Research Paper

The Effect of Electrical Fields From High-voltage Transmission Line on Cognitive, Biological, and Anatomical Changes in Male Rhesus macaque Monkeys Using MRI: A Case Report Study

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ABSTRACT

Introduction: Living near high-voltage power lines and exposure to high-frequency electromagnetic fields (EMFs) is a potentially serious hazard to animal and human health. The present study was conducted to evaluate the effect of high-frequency EMFs from simulated high-voltage electric towers on cognitive, anatomical, and biological changes in the male macaque.

Methods: In this study, two Rhesus macaque were recruited, one experimental and one control. The experimental subject was exposed to EMFs from 3 kV/m simulated electric towers with a specific protocol and the control subject was tested without irradiation (4h per day, for 30 days). All required tests were performed before and after the intervention on experimental and control monkeys. The anatomical alternation of the prefrontal area (PFA) was measured by MRI images. All tests were performed on irradiated and control animals before and after the intervention and the results were compared between irradiated and control animals.

Results: The results of the present study indicated increased white blood cell counts after high-frequency EMFs irradiation. Also, the red blood cell counts showed a decreasing trend after irradiation. The plasma adrenaline level increased after irradiation. Besides, the blood glucose levels increased after irradiation. The PFA was different before and after the irradiation. Moreover, some behavioral disorders, such as fatigue, drowsiness, anorexia, and insomnia were observed after irradiation.

Conclusion: The results of biological tests and MRI showed an elevated risk of immunodeficiency disorders, weakness, and behavioral disorders. People who live or work near high-voltage electric towers with high-frequency EMFs are warned.

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Highlights

● Magnetic, and electric fields from high pressure towers caused negative effects in terms of biology and even anatomical changes in the prefrontal part of the brain.

● Disturbance in the prefrontal part of the brain caused the monkey's cognitive and behavioral disorder.

● An increase in white blood cells, a decrease in red blood cells, and an increase in the adrenaline and blood sugar were indicative of biological disorders after wave exposure in male rhesus monkeys.

● The effects of magnetic and electric fields resulting from high pressure towers on the nerves and psyche require health researchers to do more studies.

Plain Language Summary

Today, one of the factors that threaten the cognitive and behavioral health of humans and animals is living in the vicinity of magnetic and electric fields resulting from the power transmission of high-pressure towers. These fields cause cognitive and behavioral disorders in living beings. Therefore, because it threatens the cognitive health of creatures, it needs more research.

1. Introduction

Nowadays, exposure to high-frequency electromagnetic fields (EMFs) is a potentially serious hazard to animal and human health (Hamed Aliyari, Hedayat Sahraei, Mohammad Reza Daliri, Beh Minaei-Bidgoli, et al., 2018; LaBar & Cabeza, 2006). According to the literature, people exposed to EMFs are more likely to develop any type of blood cancer, abortion due to poor fetal implantation, and neurological disorders, such as stress, depression, and insomnia due to degradation in neuronal function and dysfunction by reactive oxygen species (ROS) molecule (Bayr, 2005; Garip & Akan, 2010). The ROS may harm the function of hippocampus neurons and is a major contributor to mental illnesses, such as Alzheimer's disease (Aliyari, Hosseinian, Sahraei, & Menhaj, 2018; Harach et al., 2015; Sobel & Davanipour, 1996). Electric fields and currents exist in the body of all living organisms acting as a contributor to physiological control mechanisms, such as the nervous system, cell death, growth, tissue growth, and repair (Cook, Thomas, & Prato, 2002; Paz-Caballero, Cuetos, & Dobarro, 2006). The EMFs are associated with many symptoms, such as dizziness, tinnitus, weakness and fatigue, blurred vision, and drowsiness during work, as well as the emergence of unknown diseases, altered blood composition, impaired musculoskeletal system, and immune system dysfunction among animals and humans (Kazemi et al., 2018a; McGaugh & Roozendaal, 2002; Orban et al., 2003; Elaheh Tekieh et al., 2017). Impaired secretion of hormones may lead to behavioral and cognitive disorders (Hamed Aliyari, Hedayat Sahraei, Mohammad Reza Daliri, Beh Minaei-Bidgoli, et al., 2018). Accordingly, EMFs adversely affect the secretion of protein and amine hormones by activating G-protein coupled receptors and membrane enzymes (Kazemi et al., 2018; Elaheh Tekieh et al., 2017). The adrenocorticotropic hormone (ACTH) secreted from the anterior pituitary, acts to stimulate the adrenal cortex hormones and regulates the secretion of cortisol and adrenaline (Fereidouni, Vahidi, Shishehgar, Mehr, & Tahmasbi, 2014; Kazemi et al., 2018). The results of many studies indicate the themes of simulated high voltage towers, the reduction of melatonin secretion resulting in sleep, attention, learning, and memory disturbances, and the development of mental illness, such as depression in Rhesus monkey (H Aliyari et al., 2018; Aliyari, Hosseinian, Menhaj, & Sahraei, 2018; Aliyari et al., 2015; Aliyari, Sahraei, Daliri, Beh Minaei-Bidgoli, et al., 2018; Aliyari, Sahraei, Erfani, Mohammadi, Kazemi, Daliri, Minaei-Bidgol, et al., 2020; Aliyari, Sahraei, Golabi, et al.; Aliyaria et al., 2019; Brady, Konkle, & Alvarez, 2011; Fereidouni et al., 2014; Kazemi et al., 2018, 2018b; Elaheh Tekieh et al., 2017).

Increased secretion of adrenaline increases glucose release from the liver leading to increased blood glucose levels. Thus, the required energy for muscle and nerves is supplied (Aliyari et al., 2015; Brady et al., 2011; Harach, 2010; Eaheh Tekieh et al., 2017). Secretion of adrenaline increases due to stress and abnormal conditions. Producing more adrenaline, in turn, helps increase the amount of energy to adapt to new conditions. Besides, further production of adrenalin may deplete sugar supplies (De Pittà, Volman, Berry, & Ben-Jacob, 2011; Hickie &

Rogers, 2011). In response to environmental factors in stress conditions, the production of T-cell lymphocytes increases (R. Liburdy, Sloma, Sokolic, & Yaswen, 1993; Liburdy, 1992; Poiesz et al., 1980). The number of lymphocytes is 70% in apes and 30% in human blood. Environmental factors and stressors can increase white blood cells (WBC) or leukocytes. The abnormal increase in WBC counts may cause immune deficiency, cognitive impairment, infectious diseases, bone marrow failure, and leukemia (Monti et al., 1991). Several studies have shown that the EMFs generated from the simulated high voltage towers reduce the area of the hippocampus and the amygdala in Rhesus monkeys (Duan et al., 2014; Elahe Tekieh et al., 2018). Therefore, this study aimed to investigate the effect of high-frequency EMFs from simulated high-voltage electric towers on cognitive, anatomical, biological, biochemical, and hormonal changes in male Rhesus macaque monkeys.

2. Materials and Methods

Animals

Two Rhesus monkeys (Macaca mulatta) aged 4-5 years with an average weight of 4 kg were recruited. All ethical standards regarding animal confinement, transport, location, and maintenance were observed under the international laws and regulations (IR.BUMS.REC.1394.112).

Experimentation protocol and simulation of high-frequency electromagnetic fields (EMFs)

First, pretests were conducted on study subjects. Of the two selected monkeys, one subject was irradiated by 3 kV/m high-voltage EMF, 4h per day for 30 days (Aliyari, Hosseinian, Sahraei, & Menhaj, 2019; Kazemi et al., 2018, 2018b), and one subject was maintained in a non-irradiated environment and tested without irradiation (Aliyari, Hosseinian, Sahraei, & Menhaj, 2019; Kazemi et al., 2018, 2018b),. The monkeys were kept in Teflon cages which, in addition to having special conditions for keeping the animal, such as strength, portability, and washability, had special properties to conduct scientific experiments (with the highest transfer properties and lowest resistance) (H. Aliyari et al., 2019; Kazemi et al., 2018). High voltage EMF (3 kV/m) was produced and simulated by a team of experts at Amir Kabir University, Tehran City, Iran. Two metal plates (2×2m) were placed in the upper part and one in the lower part of the cage at a 2 m distance, and a 6 kV EMF was released to produce a uniform EMF of 3 kV inside the cage (1×1×1m) (H Aliyari et al., 2018; Kazemi et al., 2018a; Tekieh et al., 2017).

Behavioral tests

In this study, the monkeys were vaccinated against tetanus, pertussis, diphtheria, and polio before entering the laboratory. After entering the laboratory, it took three months to adapt to the environment and adapt to the researchers. After this period, two perfectly healthy monkeys were included in the study. The monkey that was subjected to high-pressure surges was the freshest, smartest, and most active monkey in the laboratory. For this purpose, all observable behavior in subjects, such as sleeping patterns, sedentary and natural appetite, drowsiness, and depression were observed and recorded before, during, and after intervention by video cameras (Hamed Aliyari, 2018; Aliyari, Sahraei, Erfani, et al.; Aliyari, Sahraei, Erfani, Mohammadi, Kazemi, Daliri, Minaei-Bidgoli, et al., 2020; Aliyaria et al., 2019).

Biological test

Biological tests were performed on the irradiated and control subjects before and after the intervention and during the recovery period, and the obtained data were analyzed. According to the experimental protocol, a fasting period of 15h was required for the monkeys. For biological analysis, a total of 10 cc of blood was taken in three stages of pre-, post-irradiated, and recovery from the femoral artery of the animals, of which 5 cc was used to evaluate changes in adrenaline levels using the primate custom positive selection kit (MyBioSource, USA) at three stages. Another 5 cc of blood samples were used to measure fasting blood sugar, WBC counts, and red blood cell (RBC) count in three stages (H Aliyari, 2018; Hamed Aliyari, Seyed Hossein Hosseinian, et al., 2018; Hamed Aliyari, Hedayat Sahraei, Mohammad Reza Daliri, 2018; Kazemi et al., 2018a; Elahe Tekieh et al., 2018).

The anatomical alternation of the profunda femoris artery (PFA) was measured by MRI images and digital imaging and communications in medicine (DICOM) LiteBox files before and after the intervention (Hamed Aliyari, 2018; Servien, Viskontas, Giuffre, Coolican, & Parker, 2008).

Recovery phase

Both two selected monkeys, one subject exposed to irradiation and one subject maintained in a non-irradiated environment, stayed in the same previous place and situation but both were without irradiation for up to one month (H Aliyari et al., 2019).

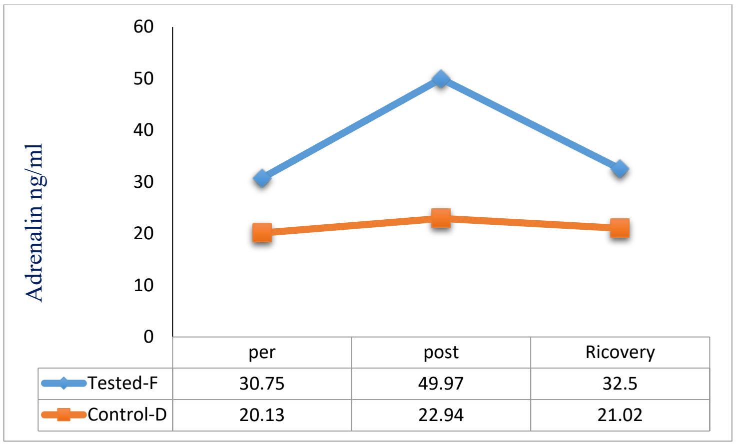

Figure 1. Adrenaline plasma levels (pre-test, post-test, recovery)

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The serum adrenaline levels were shown to elevate after irradiation. The adrenaline levels during the recovery phase declined to the pre-irradiation phase.

3. Results

The behavioral results of the study showed that in the tested monkey exposed to the electric field of the simulated high-pressure rig, the behavioral-cognitive indices change over time. From the first day to the 30th day of the waving, cognitive changes were visible to the naked eye (recording behavior by camcorders) Our observations of monkeys under a high-pressure electric field showed states of impatience, lethargy, anorexia, sleep disturbance, inactivity, and state of depression.

Behavioral tests investigated observable cognitive changes in the study subjects, including drowsiness, loss of appetite, sleep deprivation, fatigue, inactivity, and depression (recorded by video cameras). Behavioral results showed an increasing trend in the mentioned criteria during thirty days of irradiation. The behavioral analysis was performed one month before, during, and after irradiation (recovery phase). Behavioral tests were also performed on the control animal at three stages without irradiation, and no difference was observed in the control monkey.

The serum adrenaline levels were shown to elevate after high-frequency EMFs irradiation compared to the control monkeys. In addition, the adrenaline levels declined during the recovery phase to the pre-irradiation phase. No difference was observed in the three phases in the control monkeys (Figure 1).

The fast blood glucose levels were shown to increase after high-frequency EMFs irradiation compared to the control monkeys. Also, the blood glucose levels declined

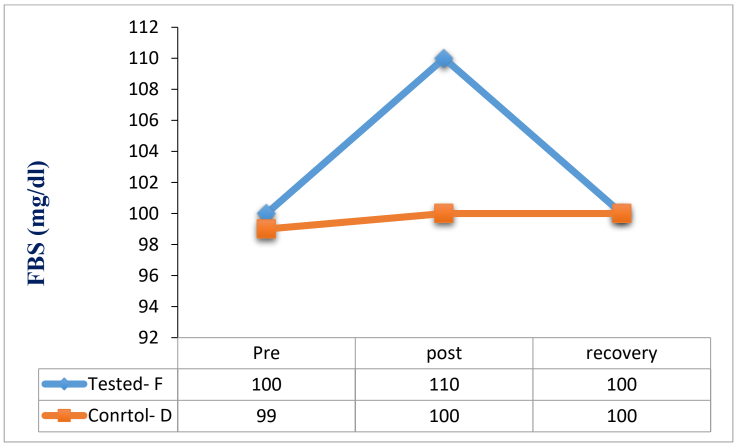

Figure 2. Fast blood sugar levels (pre-test, post-test, recovery)

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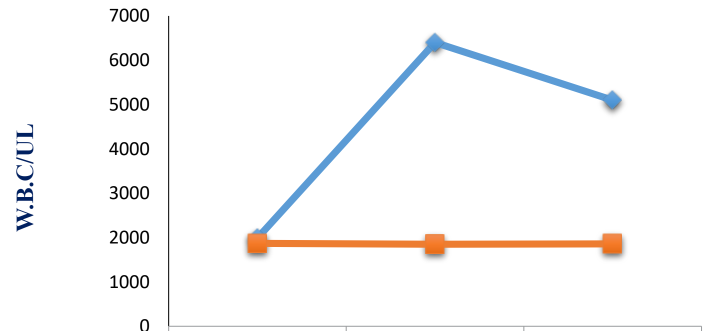
The increasing trend of fast blood glucose levels after irradiation. The fast blood glucose levels during the recovery phase were declining to the pre-irradiation phase



	pre	post	recovery
Tested-F	1990	6400	5100
Control- D	1870	1850	1860

Figure 3. White Blood Cells (WBC) counts (pre-test, post-test, recovery)

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The increasing trend of WBC counts after irradiation. The WBC counts during the recovery phase declined to the pre-irradiation phase.

during the recovery phase to the pre-irradiation phase. No difference was observed in the three phases in the control monkeys (Figure 2).

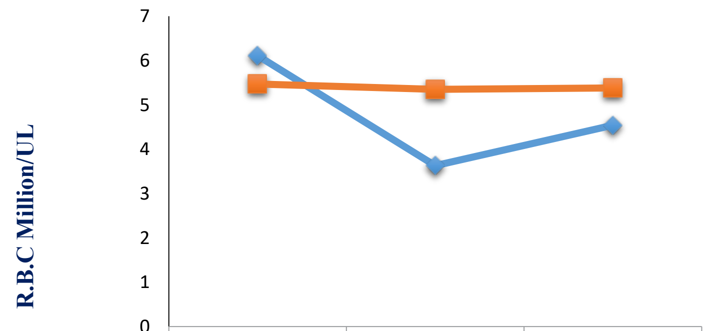
The WBC counts showed an increasing trend after high-frequency EMF irradiation compared to the control monkey (Figure 3).

The RBC counts were shown to decrease after high-frequency EMFs irradiation compared to the control monkeys. Besides, the RBC counts increased during the recovery phase to the pre-irradiation phase. No difference was observed in the three phases in the control monkeys (Figure 4).

The PFA decreased after irradiation in the experimental monkey compared to the control monkeys. Also, the PFA during the recovery phase increased to the pre-irradiation phase. No anatomical difference was observed in the control monkey (Figures 5).

4. Discussion

Today, industrialization has remade a major part of people's life. Rapidly growing industrialized cities increase the growth of power lines and the proximity of overhead electric towers to residential and occupational places increases the risk of EMFs harm as a global public concern. According to the literature, the EMFs generated by high-pressure electric towers are a serious threat to the environment of animals and humans. This destructive environmental factor adversely affects health and lifestyle and causes cognitive and behavioral changes in animals and humans (Aliyari et al., 2015; Hamed Aliyari, Hedayat Sahraei, Mohammad Reza Daliri, Beh Minaei-Bidgoli, et al., 2018; Kazemi et al., 2018; Liburdy et al., 1993; Monti et al., 1991).



	pre	post	recovery
Tested- F	6.11	3.63	4.54
Control- D	5.47	5.35	5.38

Figure 4. Red Blood Cell (RBC) counts (pre-test, post-test, recovery)

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The RBC counts were shown to decrease after irradiation. The RBC counts during the recovery phase elevated to the pre-irradiation phase.

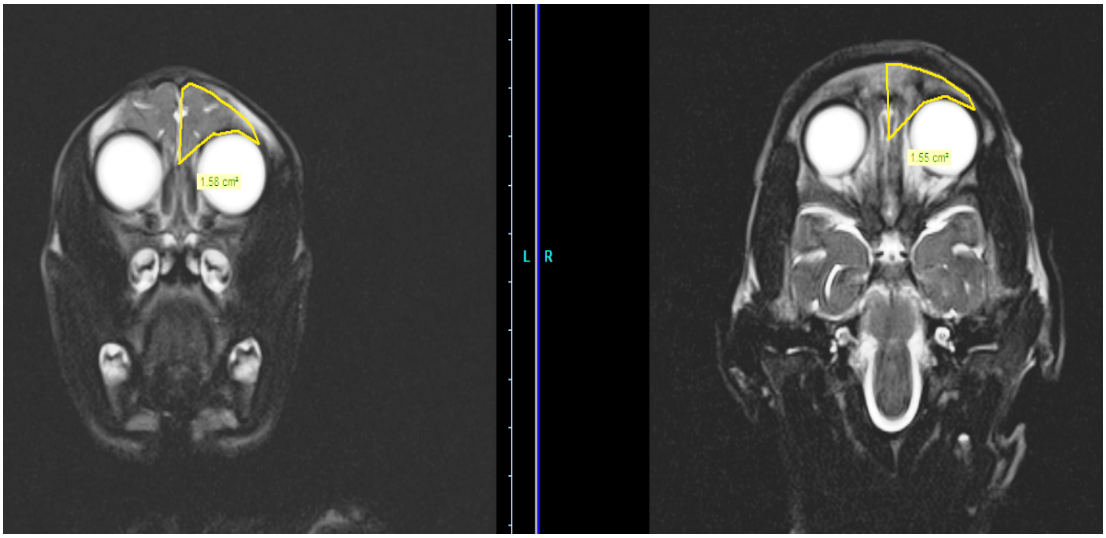

Figure 5. Pre-frontal Area (PFA)

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The pre-frontal area was shown to decrease after irradiation. The pre-frontal area during the recovery phase elevated to the pre-irradiation phase

Based on our results, the cognitive and behavioral elements were different after exposure to EMFs from simulated high-pressure towers in the irradiated subjects. Behavioral analysis of experimental and control monkeys revealed that homogeneous behavioral indices, such as refreshment, sedentary, and natural appetite were observed in control monkeys, whereas experimental monkeys showed drowsiness, loss of appetite, sleep deprivation, fatigue, and depression after EMFs irradiation. These behavioral and cognitive changes in the tested monkey showed an increasing trend from the first day to the last day of the waving. On the other hand, from day 30 onwards, with the interruption of the waving, cognitive and behavioral changes returned to the initial state before the waving. It indicates the reversible effects of the fields caused by high-pressure rigs. According to research, people who live near high-pressure towers develop cognitive impairments (Aliyari, Hosseinian, Menhaj, & Sahraei, 2019). The results of this study showed that exposure to high-frequency EMFs reduced melatonin secretion leading to sleep deprivation and immune deficiency in male Rhesus monkeys. sleep deprivation and immune deficiency are major contributors to depression (Burke, Davis, Otte, & Mohr, 2005; Hickie & Rogers, 2011; Thibodeau, Jorgensen, & Kim, 2006). Besides, high-frequency EMFs have shown to reduce gene expression of the NMDA receptor and subsequently reduce plasma sodium and potassium levels. Sodium and potassium are the most important biological ions that cause irritability of the neurons and transmissions of nerve impulses. It is fundamental to note that sodium, potassium, and the NMDA receptor gene are crucial elements in learning and memory processes (Basar, 2016; Clark & Mayer, 2016; De Zeeuw & Ten Brinke, 2015; Devesa, Lema, et al., 2016; Gruart, Leal-Campanario, López-Ramos, & Delgado-García, 2015). Exposure to extremely low-frequency EMFs (ELF-EMF 12Hz) has been shown to increase melatonin secretion. The metallothionein-1 (MT1) (or Mel1A) and metallothionein-2 (MT2) (or Mel1B) are two major receptors of melatonin which areg protein-coupled receptors (GPCR). When receptors of melatonin bind to melatonin, the protein kinase A (PKA) or Protein kinase C (PKC) enzymes are activated (Kazemi et al., 2018a; Elahe Tekieh et al., 2018). Also, ELF-EMFs at a frequency of 12 Hz increase gene expression of N-methyl D-aspartate (NMDA), and subsequently improve visual memory of male Rhesus monkeys. The ELF EMFs stimulate glutamate on NMDA receptors and inhibits magnesium from the NMDA membrane receptor, resulting in more sodium outside and more potassium inside the cell (Kazemi et al., 2018a; Lau & Zukin, 2007; Salunke, Umathe, & Chavan, 2014). The highest density of the NMDA receptor gene is found in the hippocampus, amygdala, and prefrontal cortex in the central nervous system which plays a vital role in learning and memory processes (H Aliyari et al., 2018; Aliyari et al., 2015; Hamed Aliyari, Hedayat Sahraei, Mohammad Reza Daliri, Beh Minaei-Bidgoli, et al., 2018; Basar, 2016; Devesa, Lema, et al., 2016; Elahe Tekieh et al., 2018).

The findings of the current study also reveal that the plasma concentration of adrenaline increased after high-frequency EMF irradiation in the experimental monkeys. Adrenaline is a catecholamine secreted from the central part of the adrenal gland, and when cortisol levels are low, adrenaline is secreted in response to anxiety and helps to chill and cope with tragedies. Increased adrenaline levels among study subjects may be due to impaired behaviors in this study. The activity of the adrenaline hormone is dependent ong protein-coupled receptors (GPCR), and the activity of adenylate cyclase and increased cyclic adenosine monophosphate (cAMP) as a secondary messenger activates adrenaline (McGaugh & Roozendaal, 2002; Miao, Jänig, & Levine, 2000).

Hormones are chemicals released to develop and enhance cognitive capabilities, and any stimulus, environmental factor, or behavioral and cognitive impairments influence their secretion. Evidence shows that stress coping strategies in male Rhesus monkeys are different, and the cortisol and adrenaline secretion varies depending on the personal characteristics of the animals (Aliyari et al., 2015; Devesa, Almengló, & Devesa, 2016; Tekieh et al., 2017). Biochemical studies have shown that blood glucose increased after exposure to simulated high-frequency EMFs. Adrenaline (epinephrine) is shown to elevate blood glucose which is consistent with the findings of this study. Moreover, results from hematological studies indicated a reduction in RBC counts among irradiated monkeys after exposure to high-frequency EMFs. Reduced RBC counts (anemia) are associated with drowsiness, fatigue, immune deficiency, and depression in irradiated animals, which is consistent with the results of behavioral tests in subjects exposed to high-frequency EMFs radiation.

Previous studies have shown that exposure to high-voltage electric fields is associated with sleep and depression in male Rhesus monkeys (Hamed Aliyari, 2018; Hickie & Rogers, 2011). Results from hematological studies also showed an increase in the WBC counts after irradiation. Increased WBC counts as an infectious agent may impair normal immune function. The results from behavioral tests indicate a weakened immune system, drowsiness, and inactivity amongst subjects exposed to simulated high-frequency EMFs, which can be attributed to the immune deficiency of the male Rhesus monkey.

The anatomical assessment by MRI is a common and non-invasive technique used by neurologists to examine neurological disorders, such as Alzheimer's disease. Cerebral atrophy in MRI of the hippocampus indicates the presence of Alzheimer's disease. According to the results from anthropometric measurements of PFA by MRI via DICOM LiteBox, the irradiated subject showed a decreasing trend in PFA after the irradiation compared to the control monkeys (Servien et al., 2008).

The frontal lobes are involved in behavior and personality. The smallest anatomical changes in the PFA can rapidly alter behavior and personality and cause behavioral and cognitive impairments. The frontal lobe is the vital part of the brain that plays a major role in cognition and behavior. Disruption in it disrupts natural behaviors and cognitive indicators (Kazemi et al., 2018a). Previous studies have shown that high-frequency EMFs can cause anatomical changes in the hippocampus and amygdale MRI of male Rhesus monkeys (Laakso et al., 1995; Soininen et al., 1994). Kazemi et al. argued that no changes were observed in hippocampus MRI of male Rhesus monkeys after exposure to low-frequency EMFs at a frequency of 12 Hz (Kazemi et al., 2018a).

It is essential to note that the recovery phase is a period in which the subject is recovered to the pre-irradiation level. Although the effect of high-frequency EMFs is temporary, the subject was irradiated 4h a day for four months. Besides, people living near high-voltage power lines are constantly exposed to high-frequency EMFs. Thus, further research is required to precisely examine the various pathological conditions.

5. Conclusion

The findings of the present study showed that the observable behavioral disorders, such as fatigue, anorexia, sleep deprivation, and depression in the experimental subject exposed to the electric field from simulated high-pressure towers were consistent with the results of other tests. The increase in adrenalin concentration increases glucose levels. Increased WBC counts cause immune deficiency. Decreased RBC counts lead to anemia, fatigue, and drowsiness in the experimental monkeys. All matched the monkey's behavior. It can be concluded that the EMFs from high-pressure electric towers are a serious hazard to cognitive abilities and can lead to mental disorders in humans and animals.

Ethical Considerations

Compliance with ethical guidelines

All ethical considerations based on the international standard were observed (IR.BUMS.REC.1394.112).

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Authors' contributions

Conceptualization: Hamed Aliyari, Seyed Hossein Hosseinian, and Mohammad Bagher Menhaj; Methodology: Hamed Aliyari, Masoomeh Kazemi, Hedayat Sahraei, and Sahar Golabi; Investigation: Masoomeh Kazemi, Sahar Golabi, and Hamed Aliyari; Writing-original draft: Masoomeh Kazemi, Sahar Golabi, and Hamed Aliyari; Writing-review, and editing: Hedayat Sahraei, Hamed Aliyari, and Sahar Golabi; Resources:h Seyed Hossein Hosseinian; Supervision: Seyed Hossein Hosseinian.

Conflict of interest

The authors declared no conflict of interest.

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