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Review

ELECTROMAGNETIC FIELDS OF CELLULAR COMMUNICATION AS RISK FACTORS ABLE TO PRODUCE NEGATIVE EFFECTS ON THE CENTRAL NERVOUS SYSTEM OF CHILDREN AND ADOLESCENTS (REVIEW). PART 1. MODELING. PARAMETERS OF ELECTROENCEPHALOGRAPHY AND SENSORIMOTOR REACTIONS

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It is quite relevant to investigate possible outcomes of exposure to radio frequency electromagnetic fields (RF EMF) since contemporary children and adolescents have become active users of the most advanced technologies. They are especially susceptible to electromagnetic factors; therefore, it is necessary to have a proper insight into outcomes of such exposures for the body.

The central nervous system (CNS) is one of the main targets under exposure to RF EMF. In most cases, users hold mobile phones close to their heads thereby directly exposing their brains to RF EMF.

As the analysis of literature data has shown, there are few studies in this area; however, proposed options for assessing the impact of RF EMF on children and adolescents are very diverse.

This part of the review focuses on various types of modeling. These are not only phantom, voxel models or the finite difference method but also new approaches such as distribution matrices, Monte Carlo simulations and an integrated radio frequency model based on the results of magnetic resonance imaging of the brain and other methods.

The review provides the results obtained by investigating encephalography under exposure to RF EMF created by mobile communication devices. They are rather contradictory; however, changes in the bioelectrical activity of the brain are detected in most cases, in particular, a decrease in the alpha rhyme.

Since the characteristics of sensorimotor reactions quite clearly reflect the power relations in the cerebral cortex, we analyzed changes in the parameters of simple auditory-motor and visual-motor reactions in children and adolescents who were mobile communication users. In addition, the review covers the results of changes in working capacity, fatigue, the duration of an individual minute and the reproduction of a given rhythm.

Keywords: *radio frequency electromagnetic field, central nervous system, modeling, electroencephalography, psychophysiological indicators, children, adolescents, risk factor.*

At present, radio frequency electromagnetic fields (RF EMFs) are a constant source of technogenic pollution in the environment. Radiation created by base cellular communication stations is their primary example. Such stations generate RF EMFs round the clock and create lifetime exposure to them for the whole population, children included.

In addition to them, RF EMFs are also created by Wi-Fi sources as well as by multiple gadgets that have started to employ 5G technologies. Even if we believe these radiations to be ‘less intensive’, their combined effects on the population, including children and adolescents, can induce variable outcomes, which are very hard to predict or estimate.

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By now, a body of evidence has been accumulated on negative effects produced by RF EMFs at any organizational level, from the molecular one to the whole body. Assessment of these effects on children and adolescents occupies a special place among such studies since these population groups are the most susceptible to any external exposure. Undoubtedly, this primarily concerns the central nervous system (CNS) and despite some existing controversies on the matter [1], it is a well-known fact that wide use of wireless communication devices leads to negative health outcomes [2–4].

At present, effects produced by RF EMFs on the CNS of children and adolescents are being investigated per several directions: modeling, assessing parameters of sensorimotor reactions, electroencephalography (EEG) indicators and cognitive functions. The reason is that children and adolescents hold mobile phones close to the head when using them; therefore, most studies focus on identifying likely negative effects primarily on the CNS, the brain being the key 'target'. Moreover, if we remember that even six-month old children can be active gadget users [5, 6], it seems extremely relevant to assess effects of exposure to RF EMFs on the younger generation.

Modeling of RF EMF exposure effects on children and adolescents. As the analysis of literature data has shown, there are few studies in this area; however, proposed options for assessing the impact of RF EMF on children and adolescents are very diverse.

Phantom models were employed by P. Dimbylow et al. (phantoms of a male infant aged 9, 11 and 14 months and a female child aged 4 and 8 years) [7] and by B.B. Beard and W. Kainz (the head model of a child aged 7 years) [8]; voxel models were used by P. Dimbylow et al. (a female newborn) [9], R.P. Findlay et al. (a 10-year old child) [10]. The finite differences method was actively used by O.P. Gandhi et al. in their cycle of research works [11–14] and J. Keshvari et al. (3 and 7-year old models) [15, 16], studies by J. Wiart (5- and 8-year old models) [17, 18], as well as in a study by M.S. Morelli et al. (a male and female child) [19] to assess absorption of radio frequency (RF) energy at 28 GHz concerning use of smartphones / tablets.

There are new approaches to modeling: distribution matrices [20], an approach that was patented in 2017[1]; Monte-Carlo simulations in uncertainty analysis of mobile phone use [21]; the integrated radio frequency model based on volumes of the brain obtained by magnetic resonance imaging [22]; methods that involve dose modeling [23–25]; as well as the near-surface tissue model illuminated by a plane wave to assess exposure to a millimeter wave range (5G technology) [26].

As the analysis of literature data has shown, there are few studies that involve modeling of RF EMFs exposure considering age-related specific features. Nevertheless, the analysis results give grounds for paying much closer attention to the electromagnetic radiation burden for children and adolescents who use up-to-date gadgets.

Undoubtedly, there are instrumental methods for assessing RF EMFs exposure but their analysis is beyond the scope of the present review.

Electroencephalogram (EEG) parameters in children and adolescents. EEG parameters are known to be eligible for examining morphofucntional maturity of the brain and its systems; therefore, it is relevant to pay attention to likely changes in EEG parameters in children and adolescents upon exposure to RF EMFs. However, our literature analysis has established that such studies are scarce.

In particular, a study with is focus on effects of 2G and 3G on respondents from different age groups established that the alpha rhythm amplitude grew only in 2G-exposed adolescents [27]; when EEG and cognitive functions were being registered simultane-

[1] Babalyan A.V., Karelin A.O., Starun R.G. Method of measuring the density of the electromagnetic radiation energy flow from mobile phone: the patent RU 2 626 049 C1. *Izobreteniya. Poleznye modeli. Ofitsial'nyi byulleten' Federal'noi sluzhby po intellektual'noi sobstvennosti (Rospatent).* Moscow, FIPS, 2017, bulletin 21, 11 p. (in Russian).

ously, less accurate performance was detected, which was more manifested in adolescents upon exposure to 3G against 2G [28].

O.A. Vyatleva with colleagues reported a significant EEG-effect in their cycle of research works, which was detected in registering EEG changes in children aged 6–13 years even upon a short-term (3 minutes) exposure to RF EMFs created by mobile phones (MP). This effect was a decline in the absolute alpha rhythm capacity. However, intensity of this effect, as shown in the studies, depended on a MP RF EMF dose and a respondent's age. Thus, an effect on EEG caused by MP with the energy flux density (EFD) being approximately 100 μW/cm² caused a decline in alpha activity in all respondents and was bilateral with ipsilateral prevalence (on the same side with a radiation source). The authors believe this is evidence that radiation of such intensity is able to influence not only surface cortical zones of the ipsilateral hemisphere but also deep synchronizing brain structures. Less intensive EFD (lower than 1 μW/cm²) produced an effect on EEG only among children aged 6-10 years and was local ipsilateral, which indicates that radiation of such intensity is able to affect only surface cortical areas in the ipsilateral hemisphere [29]. In addition to that, active MP use (the highest EFD is above 100 μW/cm²) not only inhibits bioelectrical activity in the deep areas of the brain but also weakens generalized paroxysmal activity together with stimulating activity of the sympathetic nervous system centers that regulate heart rate [30]. An association was also established between MP use, changes in EEG, a total absorbed dose of electromagnetic radiation and parameters of the short-term auditory and speech memory [31].

However, some studies do not report any changes in EEG parameters or cognitive processes in adolescents aged 11–13 years [32]. The conclusions were made based on results of a short-term exposure to RF EMFs. Moreover, later this author, though in collaboration with other experts, put forward a hypothesis that adverse effects on cognitive functions and EEG parameters corresponded exclusively to the thermal mechanism of exposure [33].

Nevertheless, among such studies, a work by A.V. Gilev and O.B. Gileva [34] deserves special attention; the authors compared EEG parameters during simultaneous solving of an arithmetical problem, verbal-logical problem and a problem that requires spatial thinking. The problems were solved by 12-year old adolescents who attended a digital school and a school that mostly relied on conventional teaching technologies. Thus, when children from a conventional school tried to solve experimental tasks, a growth in bioelectrical activity in teta- and beta- ranges was apparent and distributed correctly over cortical areas. In contrast to that, teta-rhythm capacity grew only in the polar derivations in adolescents from a digital school. This may indicate deficiency of attention, memory, motivation and targeted behavior, which manifested itself through low efficiency in solving experimental tasks.

Since a digital school means wide use of various electronic teaching aids, which, in their turn, are powerful RF EMFs sources, we can obviously expect the total electromagnetic background being higher under such learning conditions than under conventional ones. Consequently, it can lead to changes in EEG parameters and levels of cognitive processes.

In addition to EEG parameters registration, there are simpler methods that make it possible to assess the CNS functional state. They include identification of time required for simple sensorimotor reactions, which are commonly used in psychophysiological investigations since they quite clearly reflect power relationships in the brain cortex.

Sensorimotor reactions and other psychophysiological indicators as criteria for assessing RF EMF effects on the CNS of children and adolescents. A possibility to use descriptions of sensorimotor reactions as indicators of the CNS functional states has been analyzed in reviews by S.V. Shutova with colleagues [35], A.N. Nekhoroshkova with colleagues [36] and a study by S.S. Geertsen and others [37].

However, parameters of sensorimotor reactions are very rarely used to assess effects of

RF EMFs created by mobile phones on the CNS of children and adolescents.

Nevertheless, our investigations that have been conducted since 2006 within surveillance of children and adolescents' psychophysiological indicators have established certain regularities as regards changes in parameters of sensorimotor reactions in children and adolescents who are active mobile phone users.

An effect of a longer time needed for simple audio-motor reaction both upon stereo- and mono-presentation of an audio signal manifests itself only upon reaching a certain total time of mobile phone use by a child: 360 minutes in case a child started to use a mobile phone at the age of seven years and 750 minutes for children who did it at nine. We were the first to establish that all children who used MP more frequently had impaired phonemic perception (incorrect perception of similar sounding or similarities in articulation of speech sounds manifested through replacement of letters and syllables, incorrect reading or word pronunciation, etc.). We also registered a contralateral effect (on the side opposite to RF EMF exposure created by a mobile phone) in 79.3 % of cases [3]. However, this contralateral effect weakens with age whereas the ipsilateral one only grows but the process is not linear: a value of changes in parameters of simple audio-motor reaction can be used as a predictive index by changing a time of a reaction to an audio signal in mobile communication users[2]. In addition, peculiarities of the contralateral and ipsilateral effect for each age group depend both on a time daily spent on using a mobile phone and on the total duration of its use [38].

Moreover, we were the first the reveal an association between parameters of simple audio audio-motor reaction and parameters of the reproduction of a given rhythm with three frequency ranges, 1000 msec, 750 msec and 1500 msec and the duration of the individual minute [39]. Longer reaction time in children and adolescents who were active mobile communication users was also established for visual-motor reaction[3].

We compared dynamics of changes in audio- and visual-motor reactions. As a result, it was established that a time of a reaction to an audio signal, that is, parameters of simple audio-motor reaction, could be considered a 'more sensitive' indicator under exposure to mobile phone radiation. In particular, the total time of mobile phone use that leads to longer time of a reaction to a light signal in 7-year old children equals 730 minutes for visual-motor reaction and 360 minutes for simple audio-motor reaction [3].

In addition to sensorimotor reactions, some other indicators are employed to estimate the CNS functional state. They include fatigue (measured by using muscle strain level established by tremor assessment) and work capacity (measured by the tapping test). Children and adolescents who were active mobile communication users were established to have elevated fatigue levels together with lower work capacity [3].

It should be noted that sensorimotor reactions are used as mediated characteristics of cognitive processes. This is related to the fact that such indicators as 'reaction time' and 'reaction accuracy' correlate with the R2 component of the brain EEG, which denominates evoked cognitive potentials, and allow establishing maturity of a child's perception processes [40], which are sex-related [41]. As A.N. Nekhoroshkova with colleagues pointed out in their review [36], methods applied to measure indicators of sensorimotor reactions are quite relevant for psychophysiological investigations of both human cognitive and emotional-personal spheres.

Conclusion. In this review, we have analyzed findings reported in studies with their

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[2] Khorseva N.I., Skidanova A.A., Grigoriev P.E., Shulzhenko N.Yu. The mode of using a mobile phone and individual peculiarities of manifestation of ipsylateral and contralatory effects of simple auditory-motor reaction in children. A pilot monitoring research. *Krymskii zhurnal eksperimental'noi i klinicheskoi meditsiny*, 2018, vol. 8, no. 1, pp. 93–99 (in Russian).

[3] Khorseva N.I., Grigor'ev Yu.G., Gorbunova N.V. Change settings for visual analyzer of child users of mobile communication: longitudinal study. *Radiatsionnaya biologiya. Radioekologiya*, 2014, vol. 54, no. 1, pp. 62–71. DOI: 10.7868/S0869803114010081 (in Russian).

focus on impacts of RF EMFs on the central nervous system of children and adolescents. As a result, we have found quite a wide range of approaches to detection of these impacts starting from exposure modeling to changes in EEG parameters, sensorimotor reactions, fatigue, and work capacity.

Our findings clearly indicate that the CNS of the younger generation is affected. This again highlights the necessity to develop new approaches to regulation covering use of up-to-date gadgets as well as electromagnetic environment, in particular, in the educational process.

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