

Subjective Symptoms Among Mobile Phone Users—A Consequence of Absorption of Radiofrequency Fields?

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In a previous epidemiological study, where we studied the prevalence of subjective symptoms among mobile phone (MP) users, we found as an interesting side finding that the prevalence of many of the subjective symptoms increased with increasing calling time and number of calls per day. In this extrapolative study, we have selected 2402 people from the epidemiological study who used any of the four most common GSM MP. We used the information about the prevalence of symptoms, calling time per day, and number of calls per day and combined it with measurements of the Specific Absorption Rate (SAR). We defined three volumes in the head and measured the maximum SAR averaged over a cube of 1 g tissue (SAR_{1g}) in each volume. Two new exposure parameters Specific Absorption per Day (SAD) and Specific Absorption per Call (SAC) have been devised and are obtained as combinations of SAR, calling time per day, and number of calls per day, respectively. The results indicates that SAR values >0.5 W/kg may be an important factor for the prevalence of some of the symptoms, especially in combination with long calling times per day. *Bioelectromagnetics* 24:152–159, 2003. © 2003 Wiley-Liss, Inc.

Key words: SAR; specific absorption; headache; cellular phone

INTRODUCTION

In a previous work [Oftedal et al., 2000; Sandström et al., 2001], we studied the prevalence of subjective symptoms among mobile phone (MP) users, by sending a questionnaire to 12000 Swedish and 5000 Norwegian MP users. The main hypothesis, that GSM (digital) users would experience more symptoms than NMT (analogue) users, was falsified. However, an interesting side finding appeared: the prevalence of subjective symptoms increased with increasing calling time per day and number of calls per day. Since a certain amount of radiofrequency energy will be absorbed by the user during a MP call, it was of interest to go one step further and study whether the prevalence of subjective symptoms increased with increasing rate of absorption and the total absorbed energy per call and per day.

In this explorative study, we make use of the information about prevalence of symptoms, calling time per day and number of calls per day from the epidemiological study [Sandström et al., 2001] and combine it with measurements of the Specific Absorption Rate (SAR) of the specific MP device used by each person included in this study. The aim was to find alternative exposure/dose parameters and to generate new hypotheses to be tested in further studies.

MATERIALS AND METHODS

Cohort

Oftedal et al. [2000] found that many people claimed that the call must last at least 5 min before their symptom occurred. Therefore, only people with calling time per day (CT) > 2 min/day are included in the study, when not stated otherwise. Information about the four selected, most commonly used GSM devices from our previous study [Sandström et al., 2001] are shown in Table 1. In total, 2197 users (excluding those with CT = 2 min/day (205), 1637 Swedish and 560 Norwegian respondents) with one of the selected GSM devices were included in the study. The distribution of the exposure parameters CT and number of calls per day (NC) among the selected devices are shown in Table 2.

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Received for review 30 January 2002; Final revision received 26 July 2002

DOI 10.1002/bem.10101
Published online in Wiley InterScience (www.interscience.wiley.com).

TABLE 1. GSM Devices Included in the Study

Device	Size ^a (cm)	Antenna length (cm)
M1	17 × 6 × 5	2.3
M2	15 × 5 × 3	3.1
M3	13 × 5 × 4	3.4
M4	15 × 5 × 3	13

^aThe size of the chassis are given as height × width × thickness [cm].

In the questionnaire, CT and NC have ordinal answer options, which in this study were given estimated mean values (in parentheses) as follows: <2 min/day (1 min), 2–15 min/day (7 min), 15–60 min/day (23 min), and >60 min/day (70 min). The same procedure was used for NC; <2 calls/day (1), 2–4 calls/day (3), and >4 calls/day (6).

People were also asked how often they experienced the symptoms (dizziness, general discomfort, difficulties concentrating, memory loss, abnormal drowsiness/fatigue, headaches, sensation of warmth behind/around the ear, sensation of warmth on the ear, burning sensations in the facial skin, tingling/tightness sensation in the facial skin, and other symptoms) during the last year, regardless of connection to MP use. The answer options were never, less than once a week, one to four times per week, and more than four times per week. An individual was defined as having a symptom if he/she had indicated that the symptom occurred at least once a week. For further details about the questionnaire, see [Hansson Mild et al., 1998].

Measurement

By the use of twin phantoms (DASY 3) at Ericsson Radio Systems AB and Nokia Research Center and a three component E field probe, the E field (rms) distribution was measured in a volume of ~0.5 dm³ inside the phantom. The phone was held in intended use

position and measurements were taken both on the left and the right hand side. The electrical conductivity (σ) was measured after the E field measurement for each device and ranged from 0.83 to 0.87 S/m. The SAR values at each point were obtained by using the relationship stated in Equation 1 with $\rho = 1.00 \times 10^3 \text{ kg/m}^3$:

$$\text{SAR} = \frac{\sigma \cdot E^2}{\rho}. \quad (1)$$

To be able to measure the SAR distribution in a rather large volume without a significant loss of battery power in the test phones, in the phantom, the measurement grid ($x \times y \times z$) was set to $8 \times 8 \times 4 \text{ mm}$. During the measurement of each phone model, the output power was set at maximum level. The output power was measured before and after each set of measurements.

Definition of the Volumes

Different MP devices deposit the energy with different anatomical localization. The antenna, the chassis, as well as the internal structure of the device affect the absorption. We have, therefore, defined three volumes in the head and from the measured values calculated the maximum SAR averaged over a 1 g cube of tissue (SAR_{1g}) in each volume for four of the most commonly used GSM devices from our previous epidemiological study. The volumes in the phantom head are defined as shown in Figure 1. In general, volume 1 is the region above the ear, volume 2 is on and around the ear, and volume 3 is below the ear, on the cheek. The depth of the volumes is ~4 cm.

Calculations

Specific absorption rate. Since the E field probe is not able to take measurements near the surface of the phantom, the measured values in z direction were

TABLE 2. Number of Respondents (N) for Various Combinations of the Exposure Parameters

		M1 N (%)	M2 N (%)	M3 N (%)	M4 N (%)	Total
CT ^b	< 2 min/day	23 (12) ^a	78 (8)	75 (8)	29 (11)	205
	2–15 min/day	87 (44)	478 (47)	422 (46)	126 (46)	1113
	15–60 min/day	65 (33)	345 (34)	349 (38)	98 (36)	857
	> 60 min/day	22 (11)	106 (11)	72 (8)	19 (7)	219
	Missing	1 (0)	5 (0)	1 (0)	1 (0)	8
NC ^b	< 2 calls/day	29 (15)	125 (13)	127 (14)	48 (18)	329
	2–4 calls/day	59 (30)	336 (33)	278 (30)	76 (28)	749
	> 4 calls/day	109 (55)	548 (54)	513 (56)	148 (54)	1318
	Missing	1 (0)	3 (0)	1 (0)	1 (0)	6
Total		198	1012	919	273	2402

^aPercentage in parenthesis.

^bCalling time/day (CT) and Number of calls/day (NC) for each device (M1-M4).

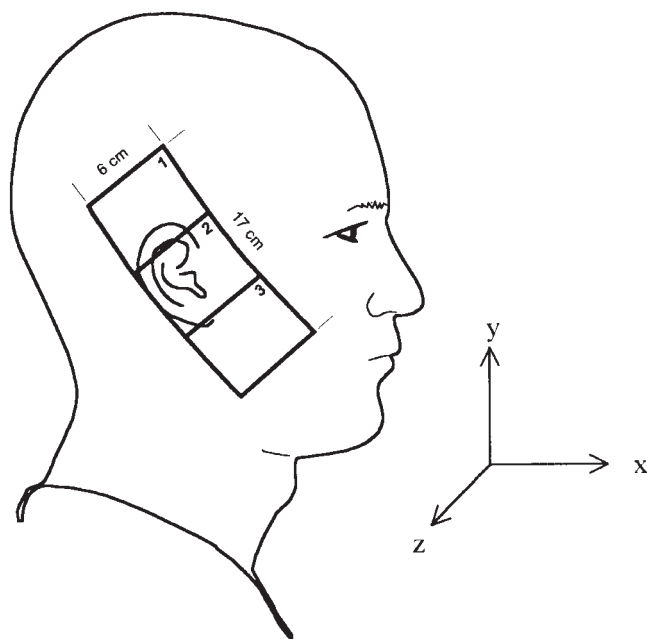


Fig. 1. Definition of the three volumes used, above the ear (Vol. 1), on the ear (Vol. 2), and below the ear (Vol. 3).

extrapolated toward the surface ($\Delta z = 4.12$ mm) using spline functions (MATLAB). Spline functions were also used to interpolate the measured values to a grid size of $1 \times 1 \times 1$ mm.

SAR_{1g} was used as exposure parameter, which was calculated in each volume by moving a $10 \text{ mm} \times 10 \text{ mm} \times 10 \text{ mm}$ cube in steps of 1 mm across the volume surrounding the point of the maximum SAR_{peak} value (± 10 mm in all three orthogonal directions). In the analyses, the average values of SAR_{1g} from the measurements on the left and the right hand side of the phantom were used.

In some analyses, the SAR values have been categorized into two groups with a cut point of 0.5 W/kg, e.g., $SAR \leq 0.5 \text{ W/kg}$ and $SAR > 0.5 \text{ W/kg}$. The rationale for using this cut point is to obtain groups of fairly equal size.

Specific absorption (SA). The specific absorptions (J/kg), averaged over 1 g tissue, per phone call (SAC), and per day (SAD), were calculated for each individual in the measurement volumes by the use of the SAR_{1g} value, CT (in minutes), and NC, and converting minutes to seconds (60).

$$SAD = SAR_{1g} \cdot CT \cdot 60$$

$$SAC = \frac{SAD}{NC}$$

Statistical Methods

Due to the relatively large number of cases, the normal distribution based, one way analysis of variance (ANOVA) has been used to evaluate differences in mean values of different exposure parameters, e.g., SAR_{1g} , CT, NC, SAC, and SAD, between people with and without symptoms. In many comparisons, the P values were < 0.001 , which makes a comparison difficult, and therefore, F values have also been used to evaluate the results.

RESULTS

SAR Measurements

Figure 2 shows the measured SAR distributions on the right hand side of the phantom of each device. The calculated SAR_{1g} values are presented in Table 3 as an average value of the calculated values of the left and right hand side of the phantom. The relative difference between the calculated values of the left and right hand side was $\leq 13\%$ for each volume and device.

Prevalence of Symptoms

In Figure 3a,b,c, the prevalence of symptoms for people with $SAR_{1g} \leq 0.5 \text{ W/kg}$ and $SAR_{1g} > 0.5 \text{ W/kg}$ in combination with short CT (0–15 min) and long CT (> 15 min) are presented. The prevalence, in percentage, shows the relative number of people with long or short CT and $SAR \leq 0.5$ or $SAR > 0.5 \text{ W/kg}$ who claim that they experience a specific symptom. The ratios for the prevalence of symptoms between SAR values $> 0.5 \text{ W/kg}$ and $\leq 0.5 \text{ W/kg}$ are also shown in the figures. Note that people with $CT < 2 \text{ min/day}$ are also included in this analysis. For volume 2 (on the ear) and volume 3 (below the ear), the categorization of the SAR_{1g} values resulted in the same subgroups; therefore, the results will be equal for those volumes.

For most of the symptoms, the prevalence increased with higher SAR_{1g} values. But perhaps even more interesting is that for some of the symptoms, especially *discomfort* and *dizziness* in volume 2 (on the ear) and volume 3 (below the ear), the ratio of the prevalence of

TABLE 3. Calculated Maximum SAR_{1g} (W/kg) in Each Specified Volume, Above the Ear (Vol. 1), On the Ear (Vol. 2), and Below the Ear (Vol. 3) for Each Device

	Vol. 1 (above the ear)	Vol. 2 (on the ear)	Vol. 3 (below the ear)	Any Vol. (max)
M1	0.10	0.14	0.03	0.14
M2	0.20	0.79	0.60	0.79
M3	0.29	0.70	0.81	0.81
M4	0.51	0.45	0.14	0.51

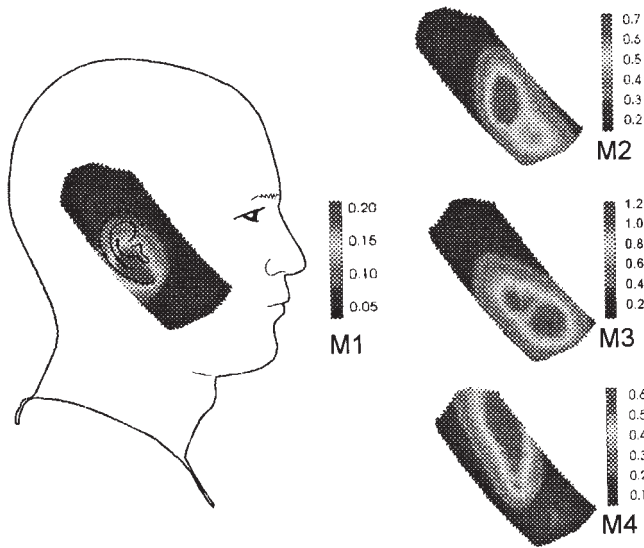


Fig. 2. Schematic drawing of the distribution of Specific Absorption Rate (SAR) (W/kg) for the devices used in the study (M1-M4). The figures show the measured SAR on the right hand side of the phantom.

symptoms between SAR values: >0.5 W/kg and ≤ 0.5 W/kg was larger for long than for short CT (Fig. 3a).

For the warmth sensations (Fig. 3b), e.g., *warmth behind the ear*, *burning face*, and *tingling*, the differences between long and short CT were small or near unity with one exception: for *warmth on the ear* for volume 2 and 3, the ratios between SAR values >0.5 W/kg and ≤ 0.5 W/kg were larger for long CT than for short CT.

Memory loss showed no consistent increase with SAR_{1g} and CT in any of the volumes; and for *fatigue*, the increase in the prevalence of symptoms was small or deficient with no obvious differences between long and short CT (Fig. 3c). For *headaches*, an increase in the prevalence of symptoms was seen for people with long CT compared to those with short CT in volume 1 (above the ear).

Comparison of Mean Values for SAR_{1g} , SAC, and SAD

The quotients $(W-S_{mean}/WO-S_{mean})$ where $W-S_{mean}$ and $WO-S_{mean}$ are the mean values of the SAR_{1g} values in each volume for people with (W-S) and without symptoms (WO-S) are shown in Table 4. The differences between $W-S_{mean}$ and $WO-S_{mean}$ were in general small, but it is interesting to note that in 30 out of 44 comparisons the quotients $(W-S_{mean}/WO-S_{mean})$ are larger than unity. For *discomfort* and *concentration* in volume 3 (below the ear), the corresponding differences were larger than 10%.

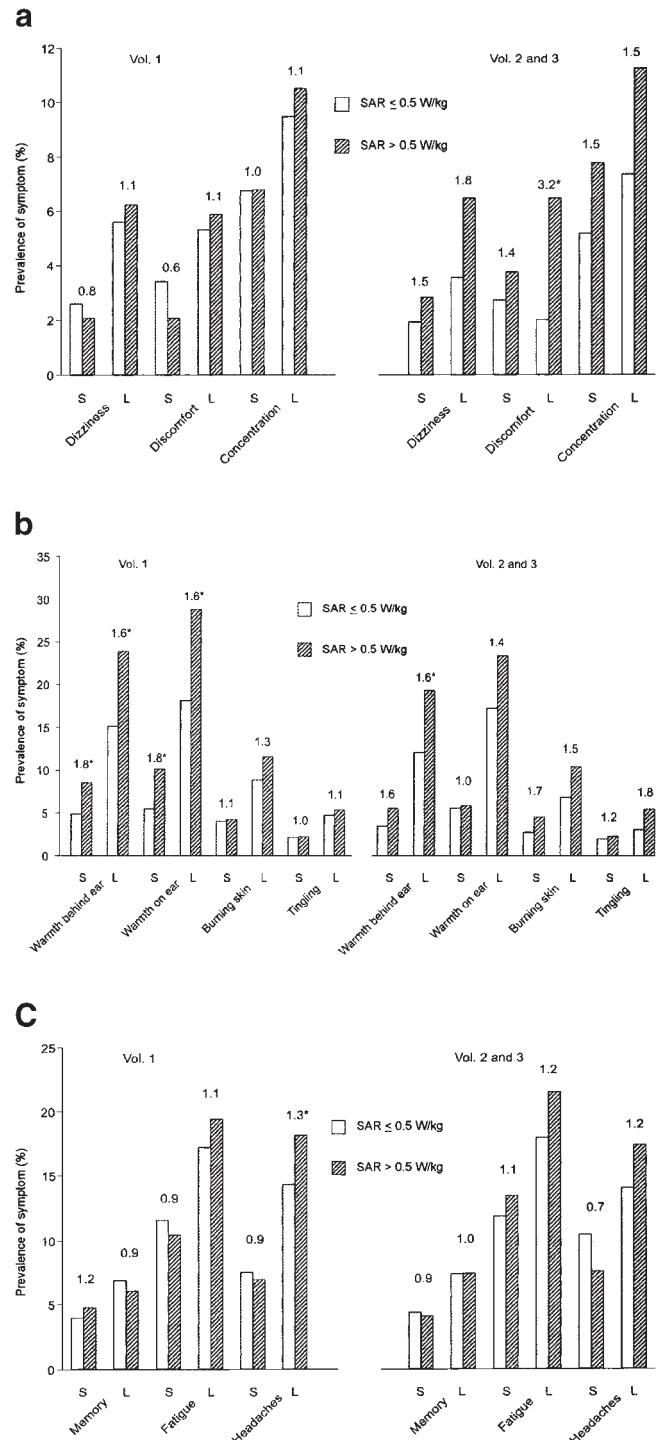


Fig. 3. a-c: Prevalence of various symptoms (%) for people with low (≤ 0.5 W/kg) and high (> 0.5 W/kg) SAR values in volume 1 (above ear), volume 2 (on the ear), and volume 3 (below the ear). The bars are divided into short, S (≤ 15 min/day) and long, L (> 15 min/day) calling time. The ratio of the prevalence of symptoms for the high SAR group and the low SAR group is displayed in the diagram for each symptom. Differences between SAR > 0.5 W/kg and SAR ≤ 0.5 W/kg where $P = 0.05$ are marked with *.

TABLE 4. Calculated Mean Values of SAR_{1g} in the Specified Volume for People Who Experience the Particular Symptom (W–S) and for Those Who Do Not Experience the Symptom (WO–S)

			Vol. 1 (above the ear)		Vol. 2 (on the ear)		Vol. 3 (below the ear)		Any Vol. (max)		
			N	SAR _{1g}	W-S/ WO-S	SAR _{1g}	W-S/ WO-S	SAR _{1g}	W-S/ WO-S	SAR _{1g}	W-S/ WO-S
Dizziness	W-S	88	0.30 (0.05) ^a	1.00	0.67 (0.14)	1.05	0.62 (0.23)	1.03	0.72 (0.16)	1.03	
	WO-S	2101	0.30 (0.06)		0.64 (0.18)		0.60 (0.27)		0.70 (0.20)		
Discomfort	W-S	95	0.31 (0.05)	1.03	0.68 (0.13)	1.06	0.67 (0.23)	1.14	0.75 (0.15)	1.09	
	WO-S	2094	0.30 (0.07)		0.64 (0.18)		0.59 (0.27)		0.69 (0.20)		
Concentration	W-S	180	0.31 (0.05)	1.03	0.67 (0.15)	1.05	0.65 (0.25)	1.10	0.74 (0.17)	1.07	
	WO-S	2009	0.30 (0.07)		0.64 (0.18)		0.59 (0.27)		0.69 (0.20)		
Memory	W-S	119	0.31 (0.06)	1.03	0.64 (0.17)	1.00	0.60 (0.27)	1.00	0.70 (0.20)	1.00	
	WO-S	2070	0.30 (0.06)		0.64 (0.18)		0.60 (0.27)		0.70 (0.20)		
Fatigue	W-S	321	0.30 (0.06)	1.00	0.65 (0.17)	1.02	0.61 (0.27)	1.03	0.71 (0.20)	1.01	
	WO-S	1868	0.30 (0.06)		0.64 (0.18)		0.59 (0.27)		0.70 (0.20)		
Headaches	W-S	240	0.30 (0.06)	1.00	0.64 (0.18)	1.00	0.59 (0.27)	0.98	0.69 (0.20)	0.99	
	WO-S	1949	0.30 (0.06)		0.64 (0.18)		0.60 (0.27)		0.70 (0.20)		
Warmth behind ear	W-S	223	0.31 (0.05)	1.03	0.67 (0.14)	1.05	0.62 (0.24)	1.05	0.72 (0.17)	1.04	
	WO-S	1966	0.30 (0.07)		0.64 (0.18)		0.59 (0.28)		0.69 (0.21)		
Warmth on the ear	W-S	262	0.30 (0.06)	1.00	0.65 (0.16)	1.02	0.60 (0.25)	1.00	0.71 (0.18)	1.01	
	WO-S	1927	0.30 (0.07)		0.64 (0.18)		0.60 (0.28)		0.70 (0.20)		
Burning face	W-S	144	0.30 (0.06)	1.00	0.66 (0.16)	1.03	0.62 (0.25)	1.05	0.71 (0.19)	1.01	
	WO-S	2045	0.30 (0.06)		0.64 (0.18)		0.59 (0.27)		0.70 (0.20)		
Tingling	W-S	74	0.30 (0.06)	1.00	0.66 (0.17)	1.03	0.64 (0.26)	1.08	0.73 (0.20)	1.04	
	WO-S	2115	0.30 (0.06)		0.64 (0.18)		0.59 (0.27)		0.70 (0.20)		
Other	W-S	98	0.30 (0.05)	1.00	0.67 (0.14)	1.05	0.64 (0.24)	1.08	0.73 (0.17)	1.04	
	WO-S	2091	0.30 (0.06)		0.64 (0.18)		0.59 (0.27)		0.70 (0.20)		

^aStandard deviation in parentheses.

The corresponding quotients for CT, NC, SAC, and SAD are presented in Table 5. By comparing the quotients for CT, NC, CC, SAD, and SAC for each symptom, it can be seen that for all symptoms except

from *memory loss*, SAD especially in volume 2 and 3 (on and below the ear), showed the highest quotient, e.g., largest difference in mean value between symptom vs. nonsymptom group.

TABLE 5. The Ratio (W–S)/(WO–S) of the Mean Values of the Exposure Factors (SAC, SAD, CT, NC, and the Mean Calling Time Per Call (CC)) for People Who Experience the Particular Symptom (W–S) Versus Those Who Do Not Experience the Symptom (WO–S)

				SAD				SAC			
				Vol. 1 above the ear	Vol. 2 on the ear	Vol. 3 below the ear	Any Vol. max	Vol. 1 above the ear	Vol. 2 on the ear	Vol. 3 below the ear	Any Vol.
Dizziness	1.43	1.09	1.29	1.49	1.52	1.56	1.53	1.33	1.37	1.40	1.37
Discomfort	1.38	1.07	1.23	1.43	1.49	1.57	1.51	1.25	1.32	1.38	1.32
Concentration	1.13	1.07	1.07	1.15	1.18	1.21	1.18	1.09	1.13	1.18	1.14
Memory	1.29	1.08	1.18	1.30	1.29	1.26	1.28	1.18	1.19	1.17	1.18
Fatigue	1.29	1.09	1.14	1.30	1.32	1.34	1.32	1.14	1.17	1.19	1.17
Headaches	1.41	1.10	1.25	1.39	1.46	1.46	1.45	1.22	1.27	1.27	1.26
Warmth behind ear	1.62	1.17	1.36	1.66	1.70	1.71	1.70	1.38	1.42	1.43	1.42
Warmth on the ear	1.62	1.18	1.34	1.63	1.68	1.67	1.67	1.35	1.39	1.39	1.38
Burning face	1.46	1.10	1.29	1.44	1.51	1.56	1.52	1.28	1.34	1.38	1.34
Tingling	1.39	1.09	1.24	1.37	1.44	1.51	1.45	1.22	1.28	1.34	1.29
Other	1.43	1.09	1.29	1.49	1.52	1.56	1.53	1.33	1.37	1.40	1.37

It is known from our previous study that CT and NC are of importance for the prevalence of most of the symptoms. By comparing the F values from the ANOVA analyses for CT and the F values of the SAC and SAD values (Table 6), which both depend on the difference in the mean values and also of the variances, it was seen that for some of the symptoms (*dizziness*, *discomfort*, *concentration*, and *warmth on/behind the ear*) the SAD might be an interesting parameter for the prevalence of symptoms.

DISCUSSION

Since we only have measured the SAR distribution for one phone of each model and we are generalizing the results for all people in the study, some errors will be introduced. Below, we address the most dominant errors in our analyses.

For the calculated SAR_{1g} value, we estimate a total error of ~40%, which includes differences in output power between devices of the same model, personal handling of the device, power drift during measurements, anatomical differences of the head and ear between different users, and differences between the measurement procedure of the two laboratories used. During a call, the base station regulates the output power of the MP depending on the receiving conditions. It was not possible to take this variation into consideration, but we assume that this error, as well as other dominant errors due to the generalization that the measured SAR is valid for everyone who used that specific device, is randomly distributed, which means that it might mask a possible association between exposure and symptoms.

Sandström et al. [2001] found that confounding factors such as psychosocial workload, occupation, and gender might affect the prevalence of symptoms. We have not been able to adjust for these parameters in the analyses due to the relative small number of cases. The distribution of people in different categories of the confounding factors was, however, rather homogenous between the four GSM devices user groups, which suggests that they should not affect the results significantly. The correlation between CT and NC with prevalence of symptoms which was found in Sandström et al. [2001] could be an effect of absorption of radiofrequency energy but also other time related factors such as lifestyle, stress etc. might be of importance.

In addition to SAR_{1g}, two new exposure parameters, SAC and SAD were introduced. The aim was to evaluate the importance of these parameters when discussing subjective symptoms and MP use and the possible need to include them in further studies.

TABLE 6. Analyses of Variance (F Values) for the Difference in Mean Values of the Exposure Parameters (CT, NC, SAC, SAD, and SAR) for the W-S Group Versus the WO-S Group

SAR and Subjective Symptoms												
		Dizziness	Discomfort	Concentration	Memory	Fatigue	Headaches	Warmth behind ear	Warmth on the ear	Burning face	Tingling	Other
CT		17.2	14.1	2.9 ^a	10.4	24.8	38.5	80.4	89.9	30.2	12.3	2.4 ^a
		5.4	3.2	5.1	4.9	15.8	15.5	43.4	56.3	8.8	3.9	1.2 ^a
	All volumes	18.0	13.9	4.5	6.4	11.6	22.7	53.9	51.8	23.1	7.8	2.1 ^a
	Volume 1	11.9	6.3	1.1 ^a	4.8	4.6	9.8	34.9	32.8	9.9	3.3 ^a	0.0 ^a
SAD	Volume 2	17.4	13.0	4.1	6.7	11.5	23.6	54.0	52.5	22.6	7.0	2.6 ^a
	Volume 3	16.4	15.5	6.2	4.5	11.7	19.4	44.5	41.7	23.4	9.6	2.2 ^a
	All volumes	22.6	20.9	5.1	9.2	25.6	38.4	88.0	92.9	31.4	12.4	4.8
	Volume 1	17.7	13.4	3.1 ^a	8.9	17.9	21.5	69.5	69.3	18.8	6.4	1.0 ^a
SAR	Volume 2	21.9	19.5	4.7	9.4	25.1	39.1	86.9	93.4	30.1	11.6	5.3
	Volume 3	20.9	22.8	5.8	6.4	24.0	34.8	76.1	77.8	32.6	14.5	4.6
	All volumes	1.7 ^a	6.5	7.1	0.1 ^a	0.7 ^a	0.2 ^a	3.8 ^a	0.8 ^a	1.2 ^a	1.6 ^a	2.9 ^a
	Volume 1	0.2 ^a	0.6 ^a	3.0 ^a	1.5 ^a	0.1 ^a	1.2 ^a	1.0 ^a	0.5 ^a	0.6 ^a	0.2 ^a	0.0 ^a
	Volume 2	2.9 ^a	6.1	5.2	0.0 ^a	0.6 ^a	0.0 ^a	6.1	1.8 ^a	2.0 ^a	1.0 ^a	3.7 ^a
	Volume 3	0.9 ^a	6.3	7.2	0.1 ^a	0.9 ^a	0.4 ^a	2.0 ^a	0.2 ^a	1.0 ^a	2.4 ^a	2.6 ^a

All analyses give a *P* value < 0.05 except for those marked with ^a.

This study indicated that SAR might be an important factor when discussing prevalence of subjective symptoms. This was especially true for longer *calling time per day*. For short *calling time per day* (<15 min/day), the ratios between SAR values >0.5 W/kg and ≤0.5 W/kg were closer to unity. This might be an indication of a threshold effect, e.g., the total absorbed energy needs to exceed a certain value before the symptoms occur.

The ratios of the mean values of SAR_{1g} between people with and without symptoms were close to unity (Table 4). The reason might be that SAR_{1g} alone, which defines the rate of energy absorption in 1 g of tissue in the head, is not a good estimate of exposure when discussing subjective symptoms, at least not without also taking the calling time per day into account as well. Worth noting is that for *discomfort* and *concentration*, the differences in mean values of SAR_{1g} reached significance in volumes 2 and 3. This is also true for *warmth behind ear* in volume 2. In the comparison in Table 4, only people with CT > 2 min/day were included. We have also done this comparison for people with CT > 15 min/day; it showed larger differences in the mean values, but with too small groups to give significant differences (not shown).

Due to heating of the electrical components in the MP, the phone gets warm during a call. The temperature increase depends on many factors such as power level, DTX function, and heat conduction conditions [Törnevik et al., 1998; Straume, 2002]. Since the phones used in the study all have SAR values below the present RF exposure guidelines, it is not likely that the feeling of warmth is directly caused by the absorption of RF. One might, therefore, suspect that conductive heating of the phone rather than penetration of RF causes the symptom *warmth on ear*.

On the other hand, RF fields might be able to cause disturbances in blood flow [Hober et al., 2002], which could result in a sensation of warmth. This is especially of interest when discussing the symptom *warmth behind the ear*, which in this study shows a statistically significant association with SAR_{1g} in volume 2 (on the ear). To get warm behind the ear due to conductive heating is less probable. Another possible reason for the lack of difference in mean SAR_{1g} could also be the relatively small range of SAR_{1g} in this study, which implies that potential differences in mean values of SAR_{1g} between people with and without symptoms are difficult to analyze. This is particularly true for volume 1 (above ear), where the differences in SAR between the different devices were small. Also, the maximum SAR_{1g} is smaller in volume 1 than in the two other volumes (0.51 compared to 0.79 and 0.81 W/kg). Perhaps, the total absorbed energy in

volume 1 does not reach the threshold level needed to cause symptoms.

When combining the time spent on the phone with the SAR_{1g} values (SAC and SAD), larger differences appeared between people with and without symptoms. For *dizziness* and *discomfort*, the W–S/VO–S ratio increased ~10% when the SAD value was applied in the volume below the ear compared to the ratio derived from CT. Table 5 also points toward the conclusion that the SAD might be a better estimation of the exposure than the SAC. This suggests that if the radiofrequency field emitted from a MP is of importance for subjective symptoms, it might be of cumulative nature rather than acute.

The differences between the anatomical localization of higher SAR_{1g} values were more difficult to analyze. For some of the symptoms, higher SAR_{1g}, SAC, and SAD in volume 2 (on the ear) and volume 3 (below the ear) seemed to be a better estimate of exposure than in volume 1 (above the ear). But since the maximum SAR in volume 1 was smaller than in volume 2 and 3, it is difficult to draw any conclusions from this. To explore the role of the anatomical localization in further studies, it would be of interest to evaluate the SAR distribution and to choose appropriate sources of exposure.

In recent provocation studies [Koivisto et al., 2001; Hietanen et al., 2002], no associations between RF exposure from mobile phones and subjective symptoms were found. No information was, however, given about SAR distributions. In future provocation studies, it would be useful to set up a clear hypothesis about anatomical localization of the absorption, relevant to the symptom studied; and the SAR in combination with the exposure time would also be interesting to study.

In this study where data from a previous epidemiological study were used to explore the possible role of absorption to RF fields to cause subjective symptoms, two new hypotheses were generated:

- Subjective symptoms, especially dizziness, discomfort, and warmth sensations behind the ear are correlated with high SAR_{1g} values in combination with longer calling time per day.
- SAR_{1g} alone, in the volume on the ear is an explanation for sensation of warmth behind the ear, while conductive heating from the phone causes sensation of warmth on the ear from the phone.

The importance of anatomical localization of high SAR values was more difficult to analyze; but in coming provocation studies, this is an important factor to discuss.

ACKNOWLEDGMENTS

The authors thank Christer Thörnevik and Martin Siegbahn at Ericsson Radio System AB and Anssi Toropainen and Petri Sinisalo at Nokia Research Center for excellent help with measurements of the phones. Thanks also to Anita Stenudd and André Berglund for great help with preparation of figures. We also wish to express our gratitude to Gunnhild Oftedal for careful reading and giving valuable comments to the paper.

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