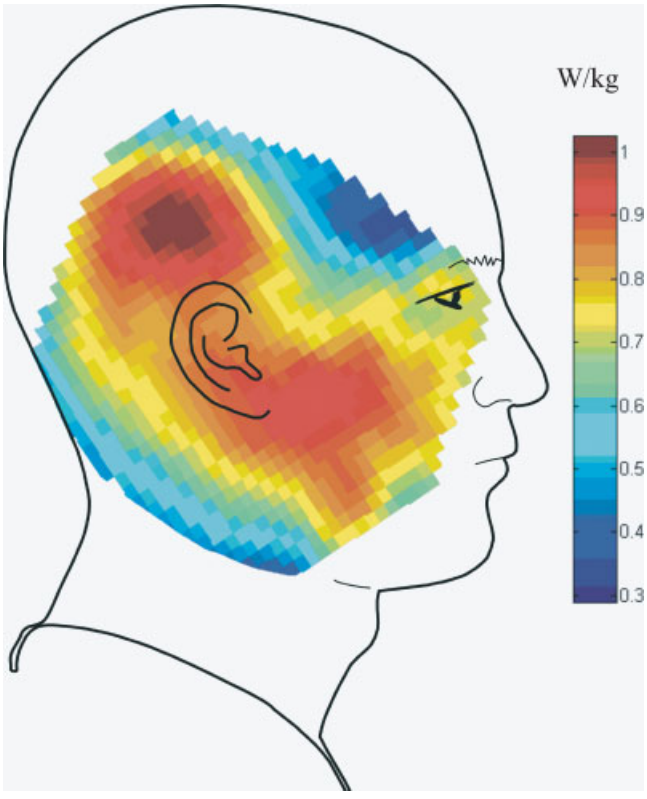

Fig. 2. The SAR distribution (W/kg) from the antenna. SAR_{1g} = 1.0 W/kg, SAR_{10g} = 0.8 W/kg.

Physiological Measurements

Heart rate variability, local blood flow, electrodermal activity, and respiration rates were recorded using an MP 100 data acquisition unit (BIOPAC Systems, Inc., Goleta, GA, USA) and analyzed using ACQKnowledge III (BIOPAC Systems, Inc.), and Matlab 6.0 (Mathworks, Inc., Natick, MA, USA) software. All variables were continuously recorded during the experiment.

Heart rate and heart rate variability. The heart rate was recorded using standard ECG electrodes placed on the chest and on the forearm and elbow (reference) of the left arm. The heart rate variability recordings were digitized, visually inspected for artifacts, and analyzed both in the time domain and in the frequency domain. The results from the time domain analysis were not further investigated. The power spectral analysis was performed by means of Fast Fourier Transformation, using standard ranges for the very low (VLF), low (LF), and high frequency (HF) bands ($VLF \leq 0.04 \uparrow Hz \leq LF \leq 0.15 \uparrow Hz \leq HF \leq 0.4 \uparrow Hz$). [The European Society of Cardiology, The North American Society of Pacing and Electrophysiology, 1996]. The normalized power in the LF and HF bands was computed ($LFn = LF/(Total\ power - VLF) \times 100$; $HFn = HF/(Total\ power - VLF) \times 100$) as well as the LF/HF-ratio.

Respiration. The respiration rate was recorded with a thermistor placed under the subject's nose and connected to a Biopac RSP100 respiration pneumogram module. The recorded pneumogram was scrutinized for artifacts, and an in-house made Matlab program was used to calculate the breath-to-breath respiration rate.

Mean values of the respiration rate during particular experimental stages were then calculated and further analyzed.

Local blood flow. Local finger blood flow was measured using photoplethysmography, with the infrared photoelectric transducers placed on the ring finger of both hands. Biopac PPG100B photoplethysmogram amplifiers were used for the recording. The pulse pressure wave was rectified and integrated in 15 s wide bins using Matlab in order to obtain a measure of local vasoconstriction.

Electrodermal activity. Electrodermal activity assessed as skin potential was recorded using disk electrodes attached to the center of the palm (active) and dorsum (referent) of both hands. Biopac ERS100 evoked-response low-noise differential amplifiers were used for the task. The electrodermal activity curve was checked for artifacts, smoothed using a 1 s wide moving-average window, and a Matlab program was run in order to detect spontaneous activity peaks. The number of spontaneous activity peaks and their intensity assessed as an integral of the rectified activity curve were then calculated.

CFFT Test

As the critical flicker fusion threshold (CFFT) is a function of the activity of both the eye and the cerebral cortex and is usually not changed by practice effects [Curran and Wattis, 1998], it is often used in neurophysiological examinations to give an estimate of the arousal/vigilance of subjects or their current CNS processing capacity. In this study, the CFFT was measured using a 12×12 cm LED display (wavelength: 635 nm). A square wave signal with a frequency varying between 25 and 75 Hz was used as a stimulus. The frequency modulation of the signal was electronically controlled. This method and equipment have been used in previous studies and are further described elsewhere [Lyskov et al., 2001b; Johansson and Sandström, 2003]. In this study, seven runs were carried out in ascending (increasing flicker frequency) and descending (decreasing flicker frequency) direction, and the first two runs in each direction were regarded as test runs and excluded from later processing. The mean values of the five remaining runs in ascending and descending order, respectively were considered to be the ascending and descending threshold values of a specific subject.

Memory Test

Short-term memory and reaction times were tested using an adjusted version of the Sternberg memory test adapted for Matlab 6.0 [Sternberg, 1966]. This test (further referred to as the ''memory test'') was performed with a computer. Number sequences of 1–8 characters were shown on the computer screen followed by a single number. Each time the subject had to try to remember if the single number had been present in the previous sequence. A positive (presence) or a negative (non-presence) answer was indicated using the computer mouse. The number of correct and incorrect answers was registered, as was the number of time outs (delayed answers) and the reaction time in seconds. The whole procedure lasted about 10 min.

The CFFT and memory tests were used in order to examine possible effects of the exposure on the central nervous system (i.e., on CNS arousal levels) and cognitive functions. The tests were also considered as psychophysical stressor tasks with respect to the reactivity of autonomic nervous system (ANS) variables.

Experimental Procedure

The subjects were tested on two separate days, one day with sham exposure and one with true exposure in random order. Sham and true exposure experiments were performed at the same time of day, that is, either A.M. or P.M. The matched pairs of test and control subjects were tested roughly at the same time of day (A.M. or P.M.), which was the closest achievable time correspondence. The subjects were reimbursed for their participation.

After an introduction to the experiment, the electrodes and sensors were attached and the recording of the physiological parameters began. The subject was then left alone in the exposure chamber for a 10 min adaptation period. The physiological measurements ran throughout the whole experiment. The data recorded during adaptation were considered as resting values (relaxed state), and later used for comparison with the data obtained after provocation, as well as the data obtained during the various tests. After the adaptation period, a first (pre-exposure) CFFT test was performed. This was followed by a pre-exposure memory test as described above. The results from the pre-exposure tests on day 1 were considered as baseline data for cases and control subjects.

After performing the CFFT and memory tests, the antennas were correctly positioned and the exposure period started. The exposure condition (on/off) was assigned randomly by the responsible technician and was not known by the experimenter or the subjects. It was not possible to keep the study double blind, since the physiological recordings were distorted by the MP signal during exposure in a mode clearly visible to the experimenter. However, there were no cues, for

Adaptation	CFFT test	Memory test	Exposure/Sham	CFFT test	Memory test
10 min	*10 min*	*10 min*	*30 min*	*10 min*	*10 min*

Fig. 3. Schematic drawing of the experimental procedure during Day 1 and Day 2.

example, visible, auditory or vibratory, through which the subjects could detect the exposure conditions. During the exposure, which lasted 30 min, a film was shown on a LCD computer screen (''The Blue Planet,'' BBC) in order to create a relaxed atmosphere and to pose a similar degree of mental load on the subjects.

The CFFT and the memory tests were repeated after the provocation. The subjects were video monitored during the whole test procedure. The experiments were performed during a period of approximately 3 months. The experimental procedure is shown in Figure 3.

Statistical Analysis

The statistical processing and analysis of both the physiological data and the questionnaire data were performed using SPSS (Statistical Package for the Social Sciences, SPSS, Inc.) for Windows 11.0. Multivariate analysis of variance (MANOVA) with exposure, sequence of experiments (exposure first, exposure last), and group as between-subject variables was used in the analysis of physiological data. The effects of exposure on physiological data and task performance were evaluated using repeated-measures analysis of variance. The Bonferroni correction for multiple outcomes was applied both to the MANOVA and to the repeated measures ANOVA. Differences between cases and controls in symptom experience during exposure/sham were evaluated using Chi-squared tests. Significance level was taken at $P \leq .05$.

RESULTS

Comparison of Case and Control Subjects

There were no obvious differences between the subject groups with respect to occupation, psychosocial workload, and exercise activity; but fewer cases reported their state of health as ''good'' compared to the controls, and the controls reported more VDT work than the cases. The subjects in the case group had both longer calling MP times and a larger number of calls per day than the control subjects. The cases had also been using an MP for a longer time than the controls (mean, cases: 12.3 years; mean, controls: 8.9 years). All of these differences were significant. In Table 1, a detailed description of the subjects is given.

The cases reported more symptoms than the controls not only in connection with MP use, but also in general (Table 2). The number of general symptoms reported by the cases exceeds that of the number reported by the Swedish general population [Eriksson et al., 2000]. The controls, on the other hand, tend to report fewer symptoms than does the general population. The most commonly reported symptoms were fatigue, memory loss, concentration difficulties, and warmth sensations on and behind the ear. Symptoms perceived in connection with MP use were mainly reported to occur in connection with long calling times (17/20). Among the cases, a tendency was observed toward an increased number of MP-related symptoms with a longer time of MP use (in years), longer calling times per day, and a larger number of calls per day. It should be noted that neither of the groups can be viewed as representative for the general population, since the subjects were not randomly selected.

Eighteen out of 20 cases had taken measures to alleviate the symptoms by reducing the MP exposure. The most commonly used methods were reducing calling times, changing from an MP to an ordinary phone, and/or using hands-free equipment. Other attempts to reduce perceived symptoms included, for example, changing of MP model/type, switching ears, and/or not holding the MP directly against the head during calls. Shorter calling times, changing to an ordinary phone, and using a hands-free set seem to be the most effective methods in terms of actually reducing the symptoms.

TABLE 2. Number of Subjects With Self-reported Symptoms Occurring at Least Once a Week

	Cases ($n = 20$)		Controls ($n = 20$)
	In general	MP-related	In general
Dizziness	4	2	1
Discomfort	5	4	1
Concentration difficulties	6	5	2
Memory loss	7	3	1
Fatigue	9	5	4
Headaches	7	4	1
Warmth behind ear	9	9	0
Warmth on ear	8	8	0
Burning skin	3	3	1
Tingling/tightness	5	3	0
Others	3	1	0

Symptoms reported in general are not necessarily attributed to MP use, while MP-related symptoms are.

TABLE 3. Number of Cases and Controls Reporting Symptoms in Connection With the Experiments for the Day of Exposure, the Sham Day, and Both Days

	Cases ($n = 20$)	Control ($n = 20$)
Exposure day	8	0
Sham day	4	0
Both days	6	0
None	1	18
Missing	1	2

Those who never reported any symptoms are presented as "none."

The pre-exposure memory function parameters showed that the control subjects performed better than the cases, that is, they achieved significantly more corrects answers and had shorter reaction times than the cases (Table 4). The difference in reaction time was no longer apparent the second time the memory test was conducted. A trend toward a lower number of correct answers in the case group remained, but the difference was no longer significant. The baseline CFFT data showed no significant differences between the cases and the controls.

No significant differences in heart rates, breathing rates, or electrodermal activity between the cases and the control group could be found (Tables 5–7). The cases displayed a significantly higher activity in the LF band during the test periods than did the controls, as well as a significantly lower activity in the HF band, with a resulting higher LF/HF ratio (Table 8a–c). Possible gender differences were not evaluated due to the small number of female subjects.

Effects of RF Exposure

No significant effects of exposure were found on the CFFT, the memory function, or the physiological data (Tables 5–8).

Out of 20 cases, 18 experienced symptoms like warmth sensations on and around the ear, burning sensations in the skin, fatigue, and feelings of general discomfort during or after the experiment on any day (Table 3), but there was no significant relation between experienced symptoms and exposure ($P = .13$). No symptoms were experienced among the controls. Only two test subjects (one case, one control) reported feeling stressed or anxious during the experiment.

DISCUSSION

The absence of a relation between RF exposure and perceived symptoms in this study is similar to the results of previous work [Koivisto et al., 2001; Hietanen et al., 2002], despite excluding people reporting general EHS and using a well-controlled exposure set-up in which a large area of the head is exposed. One of the hypotheses in our previous studies [Sandström et al., 2001; Wilén et al., 2003] was that the RF exposure from the MP might be a possible explanation of the perceived symptoms. The findings in this study do not support that hypothesis. The people in this study are not randomly selected and might not form a representative sample of all people experiencing MP-related symptoms. The symptom description, however, is similar to that found in Sandström et al. [2001]. Similarly to a recently reported study [Haarala et al., 2004], we could not find any effect of RF exposure on short term memory function, although we have used an exposure system that exposes a larger area than does the ordinary MP used by the mentioned research group. There is a possibility, though, that the maximum SAR_{1g} and SAR_{10g} in some cases could be higher from commercially used MPs where the limit values are $SAR_{1g} = 1.6$ W/kg [IEEE, 1999] and $SAR_{10g} = 2.0$ W/kg [ICNIRP, 1998].

The baseline physiological recordings revealed no difference between the subject groups. We found a significant difference between the cases and the controls with respect to the HRV function (LF/HF) during the test stages of the experimental session, which was not related to the RF exposure. In contrast to this, the subjects reporting MP-related symptoms displayed

TABLE 4. Basal Short-Term Memory Functions for Cases and Controls

	Mean day 1			Mean day 2		
	Case	Control	*P*-value*	Case	Control	*P*-value**
Correct	79 (7.8)	85 (4.6)	.01	84 (8.4)	87 (2.5)	.07
Incorrect	5.9 (7.4)	2.2 (2.3)	.04	3.6 (6.0)	1.5 (1.5)	.13
Time-outs	7.9 (11)	3.1 (3.5)	.07	3.0 (4.7)	1.4 (2.0)	.19
Reaction time (s)	1.6 (0.3)	1.4 (0.2)	.04	1.4 (0.2)	1.4 (0.2)	.17

Percentage of correct and incorrect answers and time outs and the mean reaction time in seconds (standard deviation in brackets).
**P*-values MANOVA (comparison between cases and controls, day 1).
***P*-values from repeated measures ANOVA (comparison between cases and controls, day 1 and day 2).

TABLE 5. Mean Values and Standard Deviation (in brackets) of Heart Rate (beats/min) During Relaxed and Test Periods and for Sham and Exposure Conditions

	Heart rate				
Group	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	71 (3.4)	71 (3.2)	75 (3.8)	68 (3.1)	71 (3.7)
Sham day	74 (5.6)	73 (5.8)	78 (6.3)	71 (5.8)	73 (6.2)
Controls ($N = 20$)					
Exp. day	72 (3.5)	71 (3.3)	74 (3.9)	69 (2.5)	70 (3.0)
Sham day	73 (4.6)	73 (5.0)	75 (5.3)	70 (5.1)	72 (5.7)
			P-values**		
Group	.40	.34	.48	.43	.39
Exp. day/sham day	—	.91	.71	.96	.99
Exp./sham × group	—	.94	.57	.84	.96

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.

no signs of stress or heightened arousal in the relaxed condition.

The HRV data recorded during the various tests differed significantly between the cases and the controls. The higher LF activity and the lower HF activity might be interpreted as a shift in the autonomic regulation towards sympathetic activity. This in turn is often regarded as a sign of an elevated stress level. The finding that the HRV differences were more evident during the memory test than during the CFFT measurements might be explained by the cases showing an enhanced stress response in the memory test situation. This could be an effect of the subjects experiencing the memory test as a performance test to a higher degree than the CFFT test. The results from the physiological examination differed in part from those obtained in previous studies with EHS subjects [Lyskov et al., 2001a,b]. In these studies, EHS subjects displayed significantly higher values in HR, breathing rate, EDA, CFFT, and an elevated LF/HF ratio compared to healthy controls, not only in the relaxed condition, but also during the functional tests. This has been interpreted partly as an effect of an elevation in sympathetic tone (and responsitivity to sensory stimulation) among the EHS subjects, and partly as an effect of the EHS subjects initially experiencing a higher degree of emotional stress at the prospect of being exposed. However, the MP group did not differ from the controls with respect to initial resting values, but only with respect to HRV data recorded during the CFFT and memory tests. This may be an indication that EHS and people with MP related complaints represent different groups.

The results from the memory test improved significantly with an increasing number of test events for both the cases and the controls. This is most likely

TABLE 6. Mean Values and Standard Deviation (in brackets) of Breathing Rate (no./min) During Relaxed and Test Periods and for Sham and Exposure Conditions

	Breathing				
Group	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	15 (0.8)	17 (0.7)	17 (0.9)	17 (0.8)	17 (1.0)
Sham day	16 (0.7)	16 (0.7)	18 (1.3)	17 (1.0)	17 (1.4)
Controls ($N = 20$)					
Exp. day	16 (1.3)	17 (1.4)	18 (1.4)	17 (1.3)	18 (1.4)
Sham day	17 (1.3)	18 (1.3)	19 (1.4)	17 (1.1)	18 (1.4)
			P-values**		
Group	.07	.06	.18	.46	.24
Exp. day/sham day	—	.88	.88	.70	.86
Exp./sham × group	—	.65	.95	.97	.92

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.

TABLE 7. Mean Values and Standard Deviation (in brackets) of Electrodermal Activity (peaks/min) During Relaxed and Test Periods and for Sham and Exposure Conditions

	EDALP				
	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	1.7 (0.5)	2.3 (0.7)	2.5 (0.6)	2.1 (0.7)	1.9 (0.6)
Sham day	1.9 (0.7)	2.2 (0.6)	2.6 (0.5)	1.8 (0.5)	2.2 (0.5)
Controls ($N = 20$)					
Exp. day	1.7 (0.6)	2.1 (0.7)	2.5 (0.5)	1.7 (0.5)	2.1 (0.4)
Sham day	2.0 (0.5)	2.4 (0.5)	2.5 (0.6)	1.6 (0.4)	2.5 (0.5)
			P-values**		
Group	.83	.98	.70	.23	.28
Exp. day/sham day	—	.35	.40	.60	.16
Exp./sham × group	—	.57	.87	.72	.91

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.

due to a practice effect [Kihlström and Park, 2002]. The cases had significantly poorer results compared to the controls in the initial memory test (fewer correct answers, longer reaction times), but this difference gradually decreased in the later tests, and finally disappeared. Seemingly, the cases thus caught up with the controls once they had become acquainted with the test, but the reason for their initially poorer performance is not entirely clear. The baseline data contradict a higher physiological stress level among the cases than among the controls, but a difference in subjectively perceived stress might be present. A higher level of perceived stress among the cases might lead to difficulties in focusing on the task, resulting in a poorer performance. It also seems plausible that a difference in performance caused by differences in subjective stress experience would have decreased in the second experimental session, when the subjects were accustomed to the situation.

In order to further explore the reasons for the encountered differences in memory functions and the autonomic regulation, it might be of interest to perform a characterization of this group of people with respect to psychological factors such as personality traits, stress, somatoform symptoms, and the individual's focus on autonomous sensations. A study at this level might also be of interest in order to explore whether people perceiving MP-related symptoms represent a separate group, and to what extent this coincides with similar phenomena, such as EHS.

CONCLUSIONS

The results of our study do not support the hypothesis that exposure to MP-like RF fields can explain perceived MP-attributed symptoms, nor that exposure affects memory functions. However, we have demonstrated a difference between the cases and

TABLE 8a. Mean Values and Standard Deviation (in brackets) of Normalized Low Frequency Power (LFn) During Relaxed and Test Periods and For Sham and Exposure Conditions

	LFn				
Group	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	0.53 (0.1)	0.60 (0.1)	0.60 (0.1)	0.65 (0.1)	0.65 (0.1)
Sham day	0.57 (0.1)	0.62 (0.1)	0.62 (0.1)	0.68 (0.1)	0.63 (0.1)
Controls ($N = 20$)					
Exp. day	0.52 (0.1)	0.56 (0.1)	0.55 (0.1)	0.60 (0.1)	0.55 (0.1)
Sham day	0.53 (0.2)	0.55 (0.2)	0.53 (0.2)	0.59 (0.2)	0.56 (0.1)
			P-values**		
Group	.51	.06	.01	.03***	.001
Exp. day/sham day	—	.91	.96	.81	.83
Exp./sham × group	—	.69	.60	.60	.65

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.
***Not significant with Bonferroni correction.

TABLE 8b. Mean Values and Standard Deviation (in brackets) of Normalized High Frequency Power (HFn) During Relaxed and Test Periods and for Sham and Exposure Conditions

	HFn				
Group	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	0.40 (0.1)	0.34 (0.1)	0.33 (0.1)	0.29 (0.1)	0.30 (0.1)
Sham day	0.36 (0.1)	0.32 (0.1)	0.36 (0.1)	0.27 (0.1)	0.31 (0.1)
Controls ($N = 20$)					
Exp. day	0.40 (0.1)	0.36 (0.1)	0.38 (0.1)	0.33 (0.1)	0.38 (0.1)
Sham day	0.38 (0.1)	0.37 (0.1)	0.39 (0.1)	0.34 (0.1)	0.37 (0.1)
			P-values**		
Group	.71	.12	.01	.04***	.001
Exp. day/sham day	—	.97	.95	.83	.84
Exp./sham × group	—	.68	.60	.59	.66

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.
***Not significant with Bonferroni correction.

TABLE 8c. Mean Values and Standard Deviation (in brackets) of Low Frequency/High Frequency Ratio (LF/HF) During Relaxed and Test Periods and for Sham and Exposure Conditions

	LF/HF				
Group	Relaxed*	CFFT test 1	Memory test 1	CFFT test 2	Memory test 2
Cases ($N = 20$)					
Exp. day	1.9 (0.7)	2.6 (0.7)	2.4 (0.5)	3.6 (0.9)	2.8 (0.5)
Sham day	2.2 (0.5)	2.5 (0.4)	2.6 (0.5)	3.5 (0.8)	2.8 (0.6)
Controls ($N = 20$)					
Exp. day	1.8 (0.5)	2.0 (0.4)	1.8 (0.4)	2.7 (0.7)	1.9 (0.4)
Sham day	2.1 (0.6)	2.2 (0.6)	2.0 (0.5)	2.8 (0.8)	2.0 (0.4)
			P-values**		
Group	.66	.16	.03***	.05***	.001
Exp. day/sham day	—	.95	.68	.90	.88
Exp./sham × group	—	.77	.90	.86	.94

*Baseline data recorded during adaptation on Day 1.
***P*-values from MANOVA.
***Not significant with Bonferroni correction.

control group with respect to their autonomic nervous system regulation and working memory functions. These findings are interesting for further study and it might also be worthwhile to perform a personality inventory among this group of people.

ACKNOWLEDGMENTS

The authors wish to express their special thanks to Prof. Kjell Hansson Mild, for excellent guidance and advice during the project. Olov Stensson also deserves appreciation for his help with instrumentation during the test sessions. We thank Jürgen Schuderer for guidance and help with the choice of exposure system and Centurion AB for help with the SAR measurements. Finally, our appreciation goes to all of those who participated in the study.

REFERENCES

Arbetsmarknadsstyrelsen. 1996. AMS Yrkesklassificering (AMSYK) och Standard för svensk yrkesklassificering (SSYK). Arbetsmarknadsstyrelsen, editor. Gnesta: AMS Förlagsservice.

Curran S, Wattis J-P. 1998. Critical flicker fusion threshold: A useful research tool in patients with Alzheimer's disease. Hum Psychopharmacol Clin Exp 13:337–355.

Eriksson N, Höög J, Hansson Mild K, Sandström M, Stenberg B. 2000. Förekomst av symtom liknande ''sjuka hus-sjuka'', bildskärmsrelaterade hudbesvär och ''elöverkänslighet'' i den vuxna svenska befolkningen. Arbetslivsrapport Nr 2000 5: The National Institute for Working Life. [www.arbetslivsinstitutet.se]

Haarala C, Ek M, Björnberg L, Laine M, Revonsuo A, Koivisto M, Hämälainen H. 2004. 902 MHz mobile phone does not affect short term memory in humans. Bioelectromagnetics 25(6): 452–456.

Hansson Mild K, Oftedal G, Sandström M, Wilén J, Tynes T, Haugsdal B, Hauger E. 1998. Comparison of symptoms experienced by users of analogue and digital mobile phones; a Swedish-Norwegian epidemiological study. Solna, Sweden: National Institute of Working Life. Report nr 1998:23. [www.arbetslivsinstitutet.se]

Hietanen M, Hämälainen AM, Husman T. 2002. Hypersensitivity symptoms associated with exposure to cellular telephones: No causal link. Bioelectromagnetics 23(4):264–270.

Huber R, Schuderer J, Graf T, Jutz K, Borbely AA, Kuster N, Achermann P. 2003. Radio frequency electromagnetic field exposure in humans: Estimation of SAR distribution in the brain, effects on sleep and heart rate. Bioelectromagnetics 24(4):262–276.

ICNIRP. 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). International Commission on Non-Ionizing Radiation Protection [published erratum appears in Health Phys 1998 Oct;75(4):442]. Health Phys 74(4):494–522.

IEEE. 1999. IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz. New York: The Institute of Electrical and Electronics Engineers, Inc. Report nr C95. 1–1999.

Johansson A, Sandström M. 2003. Sensitivity of the human visual system to amplitude modulated light. Arbetslivsrapport 2003:4. Umeå. [www.arbetslivsinstitutet.se]

Kihlström J, Park L. 2002. Cognitive psychology, overview. In: Ramachandran V, editor. Encyclopedia of the human brain. San Diego: Academic Press. p 839–853.

Koivisto M, Revonsuo A, Krause C, Haarala C, Sillanmäki L, Laine M, Hämäläinen H. 2000. Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans. Neuroreport 11(2):413–415.

Koivisto M, Haarala C, Krause CM, Revonsuo A, Laine M, Hämälainen H. 2001. GSM phone signal does not produce subjective symptoms. Bioelectromagnetics 22(3):212–215.

Kuster N, Schuderer J, Christ A, Futter P, Ebert S. 2004. Guidance for exposure design of human studies addressing health risk evaluations of mobile phones. Bioelectromagnetics 25(7): 524.

Lyskov E, Sandström M, Hansson Mild K. 2001a. Neurophysiological study of patients with perceived 'electrical hypersensitivity'. Int J Psychophysiol 42(3):233–241.

Lyskov E, Sandström M, Hansson Mild K. 2001b. Provocation study of persons with perceived electrical hypersensitivity and controls using magnetic field exposure and recording of electrophysiological characteristics. Bioelectromagnetics 22(7):457–462.

Oftedal G, Wilén J, Sandström M, Hansson Mild K. 2000. Symptoms experienced in connection with mobile phone use. Occup Med-Oxf 50(4):237–245.

Preece AW, Iwi G, Davies-Smith A, Wesnes K, Butler S, Lim E, Varey A. 1999. Effect of a 915-MHz simulated mobile phone signal on cognitive function in man. Int J Radiat Biol 75(4):447–456.

Sandström M, Wilén J, Oftedal G, Hansson Mild K. 2001. Mobile phone use and subjective symptoms. Comparison of symptoms experienced by users of analogue and digital mobile phones. Occup Med-Oxf 51(1):25–35.

Sandström M, Lyskov E, Hörnsten R, Hansson Mild K, Wiklund U, Rask P, Klucharev V, Stenberg B, Bjerle P. 2003. Holter ECG monitoring in patients with perceived electrical hypersensitivity. Int J Psychophysiol 49(3): 227–235.

Sternberg S. 1966. High-speed scanning in human memory. Science 153:652–654.

Straume A, Oftedal G, Johnson A. 2005. Skin temperature increase caused by a mobile phone: A methodological infrared camera study. Bioelectromagnetics 26:510–519.

The European Society of Cardiology, The North American Society of Pacing and Electrophysiology. 1996. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. 354–381 p.

Wilén J, Sandström M, Hansson Mild K. 2003. Subjective symptoms among mobile phone users—A consequence of absorption of radiofrequency fields? Bioelectromagnetics 24(3):152–159.