The influence of low-frequency electromagnetic field (50 hz) on oxidative status and stress reactions in rats – hormetic effect

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Abstract

The extremely low-frequency electromagnetic field (EMF) is generated by electrical devices and overhead power lines. The increasing number of anthropogenic sources of EMF prompts scientists to consider its impact on living organisms, including the functioning of the nervous system. For urbanized societies, the identification of potential risks associated with EMF and establishing safe exposure limits is particularly important. The effects of EMF are ambiguous (positive or negative), but certainly not neutral, and the analysis of available literature does not provide answers to questions regarding all potential health effects of exposure to this environmental factor. The current state of knowledge allows for the hypothesis that EMF exhibits hormesis, i.e., a two-way action dependent on the value of magnetic induction. EMF induces many modifications in intracellular processes, the consequences of which may significantly disrupt the functions of the organism. Special attention is paid to the EMF-induced changes in the oxidative-antioxidative balance. Moreover, many studies indicate that EMF is a stress factor that triggers cellular/organismal reactions characteristic of general stress responses.

It is assumed that the proposed hormetic effect (bidirectional) of EMF action is associated with different levels of oxidative stress and changes in the activation of stress systems, such as the hypothalamic-pituitary-adrenal (HPA) axis and the noradrenergic system (LC-NA). Stress hormones, mainly corticosterone and noradrenaline, can modulate hippocampal function and influence plasticity processes in this brain region. It is hypothesized that repeated exposure to electromagnetic fields (EMF) leads to the establishment of a new set-point for the activity of oxidative-antioxidative processes and stress systems, with the direction and dynamics of these changes depending on the value of magnetic field induction. As a result, EMF may modify the organism's response to subsequent stressors and alter susceptibility to diseases, especially those related to the nervous system.

The aim of the research was 1) to determine whether EMF exhibits hormesis, i.e., a bidirectional effect dependent on the value of magnetic induction, and 2) to elucidate the mechanism of this phenomenon using an animal model.

The research verified four detailed working hypotheses:

1. The bidirectional action of the EMF is based on changes in oxidative-antioxidative status in the brain (Hypothesis I).

2. EMF initiates changes in the stress response, the direction and intensity of which depend on the magnetic induction of the field (Hypothesis II).

3. EMF permanently modifies the activity level of stress systems, thereby altering the stress response to subsequent stressors (Hypothesis III).
4. Changes in the stress response induced by EMF modulate brain plasticity (Hypothesis IV).

To verify the hypothesis of the hormetic action of EMF, adult Wistar rats were subjected to repeated exposure to EMF (50 Hz) of two values of magnetic induction (1 or 7 mT). Exposures (1 hour per day for 7 consecutive days) were repeated three times at 3-week intervals. Levels of oxidative stress markers and antioxidants in the prefrontal cortex were determined, as well as changes in the levels of stress hormones and the expression of their receptors in structures and tissues belonging or related to the HPA axis and the LC-NA system: HPA axis: hypothalamus, pituitary gland, adrenal glands; LC-NA system: locus coeruleus, hypothalamus, and adrenal glands; as well as in serum. In the hippocampus, levels of glucocorticoid receptors (GR) and mineralocorticoid receptors (MR) were measured, along with β2-adrenergic receptors (β2-AR), which play an important role in modulating brain plasticity. Additionally, hormonal and behavioural changes in animals exposed to EMF in response to a subsequent stressor were verified using the open field test and elevated plus maze test. All parameters were analyzed after each of the 3 repeated exposures to EMF to assess the direction and dynamics of changes in their levels.

The conducted experiments revealed that repeated exposure to EMF alters the oxidative-antioxidant status in the prefrontal cortex of rats in a manner dependent on the magnetic induction value of EMF and the number of exposures. The level of oxidative stress markers and total antioxidant capacity (TAC) in rats exposed to EMF of 1 mT did not significantly differ from the control values. However, exposure to EMF of 7 mT resulted in an increase in oxidative stress levels and a limitation of antioxidant defence.

Changes in the levels of hormones of the HPA axis and LC-NA system in rats exposed to EMF of 1 mT were maximal after the first exposure, with subsequent exposures leading to a return to baseline levels. Conversely, a cumulative effect of individual exposures to EMF of 7 mT was observed, with each successive exposure resulting in increasingly visible changes in the levels of the verified parameters.

Repeated exposure to EMF of 1 mT induced a moderate stress response, activating compensatory mechanisms leading to adaptation to this type of stress. In contrast, in animals exposed to EMF of 7 mT, a shift in the set-point of stress system activity towards increased sensitivity to this stressor was found. Consequently, the shift in the set-point of endocrinological regulation altered the response to subsequent stressors - the open field test and elevated plus maze test.

For the first time, an increase in MR mRNA expression in hippocampal neurons in response to EMF of 1 mT has been demonstrated. This phenomenon may represent an endogenous response aimed at protecting the brain from potential damage. Conversely, a statistically significant decrease in β2-AR receptor mRNA levels in the hippocampus was observed in the group exposed to EMF of 7 mT after each successive exposure. The crucial role of β2-AR receptors in inducing brain plasticity suggests that exposure to EMF at 7 mT strongly inhibits neuroplastic processes in the hippocampus.

The performed studies demonstrated a bidirectional influence of EMF dependent on the magnetic induction value regarding the oxidative-antioxidant status, stress response, as well as modulation of brain plasticity. Additionally, it was found that the effects of EMF exposure may be long-lasting and influence the organism's response to subsequent stressful events. On one hand, weak EMF (1 mT) may positively impact brain plasticity reinforcement, facilitating neuroadaptation to subsequent stressors. On the other hand, strong EMF (7 mT) may disrupt stress response and in this way increase the sensitivity to subsequent stressful stimuli and potentially increase the risk of stress-related disorders. The results of the experiments for the first time document the existence of the "hormetic mechanism of action" of EMF (50 Hz) in vertebrates, which has been verified in the rat model. These findings may contribute to a better understanding of the fundamental mechanisms of bidirectional response to EMF, provide new data on the potential therapeutic properties of electromagnetic fields, and open new perspectives in the assessment of the risk associated with EMF exposure.

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