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Effects of Electromagnetic Fields on Memory and Learning

A large and growing body of scientific research indicates that microwave RF radiation from wireless technologies (including mobile phones, Wi-Fi, and mobile base stations) as well as low-frequency electromagnetic fields (EMF) can adversely affect memory, learning, and cognitive function. These effects have been observed in animal experiments, human observational studies, case studies, and systematic reviews, often at exposure levels well below current regulatory limits. This paper presents a list of over 70 studies showing these effects. The majority, or nearly 60 studies, are microwave RF-studies.

Scope of Evidence

- The evidence spans **over 30 years of research (1994–2025)**.
- Studies include **humans (including children)** and **animals**
- Frequencies examined range from **low-frequency magnetic fields** to **microwave and 5G-relevant frequencies (≈900 MHz–10 GHz)**.

Key Findings

1. **Memory and learning impairment**
   Numerous studies report reduced memory performance, impaired learning ability, and decreased attention following EMF or microwave exposure.
2. **Hippocampus vulnerability**
   The hippocampus—central to memory and learning—is repeatedly identified as a target, with findings including:
   - Neuronal loss
   - Apoptosis and ferroptosis
   - Inflammation and oxidative stress
   - Altered neurotransmitter systems (e.g., serotonin, dopamine, GABA)
3. **Effects below current safety limits**
4. **Children and adolescents appear especially vulnerable**

Public Health Implications

- Memory and learning are foundational to **education, productivity, and long-term brain health**.
- Widespread and increasing exposure to wireless technologies means even **small individual effects could have large population-level consequences**.

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Research showing effects from microwave RF radiation and EMF on memory and learning. (There may be additional studies)

1. People exposed to elevated levels of microwave radiation from mobile phone base stations have an increased prevalence of sleep difficulties, headaches, fatigue, anxiety, memory problems, and more, despite measured radiation levels being 1,250 times or more below current limit values. Over 90% of participants in the most highly exposed group had memory problems. *July 2025*
2. Rats exposed to multiple pulse-modulated frequencies between 1 and 4 GHz, 2 hours per day, 5 days per week for 8 weeks, developed impaired memory and stress effects. *March 2025*
3. Animal study in which rats were exposed to 900 MHz, 1 hour per day for 4 weeks, showed effects on memory. The exposure caused apoptosis in the hippocampus, the brain region important for memory. Apoptosis and lymphocytic infiltration were also observed in the adrenal gland. *March 2025*
4. Rats exposed to 5G-like radiation (3.5 GHz) at levels far below current limit values (0.19 W/kg), 1 hour per day, 5 days per week for 6 weeks, did not show impaired memory, but did show significant gene effects that could potentially affect glutamate synapses and mitochondrial activity. The researchers do not exclude that other memory tests than those used in the study might have shown negative effects on memory. *March 2025*
5. Animal studies (rats) show that simultaneous exposure to 2.8 GHz and 9.3 GHz caused damage to hippocampal tissue, inhibited brain activity, and affected hippocampal neuron metabolism. Learning and memory ability were impaired. Combined exposure to both 2.8 and 9.3 GHz reduced learning and memory more than exposure to a single frequency. The exposure was relatively high but at non-thermal levels. *January 2025*
6. Review article on cognitive effects of Wi-Fi radiation in children/adolescents aged 14–17 concludes that exposure leads to impaired attention and memory. *2024*
7. Review article concludes that EMF can affect cells and molecular mechanisms in the brain that may lead to impaired memory and cognitive ability. *2024*
8. Review article concludes that exposure to certain forms of EMF can cause learning and memory problems, depression, and anxiety. *November 2024*
9. Prenatal exposure to mobile phone radiation leads to impaired memory and learning ability and stress behavior in offspring (animal studies). *July 2024*
10. Case studies of 16 people exposed to 5G near their homes show that they rapidly developed sleep problems, headaches, fatigue, increased irritability, concentration and memory problems, which were the most severe and common symptoms. *June 2024*
11. Quails exposed to 2.45 GHz Wi-Fi radiation showed harmful effects on the brain and hippocampus (including inflammation, a significant reduction of Nissl substances in the hippocampal region, indicating neurodegeneration via oxidative stress-mediated hippocampal apoptosis). *March 2024*
12. Low-frequency magnetic fields impair memory in animal experiments. *December 2023*
13. Combined exposure to microwaves and electromagnetic pulses impairs memory and learning in animal experiments. Each exposure individually impaired memory and learning. The radiation caused ferroptosis, programmed cell death, in the hippocampus. *July 2023*
14. Exposure to 2.856 and 9.375 GHz causes impaired memory in animal experiments. *February 2023*
15. Mice exposed to microwaves at 2.856 GHz showed altered brain function leading to impaired memory. *April 2023*

16. Research review concludes that chronic exposure to low-frequency magnetic fields can impair memory. *February 2023*
17. Glucocorticoid receptors in the hippocampus, important for cognitive function and memory, are affected when rats are exposed to 2.45 GHz microwaves. *December 2022*
18. Rats exposed to non-thermal microwave radiation at 1.5 GHz show impaired memory and changes in the hippocampus. *December 2022*
19. Exposure to 2.45 GHz microwave radiation causes brain changes relevant to learning and memory. The radiation damaged both exposed fetuses and adult animals and may affect future generations. *December 2022*
20. Animal studies show that exposure to continuous 2450 MHz before and after birth can cause changes in MAPK signaling pathways, affecting learning and memory, damaging fetal and adult brain tissue, and potentially affecting future generations. *November 2022*
21. Simultaneous exposure to 1.5 GHz and 4.3 GHz mobile phone radiation impairs memory in animal experiments. *September 2022*
22. Case study: A person exposed to 7,852 µW/m² from a 4G base station above the workplace rapidly developed microwave syndrome including impaired memory. *March 2022*
23. Rats exposed to mobile phone radiation at 2.1 GHz showed impaired learning and cellular damage in the hippocampus. *2020*
24. Rats exposed to mobile phone radiation up to 4 hours per day for 90 days showed impaired memory. *July 2020*
25. Rats exposed to mobile phone radiation during the first 19 days of gestation showed impaired memory and learning ability, with effects persisting into older age. *June 2020*
26. Impaired memory observed in rats exposed to mobile phone radiation. *May 2020*
27. Exposure to 1800–2100 MHz causes damage and reduced neuron numbers in the hippocampus, impairing learning and memory (animal study). *February 2019*
28. Children aged 13–16 years exposed to radiation from base stations near schools show impaired memory and attention. *January 2019*
29. Research review shows consistently impaired memory among adolescents exposed to 1,000–4,000 mJ/kg daily for one year. Authored by a former ICNIRP member now critical of ICNIRP's extremely high exposure limits. *February 2019*
30. Adolescents aged 15–19 who use mobile phones show impaired memory function. Study of 670 mobile-phone-using adolescents in Switzerland. *July 2018*
31. Animal studies show that mobile phone radiation (GSM 900) impairs memory. Rats exposed for 4 weeks. *July 2018*
32. Animal studies show that mobile phone radiation causes harmful changes in brain cell gene expression, which may explain memory impairment observed in earlier studies.
33. Rats exposed to Wi-Fi radiation at 2.45 GHz showed behavioral changes and increased markers of cell death (caspase-3) and oxidative stress in the brain. Exposure at 2.45 GHz had greater effects than 1.8 GHz and 900 MHz. Rats were exposed 4 hours per day for 45 days. Researchers concluded the study clearly shows harmful brain effects leading to impaired learning and memory and anxiety-like behavior. *March 2018*
34. Animal studies show that magnetic fields at 7.5 kHz affect learning and memory, likely via inflammatory reactions in the hippocampus. *December 2017*
35. Exposure to microwave radiation at 10 GHz damages the brain in animal studies, including impaired memory and learning and oxidative stress. *May 2017*
36. Mobile phone use significantly negatively affects working memory in provocation studies. Effects observed after only 5 minutes, with greatest impact in people over 60 and those with cognitive problems. *September 2017*
37. Mobile phone radiation (GSM 900 and 1800) damages hippocampal cells in animal studies. *March 2016*

38. Elevated low-frequency magnetic fields cause impaired memory. *June 2016*
39. Greater mobile phone use or exposure is associated with poorer memory among adolescents. *July 2015*
40. Low-level mobile phone radiation, 1 hour per day over longer periods (8 weeks in mice), affects genes and may impair learning and memory by altering proteins and metabolic processes related to brain function and disease. *September 2015*
41. Chronic exposure to mobile phone radiation at 1800 MHz leads to reduced levels of neurotransmitters (serotonin, dopamine, etc.), important for memory, learning, and mental health. *February 2015*
42. Mobile phone radiation affects serotonin production, relevant for memory, learning, and mental health. *February 2015*
43. Mice exposed to mobile phone radiation, 3 hours per day for 28 days, showed impaired memory and increased permeability of the blood–brain barrier. *January 2015*
44. Rats exposed to mobile phone radiation showed harmful brain cell changes, oxidative stress, and impaired memory and learning. *December 2014*
45. Mice exposed to microwave radiation showed impaired memory; GABA, an important neurotransmitter for memory, was affected. *April 2014*
46. Low-frequency electromagnetic fields affect brain functions related to memory and learning. *April 2014*
47. Mice exposed to mobile phone radiation during gestation showed impaired memory and learning ability. *March 2014*
48. Exposure to GSM 1800 mobile radiation, up to 120 minutes daily for 30 days below limit values, impaired memory and learning in mice. Selenium supplementation had a protective effect. *February 2014*
49. Exposure to low-frequency electromagnetic fields causes brain changes explaining impaired learning and memory. *January 2014*
50. Aluminum and low-frequency electromagnetic fields have similar negative effects on the brain, impairing memory and antioxidant defenses. *October 2013*
51. Mobile phone radiation far below limit values alters neurotransmitters in mice, explaining reported memory, learning, and brain stress effects. *July 2013*
52. Mobile phone radiation causes DNA damage in mouse brains, potentially leading to neurodegenerative diseases and cancer. *July 2013*
53. Significantly increased prevalence of sleep problems, headaches, dizziness, discomfort, depression, memory disturbances, irritability, and nervousness among residents living within 300 meters of mobile phone base stations compared with those living farther away. *2013*
54. Mobile phone radiation (GSM 1800) impaired memory in mice exposed 90 minutes per day for up to 148 days at levels far below limit values (0.11 W/kg). *January 2013*
55. Wi-Fi-like signals (2450 MHz) impair glucose uptake in the brain, which may lead to poorer memory and learning. *November 2012*
56. Short-term mobile phone radiation exposure (2 hours) affected orientation, behavior, and caused oxidative stress changes in rats. *November 2012*
57. Mobile phone radiation below limit values caused poorer memory and brain damage in mice exposed for up to one month. *September 2012*
58. Mouse fetuses exposed to very low-frequency EMF developed permanent brain damage manifested as behavioral changes. *July 2012*
59. Mice exposed to electromagnetic radiation for 200 hours at very low levels (3 µT) developed depression/anxiety-like symptoms and elevated corticosterone, associated with stress and impaired memory. *July 2012*
60. Ants showed impaired orientation and memory after GSM radiation exposure. *June 2012*
61. Low-frequency EMF impaired memory in mice. *April 2012*

62. Prenatal exposure to mobile phone radiation below limit values caused behavioral disorders (ADHD-like) and impaired memory in mice. *March 2012*
63. Children aged 7–12 using mobile phones showed impaired memory and increased fatigue. *September 2011*
64. Mice exposed 8 hours per day for 3 weeks showed increased brain proteins associated with brain damage and poorer memory. *October 2010*
65. Mice exposed to a mobile phone 1 hour per day for 4 weeks showed impaired memory and damaged brain cells. *January 2010*
66. Mobile phone radiation impaired memory and cognitive ability in rats. *April 2009*
67. Young mice exposed to mobile phone radiation showed reduced cell numbers in the hippocampus. *February 2009*
68. Mobile phone radiation impaired memory in mice exposed 2 hours per day for 55 weeks at levels far below limit values. *April 2008*
69. Health study of residents near mobile phone base stations showed that headaches, memory disturbances, irritation, and sleep problems increased most among those living close to the mast. *2006*
70. Wi-Fi-like radiation at 2.45 GHz impaired memory/orientation in exposed animals. *2000*
71. Wi-Fi-like radiation at 2.45 GHz impaired memory and orientation in exposed rats. *1994*

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