UDC 57.042+57.049+614
DOI: 10.21668/health.risk/2024.3.15.eng

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Review

ASSESSING THE RISK OF NEGATIVE EFFECTS PRODUCED BY ELECTROMAGNETIC FIELDS OF CELLULAR COMMUNICATION ON THE CENTRAL NERVOUS SYSTEM OF CHILDREN AND ADOLESCENTS (REVIEW). PART 2. INDICATORS OF COGNITIVE PROCESSES

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This paper continues the authors' review that dwells on modeling radiofrequency electromagnetic fields (RF EMF) and results obtained by measuring electroencephalography indicators, sensorimotor reactions, fatigue, work capacity, duration of an individual minute and the reproduction of a given rhythm in children and adolescents.

Health risk assessment is always based on data obtained by either laboratory tests or epidemiological studies. This paper analyses publications that describe effects of RF EMF exposure, including Wi-Fi, on cognitive processes in children and adolescents as well as methodical approaches to investigating this exposure. However, there are few such studies; in particular, effects produced by Wi-Fi exposure on cognitive indicators of adolescents aged 14–17 years, were found only in two publications.

Literature analysis has established that research findings do not always give an unambiguous estimation of RF EMF effects. The review covers the reasons for ambiguous interpretation of research results: a variable range of test-systems used for investigating indicators of cognitive processes; simultaneous analysis of single exposures including descriptions of 'effect of improvement' in indicators; changes in cognitive indicators registered for a group of children and adolescents in a wide age range.

Nevertheless, most results give evidence of negative changes in attention and memory of children and adolescents. Given that, longitudinal studies are becoming especially relevant since they estimate changes in various indicators in dynamics, including those induced by changes in mobile phone use. The review highlights the relevance of comprehensive investigations with their focus on health outcomes of RF EMF exposure intrinsic to 5G technologies considering their global implementation.

Keywords: *radiofrequency electromagnetic field, Wi-Fi, central nervous system, brain, attention, memory, children, adolescents.*

There are surprisingly very few studies on effects produced by radio frequency electromagnetic fields (RF EMF) on cognitive function in children and adolescents despite the issue being topical at present. This review focuses on studies that investigate changes in cognitive processes in children and adolescents, who actively use mobile communication, and primarily concentrate on chronic RF EMF exposure.

At present, authors of reviews that analyze accomplished studies in the sphere mostly highlight ambiguous and even controversial results obtained in investigating effects produced by RF EMF on cognitive function indicators in children and adolescents [1, 2].

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T. Ishihara et al. [3] and J.-H. Moon [4] suggest a very cautious approach to assessing RF EMF exposures, including their effects on cognitive function in children and adolescents, in their works published in 2020.

In particular, having analyzed findings reported in 12 relevant studies, T. Ishihara et al. pointed out that no significant negative effects of RF EMF on cognitive function in children and adolescents were detected in 86 % of the analyzed cases. However, the authors selected very dissimilar studies for their analysis as regards both respondents' age and duration of use, mobile phones (MP) included, and analyzed parameters. We believe this to be the reason for such ambiguous conclusions.

A study by C. Sage et al. [5] presents a very nontrivial approach to investigating RF EMF effects on cognitive function in children and adolescents: analysis of epigenetic research. However, this work was criticized by D.R. Grimes and D.V.M. Bishop, who stated that overwhelming majority of available research data give evidence that microwave and radio frequencies employed in up-to-date communication devices are quite safe [6]. However, it is unclear what was used by the authors as solid grounds for such categorical statements.

On the contrary, a review by O.A. Vyatleva illustrates that intensive use of smartphones by children and adolescents results in declining cognitive function as well as slower maturation of the cortical zones responsible for speech, attention, emotion, reinforcement, and executive functions [7]. These statements are further confirmed by findings reported in the previous studies by J. Ferreira et al. and C. Fernández et al. that involved modeling of RF EMF exposures for mobile phone and tablet users [8, 9].

We believe there are several reasons for this 'ambiguity' related to negative RF EMF effects on cognitive function in children and adolescents.

First, many diverse test-systems are employed in the analyzed studies to investigate changes in indicators of cognitive processes upon RF EMF exposure.

In particular, foreign studies employ a wide range of tests to assess cognitive function upon RF EMF exposures including the Woodcock – Johnson Letter-Word and Passage Comprehension test [10]; assessment of inattention as defined for the Attention Deficit component of Attention deficit / Hyperactivity disorder (ADHD) [11]; N-back test [12]; 'Go / No Go' and 'Groton maze' learning tasks [13]; neuropsychological tests (Hanoi tower test, digit span test, K.A.S. test, stroop test, digit symbol test, Beck depression inventory test and Benton judgment of line orientation test) [14]; the Amsterdam Neuropsychological Tasks [15]; visual discrimination task and a modified Sternberg working memory task [16]; wide variety of computer test systems [17–23]; CogHealth™ specialized software package [13, 24].

Russian researchers also employed several methods in their studies including questioning [25], filling in the forms 'Arranging Numbers' and 'Memorizing Numbers' [26], instrumental tests performed on an automated psychophysiologist work station [27], LUM (local universal monitoring) software package [28].

Nevertheless, despite this wide range of test systems, few studies investigate RF EMF effects on cognitive function in children and adolescents.

Second, reviews very often cover findings reported in studies that investigate only one-time RF EMF exposure and sometimes even describe some improvement in cognitive indicators [19, 29].

Multidirectional effects were reported for primary schoolchildren of the 1^{st}–3^{rd} grade in a study by O.A. Vyatleva and A.M. Kurgansky. Some negative effects were detected but still the authors found negative correlations between attention and memory and duration of active MP use. The authors labeled these effects as 'stimulating influence', which was not associated with exposure to MP ra-

diation but rather depended on skills of MP use [25]. However, changes in cognitive function were assessed by questioning in this study and not by using special diagnostic methods.

It is worth noting that such effects of 'seeming improvement' in psychophysiological indicators were described in our works as well when we performed longitudinal studies to investigate changes in psychophysiological indicators of children and adolescents who actively used mobile communication. We believe that this effect may be caused by adaptation responses to this external exposure being rather new for children and adolescents as well as by the exposure being quite short-term (including cases of short experience of MP use) [27].

In addition to that, reviews often cover studies without any detected exposure effects reported in them. These controversial effects produced by RF EMF exposure on cognitive function in children and adolescents were previously discussed in the book [27] and monograph [28].

Third, changes in cognitive function are usually registered for groups of children and adolescents with wide age ranges; practically all studies perform age-specific analysis of using MP or other gadgets for each age group but cognitive function is typically characterrized for the whole data array without considering age-specific features. This group of studies can be tentatively divided into several basic groups:

1. Studies that investigate changes in cognitive function with simultaneous instrumental assessment of levels of exposure to affecting RF EMF. Studies by O.A. Vyatleva with colleagues [25] and S.A. Meo et al. [30] are good examples of this approach. The former work reported a 'stimulating effect' of exposure to MP RF EMF [25]; the latter reported that higher RF EMF created by base stations resulted in delayed spatial working memory and attention and affected fine and gross motor skills [30].

2. Studies that investigate combined RF EMF exposures coming from various sources. Thus, M. Guxens et al. employed a 3D spatial model to assess the relationship between residential RF EMF exposure from mobile phone base stations, residential presence of indoor sources, personal cell phone and cordless phone use, and children's cognitive function at 5-6 years of age. Yet, the study findings were rather controversial [15]. In contrast to the study by M. Guxens et al., A. Cabré-Riera et al. assessed RF EMF doses for two groups of adolescents aged 9–11 years and 17–18 years in 2 population cohorts in the Netherlands and Spain not for all analyzed sources combined but separately (mobile phones, screen activities and far-field). The study established that higher overall estimated whole-brain RF EMF doses from all RF EMF sources together and from phone calls were associated with lower non-verbal intelligence score [31].

3. Studies that focus on the relationship between indicators of cognitive processes [11, 17, 18, 21] and academic performance [32] and the MP use mode. Although authors of most publications detected certain negative changes in cognitive function, the very approach to such studies is rather questionable. In particular, M.J. Abramson et al. accomplished their study on adolescents aged 11–14 years where they established poorer accuracy of working memory and longer completion time for tasks both for adolescents who used MP most frequently and for people who sent many SMS. On this basis, the authors assumed that cognitive changes were unlikely due to exposure to radiofrequency [17]. We believe that such conclusion can be made only basing on comparison of cognitive indicators identified for students who used SMS only and those identified for students who used MP exclusively for talking. Practically the same results were obtained by S. Thomas et al. (adolescents aged 12–13 years) [18]; however, in contrast to M.J. Abramson et al. [17], the authors investigated changes in cog-

nitive function in dynamics one year after considering changes in the MP use mode, including voice calls and SMS. They detected changes in simple reaction time and working memory task but no correlation was identified between mobile phone exposure and cognitive test completion. However, the authors make the same methodical mistakes in this study as M.J. Abramson et al. did when interpreting their study findings. F. Zheng et al. detected higher inattention in those secondary school students (aged 12–20 years) who played games on their MP for more than one hour a day [11]. In this case, we believe the detected effects to be more closely associated with 'screen time' of a gadget than to its electromagnetic radiation. Finally, by using questioning, X. Liu et al. established a correlation between duration of MP use and academic performance of schoolchildren aged 12–18 years: those adolescents who actively used MP (≥ 2 hours/day on weekdays and ≥ 5 hours/day on weekends) had a considerable decline in academic performance against those who used MP less actively [32]. However, the authors did not provide any information about what adolescents used their MP for (voice calls, SMS, MMS, watching videos, etc.).

4. Studies that compare effects of MP exposure and exposure to cordless phones (CP) on students' cognitive function. M. Redmayne et al. detected poorer cognitive function in a cohort of schoolchildren aged 8–11 years due to MP and CP use; however, the authors believe that their study findings do not give unambiguous evidence of negative effects produced by MP and CP RF EMF [21]. Prospect (longitudinal: the authors' remark) studies hold a significant place here [20, 23, 33, 34], in particular, cohort studies on cognitive function of Swiss adolescents aged 12–17 years with simultaneous assessment of RF EMF cumulative dose [20, 23, 24, 33]. Yet, the obtained results are still ambiguous. For example, A. Schoeni et al. believe that RF EMF exposure affects memory since a decline in figural memory performance was more apparent in MP users against CP users [20]. Nevertheless, in another study, the same authors did not find any negative changes in attention concentration and behavior in adolescents who used MP and CP [32]. A study by M. Foerster et al. [23] compared indicators of cognitive processes in adolescents from the 7–9th grades with a cumulative individual microwave radiation dose from mass media, both associated and not associated with RF EMF (in particular, mobile phones). The authors established poorer figural memory in MP users. Similar results were reported in a prospect study accomplished in Australia on primary school students as poorer cognitive function was detected in MP users and not CP users [24]. We believe that the obtained results were so ambiguous because all these studies analyzed indicators detected for the whole data array without considering age-specific features of the analyzed groups.

5. Complex studies with their focus on psychophysiological indicators, including those describing how well cognitive function is developed in children and adolescents who are active mobile communication users. Among such works, we should mention longitudinal cohort studies involving children and adolescents aged 5–16.5 years that have been accomplished in Russia since 2006 [27, 28]. In contrast to most studies, cognitive indicators are assessed separately for each age group and any dynamics of changes in them is estimated considering MP use mode. Semantic memory has been established to decline more than volitional attention in children who are active mobile communication users; also, many indicators in them are at the bottom limit of the age-specific physiological norm or already below it. The obtained results confirm that chronic exposure to MP electromagnetic radiation can have considerable effects on psychic cognitive processes in children and affect their academic performance. It should be noted that preventive measures taken within this monitoring and

aimed at implementing safe culture of modern gadget use (first of all, MP) have been proven to be effective. Psychophysiological indicators of schoolchildren who adhered to safe user modes improved significantly and returned to their age-specific physiologic range [28, 35, 36].

At present, new technologies, Wi-Fi among them, are being implemented quite actively and are being used everywhere, including educational establishments. However, many researchers do not pay any attention to likelihood of negative effects that might be caused by this implementation. There is an established opinion that since values of electric field intensity and power density are below the threshold values stipulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), any risks of negative effects are minimal. However, the issue is far from being resolved and accumulated experimental studies, which we presented in the previous review, are clear evidence of it. In addition to that, many countries (France, Italy, Greece, Germany – Bavaria, Belgium, Great Britain, Tajikistan, Azerbaijan, Belarus, and Bangladesh) have introduced the full prohibition on using this technology in schools or imposed considerable limitation on its use. This was done to prevent possible negative effects on children and adolescents.

The literature analysis shows that very few studies investigate influence on children and adolescents. In particular, we can mention works by K. Bamdad et al. and M.A. Hosseini et al. The former reported the adverse consequences of 2.4–2.48 GHz radiofrequency electromagnetic fields of Wi-Fi router devices on divided attention levels of female university students (aged 14–17 years) [37]; the authors of the latter did not establish any effects on cognitive function upon short-term exposure to Wi-Fi waves [38].

At present, special attention should be paid to wide-scale implementation of 5G technologies. Although there still have not been any studies on biological effects of the 5G standard [39], nevertheless, likely impacts on population health remain the most acute issue [40].

Given that, general polemics about biological effects of 5G should, in our opinion, primarily include a discussion about how this standard may affect children and adolescents. This age groups happens to not only be the most sensitive to changes in any environmental factors but also have a greater 'potential' to become vulnerable to EMF created by the 5G standard. This is because higher frequencies of the standard are intensely 'absorbed' from ambient air into the water component in human sweat and derma cells thus resulting in higher absorption [41]; since children tend to have more 'watery' skin than adults, this potentially increases their radiosensitivity.

The fact is that at present active implementation of 5G technologies is considerably ahead of hazard assessment for lifelong millimeter range exposures on skin and eye sclera, primarily in children and adolescents [42, 43].

We believe the problem requires immediate solution in order to identify potential adverse effects of such exposures.

Conclusion. A developing body is known to be especially sensitive to electromagnetic environmental factors. In particular, this concerns the central nervous system. Since most children start to use gadgets with active RF EMF already at preschool age, this calls for revision of approaches to assessing risks caused by such exposures. This means developing new methods for modeling both absorbed RF EMF doses and effects of acute and chronic exposure to RF EMF of mobile communication devices assessed per intensity of their use.

Most researchers highlight negative RF EMF effects on functional indicators of the central nervous system, cognitive function in particular. Still, some studies have established no adverse effects. We believe this is due to different methodical approaches and many

diverse tests systems employed to detect any possible effects.

At present, it is important to continue studies with their focus on possible negative effects produced by RF EMF on the central nervous system in children and adolescents. We believe it might be useful to adopt useful practices from other countries where use of some technologies, Wi-Fi for example, is limited in educational establishments. In additional to that, researchers should pay the greatest attention to establishing every possible effects caused by exposure to RF EMF created by 5G-based devices.

Funding. The study was accomplished with the state task given to Institute of Biochemical Physics of the Russian Academy of Sciences named after N.M. Emanuel (44.1, the state registration No.: 0084-2019-004).

Competing interests. The authors declare no competing interests.

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Received: 24.08.2024
Approved: 13.09.2024
Accepted for publication: 20.09.2024