ORIGINAL ARTICLE

UDC: 613.168:[621.395.721.5:537.8
DOI: 10.2298/VSP140119013B

The assessment of electromagnetic field radiation exposure for mobile phone users

Određivanje izloženosti korisnika mobilnih telefona zračenju elektromagnetnog polja

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Abstract

Background/Aim. During recent years, the widespread use of mobile phones has resulted in increased human exposure to electromagnetic field radiation and to health risks. Increased usage of mobile phones at the close proximity raises questions and doubts in safety of mobile phone users. The aim of the study was to assess an electromagnetic field radiation exposure for mobile phone users by measuring electromagnetic field strength in different settings at the distance of 1 to 30 cm from the mobile user. **Methods.** In this paper, the measurements of electric field strength exposure were conducted on different brand of mobile phones by the call-related factors: urban/rural area, indoor/outdoor setting and moving/stationary mode during calls. The different types of mobile phone were placed facing the field probe at 1 cm, 10 cm, 20 cm and 30 cm distance. **Results.** The highest electric field strength was recorded for calls made in rural area (indoors) while the lowest electric field strength was recorded for calls made in urban area (outdoors). Calls made from a phone in a moving car gave a similar result like for indoor calls; however, calls made from a phone in a moving car exposed electric field strength two times more than that of calls in a standing (motionless) position. **Conclusion.** Electromagnetic field radiation depends on mobile phone power class and factors, like urban or rural area, outdoor or indoor, moving or motionless position, and the distance of the mobile phone from the phone user. It is recommended to keep a mobile phone in the safe distance of 10, 20 or 30 cm from the body (especially head) during the calls.

Key words:
electromagnetic fields; cellular phone; risk assessment; health.

Apstrakt

Uvod/Cilj. Tokom zadnjih godina rasprostranjeno korišćenje mobilnih telefona ima za posledicu povećano izlaganje ljudi zračenju elektromagnetnog polja, a time i rizicima za svoje zdravlje. Povećano korišćenje mobilnih telefona na malom rastojanju nameće pitanja i izaziva sumnju u bezbednost njihovih korisnika. Cilj ove studije bio je da utvrdi izloženost korisnika mobilnih telefona zračenju elektromagnetnog polja merenjem jačine elektromagnetnog polja u različitim okruženjima na rastojanju od 1 do 30 cm od korisnika telefona. **Metode.** U ovoj studiji vršena su merenja izloženosti korisnika raznih marki mobilnih telefona zračenja elektromagnetnog polja mobilnih telefona pomoću faktora koji se odnose na poziv: gradska/seoska zona, zatvoren/otvoren prostor i kretanje/mirovanje tokom poziva. Razni tipovi mobilnih telefona postavljani su okrenuti prema sondi za merenje na rastojanja od 1 cm, 10 cm, 20 cm i 30 cm. **Rezultati.** Najjače elektromagnetno polje zabeleženo je kod poziva u seoskoj zoni (zatvoren prostor), dok je najslabije zabeleženo za one u gradskoj zoni (otvoren prostor). Pozivi sa telefona iz kola koja se kreću pokazali su slične rezultate kao pozivi iz zatvorenog prostora; međutim, pozivi sa telefona iz kola koja se kreću izlažu korisnika duplo jačem električnom polju nego pozivi iz mirovanja (bez kretanja). **Zaključak.** Zračenje elektromagnetnog polja zavisi od snage mobilnog telefona i faktora kao što su gradska ili seoska sredina, otvoren ili zatvoren prostor, kretanje ili mirovanje, i rastojanje mobilnog telefona od korisnika telefona. Preporučljivo je držati mobilni telefon na bezbednom rastojanju – 10, 20 ili 30 cm od tela (naročito glave) tokom razgovora.

Ključne reči:
elektromagnetna polja; mobilni telefon; rizik, procena; zdravlje.

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Introduction

During recent years, the widespread use of mobile phones has resulted in increased human exposure to electromagnetic field and radiofrequency field. Although national and international agencies have established safety guidelines for exposure to these fields, concerns remain about the potential adverse health risks and health outcomes from power-frequency fields [1, 2].

Adverse effects investigated by various clinical trials include the possible link to increased risk of leukaemia, sleep disturbances and brain tumours [1, 3]. Health endpoints reported to be associated with electromagnetic and/or radiofrequency fields include genotoxic effects, neurological effects and neurodegenerative diseases, immune system deregulation, allergic and inflammatory responses, breast cancer, miscarriage and some cardiovascular effects. It was stated that a reasonable suspicion of risk exists based on clear evidence of bioeffects at environmentally relevant levels, which, with prolonged exposures may reasonably be presumed to result in health impacts [1].

There are reports stating that an intensive use of the mobile phone can cause headache, fatigue, insomnia, muscle pains, hearing and eyesight defects, failures of memory, neck and facial skin redness, and can increase stress [4, 5]. The mentioned symptoms can short-termed arise either during or sometime after a phone conversation [6]. Some uncertainties concerning possible carcinogenic effects should also be considered. According to epidemiological studies of mobile phones and cancer, it was concluded that the possibility of an enhanced cancer risk cannot be excluded [2]. The use of mobile phones is associated with an increased risk for brain tumour after 10 years [1]. The International Agency for Research on Cancer stated overall evaluation that radiofrequency electromagnetic fields are possibly carcinogenic to humans [7].

Mobile communication is a technology that enables data exchange with the help of radio signals [8]. A mobile network nowadays covers the whole world and electromagnetic waves are lingering around us but we cannot smell, see or touch them [9, 10]. Mobile network has received mass application, but nobody gives a thought to the principles of its operation and to the possible damage caused by what we even do not feel [11]. Electromagnetic radiation emitted by mobile phones and antennas of their base stations affects a human being at the cell level and causes damage to health [12, 13].

At radiofrequencies, electromagnetic field penetrates into human body. The exposure to radiofrequency radiation is usually described by the "Specific absorption rate" (SAR). It is the amount of energy absorbed per mass of tissue and has units of watts per kilogram (W/kg) [14, 15]. As the mobile phone is always very close to its owner, it necessarily has some effect on him/her [16]. When speaking over the phone an electromagnetic field exposure is targeted directly to the brain. The strongest electromagnetic field is generated at a distance of 1 to 10 centimetres from the phone antenna and the largest amount of electromagnetic radiation is absorbed in skin, at a depth of 1 cm [17]. When the phone is in a standby mode, the levels of emitted radiation are particularly low and nearly insensible. However, the power of radiation is largely dependent on a distance from the base station. The shorter the distance is the lower radiation is [18].

Mobile phones can radiate very strong electromagnetic fields. Analogous communication generates stable, while digital-pulsed electromagnetic fields. Electromagnetic fields and waves are generated during the change of electric charges [19]. These are turbulent electric and magnetic fields, invisible to eye, and propagating in the space at the speed of light. Biological effects of electromagnetic radiation depend on the power of its energy, impact duration and individual characteristics of the organism. Live organisms either reflect or absorb electromagnetic waves [20]. Absorption of electromagnetic radiation by tissues leads to the changes in the spatial arrangement of water and protein molecules, which become positioned in accordance with a certain axis, i.e. electrify themselves. The transformation of this radiation into thermal energy produces a thermal effect [14, 21].

The larger the number of people speaking over mobile phones is the higher environmental electromagnetic pollution is [22, 23]. The electromagnetic field safety of base stations and mobile phones has been broadly investigated and discussed worldwide. More and more scientific data are obtained on harm to human health caused by electromagnetic field emitted from the base stations and mobile phones [24].

The aim of the study was to assess an electromagnetic field radiation exposure for mobile phone users by measuring electromagnetic field strength in different settings at the distance of 1 to 30 cm from the mobile user: in urban/rural area, indoor/outdoor setting and at moving/stationary position.

Methods

The exposure of electric field strength radiated from the sampled mobile phones of different brands and models was measured. For the study, the measurements from Global System for Mobile Communications (GSM) 900 and GSM 1800 cells mobile phones were conducted in different settings (urban/rural area, indoor/outdoor setting and moving/stationary), and in both the worst case was recorded.

A broadband electromagnetic field meter NBM-550 with isotropic probe EF 0392 (electronic field, flat) was used for investigations. The operating frequency range of the broadband electromagnetic field meter NBM-550 with an isotropic probe was 100 kHz – 3000 MHz. It corresponds to the range in which a possible radiation sources that can cause hazard (for instance, base stations of mobile communications, mobile communication antennas and mobile phones) can operate. The broadband electromagnetic field meter NBM-550 with an isotropic probe is distinguished by its high sensitivity: it measures electric field strength from 0.01 V/m, a magnetic field strength from 0.01 mA/m, and electromagnetic field energy flux density from 0.001 mW/m^2 or 0.1 nW/cm^2.

Dynamic coverage of the device: for electric field strength 0.01 V/m – 100 kV/m; for magnetic field strength 0.01 mA/m – 250 A/m; for electromagnetic field energy flux density 0.001 mW/m^2 – 25.00 MW/m^2; and for electromagnetic field energy flux density 0.1 nW/cm2 – 2.5 kW/cm^2. A larger dynamic coverage of the broadband electromagnetic field meter NBM-550 with an isotropic probe means that the measurement of electric field strength covers a wider interval.

The measurements were performed at 1cm, 10 cm, 20 cm and 30 cm away from the probe during calls (Figure 1). power was between 10 and 500 W. The antenna of microcell base station in urban area was mounted on the roof of building (15 m) and was used to add additional capacity for a high number of users. The output power from the antenna of the microcell base station was between 10 W and 50 W. Calls were made during two days at 8 a.m. to 5 p.m.

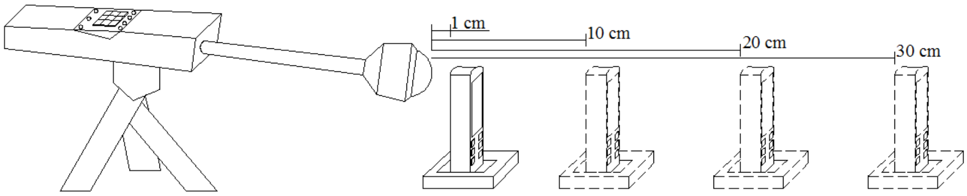

Fig. 1 – Measurement scheme of mobile phone's electric field strength

The first point of the measurements was the main one, because the mobile phones were placed facing the field probe at the similar position as of the ear. The duration of one measurement took 6 minutes. Measurements were taken during an outgoing call from a mobile phone.

The different models of the GSM mobile phones, with different SAR types, and different technical characteristics were used for the study (Table 1). Not all mobile phones have the same maximum power output level, so we have chosen traditional mobile phones with maximum power output up to 2 W. There are mobile phones with maximum power output of 4 W, 5 W or 8 W, but these mobile phones are used for the special purposes (like car phones and so on), and it is difficult to find them (they are not ordinary in our country).

The measurements for the study were taken in urban and rural settings. Urban areas (central Vilnius) included 1800 MHz microcells. Rural areas (Lavoriskes) had only 900 MHz macrocells. Outdoors measurements were taken in the yard (stationary), and indoors measurements – in the room (stationary). The distance between the antenna of the base station and the measuring points in the urban area was 200 m and in the rural area – 1000 m. Moving measurements were taken in the car driving around antenna in the 200 m beam (urban area), and in the 1000 m beam (rural area). The antenna of macrocell base station in rural area was mounted relatively high – on 70 m freestanding tower in order to cover a larger surrounding geographical area. The output

Table 1

Technical characteristics of the mobile phones

Specific absorption rate (SAR)	GSM 900 maximum power output	GSM 1800 maximum power output
1.40	2 W	1 W
1.31	2 W	1 W
1.16	2 W	1 W
1.01	2 W	1 W
0.99	2 W	1 W
0.82	0.8 W	0.25 W
0.78	0.8 W	0.25 W
0.6	0.8 W	0.25 W
0.44	0.8 W	0.25 W
0.37	0.8 W	0.25 W

GSM – Global System for Mobile Communications

Results

The study results revealed the electromagnetic field strength measured in four different distances during outgoing call mode in urban/rural area, indoor/outdoor setting and in moving car. These results are plotted by 10 brand mobile phones, shown in Figures 2–5.

Figure 2a shows that the highest electric field strength emitted by the phones during call mode in urban area (GSM -1800) outdoors obtained with brand 1 (SAR-1.31) was 14 V/m and the lowest with brand 9 (SAR-0.44) was 3 V/m. The experiments revealed that the phone transmitted electric field strength depending on mobile phones SAR. Mobile phones with high SAR have much more higher maximum power output when compare with mobiles phones with low SAR. The higher SAR of mobile phone led to the higher electric field strength, which mobile phone had to emit. The electric field strength values of the mobile phones with SAR from 1.4 W/kg to 0.99 W/kg vary from 11 V/m to 14 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 2 to 5 times and vary from 3 V/m to 6 V/m.

Figure 2b shows that the highest electric field strength emitted by the phones during call mode in urban area (GSM-1800) indoors obtained with brand 4 (SAR-1.01) is 23 V/m and the lowest with brand 9 (SAR-0.44) is 5 V/m. The electric field strength values of the mobile phones with SAR

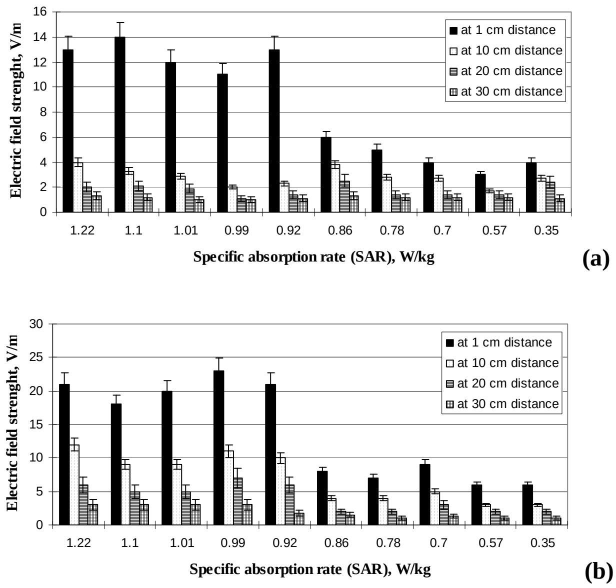

Fig. 2 – Electric field strength values of the mobile phones measured in urban area (GSM–1800) during outgoing call mode at different distances from the probe: (a) outdoors and (b) indoors.

from 1.4 W/kg to 0.99 W/kg vary from 18 V/m to 23 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 2 to 5 times and vary from 5 V/m to 9 V/m. The experiments revealed that the electric field strength is about twice as large in the urban area indoors when compared with the urban area outdoors. The electric field strength values depends not only on SAR, they depends on electromagnetic signal intensity in exploring environment too. The electromagnetic signal intensity inside was 85 dBm and outside was 75 dBm. The lower intensity of electromagnetic signal led to the higher transmitting electric field strength, which mobile phone had to emit.

Figure 3a shows that the highest electric field strength emitted by the phones during call mode in rural area (GSM-900) outdoors obtained with brand 2 (SAR-1.31) is 21 V/m and the lowest with brand 10 (SAR-0.37) is 5 V/m. The electric field strength values of the mobile phones with SAR from 1.4 W/kg to 0.99 W/kg vary from 21 V/m to 12 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 2 to 4 times and vary from 5 V/m to 9 V/m.

Figure 3b shows that the highest electric field strength emitted by the phones during call mode in rural area (GSM-900) indoors obtained with brand 2 (SAR-1.31) is 41 V/m and the lowest with brands 9 and 10 (SAR-0.44 and SAR-0.37) is 12 V/m. The electric field strength values of the mobile phones with SAR from 1.4 W/kg to 0.99 W/kg vary from 41 V/m to 35 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 3 times and vary from 12 V/m to 15 V/m.

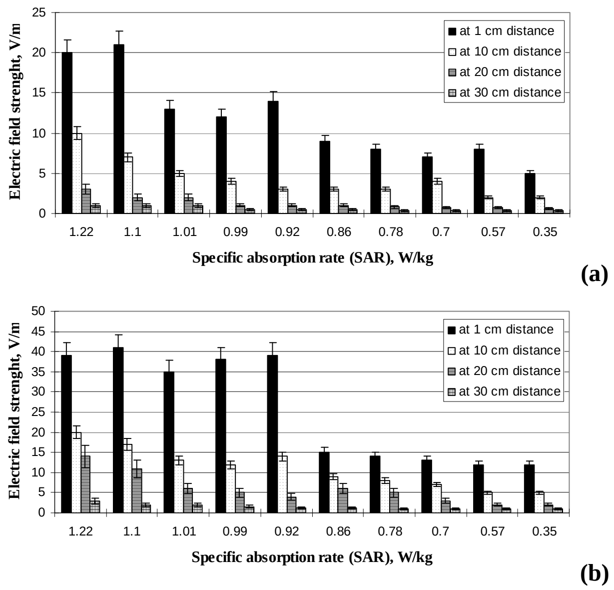

Fig. 3 – Electric field strength values of the mobile phones measured in rural area (GSM-900) during outgoing call mode at different distances from the probe: (a) outdoors and (b) indoors.

The experiments revealed that the higher exposition of the electromagnetic field radiation during calls was observed in rural area when compared with urban settings (Figures 2 and 3). It is because of different operating bands: in rural area, mobile phones are working at the 900 MHz band, while in urban settings – at the 1800 MHz band. The maximum powers that GSM mobile phones are permitted to transmit in rural area by the present standards are 2 W (900 Hz), while in urban area – 1 W (1800 Hz). Because of that, the electric field strength was about two times as high for rural area when compared with urban calls.

The electromagnetic signal intensity indoors was 100 dBm, while outdoors was 85 dBm. The lower intensity of electromagnetic signal in rural area compared with urban area led to the higher transmitted electromagnetic field strength.

Figure 4 shows that the highest electric field strength emitted by the phones during call mode in urban area (GSM-1800) moving obtained with brand 3 (SAR-1.16) is 28 V/m and the lowest with brand 10 (SAR-0.37) is 11 V/m. The electric field strength values of the mobile phones with SAR from 1.4 W/kg to 0.99 W/kg vary from 23 V/m to 28 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 2 times and vary from 11 V/m to 17 V/m.

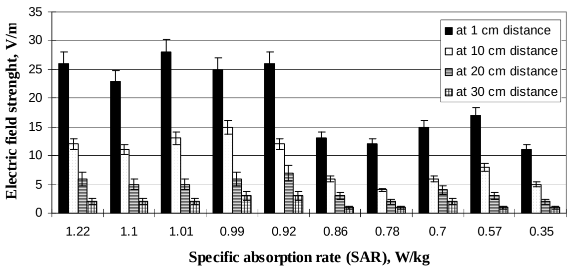

Fig. 4 – Electric field strength values of the mobile phones measured in urban area (GSM-1800) during outgoing call mode moving (at different distances from the probe).

Figure 5 shows that the highest electric field strength emitted by the phones during call mode in rural area (GSM-900) moving obtained with brand 2 (SAR-1.31) is 39 V/m and the lowest with brands 9 and 10 (SAR-0.44 and SAR-0.37) is 11 V/m. The electric field strength values of the mobile phones with SAR from 1.4 W/kg to 0.99 W/kg vary from 28 V/m to 39 V/m while mobile phones with SAR from 0.82 W/kg to 0.37 W/kg decreased by 2 to 3 times and vary from 11 V/m to 14 V/m.

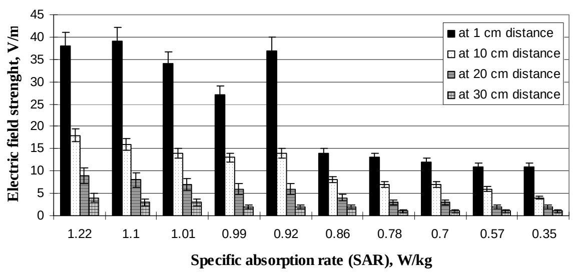

Fig. 5 – Electric field strength values of the mobile phones measured in rural area (GSM -900) during outgoing call mode moving at different distances from the probe.

The factors influencing the electric field strength level while mobile phone was in the moving car were: the distance between mobile phone and the base station, the attenuation of the electromagnetic signal, and change of connecting base station "handover". The electromagnetic signal intensity was decreasing along with the longer distance, and the signal was very poor at the end of the base station cell. The signal was worse especially when mobile phone was used in the car, and when the car was mowing. At that case in the car the intensity of electromagnetic signal was 95 dBm to 105 dBm in rural area, and 80 to 90 dBm in urban area. The lower intensity of the electromagnetic signal in rural area when compared with urban area led to the higher transmitted electric field strength. Handovers (process when the mobile phones temporarily increase electric field strength while they are connecting to a new base station) could be made as well when the mobile phones were moving closely to the boundary of the main cell covered by one base station to another cell. However, we could not evaluate that fact.

Discussion

The electric field strength of a mobile phone was found to depend on a mode of the phone, geographical factors, electromagnetic signal intensity from the antenna of the base station, shadowing, SAR, operating frequency and on a distance.

This work demonstrates that mobile phones emitted higher electric field strength in rural area, when compared with urban area. The electric field strength was about twice as large indoors, when compared with outdoors. This is because of the attenuation of the electromagnetic signal by houses. Mobile phones with high SAR have much more higher maximum power output, when compared with mobile phones with low SAR. The maximum powers that GSM mobile phones are permitted to transmit in rural area by the present standards are 2 W (900 Hz) while in urban area they are 1 W (1800 Hz). Because of that, the electromagnetic field strength of rural calls was about two times more than that of urban calls. Calls made from a mobile phone in a moving car gave a similar result like for indoor calls concerning the exposure of the electromagnetic field strength. However, calls made from a phone in a moving car exposed electric field strength two times more than that of calls in a standing (motionless) position.

Our measurements showed that in order to reduce risk for health and enhance safety it is of importance to keep safe distance between mobile telephone and human body. The experiments revealed that the electric field strength values of all mobile phones at distance of 10 cm decreased by more than 2 times, at the distance of 20 cm decreased by more than 4 times and at the distance of 30 cm decreased by more than 10 times when compared with the distance of 1 cm. Other authors underline similar solution that to make electromagnetic field safe it is important to ensure safe distance from the electromagnetic field radiation source [25]. This could protect mobile phone users from biologic effects and health problems. In addition, safe distances could prevent mobile phone users from the possible carcinogenic effects in a long run.

Various guidelines exist for limiting exposure to radio frequency electromagnetic field by different countries. The most common one is *The Council Recommendation* on electromagnetic field exposure limits (1999/519/EC). Those are the guidelines, where standards of 41 V/m and 58 V/m are set as the limits (at 900 MHz and 1800 MHz). In many others countries the guidelines are far below this limit due to a complaint and scepticism demonstrated by public. Lithuania does not have limitations for electric field strength at 900 MHz and 1800 MHz (the only limitation for electromagnetic field power density is 10 µW/cm²). According to the formulas: $S = E^2/377*100$, where E is the electric field in V/m and S is the power density in µW/cm^2, we can translate electromagnetic field power density to electric field strength: 10 µW/cm² is about 6.1 V/m. If we can do such comparison, many mobile phones are far above the guidelines set in our country.

The strength of the study was to objectively measure and to assess the electromagnetic field radiation exposed by the mobile phone to the phone user in the different settings and at the different distances. The results of the study could be used for health risk and hazard prevention of population.

Conclusion

Electromagnetic field radiation depends on mobile phone power class and factors, like urban or rural area, outdoor or indoor setting, and the distance of the mobile phone from the phone user. It is recommended to keep a mobile phone at the safe distance of 10, 20 or 30 cm from the body (especially head) during calls. This is necessary due to the uncertainties concerning mobile user safety and the lack of evidence on the direct harmful impact of mobile phone to human health.

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Received on January 19, 2014.
Accepted on February 20, 2014.
OnLine-First February, 2014.