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Mobile-Phone RF/Microwave Exposure and Memory Performance Scores in Adolescents

The marketing of mobile phones to youngsters is no longer a forbidden subject, as it once was. Mobile phones – and especially smart phones – have become such a popular phenomenon that the marketing success to young people could perhaps be looked upon as by default or maybe by design, although it might be debatable either way. However, that's for another time. Nevertheless, France, among others, has banned the use of mobile phones in primary, junior, and middle schools, both inside the classroom and even outside, in the school playground [1, 2].

What is more, hundreds of millions of toddlers and teenagers now have their own handsets, or similar wireless devices or gadgets. Indeed, mobile phones may have replaced pacifiers for toddlers, or become high-tech babysitters for others. Mobile phones are turning up as common accessories for most teens. Reports suggest 95% of teens now have access to a smart phone [3]. Nevertheless, the potential impact of microwave and radio-frequency (RF) electromagnetic fields and radiation emitted by mobile phones and wireless devices on the cognitive functions of adolescents persists as a public-health worry [4, 5].

There are concerns because, for children who still have years of development ahead of them, any disturbance to brain function could lead to impaired learning ability. A remarkable cascade of neural activities is invoked during learning and memory, which include such functions as encoding, processing, and retrieval of information. Moreover, any lasting neurochemical effects could have important consequences in children's lives, including potential behavioral issues.

Some investigations have reported that exposure to mobile-phone RF/microwave radiation can affect such cognitive functions as attentional function, short-term memory tasks, information manipulation, or response reaction times in adults [6]. However, due in part to ethics issues regarding research studies involving children, very few studies have targeted adolescents and preteens.

A dozen years ago, two small-scale studies of young users were conducted using standard GSM 900 MHz mobile phones (a Nokia 3110 headset in normal-use position with a typical 0.25 W output power). One paper from the UK reported a slight trend toward speeding up of simple reaction time [7], whereas the other study from Finland did not detect any change in cognitive functions [8].

In the UK investigation, the effect on cognitive function was studied in 18 preteens who were 10 to 12 years of age [7]. The study involved a series of tests with three measures of cognitive performance: (a) reaction time (in ms), (b) accuracy for percent correct, and (c) a sensitivity index, which is a measure of the effect of distracting or novel information. The test sessions were conducted on sequential days. Each session took about 30 to 35 minutes to complete. This study found some trends toward faster reaction times, higher accuracy, and higher sensitivity in the presence of RF/microwave radiation from a GSM mobile phone than

under sham exposure (power-off) conditions. However, none of these effects reached statistical significance.

The study in Finland recruited twice as many subjects, ranging from 10 to 14 years of age [8]. The subjects performed a battery of eight cognitive tests, twice in a counterbalance order, in separate sessions with the mobile phone on and with the mobile phone off, for sham exposure. The tests consisted of four reaction-time tasks and four short-term memory tests. The sessions were separated by 24 hours. The study did not show any significant differences between the mobile-phone power on-off conditions in reaction times or response accuracy over all tests or in any one of the tasks.

Combining the results of this study with those of the UK investigation, it may thus be concluded that RF/microwave radiation from GSM mobile phones has no acute effect on a 10-to-14-year-old's cognitive function, as measured by response time and accuracy. However, the numbers of subjects were small in both studies, which were acute and short-term in nature. The limitations make it difficult to draw any firm conclusions concerning the sensitivity of youngsters to RF/microwave radiation from mobile phones, even for acute exposures at low levels.

A couple of recent Swiss studies of adolescents have reported adverse effects on cognitive functions (specifically, memory-performance scores) that involve brain regions exposed to higher cumulative levels of RF/microwave radiation associated with GSM (900 MHz), GSM (1,800 MHz), and UMTS (2,000 MHz) mobile-phone use [9, 10]. The latest study was a continuation and expansion of a prior study. It employed a better estimation of absorbed RF/microwave radiation.

The aim of the first study was to investigate associations between memory performance and cumulative exposure to RF/microwave radiation from mobile phones [9]. It was a prospective cohort study, with 439 adolescents from 12 to 17 years of age as participants. At baseline or the beginning of the study, 412 (93.9%) of the participants owned a mobile phone; one year later, 425 study participants remained in the study. Of those, 416 (97.9%) owned a mobile phone. Mobile-phone-operator recorded data for 234 study participants were obtained between the beginning and end of the investigation; the average interval was 12.5 months.

Verbal and figural memory tasks at baseline and after one year were conducted using standardized, computerized cognitive tests. It is noted that different brain regions are known to be involved in verbal and figural memory tasks. In general, figural memory processes predominantly involve the right-brain hemisphere, whereas verbal memory tasks mostly involve the left hemisphere.

In the verbal memory task, word groups were memorized in 1 min. After 1 min, the subjects were asked to repeat the word groups. A score of 10 was recorded for remembering the correct word groups. In the figural memory task, pairwise symbols were memorized in 1 min. After 1 min, one part of the pairwise symbols was displayed and the matching part had to be found. A perfect score of 13 was recorded for correct responses. For both verbal and figural tests, a total of 2 min was allowed for test completion. Memory performance was assessed by the correct number of memorized word groups or symbols, respectively.

Exposure-assessment methods employed included questionnaires and mobile-phone-industry (operator) recorded user data for a subgroup of 234 adolescents. Exposure to various wireless devices in the immediate environment (access points, base stations, and RF broadcast transmitters) was enquired by questionnaire. It is noteworthy that self-reported call durations were seven times higher than what was recorded by their operators. RF/microwave exposure for the brain was analyzed using a longitudinal approach to investigate whether cumulative exposure over one year was related to changes in memory performance. All analyses were adjusted for relevant confounders, including media usage and motivation of the participants. It appeared that confounding did not have a substantial impact on the results.

As a special emphasis, absorption of RF/microwave energy in the brain was computed from propagation-scenario modeling and personal dosimeter measurements. The most relevant contributors for RF/microwave power deposition in the brain were calls on the GSM mobile phone networks (on average, 93.3% for the whole sample based on self-reported data, and 58.7% for the sample with operator data using operator-recorded information).

In this case, figural memory scores were found to be associated with cumulative RF/microwave brain exposure in adolescents. However, no association was observed for verbal memory performance. Higher cumulative RF/microwave exposure of the brain was associated with a correlated decrease in figural memory performance over a one-year period, and a stronger decrease was observed in right-sided mobile-phone users. In particular, results obtained in this study showed that compared to low-exposure groups (below 7.6 min/day, 710 mJ/kg per day for brain), significant decreases ($p < 0.05$) were observed in higher-exposure groups (18.6 min/day to 293.9 min/day, 1,854 mJ/kg to 16,233 mJ/kg per day for brain). Indeed, it was more so if adjusted for age, sex, school level, physical activity, education of parents, and time between baseline and end of investigation.

As mentioned, figural memory processes in humans are known to involve the right hemisphere of the brain. The observed effects on figural performance were thus consistent with the data that indicated 81.2% of the study participants reported mainly using mobile phones on the right side. However, the study authors advised that the

observed associations should be interpreted with caution, because of the complexity and uncertainty of the correlations and exposure calculations.

The more-recent report was a follow-up study from the same research group. The analysis involved a larger population of adolescents (669 participants for figural memory and 676 participants for verbal memory). Some of the adolescents took part in the earlier study. It also used an updated individual RF/microwave exposure-estimation model [10].

The specific absorption rate (SAR) in the brain of each participant from exposure to mobile-phone emitted RF/microwave radiation was modeled. Namely, individual RF/microwave absorption in brain tissue for the population as a whole was estimated by using objectively recorded operator data from a subset of participants to calibrate self-reported call duration, to reduce misclassification.

Cognitive or memory performance was measured using a computerized testing system consisting of figural and verbal memory subtests, as in the case for the earlier study [10]. For the verbal memory task, participants were given 1 min to memorize five sets of two to five words grouped by their common higher-semantic category (for example, city: Amsterdam, Hamburg, Madrid, Rome, York). The target words were presented by starting with a different letter each time. Immediately after the presenting phase, participants were given a letter, and they had to recall the word starting with that letter and report the higher semantic category to which it belonged. This was repeated for 11 words, producing a maximum score of 11 points for the verbal memory task. For the figural memory task, participants were given 1 min to memorize 13 pairs of abstract figures. Immediately afterward, one item per pair was shown, and participants were asked to choose the correct counterpart out of five possible options. The matching task was repeated for 13 symbols, resulting in a maximum score of 13 points. For each of the two tests, 2 min were given to complete the matching task.

For each participant, the test started with the verbal-memory task. Linear-regression modeling was applied to verbal and figural memory-score changes over one year and to estimated cumulative brain exposure to RF/microwave radiation. Because of the hemispheric dependence of memory function, a laterality analysis was conducted for phone-call ear preference.

As in the earlier study, results of this one-year follow-up study did not suggest any association with verbal-memory performance. However, it found a potential adverse effect of brain exposure to RF/microwave radiation from mobile phones on figural cognitive functions that involve brain regions that were exposed during mobile-phone use. There was also a significant decrease in figural memory score with exposure of brain matter on the same hemisphere for right-side users.

The study showed decreased figural memory scores of -0.58 (95% CI: -1.17 to 0.01) per 953 mJ/kg per day increase in cumulative brain exposure of the whole sampled population ($n = 288$). The expected figural memory score could thus decrease by one unit within one year from a cumulative exposure of 1,643 mJ/kg per day (953/0.58) within that year. When only network-operator-recorded data were used for RF/microwave estimation ($n = 63$), the figural memory scores were -0.35 (-1.20 , -0.50) and 341 mJ/kg per day. This would translate to a potential expected figural memory score decrease by one unit within one year from a cumulative exposure of 974 mJ/kg per day (341/0.35) within that year. Aside from differences in sample population size, the whole-sampled population included both sample populations with operator-recorded data and self-reported exposure, after calibration using operator data, which still may not have provided comparable representation of exposure.

This inverse association of cumulative RF/microwave brain exposure was also seen in the earlier paper [9]. Using the same procedure for estimating cumulative brain exposure to RF/microwave radiation, that paper found decreased figural memory scores in association with an increase in estimated cumulative RF/microwave brain exposure: -0.14 (95% CI: -0.40 , 0.14) and 953 mJ/kg per day increase in cumulative brain exposure of the whole sampled population ($n = 381$). Accordingly, there would be an expected figural memory score decrease by one unit within one year from a cumulative exposure of 4,236 mJ/kg per day (593/0.14). When only operator-recorded data were used for RF/microwave estimation ($n = 211$), the figural memory scores were -0.25 (-0.41 , -0.09) and 341 mJ/kg per day. This would give rise to a potential expected figural memory score decrease by one unit within one year from a cumulative exposure of 1,364 mJ/kg per day (341/0.25). (The numbers of participating adolescents quoted differed slightly from those reported in the earlier paper [9].)

Combining the two studies, as was done in the most recent paper, with a total of 669 adolescent participants, the analysis showed that an increase in cumulative RF/microwave exposure of the brain was associated with a significant decrease in figural memory score: -0.22 (-0.47 0.03) and 953 mJ/kg per day increase in cumulative brain exposure of the whole study population. The estimated figural memory scores would decrease by one unit within one year from a cumulative exposure of 2,695 mJ/kg per day (593/0.22). If only operator-recorded data were used for estimating RF/microwave exposure ($n = 274$), the figural memory scores were -0.26 (-0.42 , -0.10) and 341 mJ/kg per day. This would suggest a potential expected figural memory score decrease by one unit within one year from a cumulative exposure of 1,312 mJ/kg per day (341/0.26).

A significant decrease in figural memory score with cumulative brain exposure was further seen in laterality analysis for right-side users of both the whole study

population and those with only operator-recorded data. Analysis of participants with right-side preference (whole sample, $n = 532$ and operator data sample, $n = 217$) yielded figural memory scores of -0.38 (-0.67, -0.09), for 953 mJ/kg per day and -0.29 (-0.46, -0.11) for 341 mJ/kg per day increase in cumulative brain exposure, respectively. The estimated figural memory score would thus decrease by one unit within one year from a cumulative exposure of 2,508 mJ/kg per day (593/0.38) and 1,176 mJ/kg per day (341/0.29), accordingly.

The inverse association of cumulative RF/microwave brain exposure was thus consistently seen in the two linked studies and in the combined analysis of entire sample population who participated in the two linked studies, as well as in the adolescent population with operator-recorded exposure data. However, the strength of the association somewhat differed. The association was stronger in the second study than in the first study, although with a wider confidence interval. The association was statistically significant in the operator data, but not when combined with self-reported exposure estimates.

The question of whether RF/microwave radiation emitted by mobile phones during use could disturb brain activity in children and lead to impaired learning ability or behavioral problems has persisted for some time. To date, there remains a paucity of existing scientific data and relevant knowledge, including data on cognitive functions of adolescents. The question cannot thus be easily answered, based on existing scientific evidence. While reported results may lead to the conclusion that RF/microwave radiation emitted from GSM mobile phones does not produce acute effects on an adolescent's cognitive or memory function, available data suggest that significant decreases in figural memory were found to be consistently associated with cumulative exposure of the brain of adolescents to 1,000 mJ/kg to 4,000 mJ/kg per day over one year. Perhaps, a cautionary approach to risk management, especially in relation to children and adolescents, is warranted.

References

1. "Mobile Phone Ban in France" available at https://www.euronews.com/2018/06/08/mobile-phone-ban-in-france.

2. http://www.abc.net.au/news/2018-08-01/france-bans-smartphones-and-tablets-in-classrooms/10060590.

3. M. Anderson and J. Jiang, "Teens, Social Media & Technology," available at http://www.pewinternet.org/2018/05/31/teens-social-media-technology-2018.

4. J. C. Lin, "Children's Cognitive Function and Cell-Phone Electromagnetic Fields," *IEEE Antennas and Propagation Magazine*, **47**, 6, December 2005, pp. 118-120.

5. J. C. Lin, "Cell-Phone Microwaves and Cognitive Function in Children," *IEEE Microwave Magazine*, **7**, 1, 2006, pp. 32-35.

6. J. C. Lin, "Mental Process in Humans and Exposure to Cell-Phone Radiation," *IEEE Microwave Magazine*, **5**, 4, 2004, pp. 26-30.

7. A. W. Preece, S. Goodfellow, M. G. Wright, S. R. Butler, E. J. Dunn, Y. Johnson, T. C. Manktelow, and K. Wesnes, "Effect of 902 MHz Mobile Phone Transmission on Cognitive Function in Children," *Bioelectromagnetics*, **7** (supplement), 2005, pp. S138-S143.

8. C. Haarala, M. Bergman, M. Laine, A. Revonsuo, M. Koivisto, and H. Hämäläinen, "Electromagnetic Field Emitted by 902 MHz Mobile Phones Shows No Effects on Children's Cognitive Function," *Bioelectromagnetics*, **7** (supplement), 2005, pp. S144-S150.

9. A. Schoeni, K. Roser, and M. Röösli, "Memory Performance, Wireless Communication and Exposure to Radiofrequency Electromagnetic Fields: A Prospective Cohort Study in Adolescents," *Environment International*, **85**, 1, 2015, pp. 343-351.

10. M. Foerster, A. Thielens, W. Joseph, M. Eeftens, and M. Röösli, "A Prospective Cohort Study of Adolescents' Memory Performance and Individual Brain Dose of Microwave Radiation from Wireless Communication," *Environmental Health Perspectives*, **126**, 7, 2018, pp. 077007.