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COMMENTARY

Can Wi-Fi Affect Brain Function?

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The accompanying article by Zentai *et al.* (*1*) investigates possible effects of radiofrequency (RF) energy from Wi-Fi signals on human brain wave activity. The possible existence of cognitive effects of RF energy has been one of the more contentious discussions in the forever-contentious issue of whether exposure to RF energy at levels that we all commonly encounter in the environment has any health consequences. Are there any physiological effects from such exposures; and if so, do they have any health significance to exposed individuals?

To date, more than 100 studies have been published on effects of RF energy on electroencephalograms (EEGs) recorded in sleeping or awake individuals [for reviews see Regel and Achermann (*2*) and van Rongen *et al.* (*3*)]. In addition, many studies have examined other end points related to cognition and brain function. Not unreasonably, most of these studies were directed at uncovering possible biological effects from use of mobile phones or other communications equipment held close to the head. While the results are mixed, a fairly consistent finding is that short (10–20 min) RF energy exposures to the head produce small, but statistically significant, changes in the EEG of resting and sleeping subjects, most commonly a decrease in the amplitude of the EEG signal in the alpha band (8–12 Hz). In some studies, no clear changes were observed from exposures to mobile phone RF [e.g., Loughran *et al.* (*4*)], while other studies point to RF-related electrode artifacts as a potential source of error (*5*). In their reviews of the subject, most health agencies acknowledge these findings, but do not consider them as evidence for adverse health effects. For example, a recent review sponsored by the European Commission (*6*) concluded that ''relevance of the small physiological changes remains unclear and mechanistic explanation is still lacking''.

Now Zentai and colleagues have waded into this morass, searching for effects of a single hour-long exposure to Wi-Fi signals on resting EEG and other end points related to cognition in humans. This well-designed study has meticulous exposure assessment and careful statistical analysis. Arguably, it is one of the best studies on effects of RF energy on human cognition in the literature; and its results were completely negative.

While there is a scattering of articles related to biological effects of Wi-Fi signals (*7*), there is an almost complete dearth of studies on effects of Wi-Fi signals on human cognition. In 2011, Papageorgiou *et al.* (*8*) reported that Wi-Fi exposure (from an access point mounted 1.5 m from the subjects) caused statistically significant reductions in the amplitude of event-related potentials (P300 response) in subjects performing linguistic tasks. However, the Zentai and Papageorgiou studies are quite different and their results are neither mutually supportive nor contradictory.

The frequency range of exposure (2.45 GHz) used in Zentai's study was broadly similar to the operating frequency of cellular telephones (which operate in several bands from 698 to 2,690 MHz) but the exposure levels were far smaller. Mobile phones and Wi-Fi transmitters both emit RF energy in the form of pulses, at (very roughly) similar peak output powers [up to about 0.1 W (Wi-Fi) and 1 W (cell phone)]. Phones typically transmit energy at high duty cycles (i.e., a high fraction of their time is spent transmitting). The duty cycle for Wi-Fi access points (the little boxes in the home that transmit Wi-Fi signals throughout the house) and client cards (the transmitters that are built into laptop computers and smart phones that connect the devices to the wireless network) varies tremendously depending on the user's activity and network conditions. The average duty cycle may be $<0.1\%$ for a laptop when the user is simply surfing the Internet or reading emails. But peak duty cycles for access points may exceed 50% for brief periods in very heavily loaded networks where a large number of users are uploading or downloading media.

When held against the head, a mobile phone will produce a peak specific absorption rate (SAR) in the head of the order of 1 W/kg averaged over 10 g of tissue, with very roughly ten times lower exposure levels in the brain itself. The Wi-Fi access point used in the Zentai study was

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mounted 40 cm from the subjects. The investigators calculated that the peak 10 g average SAR in the subjects' foreheads was about 9 mW/kg, with exposures in the brain itself roughly an order of magnitude smaller. This was calculated at the duty cycle of the transmitter used in the study (66%, which is far higher than will occur under almost any plausible usage scenario).

Thus, while these numbers are very approximate, it is clear that RF exposures to the head used in this study were a tiny fraction of those experienced by a mobile phone user, but also far below those received by a person using a Wi-Fi-enabled device under realistic usage scenarios.

The question arises: What does this study accomplish? Some members of the public are troubled by the possibility of health risks from Wi-Fi radiation, but health agencies have generally not expressed concern. A well-done study such as Zentai's provides reassurance to the public, at least to those who are able to understand the very technical discussion in this article.

What next? Wi-Fi is not a distinctive physical agent; the term refers to a set of communications protocols maintained by an industry group (the Wi-Fi Alliance) to ensure that different Wi-Fi devices will communicate reliably with each other. Wi-Fi presently uses two different frequency ranges (2.45 and near 5 GHz), and more frequency bands are coming. Wi-Fi signals consist of brief pulses of varying length, with a complex digital modulation scheme that varies depending on the particular ''flavor'' of Wi-Fi being used at any given time. Zentai *et al*. have explored only a small fraction of the parameter space available to Wi-Fi technology.

And now, a decade after the beginning of the revolution in digital wireless communications, the world is filled with devices that transmit RF energy in roughly similar frequency ranges at low power levels. Many more such devices are coming. Some of these devices will be worn on or near the body, such as body-mounted computers (an early example is the Google Glass), and body area networks that integrate physiological sensors mounted on the body with wireless communication. Already, wireless devices are being incorporated into ordinary household appliances (e.g., wireless-enabled light bulbs, bathroom scales, home thermostats and power outlets). In addition, utility systems around the world are currently installing wireless-enabled ''smart meters'' in consumers' homes. All of these technologies use wireless communication operating at low power levels using a variety of digital communications technologies that have been developed over the past two decades. Under realistic usage conditions, the RF exposure levels from such devices are invariably far below U.S. and international safety limits (*9*)

There has been little exploration into the possible health risks of these newer technologies; most research since the mid-1990s has focused on RF exposures from cellular telephones (which produce relatively higher exposure levels). The current exposure limits in effect in the U.S. (and nearly all other countries) are designed to avoid known hazards of excessive exposure, which with few exceptions are associated with excessive heating of tissue and are unrelated to specific technologies. Nor, after many expert reviews, have health agencies identified any particular characteristic of digital wireless signals other than time-averaged power that are relevant to assessing safety. If modulation or other particular characteristics of digital wireless communications (apart from time-averaged power density) were ever shown to be important variables in assessing risk, the landscape of RF protection would suddenly and irreversibly change.

Are the authors correct in saying that ''further studies are needed using different signal modulation schemes to reach a final conclusion on the potential acute neurocognitive effects of Wi-Fi exposure''? Apart from the impossibility in science of arriving at ''final conclusions'', it seems unlikely to us that such studies would be productive. The many previous studies related to neurocognitive effects of RF exposures at much higher exposure levels (e.g., from cell phones) have so far failed to persuade health agencies of the existence of a hazard. Further, there are no mechanistic or other hypotheses that predict that specific signal characteristics of wireless Wi-Fi radiation should be investigated more closely. The parameter space open to investigation is very large and small changes in EEG are difficult to relate to health in any event.

On the other hand, a person who spends hours a day glued to a smartphone or tablet may well experience all sorts of neurocognitive effects—from the use of the technology, not from RF exposure. EEG studies may well be useful to identify and clarify any such effects. And meanwhile, readers are reminded to closely monitor what their children are doing as they surf the Internet with their Wi-Fi-enabled computers and smartphones.

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