Mobile phone use and subjective symptoms. Comparison of symptoms experienced by users of analogue and digital mobile phones

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In 1995 many people reported symptoms such as headaches, feelings of discomfort, warmth behind/around or on the ear and difficulties concentrating while using mobile phones. The number of complaints was higher for people using the digital (GSM) system, i.e. with pulse modulated fields, than for those using the analogue (NMT) system. Our main hypothesis was that GSM users experience more symptoms than NMT users. An epidemiological investigation was initiated including 6379 GSM users and 5613 NMT 900 users in Sweden, and 2500 from each category in Norway. The adjusted odds ratio did not indicate any increased risk for symptoms for GSM users compared with NMT 900 users. Our hypothesis was therefore disproved. However, we observed a statistically significant lower risk for sensations of warmth on the ear for GSM users compared with NMT 900 users. The same trend was seen in Norway for sensations of warmth behind/around the ear and in Sweden for headaches and fatigue. Factors distinguishing the two systems (radio frequency emission, phone temperatures and various ergonomic factors) may be responsible for these results, as well as for a secondary finding: a statistically significant association between calling time/number of calls per day and the prevalence of warmth behind/around or on the ear, headaches and fatigue.

Key words: Cellular phone; fatigue; GSM; headaches; NMT; questionnaire; radio frequency field; sensation of warmth.

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Introduction

During the mid-1990s, many people experienced symptoms while using mobile phones (MPs), both in Sweden and Norway, so they contacted manufacturers, net operators or researchers working with electromagnetic fields. The majority of the callers were using the new digital system (GSM; global system of mobile communication); they had recently changed from an analogue [Nordic Mobile Telephone (NMT)] to a digital phone and their symptoms appeared only when using the digital phone. Some of the callers were new subscribers. The symptoms reported were, for example, headaches, feelings of discomfort, warmth behind/around or on the ear and difficulties concentrating. Similar symptoms were also reported from other countries at this time [1]. It is also known that people exposed to low-level radio frequency fields or microwaves at work have complained of heavy feelings in the head, headaches, fatigue, poor memory,

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etc. more often than controls [2–4]. It was noted by Cohen and White (quoted in WHO, 1993) [4] that the onset of symptoms in predisposed individuals was usually precipitated or made worse by emotion-provoking circumstances or medical illness.

In the scientific literature on biological effects of weak microwaves, there is a tendency for lower thresholds of reported biological effects caused by exposure to modulated fields [5]. Since the number of people reporting symptoms in connection with MP calls was not negligible, it was considered of interest to start an epidemiological study with the main hypothesis being that GSM users (exposed to fields with pulse modulation) experience more symptoms than NMT users. In the Nordic countries, at the time of the investigation, there were two analogue systems available, NMT 450 and NMT 900, which operate at 450 and 900 MHz, respectively. Since the digital phone at that time operated mainly at 900 MHz, we only included the NMT 900 users in the analyses, hereafter referred to as NMT, to be compared with GSM users. Besides the fact that the radio frequency fields from the GSM phones are pulsed whereas those from the NMT phones are continuous, the electromagnetic fields from the selected systems also vary with regard to intensity and low-frequency magnetic fields.

The output power of the phone is regulated through the base station: for NMTs in two levels, 0.1 or 1 W, and for GSM in 10 steps from 2 W down to 20 mW; the closer to the station, the lower the output power. For technical details of the analogue and digital systems, see McKinlay *et al.* [6] and Bach Andersen and Pedersen [7]. Comparing the NMT and GSM phones with respect to output power, the GSMs operate at a much lower level than the NMTs. The most commonly occurring situation would presumably be for the GSM phone to operate in the low milliwatts region whereas the NMT phone would use full output power, at 1 W.

The amount of microwave energy absorbed by the user is described by the specific absorption rate (SAR; given in W/kg). Recently, Kuster [8] measured 16 different European digital phones. The SAR values varied from the lowest at 0.3 W/kg to the highest at ~1.3 W/kg; all normalized to a standard output of 0.25 W. The antenna systems used are similar for the two transmitter systems, and there is no reason to believe that the way of handling the phones differs between the two systems. The actual SAR values should, therefore, generally be higher for the NMT than for the GSM phones.

The current from the battery also gives rise to a magnetic field near the phone. For GSM phones, magnetic flux densities of a few microtesla near the phone have been measured [9,10]. The fields are pulsed DC fields, with a frequency of 217 Hz. For the NMT phones, the magnetic field from the battery current is regarded as a pure DC field.

The media have focused on possible health effects caused by microwaves emitted by MPs. It is possible that fear or awareness might cause MP users to report more symptoms than people not using MPs even if the prevalence of symptoms were equal. We would be unable to estimate the impact of such a bias, and a comparison between users and non-users of MPs would therefore be difficult to interpret. Furthermore, since the number of subscribers in the Scandinavian countries is rather high, it would also be difficult to find a control group with similar work situation and not using an MP. Hence, the study population consisted of MP users only, and the transmitter system, the number of calls per day and the calling time per day were used as estimates of exposure.

Materials and methods

The design was a cross-sectional, epidemiological study of GSM and NMT 900 users and was based on a questionnaire among registered MP users.

In both countries, only one net operator supports both NMT and GSM transmission systems, and their registers were therefore used in the study. To include people with both low and high levels of MP use, we used the company register, i.e. where a company is the subscriber but an individual is assigned a phone. Thus, the study was limited to company subscribers only. In Sweden, people from the whole country were included, but in Norway the selection was limited to the southern part of the country, because the GSM system was available only there. Only people with an active subscription were included. Those having a phone with a secret number or a phone which was closed to advertisements were not available to us.

Finally, a random selection of subscribers, i.e. named users, was made, consisting of 6379 GSM and 5613 NMT users in Sweden, and 2500 for each category in Norway. The questionnaires were mailed in October–November 1996, and a reminder was sent out 1 month later. Further details can be found in the technical report [11].

The questionnaire

To be able to include the best description of subjective disorders, we contacted 10 people among those who had called us individually and asked them to participate in a medical interview. These interviews and knowledge from the literature on low-level radio frequency field effects [2,3], as well as our own experience from earlier studies of similar phenomena [12–14], formed the base for the symptom questions. These could be divided into three groups: neurasthenic, warm sensation and facial skin symptoms. An individual was defined as having a symptom if he/she had reported that the symptom occurred at least once a week during the last year regardless of their

attribution to the use of any devices. It is of importance to stress that 'symptoms' in this paper refer to self-reported symptoms and there has been no medical examination of the people in the study.

Based on previous experiences, questions about confounding factors such as age, gender, geographical location of workplace, amount of video display terminal (VDT) work, occupation and psychosocial factors were also included [12,15–17].

A pilot study involving 160 people selected from the registers tested the questionnaire during spring 1996 before the final mailing was sent out.

A psychosocial index was created based on four commonly used questions about workload, influence on work conditions, support from colleagues, and whether the work was stimulating and interesting. Each question was given a score, and the index was the sum of 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 work load. For further details, see Oftedal *et al.* [18].

The Swedish Job Classification System (AMSYK) [19] was used in order to classify different occupations into four categories: management—leading position in companies or public administration and 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.

The questionnaire contained three different exposure parameters: transmitter system, calling time per day and number of calls per day. For further details, see Hansson Mild *et al.* [11].

In Scandinavia, it is difficult to use billing records to estimate the exposure since they only include outgoing calls and not incoming ones. Since these phones were company registered phones, many people may have used the same phone; therefore, the billing record will not reflect the correct calling time of a specific individual.

The questionnaire was divided into two parts: the first to be filled in by all participants, the second only by those who experienced symptoms connected to phone use. We have published data from the second part of the questionnaire in a previous paper [18]. Only the first part of the questionnaire is included here.

Non-respondent analysis

After collection of the questionnaires, ~10% of the non-respondents in each country were randomly selected for a non-respondent analysis. The subjects were interviewed by telephone, using a questionnaire made for this purpose. Questions about reasons for no response, transmitter system used and whether symptoms had been experienced in connection with MP use were included.

In addition, because of a relative low response rate in Norway, we compared the distribution of non-respondents and respondents for various potential risk factors (transmitter system, gender, trade, geographical location). For this purpose we used information available from the subscription database provided by the Norwegian MP operator. All of these risk factors were distributed almost identically for both non-respondents and respondents.

Statistics

Multivariate logistic regression in the SPSS package (Forward Wald) was used to estimate the relative risk for the different symptoms with respect to the exposure parameters, e.g. transmitter system, calling time per day and number of calls per day. Monotonically increasing trends with respect to calling time per day and number of calls per day and the adjusted odds ratio (OR) of the symptom variables were tested using linear and quadratic regressions. A result was considered to be statistically significant when the significance probability was 5% or less.

Results

Out of the distributed questionnaires—5000 in Norway and 11 990 in Sweden—some were returned directly because of an unknown address (148 in Norway and 154 in Sweden). The number of answered questionnaires was 2828 in Norway and 7803 in Sweden. Taking the returned questionnaires into account, the response rates were 58% for Norway and 66% for Sweden. The non-respondent analysis indicated that in Norway 21% and in Sweden 43% of those who did not respond had not received the questionnaire. Subtracting the estimated total number of those who did not receive the questionnaire from the number that were selected for the study gives an estimated 'adjusted' response rate of 64% for Norway and 76% for Sweden. The response rates were almost equal for the GSM subscribers and the NMT subscribers.

As our aim was to compare experienced symptoms between GSM and NMT users, we selected those with only one MP, either GSM or NMT, from the total cohort. In Sweden, 4520 out of a total of 7803 (65%) were selected. In Norway, the corresponding figures were 1872 of 2828 people (66%).

The distribution of people in different categories of individual and work-related factors of interest, as well as factors related to MP use, is given in Table 1. The results are given for each category of transmitter system in Sweden and Norway. The distribution of users according

Table 1. Distribution of respondents for different factors as a percentage of the total number of NMT and GSM respondents, respectively

Factor	*Category*	*Norway (%)*		*Sweden (%)*	
		NMT	*GSM*	*NMT*	*GSM*
Age (years)	<30	11	9.8	5.6	5.9
	30–39	36	40	22	25
	40–49	31	30	35	34
	≥50	20	18	37	34
	Missing	1.4	1.8	0.6	0.7
Occupation	Management	21	29	26	26
	Professional	17	22	16	19
	Intermediate	36	27	34	32
	Other	17	10	16	14
	Missing	9.4	11	8.8	9.4
Psychosocial workload	Low	38	34	40	36
	Medium	44	46	42	46
	High	16	19	15	15
	Missing	1.9	0.9	2.5	2.9
VDT work (h/day)	No VDT work	24	13	23	20
	<1	22	14	11	20
	1–4	41	48	41	46
	>4	11	22	23	13
	Missing	2.9	2.1	1.6	1.7
Geography	Larger cities	48	60	11	23
	Southern Sw./No.	52	40	48	65
	Northern Sw.	–	–	40	12
	Missing	0.0	0.0	0.2	0.2
No. of calls per day	<2	11	15	22	24
	2–4	27	34	33	35
	>4	61	51	44	40
	Missing	0.4	0.1	0.3	0.4
Calling time (min) per day	<2	6.9	7.6	16	16
	2–15	47	53	56	56
	15–60	38	35	25	26
	>60	7.4	4.4	2.6	2.9
	Missing	0.4	0.0	0.3	0.4
Total no.		876	996	1902	2618

The data are stratified for transmitter system.

to gender was 90% male and 10% female in Norway, and 86 and 14%, respectively, in Sweden.

The respondents also evaluated their state of health. The relative number of respondents who estimated that their state of health was good was higher among the Norwegian respondents (83%) than among the Swedish respondents (71%). Less than 1% of the Norwegian respondents estimated that their state of health was not so good. The corresponding figure in the Swedish data was 2%. There were only small differences in the self-reported state of health between GSM users and NMT users in both countries.

The prevalence of symptoms for various categories of individual and work-related factors is given in Hansson Mild *et al.* [11], so only a brief summary is given here. Young age and female gender were both related to a higher prevalence of most of the symptoms. Psychosocial workload seems, at least for males, to be of importance, and occupation and VDT work also appear to influence the prevalence of symptoms.

The total prevalence of each symptom in Sweden and Norway is shown in Table 2. In general, a higher prevalence of reported symptoms was found among the Norwegian respondents as compared with the Swedish respondents. Furthermore, when comparing the different symptoms within the countries, fatigue seemed to be the most dominant symptom in Sweden, while warmth on and around/behind the ear was the most dominant in Norway. Four per cent in Norway and 5% in Sweden reported other symptoms, and among these eye, ear and neck problems were most often specified. In Sweden, facial skin problems were also quite commonly specified.

Crude and adjusted ORs for GSM users with NMT users as references (OR = 1) are also given in Table 2. For most symptoms, there was no statistically significant difference between the different transmitter systems with

Table 2. The percentage of the total prevalence (both NMT and GSM users) of symptoms experienced weekly for the Norwegian and the Swedish respondents, respectively

Symptoms	*Prevalence of symptom (%)*		*OR*		
	Norway	*Sweden*		*Norway*	*Sweden*
Dizziness	7.0	2.8	C	1.03 (0.72–1.47)	0.97 (0.68–1.38)
			A	1.06 (0.74–1.53)	0.91 (0.63–1.32)
Discomfort	4.6	3.0	C	1.01 (0.65–1.56)	1.40 (0.98–2.01)
			A	0.97 (0.60–1.55)	1.35 (0.93–1.95)
Concentration	8.4	6.9	C	1.30 (0.94–1.82)	0.91 (0.72–1.14)
			A	1.33 (0.94–1.88)	1.02 (0.77–1.35)
Memory loss	5.1	4.3	C	1.04 (0.69–1.57)	0.92 (0.69–1.22)
			A	1.04 (0.69–1.57)	0.91 (0.68–1.23)
Fatigue	17	11	C	1.03 (0.81–1.31)	0.87 (0.72–1.04)
			A	1.04 (0.81–1.34)	**0.80 (0.65–0.99)**
Headaches	13	8.4	C	0.88 (0.67–1.15)	0.84 (0.68–1.04)
			A	0.86 (0.64–1.16)	**0.74 (0.59–0.93)**
Warmth behind ear	22	5.3	C	**0.64 (0.51–0.80)**	**0.73 (0.56–0.95)**
			A	**0.69 (0.54–0.87)**	0.80 (0.59–1.07)
Warmth on ear	25	6.0	C	**0.65 (0.52–0.80)**	**0.66 (0.52–0.85)**
			A	**0.68 (0.53–0.86)**	**0.56 (0.43–0.73)**
Burning skin	9.1	4.3	C	0.73 (0.53–1.00)	1.00 (0.75–1.35)
			A	0.81 (0.58–1.12)	0.94 (0.67–1.32)
Tingling/tightness	4.3	2.6	C	0.83 (0.53–1.30)	0.93 (0.65–1.35)
			A	0.88 (0.54–1.42)	0.76 (0.52–1.10)
Other	4.0	3.3	C	0.85 (0.54–1.35)	1.01 (0.72–1.40)
			A	0.81 (0.51–1.29)	0.95 (0.67–1.35)

C, crude and A, adjusted ORs. In parentheses are given the 95% confidence intervals for different symptoms among users of GSM phones, with users of NMT as reference category.

Bold type indicates significance at $P < 0.05$.

regard to the prevalence of symptoms. Thus, the hypothesis originally postulated, that GSM users have a higher prevalence of symptoms than NMT users, was disproved by the study. However, in both Norway and Sweden, our findings show a statistically significant lower risk for sensations of warmth on the ear for GSM users compared with NMT users. The same trend was also seen for sensations of warmth behind/around the ear in the Norwegian data, and for headaches and fatigue in the Swedish data.

As a secondary finding, we observed pronounced positive trends for both GSM and NMT users with respect to both calling time and number of calls per day for the sensation of warmth variables and for some of the neurasthenic symptoms (see Tables 3 and 4). Among the neurasthenic symptoms, headaches and fatigue show the most consistent association.

Discussion

The hypothesis originally postulated, that GSM users had a higher prevalence of symptoms than NMT users, was nullified by the study. In fact, for some symptoms, the results came out opposite to the hypothesis, i.e. fewer GSM users than NMT users experienced the phenomena of sensations of warmth behind/around and on the ear.

An interesting incidental finding was however observed: there was a positive trend with respect to the exposure variables calling time and number of calls per day for the sensation of warmth variables and for some of the neurasthenic symptoms. One has to take into account that the trend tests are carried out on independent exposure variables (calling time and number of calls) with only three or four categories. The midpoint of each category has been used in the regression analyses. The highest category for each of these variables is open ended, and for these categories the midpoint is not well defined. Furthermore, despite the fact that the analyses suggest a positive statistical correlation for some symptoms, a causal relationship and potential reasons for such a relationship remain to be revealed. These findings are, however, of special interest to follow-up. Emission properties, design of the phone and other factors related to the use of MPs might have been responsible for the observed results concerning the GSM users versus the NMT users and the positive trends. The roles of the different factors, as well as the possible influence of

Table 3A. Crude (C) and adjusted (A) ORs and in parentheses 95% confidence intervals for symptoms experienced weekly with respect to calling time (the reference category is calling time <2 min/day) by MP users in Norway

			NMT				*GSM*			
	Type of OR	*<2 min/day (n = 137)*	*2–15 min/day (n = 416)*	*15–60 min/day (n = 331)*	*>60 min/day (n = 65)*	*Test for trend*	*2–15 min/day (n = 526)*	*15–60 min/day (n = 350)*	*>60 min/day (n = 44)*	*Test for trend*
Dizziness	C	1.0	2.46 (0.72–8.33)	**3.47 (1.03–11.7)**	**12.1 (3.33–43.8)**		2.47 (0.74–8.25)	**3.97 (1.19–13.3)**	**12.9 (3.37–49.6)**	
	A	1.0	2.55 (0.75–8.69)	**3.47 (1.03–11.8)**	**11.9 (3.27–43.4)**	a,b	2.45 (0.73–8.20)	**3.74 (1.11–12.5)**	**11.8 (3.08–45.6)**	a,b
Discomfort	C	1.0	0.91 (0.32–2.56)	1.33 (0.48–3.72)	**4.18 (1.34–13.0)**		1.24 (0.47–3.32)	1.08 (0.38–3.07)	2.60 (0.67–10.1)	
	A	1.0	0.86 (0.30–2.50)	1.07 (0.36–3.11)	**4.78 (1.47–15.6)**	a,b	0.95 (0.34–2.61)	0.92 (0.32–2.68)	2.47 (0.61–9.91)	b
Concentration	C	1.0	0.89 (0.39–2.04)	1.60 (0.71–3.58)	2.55 (0.94–6.95)		1.45 (0.67–3.15)	1.99 (0.90–4.38)	2.03 (0.63–6.58)	
	A	1.0	0.86 (0.37–2.00)	1.66 (0.73–3.75)	2.70 (0.98–7.46)	a,b	1.48 (0.68–3.24)	1.91 (0.86–4.23)	2.09 (0.64–6.81)	
Memory loss	C	1.0	1.24 (0.46–3.40)	1.42 (0.51–3.93)	2.64 (0.78–9.01)		1.30 (0.49–3.45)	1.66 (0.61–4.49)	1.90 (0.44–8.31)	
	A	1.0	1.24 (0.46–3.40)	1.42 (0.51–3.93)	2.64 (0.78–9.01)	a,b	1.30 (0.49–3.45)	1.66 (0.61–4.49)	1.90 (0.44–8.31)	
Fatigue	C	1.0	1.10 (0.62–1.97)	**1.78 (1.00–3.17)**	**2.46 (1.16–5.21)**		1.15 (0.66–2.03)	1.67 (0.94–2.97)	**4.37 (1.98–9.65)**	
	A	1.0	1.14 (0.64–2.05)	1.76 (0.99–3.15)	**2.59 (1.22–5.52)**	a	1.13 (0.64–2.00)	1.67 (0.94–2.98)	**4.16 (1.87–9.24)**	a,b
Headaches	C	1.0	1.94 (0.85–4.44)	**4.09 (1.82–9.19)**	**6.99 (2.75–17.8)**		2.18 (0.97–4.89)	**3.19 (1.41–7.20)**	**7.66 (2.82–20.8)**	
	A	1.0	1.87 (0.81–4.32)	**3.35 (1.47–7.62)**	**6.52 (2.52–16.8)**	a,b	2.10 (0.93–4.75)	**2.70 (1.18–6.17)**	**6.84 (2.44–19.1)**	a,b
Warmth behind ear	C	1.0	**3.18 (1.55–6.53)**	**6.23 (3.04–12.7)**	**22.4 (9.66–51.9)**		**2.08 (1.01–4.28)**	**4.21 (2.05–8.66)**	**20.2 (8.18–50.0)**	
	A	1.0	**2.92 (1.42–6.03)**	**5.29 (2.57–10.9)**	**20.8 (8.91–48.8)**	a,b	1.93 (0.93–3.99)	**3.51 (1.70–7.25)**	**15.6 (6.21–39.3)**	a
Warmth on ear	C	1.0	**3.11 (1.61–6.02)**	**6.59 (3.42–12.7)**	**14.9 (6.77–32.8)**		1.85 (0.95–3.58)	**5.03 (2.61–9.70)**	**9.39 (3.99–22.1)**	
	A	1.0	**2.86 (1.42–5.75)**	**5.45 (2.71–11.0)**	**13.1 (5.67–30.1)**	a,b	1.66 (0.82–3.36)	**3.91 (1.94–7.87)**	**8.21 (3.24–20.8)**	a,b
Burning skin	C	1.0	1.83 (0.62–5.40)	**5.34 (1.88–15.2)**	**14.6 (4.72–44.9)**		1.77 (0.61–5.15)	**4.11 (1.44–11.7)**	**10.9 (3.27–36.5)**	
	A	1.0	1.80 (0.61–5.36)	**4.88 (1.70–14.0)**	**13.8 (4.43–43.0)**	a,b	1.78 (0.61–5.21)	**3.86 (1.34–11.2)**	**9.21 (2.68–31.7**)	a,b
Tingling/ tightness	C	1.0	1.76 (0.50–6.13)	2.55 (0.74–8.81)	**5.31 (1.33–21.2)**		1.03 (0.29–3.69)	2.81 (0.82–9.56)	3.22 (0.63–16.6)	
	A	1.0	1.50 (0.42–5.38)	2.61 (0.74–9.15)	**4.96 (1.18–20.9)**	a,b	0.86 (0.23–3.18)	2.65 (0.77–9.16)	3.62 (0.69–18.9)	
Other	C	1.0	0.75 (0.28–1.99)	1.10 (0.42–2.88)	2.19 (0.68–7.06)		0.72 (0.28–1.86)	0.96 (0.37–2.54)	0.50 (0.06–4.27)	
	A	1.0	0.80 (0.30–2.13)	1.12 (0.43–2.95)	2.31 (0.71–7.52)	a,b	0.72 (0.28–1.88)	0.95 (0.36–2.51)	0.45 (0.05–3.89)	

n, the number of people within each category. Significant ($P < 0.05$) positive trends are marked with a (linear) and b (quadratic).

Bold type indicates significance at $P < 0.05$.

Table 3B. Crude (C) and adjusted (A) ORs and in parentheses 95% confidence intervals for symptoms experienced weekly with respect to calling time (the reference category is calling time <2 min/day) by MP users in Sweden

			NMT				*GSM*			
	Type of OR	*<2 min/day (n = 712)*	*2–15 min/day (n = 1074)*	*15–60 min/day (n = 468)*	*>60 min/day (n = 49)*	*Test for trend*	*2–15 min/day (n = 1455)*	*15–60 min/day (n = 671)*	*>60 min/day (n = 75)*	*Test for trend*
Dizziness	C	1.0	1.05 (0.57–1.95)	1.45 (0.72–2.89)	1.74 (0.39–7.75)		1.04 (0.58–1.86)	1.58 (0.85–2.96)	1.70 (0.49–5.95)	
	A	1.0	1.06 (0.56–1.99)	1.37 (0.67–2.81)	1.52 (0.34–6.87)		0.96 (0.52–1.76)	1.50 (0.79–2.86)	1.54 (0.44–5.46)	
Discomfort	C	1.0	1.24 (0.64–2.38)	1.42 (0.66–3.05)	2.12 (0.47–9.60)		1.48 (0.80–2.73)	**2.66 (1.41–5.00)**	2.07 (0.58–7.39)	
	A	1.0	1.22 (0.63–2.35)	1.25 (0.57–2.72)	1.73 (0.38–7.89)	a,b	1.34 (0.72–2.49)	**2.39 (1.27–4.53)**	1.75 (0.49–6.27)	
Concentration	C	1.0	1.19 (0.78–1.81)	**2.15 (1.37–3.36)**	2.13 (0.80–5.71)		1.19 (0.80–1.78)	**2.01 (1.32–3.07)**	1.93 (0.83–4.51)	
	A	1.0	1.08 (0.67–1.73)	**2.11 (1.28–3.48)**	1.34 (0.44–4.07)		1.31 (0.83–2.05)	**2.02 (1.26–3.25)**	1.54 (0.60–3.93)	
Memory loss	C	1.0	1.15 (0.69–1.89)	1.49 (0.84–2.63)	1.79 (0.52–6.16)		1.10 (0.68–1.78)	**1.70 (1.01–2.83)**	1.15 (0.34–3.89)	
	A	1.0	1.28 (0.76–2.16)	1.72 (0.95–3.12)	1.84 (0.53–6.42)		1.19 (0.72–1.98)	**1.82 (1.06–3.14)**	1.27 (0.37–4.39)	
Fatigue	C	1.0	1.30 (0.94–1.81)	**2.18 (1.52–3.13)**	**2.84 (1.35–5.97)**		1.25 (0.91–1.72)	**1.80 (1.28–2.54)**	1.51 (0.72–3.18)	
	A	1.0	**1.47 (1.01–2.14)**	**2.43 (1.61–3.68)**	**2.60 (1.17–5.81)**		1.33 (0.93–1.91)	**1.88 (1.27–2.78)**	1.32 (0.58–2.97)	
Headaches	C	1.0	1.46 (0.99–2.17)	**2.63 (1.73–4.00)**	**2.87 (1.21–6.81)**		1.27 (0.87–1.86)	**2.14 (1.43–3.20)**	**2.96 (1.45–6.07)**	
	A	1.0	**1.88 (1.24–2.85)**	**3.47 (2.22–5.43)**	**3.61 (1.49–8.76)**		**1.49 (1.00–2.24)**	**2.56 (1.66–3.93)**	**2.63 (1.22–5.67)**	
Warmth behind ear	C	1.0	**4.30 (1.93–9.60)**	**13.7 (6.18–30.3)**	**36.4 (13.7–96.7)**		**2.70 (1.20–6.08)**	**10.6 (4.83–23.3)**	**29.5 (11.8–74.1)**	
	A	1.0	**4.30 (1.81–10.2)**	**12.7 (5.38–29.8)**	**32.2 (11.4–90.9)**	a,b	**3.04 (1.27–7.27)**	**10.9 (4.66–25.5)**	**26.9 (10.0–72.2)**	a,b
Warmth on ear	C	1.0	**4.93 (2.34–10.4)**	**13.4 (6.37–28.3)**	**42.7 (17.0–107)**		**2.42 (1.13–5.21)**	**10.1 (4.81–21.1)**	**27.8 (11.6–66.7)**	
	A	1.0	**6.14 (2.77–13.6)**	**16.7 (7.50–37.1)**	**58.8 (22.2–155)**	a,b	**2.77 (1.23–6.25)**	**11.1 (5.02–24.5)**	**26.4 (10.3–66.9)**	a,b
Burning skin	C	1.0	0.81 (0.48–1.37)	**1.81 (1.05–3.10)**	**3.68 (1.44–9.42)**		0.84 (0.52–1.38)	**1.90 (1.16–3.11)**	**3.60 (1.62–8.00)**	
	A	1.0	1.02 (0.59–1.78)	**2.01 (1.13–3.57)**	**4.05 (1.53–10.7)**	a,b	0.85 (0.51–1.44)	**1.85 (1.10–3.12)**	2.43 (0.99–5.97)	
Tingling/ tightness	C	1.0	0.72 (0.39–1.34)	1.22 (0.63–2.39)	0.72 (0.09–5.49)		0.73 (0.41–1.29)	1.39 (0.77–2.52)	1.95 (0.65–5.86)	
	A	1.0	0.92 (0.49–1.71)	1.64 (0.83–3.24)	1.03 (0.13–7.91)		0.77 (0.43–1.38)	1.55 (0.85–2.83)	1.34 (0.39–4.68)	
Other	C	1.0	1.47 (0.79–2.73)	**2.07 (1.05–4.09)**	0.97 (0.13–7.48)		1.31 (0.72–2.39)	**2.40 (1.29–4.46)**	2.62 (0.85–8.09)	
	A	1.0	1.43 (0.76–2.70)	2.18 (1.10–4.33)	0.88 (0.11–6.87)		1.25 (0.69–2.30)	**2.08 (1.11–3.90)**	2.19 (0.70–6.86)	

See Table 3A for definitions.

Table 4A. Crude (C) and adjusted (A) ORs and in parentheses 95% confidence intervals for symptoms experienced weekly with respect to calling time (the reference category is <2 calls/day) by MP users in Norway

			NMT			*GSM*		
	Type of OR	*<2 calls/day (n = 248)*	*2–4 calls/day (n = 239)*	*>4 calls/day (n = 534)*	*Test for trend*	*2–4 calls/day (n =340))*	*>4 calls/day (n =507*	*Test for trend*
Dizziness	C	1.0	1.49 (0.56–3.98)	**3.31 (1.47–7.43)**		2.36 (0.99–5.62)	**3.24 (1.44–7.31)**	
	A	1.0	1.49 (0.55–3.99)	**3.11 (1.38–7.04)**		2.26 (0.95–5.40)	**2.85 (1.25–6.48**)	b
Discomfort	C	1.0	1.03 (0.33–3.24)	**2.56 (1.06–6.20)**		**2.63 (1.05–6.62)**	1.73 (0.69–4.34)	
	A	1.0	1.00 (0.31–3.19)	2.29 (0.91–5.79)		2.32 (0.90–6.00)	1.52 (0.58–3.95)	
Concentration	C	1.0	1.40 (0.65–3.02)	1.76 (0.91–3.38)		1.88 (0.94–3.76)	**2.37 (1.24–4.51)**	
	A	1.0	1.25 (0.57–2.78)	1.79 (0.91–3.51)		1.84 (0.92–3.69)	**2.28 (1.19–4.38)**	
Memory loss	C	1.0	1.14 (0.47–2.73)	1.41 (0.68–2.93)		1.32 (0.60–2.91)	1.33 (0.63–2.79)	
	A	1.0	1.14 (0.47–2.73)	1.41 (0.68–2.93)		1.32 (0.60–2.91)	1.33 (0.63–2.79)	a
Fatigue	C	1.0	1.32 (0.75–2.31)	**2.25 (1.42–3.58)**		**1.67 (1.01–2.77)**	**2.12 (1.33–3.38**)	
	A	1.0	1.45 (0.83–2.56)	**2.47 (1.54–3.96)**		**1.76 (1.05–2.94)**	**2.27 (1.41–3.65)**	b
Headaches	C	1.0	**2.07 (1.01–4.27)**	**4.18 (2.25–7.77)**		**2.23 (1.14–4.40)**	**3.76 (2.01–7.02)**	
	A	1.0	1.93 (0.93–4.04)	**4.21 (2.22–7.99)**		**2.07 (1.04–4.10)**	**3.23 (1.70–6.11)**	b
Warmth behind ear	C	1.0	**2.85 (1.61–5.02)**	**5.47 (3.31–9.04)**		1.55 (0.87–2.75)	**4.16 (2.50–6.92)**	
	A	1.0	**2.41 (1.32–4.40)**	**4.73 (2.78–8.03)**	b	1.39 (0.76–2.54)	**3.43 (2.01–5.85)**	a
Warmth on ear	C	1.0	**3.22 (1.86–5.58)**	**6.23 (3.81–10.2)**		**1.95 (1.13–3.37)**	**4.07 (2.87–7.72**)	
	A	1.0	**3.17 (1.76–5.69)**	**5.71 (3.37–9.67)**	b	**1.81 (1.01–3.25)**	**4.22 (2.48–7.19)**	a
Burning skin	C	1.0	1.03 (0.42–2.52)	**3.93 (2.00–7.75)**		1.32 (0.60–2.91)	**2.87 (1.44–5.74)**	
	A	1.0	1.06 (0.43–2.62)	**3.96 (1.98–7.94)**	b	1.38 (0.62–3.08)	**2.90 (1.43–5.89)**	
Tingling/tightness	C	1.0	1.67 (0.54–5.17)	**3.08 (1.19–8.00)**		1.31 (0.43–3.95)	2.60 (0.99–6.86)	
	A	1.0	1.14 (0.32–4.01)	**3.38 (1.27–8.99)**		1.21 (0.39–3.78)	2.66 (0.99–7.16)	
Other	C	1.0	1.67 (0.54–5.17)	2.57 (0.98–6.76)		1.91 (0.67–5.44)	2.08 (0.78–5.58)	
	A	1.0	1.79 (0.57–5.55)	**2.74 (1.04–7.23)**		1.94 (0.68–5.53)	2.10 (0.78–5.65)	a

See Table 3A for definitions.

methodological defectiveness and problems, will be discussed below.

Potential explanatory factors

The ability of microwaves to cause a warm skin sensation has been known for decades, but only recently has this been measured under standardized laboratory conditions [20]. The threshold for detection decreases monotonically with frequency, and at the lowest tested frequency, 2.45 GHz, the threshold is 630 W/m^2. Extrapolating the data to 900 MHz, the threshold would be in the order of 1000 W/m^2, making it less likely to obtain any radio frequency heating sensations from MPs with the output powers used.

Current exposure standards refer to the maximal SAR value, independent of the anatomical location for this value. More investigations are needed to define the most important anatomical locations for the effect of microwave exposure. When considering the microwave dosimetry, the mechanisms underlying the symptoms experienced should also be taken into account.

The fact that the prevalence of symptoms among the GSM users was not higher than among the NMT users in this study might indicate that the specific features of GSM phones, the pulse modulation of the radio frequency fields and the low-frequency magnetic fields, have no effect on symptom occurrence. Alternatively, a potential effect could have been masked by potentially more dominating factors such as differences in microwave intensity, phone heating, ergonomic factors, etc. Therefore, the role of pulse modulation and the low-frequency magnetic fields cannot be revealed by this study. Whether the absorbed microwaves have any implication for the observed side findings has to be investigated in future studies.

Table 4B. Crude (C) and adjusted (A) ORs and in parentheses 95% confidence intervals for symptoms experienced weekly with respect to calling time (the reference category is <2 calls/day) by MP users in Sweden

			NMT			*GSM*		
	Type of OR	*<2 calls/day (n = 1045)*	*2–4 calls/day (n = 631)*	*>4 calls/day (n = 841)*	*Test for trend*	*2–4 calls/day (n = 927)*	*>4 calls/day (n = 1060)*	*Test for trend*
Dizziness	C	1.0	0.88 (0.47–1.67)	1.11 (0.64–1.92)		1.01 (0.58–1.74)	1.17 (0.70–1.95)	
	A	1.0	0.93 (0.49–1.77)	1.06 (0.60–1.88)		0.98 (0.56–1.73)	1.11 (0.65–1.89)	
Discomfort	C	1.0	1.06 (0.56–2.00)	0.94 (0.52–1.72)		1.41 (0.83–2.41)	**1.68 (1.02–2.78)**	
	A	1.0	1.13 (0.59–2.16)	0.94 (0.50–1.75)		1.47 (0.84–2.55)	**1.68 (1.00–2.82)**	
Concentration	C	1.0	1.43 (0.95–2.17)	**1.76 (1.22–2.55)**		1.27 (0.87–1.87)	**1.73 (1.21–2.46)**	
	A	1.0	1.35 (0.86–2.14)	**1.62 (1.06–2.47)**		1.27 (0.82–1.97)	**1.84 (1.24–2.73)**	a
Memory loss	C	1.0	1.31 (0.77–2.22)	**1.71 (1.07–2.72)**		1.32 (0.81–2.13)	**1.77 (1.13–2.75)**	
	A	1.0	1.46 (0.84–2.53)	**1.97 (1.21–3.20)**	a	1.40 (0.84–2.33)	**1.98 (1.24–3.15)**	a
Fatigue	C	1.0	1.22 (0.88–1.71)	**1.80 (1.35–2.39)**		1.17 (0.86–1.58)	**1.57 (1.19–2.08)**	
	A	1.0	1.30 (0.90–1.88)	**1.99 (1.43–2.76)**	b	1.18 (0.84–1.65)	**1.60 (1.17–2.20)**	b
Headaches	C	1.0	1.10 (0.75–1.62)	**1.75 (1.27–2.41)**		1.00 (0.70–1.42)	**1.48 (1.08–2.02)**	
	A	1.0	1.31 (0.88–1.96)	**2.35 (1.66–3.34)**	b	1.14 (0.79–1.64)	**1.76 (1.26–2.47)**	b
Warmth behind ear	C	1.0	**2.28 (1.21–4.30)**	**6.78 (3.99–11.5)**		1.60 (0.86–3.00)	**5.59 (3.31–9.45)**	
	A	1.0	**2.28 (1.16–4.45)**	**6.44 (3.66–11.3)**	b	1.81 (0.93–3.51)	**5.98 (3.42–10.5)**	b
Warmth on ear	C	1.0	**2.74 (1.51–4.98)**	**7.59 (4.56–12.7)**		**1.90 (1.05–3.44)**	**5.47 (3.28–9.13)**	
	A	1.0	**3.54 (1.90–6.62)**	**10.1 (5.79–17.5)**	b	**2.06 (1.10–3.85)**	**6.12 (3.53–10.6)**	b
Burning skin	C	1.0	0.82 (0.48–1.42)	1.25 (0.80–1.96)		0.90 (0.56–1.44)	**1.53 (1.02–2.31)**	
	A	1.0	0.96 (0.54–1.71)	1.55 (0.96–2.50)		0.95 (0.58–1.56)	**1.56 (1.02–2.40)**	
Tingling/tightness	C	1.0	0.54 (0.26–1.12)	1.04 (0.60–1.78)		0.78 (0.45–1.38)	1.09 (0.66–1.80)	
	A	1.0	0.66 (0.31–1.43)	1.65 (0.93–2.94)		0.89 (0.50–1.62)	1.28 (0.74–2.18)	
Other	C	1.0	0.94 (0.51–1.71)	1.29 (0.78–2.16)		1.09 (0.65–1.83)	1.29 (0.80–2.10)	
	A	1.0	0.96 (0.52–1.80)	1.39 (0.82–2.37)		1.08 (0.63–1.83)	1.26 (0.77–2.07)	b

See Table 3A for definitions.

When using an MP for a long continuous period of time, the phone gets warm due to resistive heating of the amplifier in the phone. Some early NMT models built up quite an excess of heat, making it impossible to hold the phone in the same hand throughout a long phone call. Törnevik *et al.* [21] measured maximum temperature increases of 15–19°C on the phone in the area of the earpiece when the MP had been operating at maximum output for 30 min. The maximum temperature around and on the ear of volunteers holding the phone in a normal talking position ranged between 37 and 41°C for analogue phones, and between 36 and 39°C for GSM phones. This factor may, then, be of importance for the occurrence of sensations of warmth, and might explain the positive correlation with calling time and also why the prevalence of sensations of warmth was the highest among the NMT users.

In addition to factors related to electromagnetic fields, factors such as audio quality, size and shape differentiate GSM and NMT phones. In the analogue system (NMT phones), speech may be partly masked by noise, and this is most prominent when the connection with the base station is poor. On the other hand, the audio quality of the digital system may be reduced by the occurrence of silent periods. When the connection with the base station is too poor, it closes completely. All these audio disturbances may cause stress and might thereby indirectly be a source of neurasthenic symptoms.

The questionnaires were distributed in 1996, and at that time NMT phones were generally older, heavier and larger in size than GSM phones. Therefore, using NMT phones might have been less comfortable than using GSM phones. Whether this has any implication for the difference in occurrence of symptoms between NMT users and GSM users is not known.

Some respondents specified neck pain to be a symptom

attributed to MP use. For some people, therefore, the use of an MP might have caused muscle strain, which in turn could have given rise to symptoms like headaches and fatigue [22]. This may, at least partly, explain the observed increase in the prevalence of these symptoms with respect to calling time and number of calls.

Methodological bias

The selected study population, people using their MPs in their jobs, probably deviates from the total population of MP users with respect to variables related to the MP and its use, with respect to other risk factors and, consequently, with respect to symptom occurrence. The effect of various exposure factors might not necessarily be identical for private users and job-related users. Thus, the observed effect of the transmitter system, as well as those of calling time and number of calls, should be restricted to the selected study population.

The response rates were almost equal for the GSM users and the NMT users, and furthermore the distribution of other potential risk factors (gender, trade, geographical location) was almost identical for respondents and non-respondents, suggesting a minimum influence of response bias when comparing GSM users and NMT users.

For headaches and fatigue, the association with calling time and number of calls is consistent irrespective of transmitter system and country, which is not the case for any of the other neurasthenic symptoms. This should be considered when evaluating the role of recall bias for the various symptoms. A few of the respondents did not know whether they used the NMT or GSM system, which could lead to a misclassification of transmitter systems. This error ought to be random.

Most of the potential confounding factors included in the questionnaire seem to be of importance for the prevalence of symptoms [23]. However, the confounding effect of these variables with respect to the statistical associations between exposure factors and symptoms was not pronounced; the adjusted ORs did not deviate much from the crude ORs (Tables 2–4). However, there might be other confounding factors that we have not taken into consideration, e.g. lifestyle and diagnosed diseases.

The adjusted ORs for sensations of warmth on the ear for GSM users compared with NMT users are statistically significant. Furthermore, the consistency when comparing the Norwegian and the Swedish data, together with a plausible explanation for the lower prevalence of sensations of warmth, particularly on the ear, among GSM users compared with NMT users, makes it less likely that the results are due merely to chance.

Despite the consistency in the findings from the two countries, it is obvious that there are differences both with respect to who is using the MP (more women and older people in Sweden than in Norway) and how it is being used (longer total calling time and higher number of calls per day in Norway than in Sweden). In general, there was a greater prevalence of reported symptoms in the Norwegian data than in the Swedish data. Earlier studies [15,23] have shown that young people in general report more symptoms than older people; therefore, the observed difference may, to some extent, also be explained by the presence of more young people in the Norwegian cohort. Furthermore, this result should be looked at in contrast to the fact that the self-reported state of health was slightly better among the Norwegian respondents than among the Swedish respondents. Accordingly, the symptoms reported in this study do not seem to be predictive of the self-reported general health conditions of the study population. Distinctions in the cultural as well as in the social and financial situations might also contribute to the differences in distribution.

Conclusions

The hypothesis originally postulated, that GSM users have a higher prevalence of symptoms than NMT users, was nullified by the study. In fact, GSM users reported sensations of warmth on the ear less frequently than did NMT users. Based on these results, we cannot deduce the role of radio frequency emission, temperature of the phones and other physical differences between GSM phones and NMT phones.

Demonstrable statistical associations between calling time and number of calls per day and the occurrence of sensations of warmth, as well as headaches and fatigue, were found among both NMT users and GSM users in both countries. Whether this association also demonstrates a causal relationship between MP use and the genesis of the different symptoms cannot be determined. The findings do, however, give rise to the hypothesis that calling time and number of calls are associated with sensations of warmth and some neurasthenic symptoms. Further studies are required to test this hypothesis and to explore the role of the various physical factors.

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