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EEG electrode caps can reduce SAR induced in the head by GSM900 mobile phones

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Keywords
eeg, gsm900, head, sar, phones, mobile, can, caps, induced, reduce, electrode

Disciplines
Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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EEG Electrode Caps Can Reduce SAR Induced in the Head by GSM900 Mobile Phones

Denise L. Hamblin, Vitas Anderson, Robert L. McIntosh, Ray J. McKenzie, Andrew W. Wood, Steve Iskra, and Rodney J. Croft

Abstract—This paper investigates the influence of EEG electrode caps on specific absorption rate (SAR) in the head from a GSM900 mobile phone (217-Hz modulation, peak power output 2 W). SAR measurements were recorded in an anthropomorphic phantom using a precision robotic system. Peak 10 g average SAR in the whole head and in just the temporal region was compared for three phantom arrangements; no cap, 64-electrode “Electro-Cap,” and 64-electrode “Quick-Cap”. Relative to the “no cap” arrangement, the Electro-Cap and Quick-Cap caused a peak SAR (10 g) reduction of 14% and 18% respectively in both the whole head and in the temporal region. Additional computational modeling confirmed that SAR (10 g) is reduced by the presence of electrode leads and that the extent of the effect varies according to the orientation of the leads with respect to the radiofrequency (RF) source. The modeling also indicated that the nonconductive shell between the electrodes and simulated head material does not significantly alter the electrode lead shielding effect. The observed SAR reductions are not likely to be sufficiently large to have accounted for null EEG findings in the past but should nonetheless be noted in studies aiming to measure and report human brain activity under similar exposure conditions.

Index Terms—EEG electrode leads, mobile phones, SAR.

I. INTRODUCTION

Measurements of brain activity are commonly achieved using an arrangement of electrodes positioned on the scalp conveniently arranged in an electroencephalography (EEG) cap. For acute studies of mobile phone effects a number of issues arise from such arrangements including: 1) the possible corruption of recordings due to pick-up of mobile phone emissions by electrode leads; 2) the effect on specific absorption rate (SAR) in the head due to these leads being positioned between the scalp and active source of exposure.

Although these issues appear fundamental to defining the amount and type of exposure administered in various set-ups and determining the cause of subsequent findings, they are rarely accounted for or reported. We have recently addressed the issue of pick-up by electrode leads [1], and now address the issue of possible changes in SAR at the head by the arrangement of electrodes positioned on the scalp. A recent report by Angelone et al., based on computational modeling, suggested SAR enhancement of over five times due to electrodes on the scalp during MRI exposures to 128-MHz radiofrequency (RF) [2]. However, the source characteristics, field distribution and frequency of RF exposure during MRI is substantially different to that experienced from a mobile handset placed against the head. In the latter case, the phone exposure is much more localised and the coupling response of the leads at the higher frequency of 900 MHz may be substantially different.

Electroencephalography, a noninvasive measure of voltage fluctuations of large ensembles of neurons in the brain, has become a common method of investigation into the acute effects of mobile phone exposures on brain activity. There are a number of electrode positioning systems available for the measurement of human EEG. The traditional montage comprises 19 electrodes positioned in predetermined scalp locations according to the “International 10/20 System.” However, as greater spatial information can be gained from additional electrodes, elasticized caps with 32, 64, or up to 256 channels have become widely available. The commonly used “Electro-Cap” (Electro-Cap International Inc., Eaton, OH) has recessed electrodes with plastic supports and electrode wires running underneath the cap. A more recent design is the “Quick-Cap” (Neuroscan Inc., El Paso, TX), which has thicker and more elastic fabric, softer rubber supports surrounding the electrodes and bundled wiring running external to the cap.

The GSM900-type handset, operating in the frequency band of 890-915 MHz, has been the most commonly used mobile phone to study the effects of electromagnetic field (EMF) emissions on biological systems. For the purposes of testing human physiological responses to such emissions, handsets can be set via computer and manufacturer software to continuously transmit a GSM signal at a number of power levels, including the nominal maximum mean power output of 250 mW (peak power of 2 W).

II. SAR Measurements

A. Materials and Methods

SAR measurements were conducted inside an IEC 62209-1 [3] compliant Standard Anthropomorphic Model (SAM)
A 64-electrode Electro-Cap and a 64-electrode Quick-Cap were employed in the current study. For both arrangements, the left side of the cap was stretched over the phantom and taped into position with electrodes FPZ (midline pre-frontal) and OZ (midline posterior) placed relative to the nasion and inion respectively. This was done so with reference to the International 10–20 System. The side of each cap, where a chin-strap would usually attach, was taped below the ear towards the chin and the opening for the ear (featured on the Quick-Cap only) was positioned over the earlobe. The electrodes were placed directly in contact with the fiberglass shell. To replicate real testing conditions, conductive gel was injected through perforations in the electrodes via a blunt needle and electrode leads hanging from the caps were taped along the back of the phantom head, neck and torso.

Each test took 30 min, during which time the mobile phone was set to transmit a GSM digital signal (in this case at 895 MHz) at the maximum output power. Prior testing of the battery showed that it retained >90% charge for the first 2.5 hours, after which it rapidly dropped to 50%. Between tests the mobile phone was turned off and attached to a charger for approximately 30 min.

During measurement of the whole head SAR, DASY software was set to conduct an area scan (131 × 61 × 1 points, 15-mm resolution) inside the phantom opposite the phone. From this area, the probe detected the exact location of peak SAR in the head which typically occurs on the near side to the phone or 2.5 hours, after which it rapidly dropped to 50%. Between tests the mobile phone was turned off and attached to a charger for approximately 30 min.

DIELECTRIC PROPERTIES USED IN THE NUMERICAL MODELS

<table>
<thead>
<tr>
<th>Matter</th>
<th>σ (Ω/m)</th>
<th>ε&lt;sub&gt;r&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.97</td>
<td>41.5</td>
</tr>
<tr>
<td>Phantom Shell&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Electrode gel&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.2</td>
<td>60.3</td>
</tr>
</tbody>
</table>

Source: a[NATA], bData provided by Arpel Inc. for the Specific Anthropomorphic Mannequin (SAM) phantom, cDielectric properties measured.

Fig. 1. Mobile phone held in “touch” position to phantom head by vice in the Quick-Cap arrangement. I. Phantom “nose”; II. Phantom “chin”; III. Electrode lead; IV. Test phone; V. Vice.
Fig. 2. Measurement plot for maximum Head SAR during “no cap” condition. The probe conducted an area scan (131×61×1 points, 15-mm resolution) from which it determined the position of the (30-mm)\(^3\) average SAR measurement grid (7×7×7 points, 5-mm resolution) and 10 g cube with the highest averaged SAR values in the phantom head.

Fig. 3. Measurement plot for maximum Brain SAR during “no cap” condition. The probe conducted an area scan from which it determined the position of the (30-mm)\(^3\) average SAR measurement grid and 10 g cube with the highest averaged SAR values in-line with the antenna.

of highest brain SAR and hence the most indicative of any putative RF neurological effect. The same three phantom arrangements were tested. Ambient and tissue fluid temperatures were constant over the duration of each test (22.0 °C ambient, 21.8 °C liquid).

B. Results

As can be seen in both Table II and Fig. 4, there was a difference between each phantom arrangement investigated for both maximum SAR in the whole head (Head SAR) and maximum SAR in the chosen region of the brain (Brain SAR). Relative to the “no cap” arrangement, the SAR for both the Electro-Cap and Quick-Cap arrangements were reduced. This result was consistent in magnitude and direction at both measurement sites.

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Whole Head(^a)</th>
<th>Temporal Region Only(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Cap</td>
<td>0.674 (0.899)</td>
<td>0.110 (0.190)</td>
</tr>
<tr>
<td>Electro-Cap</td>
<td>0.574 (0.758)</td>
<td>0.095 (0.163)</td>
</tr>
<tr>
<td>Quick-Cap</td>
<td>0.552 (0.744)</td>
<td>0.090 (0.158)</td>
</tr>
</tbody>
</table>

\(^a\)Measured value taken from area where maximum SAR was found in the phantom head—typically on the near side of the face between temple and cheek

\(^b\)Measured value taken from region over temporal lobe (in-line with antenna)

\(^c\)SAR in units of W/kg and averaged over 10g of tissue (1g average measurements shown in brackets)

III. COMPUTATIONAL MODELING

The measured reduction in SAR is consistent with an expectation that the leads provide a partial shield to the incident RF energy. However, in light of the results reported by Angelone et al. [2], computational modeling of our test set-up was employed to explore the issue more thoroughly. In particular, we were concerned to investigate the suggestion that the presence
TABLE III
SAR, POWER, AND IMPEDANCE STATISTICS FOR VARIOUS MODEL SCENARIOS

<table>
<thead>
<tr>
<th>Model #</th>
<th>Angle between electrode leads and dipole in yz plane of Fig. 5</th>
<th>Shell present</th>
<th>Electrodes electrically connected to head</th>
<th>See Figure</th>
<th>Calculated dipole antenna data</th>
<th>SAR (W/kg) for net power normalized to 250 mW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Net power (\text{a} ) (mW)</td>
<td>Impedance (ohms)</td>
</tr>
<tr>
<td>1</td>
<td>0° (/)</td>
<td>Yes</td>
<td>No</td>
<td>5, 6B, 7A</td>
<td>163</td>
<td>19.6 – j 13.7</td>
</tr>
<tr>
<td>2</td>
<td>0° (/)</td>
<td>Yes</td>
<td>Yes</td>
<td>7B</td>
<td>160</td>
<td>19.0 – j 12.8</td>
</tr>
<tr>
<td>3</td>
<td>0° (/)</td>
<td>No</td>
<td>Yes</td>
<td>7C</td>
<td>156</td>
<td>18.2 – j 14.5</td>
</tr>
<tr>
<td>4</td>
<td>15°</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td>212</td>
<td>32.4 – j 6.1</td>
</tr>
<tr>
<td>5</td>
<td>45°</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td>239</td>
<td>47.3 – j 1.3</td>
</tr>
<tr>
<td>6</td>
<td>90° (⊥)</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td>241</td>
<td>49.6 + j 4.3</td>
</tr>
<tr>
<td>7</td>
<td>No electrodes</td>
<td>Yes</td>
<td>No</td>
<td>6A</td>
<td>241</td>
<td>49.5 – j 2.7</td>
</tr>
<tr>
<td>8</td>
<td>Dipole in free space</td>
<td>No</td>
<td>No</td>
<td></td>
<td>250</td>
<td>76.1 + j 2.4</td>
</tr>
</tbody>
</table>

\(\text{a}\)Net power = Available forward power (250 mW)—reflected power (due to presence of head and electrodes)

\(\text{b}\)14 mm in from edge of skin, beneath electrode

Fig. 5. An example of a computational model scenario considered (model #1) with the 900-MHz dipole directly adjacent to an electrode and parallel to two other electrodes (A) front view (B) side view.

A. Materials and Methods

To investigate RF pickup and conduction by the EEG leads, several computational models were constructed using commercial EM modeling software (Remcom XFDTD) based on the finite difference time domain (FDTD) technique to test various scenarios. The models (#1–7 in Table III) comprised a simplified phantom head shape (200-mm-diameter sphere with flattened surfaces on either side to represent the sides of the head) with a 2-mm-thick dielectric shell filled with homogenous tissue conforming to that used in our measurements (see Fig. 5 and Table I). The finite-difference cells were cubical with sides of length 1 mm. A simplified arrangement of three parallel EEG leads was included in the models to simulate the worst case coupling condition between the RF source (modeled as a 900-MHz dipole placed 10 mm from the side of the head) and the EEG leads, which occurs when the dipole is aligned parallel to the EEG leads nearest the dipole. The EEG electrodes and conducting gel used in the EEG caps were modeled based on their physical dimensions and measured dielectric properties.
The dipole was 157 mm long (0.47 λ) with a wire diameter of 1 mm. It was designed with a generator voltage of 8.45-V rms and antenna impedance of 73 Ω so that it was well matched into free space producing a maximum available output power of 250 mW (model #8). It is well known that antenna impedance may be significantly altered by capacitive coupling of the antenna with nearby objects (such as a head), thereby reducing its impedance match to the source and causing a reduced radiated power due to the power reflected back from the antenna feed. Our models enabled comparison of net input and reflected power due to the presence of the head and various configurations of the electrodes (Table III). In Table III the SAR values are presented when the net input antenna power is normalized to 250 mW in all models considered.

B. Results

In order to validate our measured data, we first compared the model with no electrodes around the head (model #7) to the models containing three parallel electrodes oriented at 0°, 15°, 45° and 90° to the dipole in the yz plane of Fig. 5 (models #1, 4, 5, 6). The peak 10 g averaged SAR was reduced by up to 38% when the leads were parallel to the dipole orientation (model #1), and was virtually unaffected when the leads were perpendicular (model #6; Fig. 6). See Table III for details. Further, as expected, the 10 g SAR values near the electrodes decrease substantially as the distance from the dipole to the electrode increases (last column in Table III). This is also consistent with reduced induction of RF energy into the leads when perpendicular to the axis of the dipole. We would expect measured results to occur somewhere between these two extremes, depending on the exact arrangement of the EEG leads on the head, which is not precisely reproducible from experiment to experiment and represents one of the sources of uncertainty in this study.

Second, in order to determine if the phantom shell had an effect on the conduction path between the electrode and the phantom gel, a comparison was made between model #1 and model #2. In model #1 the electrodes were attached to the shell as in the measurement situation, whereas in model #2 the electrodes were attached directly to the simulated head tissue which more accurately represents EEG placement on real human subjects. The results of this modeling indicated that when the electrode was directly connected to the head, the peak 10 g averaged SAR is 8.1% higher, and the 10 g averaged SAR near the electrode closest to the source was lower by 2.0% [Fig. 7(a) and (b) and Table III]. These differences are small in the context of the uncertainty in the measurement system (±30%) and a comparable uncertainty in the FDTD calculation [7]. Fig. 7(c) also shows the minimal effect of the presence of the shell regardless of the leads (model #3). Note also that in these three model scenarios with parallel electrodes (#1–3), that the feed point impedance of the source does not vary significantly. This is also a good indicator that the energy absorbed in the head is not much different between those scenarios. Clearly then, any measurement result will be dominated by the much larger shielding effect of the EEG leads in this test setup.

IV. DISCUSSION AND CONCLUSION

The current measurement results show that EEG electrode leads can produce a shielding effect, reducing the SAR in head regions close to the antenna and also where the maximum value is obtained. This is true for at least two electrode positioning systems commonly used in this area of research: the 64-electrode Electro-Cap and the 64-electrode Quick-Cap. This reduction in SAR was confirmed by subsequent computational modeling which suggested that the use of a nonconductive shell in this particular experimental setting did not significantly affect the results.

Although we were unable to measure possible electric field enhancement within the immediate vicinity of the electrodes (proximal resolution = 5 mm), our computational modeling does not indicate that this would be significant. Such enhancement is dependent on the particular arrangement of the lead wires and the power and properties of the exposure source in any given case, and cannot be modeled precisely. However, since the average power of the phone is 250 mW and there are many electrodes in the area over which this energy is absorbed, then in general we do not expect a noticeable amount of localized heating from the small enhancements predicted. In contrast, if the power level was greatly increased, as is possible in MRI, such as treated by Angelone et al. [2], then these small enhancements may result in measurable temperature changes near the electrodes, especially given that the SAR distribution in the head would also be much different. Overall, our investigation indicates that due to the different electrode arrangements and composition, EMF frequencies, exposure sources and experimental parameters utilized, these two studies are not comparable.

As peak and average SAR values were reduced, positive EEG findings in the area of mobile phone bioeffects may not be explained by electrode configurations acting like an antenna and greatly enhancing the SARs. As the measured reductions were less than 18.2% (worst case, Quick-Cap, brain SAR, 10 g), the current results also fail to support the view that null findings are due to grossly attenuated SARs. The reductions observed were small compared to the error budget for such measurements (typically ±30%) and SAR variation expected due to differences in positioning of the phone [7]. For accurate dosimetry, it is
nonetheless important that these reductions are accounted for and reported by those utilizing similar experimental conditions.

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REFERENCES


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