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ORIGINAL ARTICLE

Effects of Electromagnetic Radiation from Smartphones on Learning Ability and Hippocampal Progenitor Cell Proliferation in Mice

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Abstract
Objectives: Nonionizing radiation is emitted from electronic devices, such as smartphones. In this study, we intended to elucidate the effect of electromagnetic radiation from smartphones on spatial working memory and progenitor cell proliferation in the hippocampus.
Methods: Both male and female mice were randomly separated into two groups (radiated and control) and the radiated group was exposed to electromagnetic radiation for 9 weeks and 11 weeks for male and female mice, respectively. Spatial working memory was examined with a Y maze, and proliferation of hippocampal progenitor cells were examined by 5-bromo-2′-deoxyuridine administration and immunohistochemical detection.
Results: When spatial working memory on a Y maze was examined in the 9th week, there was no significant difference in the spontaneous alternation score on the Y maze between the two groups. In addition, there was no significant difference in hippocampal progenitor cell proliferation. However, immunoreactivity to glial fibrillary acidic protein was increased in exposed animals. Next, to test the effect of recovery following chronic radiation exposure, the remaining female mice were further exposed to electromagnetic radiation for 2 more weeks (total 11 weeks), and spontaneous alternation was tested 4 weeks later. In this experiment, although there was no significant difference in the spontaneous alternation scores, the number of arm entry was significantly increased.
Conclusion: These data indicate that although chronic electromagnetic radiation does not affect spatial working memory and hippocampal progenitor cell proliferation it can mediate astrocyte activation in the hippocampus and delayed hyperactivity-like behavior.

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1. Introduction

Nonionizing electromagnetic radiation is energy that is given off from energy sources, including power lines, mobile phones, common electrical devices, and some types of machinery. This type of radiation differs from ionizing radiation, such as gamma rays, X-rays, and ultraviolet light, which exhibit high-frequency waves and have enough energy to liberate an electron from molecules [1]. Although nonionizing radiation has a lower frequency and is generally considered safe, accumulating evidence suggests that some types of nonionizing electromagnetic radiation have enough energy to harm living tissues. Especially, in recent years, the number of smartphone users has tremendously increased; thus, concerns and debates regarding the effects on human health of nonionizing radiation from smartphones have emerged. Importantly, unless some protective measures, such as hands-free or Bluetooth, are employed, the majority of people speak over smartphones with them near the users' heads. Therefore, it is an urgent issue to elucidate the effect of nonionizing radiation from smartphones or mobile phones on development and brain function.

In this study, to elucidate the effect of chronic exposure to electromagnetic radiation from smartphones, we examined adult progenitor cell proliferation in the hippocampus, as well as special learning ability using a Y maze in mice.

2. Materials and methods

2.1. Animals

Male and female C57BL/6 mice (8 wk old, Koatec, Kyoungki-do, Korea) were housed at a standard temperature (22 ± 1°C), humidity (50 ± 5%), and in a light-controlled environment (lights on from 8:00 AM to 8:00 PM) with *ad libitum* access to food and water. The experimental protocol was approved by the Institutional Animal Care and Use Committee of the Catholic University of Daegu (IACUC-2012-34).

2.2. Exposure to electromagnetic radiation

Mice were divided into two groups: animals from the exposed group were housed in a cage that was placed on the smartphone (Galaxy K, Samsung Electronics, South Korea) and it was maintained on operating mode throughout the study. To imitate the condition of daily smartphone use in life, we called and let mice hear the sound from the smartphone for 10 minutes a day. In the control group, animals were housed under normal conditions without electromagnetic radiation exposure. Mice were exposed to electromagnetic radiation for 9 weeks, and spontaneous alternation was tested. To verify the effect of recovery following electromagnetic radiation exposure, female mice were further exposed to electromagnetic radiation for 2 more weeks. After the smartphone was removed, female mice were housed under normal conditions for 4 weeks to provide a recovery period, and spontaneous alternation was tested (Figure 1).

2.3. Spontaneous alternation in a Y maze

A Y maze was made from black Plexiglas and consisted of three arms with an angle of 120° between each arm. Spontaneous alternation consists of sequential entry into all three arms. Percent alternation was calculated by dividing the number of alternations by the number of possible alternations [number of alternation/(number of total arm entries − 2)].

2.4. Injection of 5-bromo-2′-deoxyuridine and immunohistochemistry

To label proliferating cells, mice received an intraperitoneal (i.p.) injection of 5-bromo-2′-deoxyuridine (BrdU; 100 mg/kg, dissolved in saline; Sigma Aldrich, St. Louis, MO, USA) and were sacrificed 1 day later. A BrdU immunohistochemistry method was described by Choi et al [2]. To label glial fibrillary acidic protein (GFAP) and CD68, sections were blocked with 10% normal goat serum, followed by overnight incubation with a mouse monoclonal anti-GFAP antibody (1:1,000; Millipore, Temecula, CA, USA) or a monoclonal anti-CD68 antibody (1:500; Biolegend, San Diego, CA, USA). After several washes with phosphate buffered saline, sections were incubated (2 h at room temperature) with secondary antibodies conjugated with horseradish peroxidase (1:1,000; Jackson Immunoresearch, West Grove, PA, USA) and developed

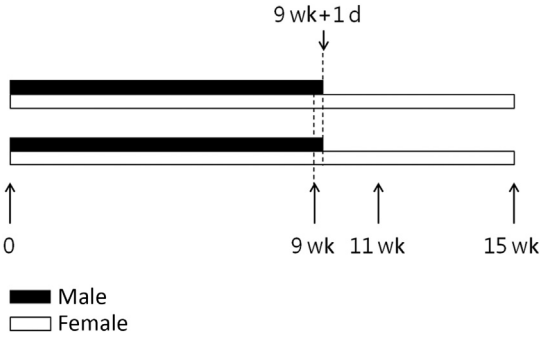

Figure 1. Summary of experimental schedule. Male and female mice were divided into control and exposed groups. Mice from the exposed group were exposed to electromagnetic radiation for 9 weeks and spatial working memory was measured. One hour after measurement 5-bromo-2′-deoxyuridine (BrdU) was injected into male mice from both groups and BrdU-injected animals were sacrificed 1 day later. Female mice were housed 2 more weeks under electromagnetic radiation or control conditions and housed for 4 more weeks without electromagnetic radiation to give the exposed group recovery. At the 15th week spatial working memory was measured again with a Y maze.