Mobile Phones, E E G And Mental Activity

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Abstract

**Background:** The published results about possible mental effects of mobile phone exposure are still inconsistent and inconclusive.

**Methods:** The sigmoid arousal-frequency correlation combined with the brain rate concept is used to characterize the effects of mobile phones on mental states.

**Results:** Pronounced asymmetries and individualities in brain rate values, characterizing EEG spectral shifts towards overarousal or underarousal, have been obtained.

**Conclusion:** The mental consequences of mobile phone use could be, in principle, detrimental or beneficial, depending on the individual initial EEG spectra and the different exposure frequencies from mobile phone technologies. Thereby, brain rate can serve as a useful preliminary indicator.

Introduction

Worldwide concern about possible mental effects of mobile phone (MP) exposure lasts for more than two decades [1-2]. However, the published results are still inconsistent and inconclusive [3-5]. So, in two recent documents from competent organizations (World Health Organization - WHO and International Commission on Non-Ionizing Radiation Protection - ICNIRP) it is stated, respectively: “To date, results of epidemiological studies provide no consistent evidence of a causal relationship between radiofrequency exposure and any adverse health effect. Yet, these studies have too many limitations to completely rule out an association”[4]; and: “The evidence for neurobehavioral effects on brain electrical activity, cognition, sleep and mood in volunteers exposed to low frequency electric and magnetic fields is much less clear”[5].

The aim of this article is to present a possible explanation for the ambiguous and inconsistent evidence about MP effects on mental activity. In addition, the applicability of brain rate concept [6] for indicating MP influences is considered.

Empirical evidence

Starting key question is: which EEG frequencies are relevant for mental activity? The well established empirical results show that these are frequencies in the extremely low (ELF) range of bellow one hundred Hz. Moreover, it appeared that the states of arousal are somehow proportional to the EEG activity represented by different frequency bands: from delta (0.5-4 Hz) till gamma (30-50 Hz). Thereby, the empirical data have shown that the delta band corresponds to deep sleep stages 3-4, theta to drowsiness and sleep stages 1-2, alpha to relaxed state, while SMR, beta and gamma to alert state, anxiety and peak performance, respectively [7, 8].

Simultaneously, ELF frequencies of the same range are also emitted by MPs of different technologies (Illustration1). Consequently, an influence of MP on EEG and mental activity is quite feasible and could be diverse [9, 10]. Actually, a number of studies on animals (Illustration2) and humans (Illustration3) has confirmed this kind of MP effects.

Modeling

Analysing the empirical input-output activation, arousal can be represented as a sigmoid function [11]. An analytical expression of the same sigmoid dependence has been derived by a quantum theoretical approach, based on the transition probabilities from the interaction of brain electric field with neuronal dipoles [12]. Combining these theoretical results with the mentioned empirical data, a summarized arousal-frequency correlation can be represented (Illustration4) [13].

However, the actual electric field in the brain (both endogenous and externally modulated) is not monochromatic, but spectral, characterized by a time-changing frequency distribution. Consequently, a spectrum weighted frequency (brain rate) parameter was introduced [6], as a useful general indicator of mental state (in parallel with temperature, blood pressure or hearth rate, indicating different bodily states) [Illustration5].
Results

The brain rate values for different mental states (sleep stages and some mental disorders), showing underarousal or overarousal, are displayed in Illustration 6.

The distribution of mean brain rate values (for 40 healthy adults), indicating the changes in different cortical regions (Frontal/Back, Left/Right and midline) are shown in Illustration 7.

Summarizing the published results, illustrations 8-10 show pronounced asymmetries and individualities of MP exposure effects on human EEG, which lead to corresponding variations of brain rate as indicator of mental activity.

Conclusions

The inconsistent and inconclusive evidence about MP mental effects could be due to subtle interplay of spectral individualities and radiation specifics, representing neurophysical substrate of mental processes. Having in mind pronounced individual differences concerning EMF effects, it is suggested to refine accordingly the sampling procedure, differentiating specific subgroups for studying.

Actually, the mental consequences of MP could be detrimental or beneficial, depending on the individual initial EEG spectra and the different exposure frequencies from MP technologies. Moreover, MP use can be considered as a sort of brain gymnastics or neurofeedback training (but still random and not “knowledge based”).

Thereby, EEG spectrum weighted frequency (brain rate), characterizing the level of mental arousal, can serve as a useful preliminary indicator of possible MP influences, and a training parameter.

Acknowledgement

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Authors contributions

JPJ contributed to neurophysical modeling.
NPJ contributed to neuromedical studies.
Both authors participated in the design and approved the final manuscript.

References

5. ICNIRP. Guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz to 100 kHz). Health Physics 2010; 99(6): 816-836.


Illustrations

Illustration 1

**EEG range frequencies from mobile phones (MP)**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Modulation frequencies (kHz)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDMA</td>
<td>8.34 PM n = 8.34 AM</td>
<td>[1]</td>
</tr>
<tr>
<td>GSM (TDMA, DTX)</td>
<td>8 (talk) 2, 8 (listen)</td>
<td>[14, 15]</td>
</tr>
<tr>
<td></td>
<td>1-32 (standby)</td>
<td></td>
</tr>
<tr>
<td>TETRA</td>
<td>17.6</td>
<td>[10]</td>
</tr>
</tbody>
</table>

Illustration 2

**MP effects on EEG [1]**

<table>
<thead>
<tr>
<th>Model</th>
<th>Exposure conditions</th>
<th>Results</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>C57Bl6</td>
<td>147 MHz; 1-15 [1] kHz, up to 10 W/m², 5 kHz, estimated as 0.045 W/kg (WHD, 1993)</td>
<td>Changes in EEG</td>
<td>[16, 17]</td>
</tr>
<tr>
<td>Rats and rabbits</td>
<td>2.45 GHz 7 W/kg for 50 days; 0.1-5 mW/m²</td>
<td>Changes in EEG</td>
<td>[18]</td>
</tr>
<tr>
<td>Rats</td>
<td>0.25 MHz; 100 W/m²; AND 2.45 GHz; 50 W/m²</td>
<td>No effects on spontaneous or evoked EEG</td>
<td>[19]</td>
</tr>
<tr>
<td>Rats</td>
<td>2.45 GHz; 2.7 W/kg; 7 h</td>
<td>No consistent changes in spectral power</td>
<td>[20]</td>
</tr>
<tr>
<td>Rats</td>
<td>2.45 GHz; GW or A/C at 16 kHz</td>
<td>Changes in spectral power with 2.5 GHz in beam at 8.5 W/kg and above</td>
<td>[21]</td>
</tr>
</tbody>
</table>
Illustration 3

**MP effects on human mental activity**

Numerous studies:

- reaction time – shorter or no change
- accuracy – poorer or no change
- memory – worse or not replicable
- sleep – delayed

*See e.g. recent comprehensive articles [3], [10] and [22]*

But: Strong inter-individual differences

Illustration 4

**Summary**

(empirical plus theoretical)
Illustration 5

Polychromatic fields

Spectrum weighted frequency (brain rate):

\[ f_b = \sum f_i \frac{v_i}{v} \]

\[ i = \delta, \theta, \alpha, ... \]

Indicator integrating relative contributions from all bands.

Illustration 6

Brain rate for sleep stages and some mental disorders

(Combining the results from [23] and [24])
Illustration 7

Mapping of brain rate

Illustration 8

EEG effects of MP exposure (1)
(six frequencies from 4 to 50 Hz)

F region: increase of alpha and beta;
B region: decrease of alpha 2 [25].

Consequence:
F brain rate increase
B brain rate decrease
- resulting in specific mental activations
Illustration 9

EEG effects of MP exposure (2)
(1.5, 2, 10 or 40 Hz)

EEG time variability and/or power density have changed individually, both in intensity and in laterality [26-29].

Brain rate: correspondingly volatile

Illustration 10

EEG effects of MP exposure (3)
(CSM MP mounted on left posterior T region)

- During encoding: increased theta ERD in left T;
- During recognition: increased theta ERD in left T and 1.5Hz ERD in right T [30].

In both active MP cases, brain rate is correspondingly diminished.
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