

Effects of Radio Frequency Electromagnetic Field Exposures on Cognitive Function of the Human Brain

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Abstract

With the development of technology, humans are increasingly exposed to radio frequency electromagnetic fields (RF-EMF). Previous studies have shown that RF radiation may affect public health, but there is no consensus on whether it affects human cognitive function, and most experimental results lack reproducibility. This paper reviews measurement and control methods for public and laboratory RF exposures, and the effects of long-term and short-term electromagnetic radiation on cognitive function and neural activity of the human brain. Current problems are summarized, prospects are discussed, and recommendations are proposed for future studies on the effects of RF-EMF on cognition.

Keywords

Radio frequency electromagnetic field; Cognitive function; Exposure level; Electroencephalogram; Functional magnetic resonance imaging

1. Introduction

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the World Health Organization (WHO) classify electromagnetic radiation in the frequency range of 100 kHz to 300 GHz as radio frequency (RF) radiation. Typical RF sources include broadcast antennas, Wi-Fi routers, mobile phones and base stations, Bluetooth devices, and radar. Since the 1950s, the rapid development of wireless communication, industrial, and medical devices has led to increasing human exposure to RF-EMF.

The specific absorption rate (SAR) is the metric used to measure RF energy absorbed by biological tissue, expressed in W/kg or W/m². According to ICNIRP, the general public safety limits are SAR_{10g} = 2 W/kg for head and trunk, and 4 W/kg for limbs. These standards have been widely adopted globally.

RF exposure can cause thermal effects (tissue heating, heat stress, burns) and non-thermal effects (stress, headaches, fatigue, anxiety, altered blood-brain barrier function, sleep disturbances, increased risks of diabetes and cancer). With respect to cognition, while thermal effects mainly impact balance via vestibular heating, most research focuses on non-thermal consequences such as attention, working memory, and cognitive flexibility.

2. Measurement and Control of RF-EMF Exposure

RF exposure can be divided into public exposure (long-term environmental exposure) and laboratory exposure (short-term controlled experiments). Public exposure assessment methods include direct field measurements near base stations, propagation modeling, and questionnaire-based exposure estimates. Laboratory exposure studies typically use cross-over designs with single- or double-blinding, controlling for confounders such as learning effects or psychological expectations. Exposure sources include simulated antennas, controlled mobile devices, and signal generators across 1G to 5G technologies.

3. Effects of RF-EMF on Cognitive Function

Research findings remain inconsistent. Some longitudinal and cross-sectional studies suggest long-term RF exposure can impair attention, working memory, executive function, visuomotor coordination, language, and associative memory. For example, large cohort studies in school children report associations between wireless phone use and increased risk of ADHD, as well as impaired memory performance. In contrast, most short-term laboratory studies have not found significant cognitive changes following acute RF exposure.

4. Neurophysiological Evidence

EEG studies show RF exposure can alter alpha wave activity, though results are inconsistent, with both increases and decreases reported. Event-related potential studies also show mixed results regarding changes in latency and amplitude. Transcranial magnetic stimulation (TMS) experiments yield contradictory findings on cortical excitability. Neuroimaging (PET, fNIRS, fMRI) has shown localized changes in glucose metabolism, blood flow, or oxygenation in frontal and temporal lobes, though findings vary depending on exposure conditions and sample sizes.

5. Conclusion and Future Directions

Overall, evidence suggests that long-term RF-EMF exposure may negatively impact cognitive functions such as memory, attention, and executive control, whereas short-term laboratory exposures generally do not. Inconsistencies arise from variations in exposure parameters, participant demographics, and methodologies. Future research should prioritize longitudinal studies in newly exposed populations (e.g., children, new workers in radiation-related occupations), carefully control for confounding factors, and address technical challenges such as interference between RF signals and EEG/fMRI recordings.