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Title: Uncovering the Neurobiological Consequences of High-Voltage Electrical Field Exposure on the Visual Working Memory of Macaques and Also Using Spiking Neural Network Model

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Abstract:

High-voltage (HV) power transmission lines running near cities and villages can cause severe damage (Mental and physical). Due to the magnetic and electric fields they produce. This study aimed to investigate the effects of high-voltage (HV) electric fields on the spiking neural network model of the brain and biological and behavioral models of visual working memory.

To achieve this goal, macaques were studied for their cognitive functions, expression of the NMDA receptor gene, MRI-assisted analysis of brain anatomy, and variations in blood sodium and potassium concentrations. The experimental group of macaques was exposed to a 3kV/m high-voltage field for four hours a day for one month. Computational models were then evaluated using experimental parameters.

According to the results, it was observed that being exposed to high-voltage electric fields led to a reduction in the expression of the NMDA receptor gene, as well as a decrease in the levels of Sodium and potassium ions in the blood plasma. Additionally, analysis assisted by MRI showed a decrease in the volume of the hippocampus and amygdala after exposure to the electric field.

In conclusion, the results of cognitive, genetic, blood, and MRI tests, along with the spiking neural network model, elucidate the mechanism of the visual working memory deterioration in macaques due to high-voltage electric field exposure.

Keywords: High-voltage electric fields; Visual working memory; Spiking neural network (SNN); Monkeys (Macaques).

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Introduction

To prevent the potential effects of magnetic and electric fields generated by power transmission lines on human health, it is necessary to conduct calculations [1-4] when installing these lines near cities and villages. In recent years, there have been numerous studies investigating the effects of low-frequency electromagnetic radiation on the nervous system and memory performance in both humans and animals. The rhesus macaque, which shares 98% of its genes with humans, has been used as an important animal model in scientific studies [5-7]. Furthermore, cognitive-behavioral analyses have become a state-of-the-art research method using this animal model [8-10].

To prevent potential health effects on humans from the electric and magnetic fields generated by power transmission lines located near power generation centers, cities, and villages, it is necessary to calculate the fields in the surrounding areas. In a recent study, neural network modeling was employed in conjunction with biological, behavioral, and anatomical examinations to investigate the effects of a high-voltage electric field (400 kV transmission line) on two male rhesus macaques [11-14].

Visual memory[15] is an important cognitive factor that is substantially fostered through learning. The importance of memory, as a significant cognitive factor, has been valued by neurologists and artificial intelligence and brain engineering specialists[16, 17]. Experimental research has greatly expanded our understanding of the brain, particularly with regard to the role of the hippocampus, amygdala, and prefrontal cortex in memory, decision-making, and other mental processes. However, it is important to note that this research is limited by various factors. For example, it may be difficult to study certain brain regions or functions in humans due to ethical concerns or technical limitations. Animal models, while useful for studying certain aspects of brain function, may not always accurately represent human brain function. Additionally, experimental designs may not always fully capture the complexity of real-world scenarios. Despite these limitations, experimental research remains a critical tool for advancing our understanding of the brain and developing new treatments for neurological and psychiatric disorders. [17-21]. The precise examination of neuron behavior calls for highly expensive equipment and considerable effort, and the techniques used for this purpose are not always applicable. The first thing in studying the formation of memory in the brain is to determine the parts of the brain and neurons involved in the development of memory[22]. After understanding the relevant neurons and areas involved in the formation of memory, the activity of each neuron and region must be measured/predicted, and interpreted. It is not possible to study the brain using the invasive methods that yield the most precise results, and the experimental approach is challenged radically. Therefore, these studies are inevitably conducted on mammals with the most genetic similarity to humans, but these studies are not flawless either[23].

Experimental research is a valuable tool for studying the brain, but it has limitations that necessitate the development of alternative methods. Computational and modeling approaches have emerged as important tools for understanding brain function, using computer simulations and mathematical

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models to study complex systems and processes in the brain. These approaches can provide insights that may not be easily observed through experimental approaches alone, and can be used to test hypotheses and make predictions about brain function, potentially leading to the development of new treatments for neurological and psychiatric disorders.[24-26]. Computational models have become increasingly popular among researchers due to their ability to create precise models of complex systems, such as those found in the brain, which may not be easily studied through experimental methods. With these models, researchers are able to study element behavior and parameters that may not be able to be studied experimentally [24-26]. Given these advantages, computational models have become an important tool in studying complex systems and processes in the brain.[27-29].

Also, the neural connection is one of the chief characteristics of the brains of the vertebrae. Through this connection, a large number of neurons are linked to one another through axons and dendrites and affect other neurons and are affected by them via the axons and dendrites. The junction between two neurons is called a synapse. There are normally synaptic connections between one neuron and several thousand other neurons, and that particular neuron receives synapses from those several thousand other neurons. Synapses are among the most important brain structures due to numerous reasons. Synapses are highly organized and stable structures from a biological perspective, and they play a crucial role in information transmission and processing, enabling the brain to learn, memorize, and adapt. Synaptic disorders can lead to a range of brain and psychological disorders, given the critical role synapses play in neurotransmission. Clinically, synapses are the main targets for medicinal treatments and healthcare interventions aimed at addressing these disorders.[30-34].

This study aims to investigate the impact of high-voltage electric fields on the behavior of simulated neural models of the hippocampus, given its crucial role in learning and memory. To validate the results, the behavioral, blood, hormonal, gene, and cognitive observations from experimental examinations of two rhesus macaques that have been exposed to similar electric fields will be compared. The research question holds significant importance as it can provide insights into the potential effects of high-voltage electric fields on the brain and contribute to a better understanding of the associated risks with power transmission lines. It is important to note that the study adheres to all applicable international, national, and institutional guidelines for the care and use of animals.

Materials and Methods

Animal subjects:

The study used two adult male rhesus macaques (Macaca mulatta) aged 4 to 5 years, with an average weight of 4 kg. The macaques were kept in a controlled environment for 12 months to adapt. The room where the animals were kept had appropriate lighting, temperature, and humidity,

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and followed all ethical and international rules for the transportation, location, and maintenance of the animals [2, 3, 11].

High-voltage electric field exposure:

In this experiment, one of the rhesus macaques was exposed to a simulated high-voltage electric field of 3kV/m for 4 hours a day over the course of a month, while the other macaque was kept outside the field as a control sample. The high-voltage electric field used in the experiment had a frequency of 50Hz and was simulated in the laboratory using two metal sheets measuring 2x2 meters. The sheets were placed by a crane at the bottom and on top of a polytetrafluoroethylene (PTFE) primate cage measuring 1x1x1 meters, with a distance of 2 meters between them. The sheets were exposed to a voltage of 6kV to create a uniform 3kV/m field in the cage.[11].

Behavioral analysis:

Behavioral analyses were conducted on both macaques before, during, and after the application of electric field simulations, and were recorded on camera.

Blood analysis:

In addition to behavioral analyses, 5cc of blood was collected from each macaque and used to measure the concentrations of sodium and potassium blood electrolytes, as well as the expression of the NMDA receptor gene. Blood samples were collected before the macaques were included in the research, after the application of electric field simulations, and during the recovery phase. The expression of the NMDA receptor gene was determined using the RT-PCR method, and blood lymphocyte cells were obtained before and after applying electric field simulations and during the recovery phase. Additionally, the blood concentrations of sodium and potassium ions were measured during the same phases.

MRI analysis:

An MRI-assisted analysis of the anatomy of the hippocampus and amygdala was conducted using DICOM LiteBox before and after the application of electric field simulations.[21, 26, 35].

Neural modeling:

The neural model was simulated using MATLAB 2016b [26, 36-38].

Recovery phase:

During the recovery phase, both macaques, one of which had been exposed to the high-voltage electric field and the other kept in a non-exposed environment, were kept in the same previous place and situation without exposure to the electric field.

Cognitive tests have four phases as represented below.

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- **Phase one - the visual memory experiment**: The visual memory recording device was placed in front of the primate, and a reward was randomly put in one of the dishes. After 30 seconds, the dish on the moving stand was provided to the animal. The macaque was allowed a single attempt to access the reward, and he would be kept deprived of the reward if he failed to open the right dish. Consequently, the animal had to focus and pay attention to obtain the reward. This test was repeated three times a day before the primate's eyes[7, 39].
- **In phase two, a visual memory experiment:** was conducted with the macaques. Peanuts were placed in one of two covered dishes in front of the animal, and the dish with the peanuts was presented to the animal after a 60-second delay. The process was explained to the animal prior to the experiment.
- **Phase three - the visual working memory experiment:** Peanuts (the reward) were put in one of the covered dishes before the primate's eyes, and a curtain was placed between the primate and the reward (dish) for 30 seconds. Following this period, the dish was presented to the animal after closing the curtain. The animal had only one chance to access the reward, and therefore he had to pay attention, concentrate, and memorize.[7, 40]
- **Phase four - the visual working memory experiment:** Peanuts (the reward) were put in one of the covered dishes before the animal's eyes. A curtain was placed between the primate and the dish for 60 seconds, after which the dish was presented to the animal, and the procedure continued as described[7, 39, 40].

1) Spiking Neural Network (SNN) Models of Hippocampus

- **Neural Network**

Neural networks have various functions, including selecting input, adjusting gain, reducing turbulence, and selectively reinforcing activity. These functions form the basis of simple and complex models of primary visual cortex cells, such as short-term and hybrid memory models. Of the neural network models, the fire rate model and spiking model have received significant attention from researchers. The fire rate model features neurons that produce fire rates instead of action potentials, making it a more cost-effective and simpler model to analyze mathematically. However, it has limitations, such as being unable to analyze fire duration and correlation in networks with high simultaneity. The spiking model is capable of presenting more biological details due to its parameters and ability to analyze fire time and correlations, but it is more computationally expensive. Overall, both models have their strengths and weaknesses, and the choice depends on the specific research question being addressed.[26, 41-44].

- **Spiking Model**

Modeling neuron populations often involves generating populations using basic computational neuron models and connecting them using synaptic models. By combining a wide range of neural models and synaptic models, it is possible to describe the behavior of different brain regions with

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physiological details such as synaptic currents and their dynamics, neural receptors, and ion channels. This results in a computational model that provides insights into the complex processes and interactions within the brain.[36, 45].

Figure (1) illustrates the structure of a neural network consisting of three pyramidal neuron pools and one inhibitory neuron pool. All neurons in the network are interconnected, but the synaptic strength of the neurons within each neuron pool is higher than the connections between the pools. The figure displays the synaptic strength of the neurons and the connections between the neuron pools, with solid lines representing excitatory connections and dashed lines representing inhibitory connections. [28, 46].

The S1 and S2 neuron pools are considered attractor neurons, meaning they can maintain a stable activity state even in the absence of input. The NS neuron pool is used to describe the activities of other pyramidal neurons in the cortex region of the brain, while the IH neurons are inhibitory neurons that can modulate and control the activity of the other neurons in the network.[47-49].

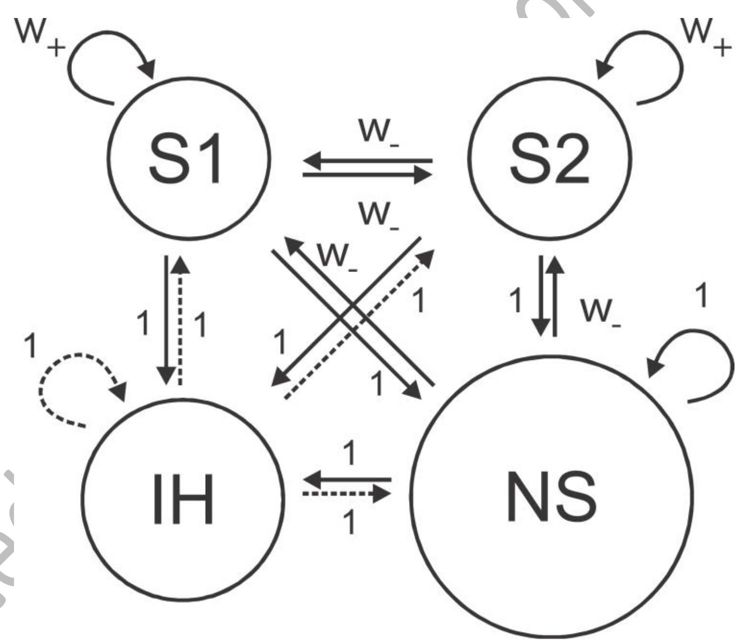

Figure (1): The Attractor Network model [2, 26, 28]

To describe the voltage dynamics of neurons in the cortex, a simple yet efficient LIF (leaky integrate-and-fire) model was utilized, with AMPA, NMDA, and GABA receptor currents serving as the synaptic currents. Each neuron in the network receives four currents: off-network AMPA receptor currents, AMPA receptor currents from intra-network excitatory neurons, NMDA receptor currents from intra-network excitatory neurons, and GABA receptor currents from intra-network inhibitory neurons. The off-network AMPA receptor currents reflect the activity of neurons in other parts of the cortex that provide input to the network. In this model, each neuron receives 800 synapses with off-network AMPA receptors, which contribute to the background activity of the neurons. Furthermore, each neuron receives 400 synapses from excitatory neurons with AMPA and NMDA receptors and 100 synapses from inhibitory neurons with GABA receptors. In the self-stimulatory state, the inhibitory current from the network's inhibitory synapses overcomes the excitatory current from the excitatory synapses. However, in a stable state, this process is reversed. The LIF equation (1) is used to calculate the cortex voltage. [26, 52].

$$C_m \frac{dV(t)}{dt} = -g_m(V(t) - V_L) - I_{syn}; if\ V(t^*) > V_{th}\ , V(t) = V_{reset}\ , t^* < t < t^* + t_{ref}\ (1)$$

Where V, V_L, V_{reset}, V_{th}, C_m, and g_m denote cortex voltage, neuron resting voltage, neuron recovery potential, neuron fire threshold voltage, membrane capacitance, and membrane electrical conductivity, respectively.

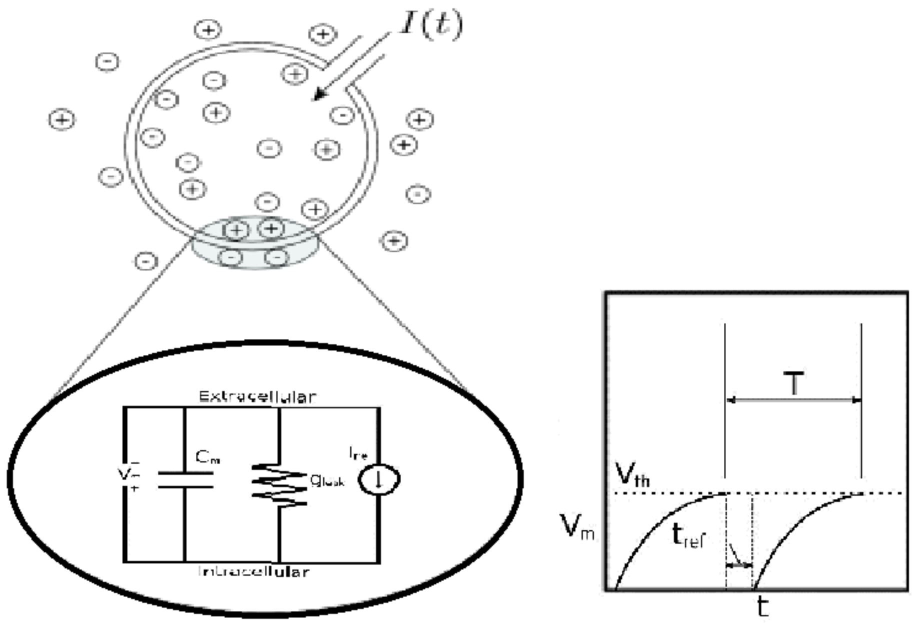

Figure (2) depicts a schematic view of the neuron cell body, its equivalent electric circuit, and the response (membrane potential difference) to the external or synaptic current, l(t)) [2, 26]

The values of the parameters in the LIF model may differ for excitatory and inhibitory neurons. Moreover, Isyn represents the synaptic current received from the neuron, which can be one of four types, as mentioned earlier. The varying gate model was used to describe the different synaptic receptor currents, which are as follows:

$$I_{syn}(t) = g_{AMPA,ext}(V(t) - V_E) \sum_{j=1}^{N_{ext}} s_j^{AMPA,ext}(t) + g_{AMPA}(V(t) - V_E) \sum_{j=1}^{N_E} w_{ji}^{AMPA} s_j^{AMPA}(t) + \frac{g_{NMDA}(V(t) - V_E)}{1 + \left(\frac{[Mg^{2+}]}{3.57}\right) \exp(-0.062V(t))} \sum_{j=1}^{N_E} w_{ji}^{NMDA} s_j^{NMDA}(t) + g_{GABA}(V(t) - V_I) \sum_{j=1}^{N_I} w_{ji}^{GABA} s_j^{GABA}(t) \quad (2)$$

Where, $s^{AMPA,ext}$,s^{AMPA}, s^{NMDA}, and s^{GABA} and the synaptic current gate variables correspond to the off-network AMPA receptors and intra-network (internal) AMPA, NMDA, and GABA receptors. In addition, $g_{AMPA,ext}$, g_{AMPA}, g_{NMDA}, and g_{GABA} show the maximum electrical conductivity of the corresponding receptors. Moreover, V_E and V_I denote the resting voltages of the excitatory and inhibitory neurons, respectively. $[Mg^{++}]$ shows the concentration of intra-neuron magnesium in the NMDA channels, and w_{ji} shows the synaptic weights of the connections between the neurons and neuron pools. The following equations are used to describe the variables regulating the current flowing through the synapses.

$$\frac{ds_j^{AMPA,ext}(t)}{dt} = -\frac{s_j^{AMPA,ext}(t)}{\tau_{AMPA}} + \sum_k \delta\left(t - t_j^k\right) \quad (3)$$

$$\frac{ds_j^{AMPA}(t)}{dt} = -\frac{s_j^{AMPA}(t)}{\tau_{AMPA}} + \sum_k \delta\left(t - t_j^k\right) \quad (4)$$

$$\frac{ds_j^{NMDA}(t)}{dt} = -\frac{s_j^{NMDA}(t)}{\tau_{NMDA,decay}} + \alpha\, x_j(t) \left(1 - s_j^{NMDA}(t)\right) \quad (5)$$

$$\frac{dx_j(t)}{dt} = -\frac{x_j(t)}{\tau_{NMDA,rise}} + \sum_k \delta\left(t - t_j^k\right) \quad (6)$$

$$\frac{ds_j^{GABA}(t)}{dt} = -\frac{s_j^{GABA}(t)}{\tau_{GABA}} + \sum_k \delta\left(t - t_j^k\right) \quad (7)$$

In addition, the time constants of the GABA, NMDA, and AMPA receptor gates are denoted by τ_GABA, τ_(NMDA,decay), and τ_AMPA, respectively. τ_(NMDA,decay) also affects the time constant of the rise of the NMDA receptor gate, and δ(t) is the Dirac function, which activates all fractions of the related receptors according to the potential. In this network, the S1 and S2 neuron pools represent two memories that switch from self-stimulatory mode to stable mode and vice versa with external excitation[46, 47, 53].

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Results and Discussion

1 Experimental phase results:

Cognitive tests were conducted before and after applying electric field simulations to examine two important cognitive factors, namely visual memory and visual working memory performance. For these tests, a device was designed to record the visual memory behavior (visible) and visual working memory performance (behind a curtain). The device was composed of two opaque dishes (each with a valve that opened in one direction). The reward (peanut) was put in a dish that was not visible to the primate and was on a moving stand [7]. The experiment started after 17 hours of hunger.

Table 1: Cognitive tests result

	Visual Memory 30'	*Visual Memory 60'*	*Visual Working Memory 30'*	*Visual Working Memory 60'*
Control Before	٥٢/90	٥٦/90	٤٧/90	60/90
Control After	50/90	٥٥/90	٤٩/90	62/90
Δ%	2	1	2	2
Experimental Before	٧٢/90	٨٠/90	٥٤/90	72/90
Experimental After	٤٥/90	٤٥/90	٤١/90	54/90
Δ%	٣٠	٣٩	١4	٢٠

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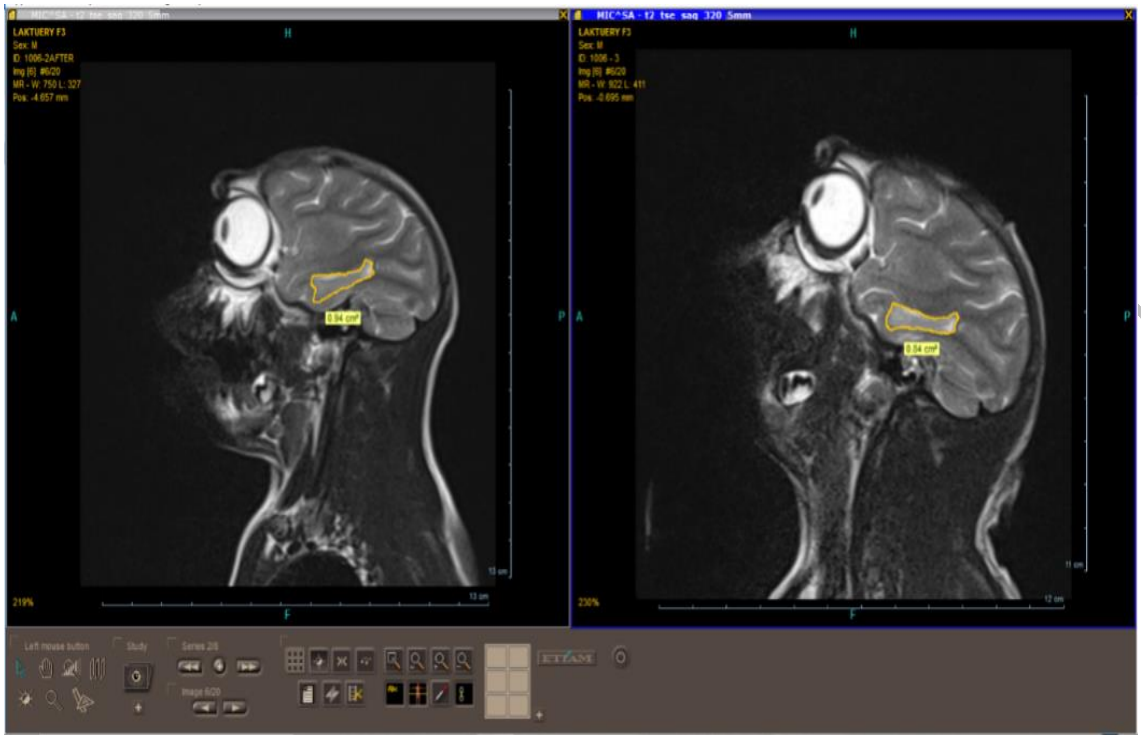

Figure (3): depicts the variations of titration of the sagittal section of the hippocampus + amygdala combination before applying electric field simulations (the left image) and after applying electric field simulations (the right image).

These variations are revealed by studying the Hippocampus and amygdala MRI images in Figure (3) with regard to the anatomy of the brain of the primate exposed to the high-voltage field. This field reduced the size of the amygdala and Hippocampus (memory and learning) of the primate by 10.5% following the treatment, but no considerable change was observed in the control sample. On the one hand, based on the MRI result, we perceived the memory decline of the primate, and on the other hand, we observed the same results from cognitive tests. And therefore, we expect to observe the same results on the SNN model of the Hippocampus (Decreasing on the raster-grams diagram).

One important research goal is to understand the cognitive effects of high-voltage fields on organisms, including humans. Memory and learning are crucial cognitive factors that can be influenced by these fields. Therefore, researchers have studied the effects of electromagnetic fields on important biological processes such as cell proliferation, ion exchanges (such as sodium and potassium ions), nerve repair, production of free radicals, and hormonal changes. The research results suggest that the expression of the glucocorticoid receptor gene plays a significant role in visual working memory. However, the effective doses of electromagnetic fields may vary depending on the organism. Additionally, variations in the levels of some membrane proteins and intracellular proteins, such as the NMDA receptor gene, can significantly affect memory and learning.[54-56].

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Figure (4) shows the variations in the expression of the NMDA receptor gene. As seen, the expression of this gene in the primate exposed to the high-voltage field decreased by approximately 56% but it increased by 18% in the control primate.

Sodium is the most important ion in the extracellular fluid (ECF) and is valuable because it retains water. Different concentrations of this electrolyte have numerous functions in the body. The nerve and muscle impulses are transferred through the pumping of sodium when potassium is discharged from a cell. Sodium and potassium effectively and substantially influence the transmission of nerve impulses [57].

Figures (5) and (6) present the blood electrolyte and potassium and sodium ion levels. As seen, these parameters show a descending trend in the primate exposed to the high-voltage field as compared to the control sample.

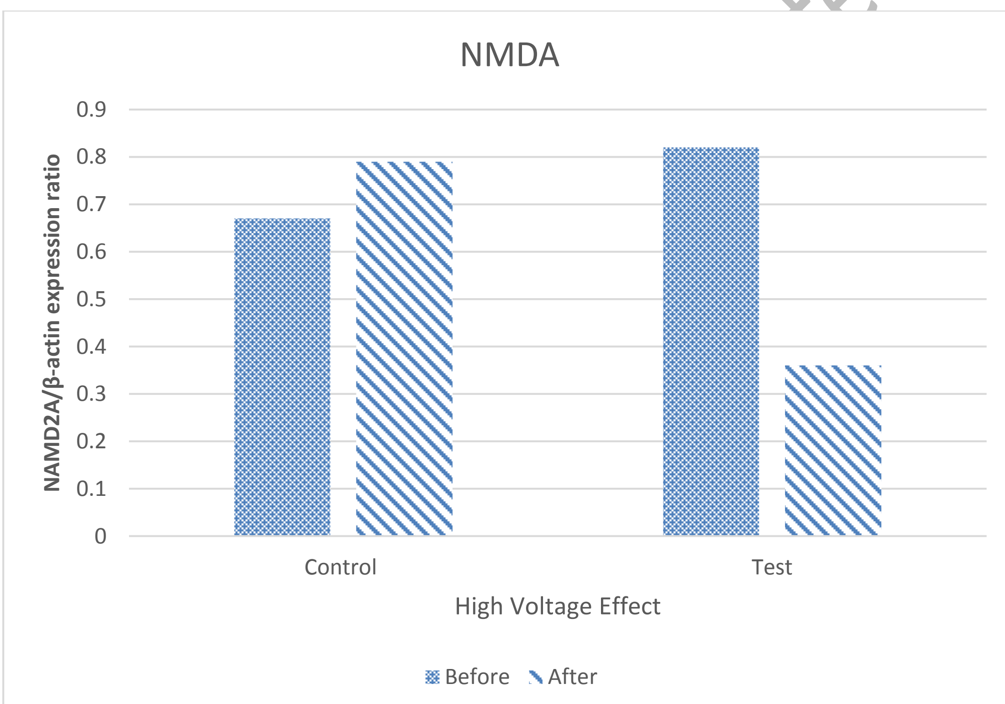

Figure (4): Variations of the expression of the NMDA receptor gene

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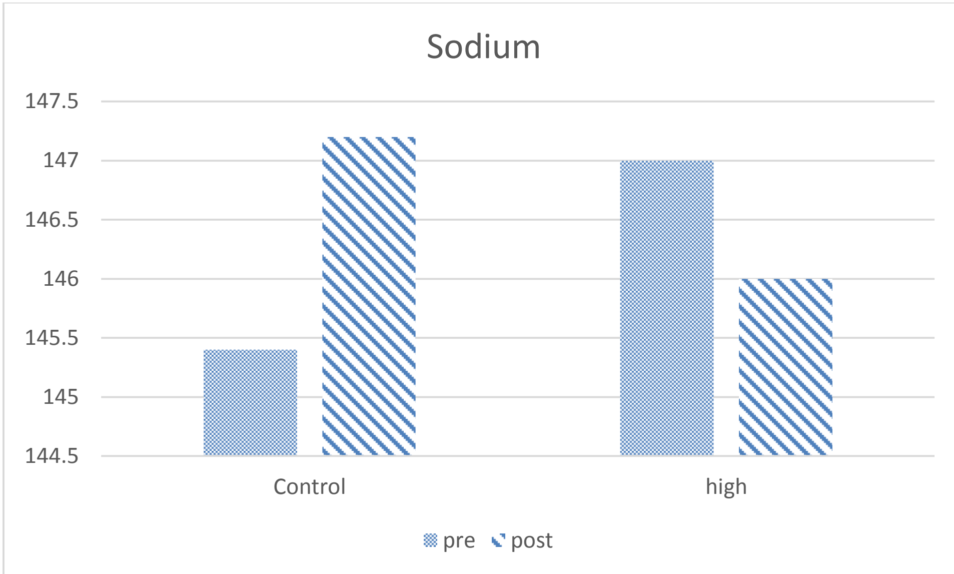

Figure (5): Variations of the blood sodium electrolyte

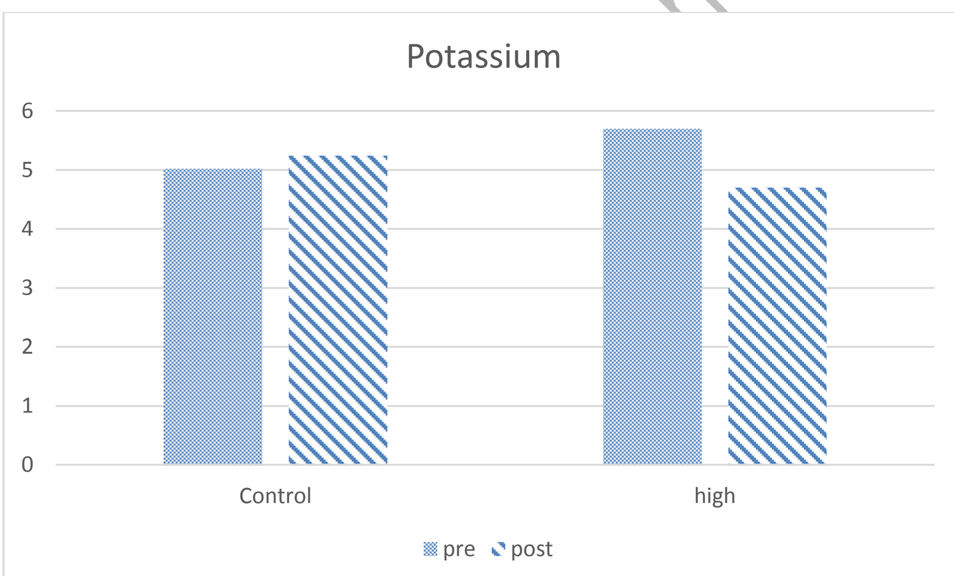

Figure (6): Variations of the blood potassium electrolyte

2 SNN model phase result:

According to the research results, in the primate exposed to the high-voltage field, the decrease in the Hippocampus resulted in a decrease in the concentration of NMDA, sodium, and potassium (fig4, fig4, fig6). In addition, in the cognitive tests (table 1) conducted in the first week after applying electric field simulations, a drastic decrease in performance was observed. Now, it should be determined whether the same result is obtained with the simulated model (the same result is expected from the SNN model. It means experimental phase results are used to evaluate SNN model results).

The activity of NMDA receptors is an important factor influencing the performance of memory in the Hippocampus. Various studies have revealed that the performance of these receptors impairs visual working memory. According to the research data, the concentration of NMDA in the blood of the primate exposed to the high-voltage field decreased, and in the simulated model, the activity of the NMDA receptors declined. As a result, the conductivity of the NMDA receptors decreased, and the excitatory current (and its mean level) also decreased. Hence,

$$V_{reset} < V_{th} \;\; \rightarrow \;\; I_{mean} - g_L V_{reset} > I_{mean} - g_L V_{th} \; (8)$$

$$\rightarrow -(I_{mean} - g_L V_{reset})\Delta I < -(I_{mean} - g_L V_{th})\Delta I \; (9)$$

$$\rightarrow -(I_{mean} - g_L V_{reset})\Delta I + (I_{mean} - g_L V_{th})(I_{mean} - g_L V_{reset}) < -(I_{mean} - g_L V_{th})\Delta I + (I_{mean} - g_L V_{th})(I_{mean} - g_L V_{reset}) \; (10)$$

$$[(I_{mean} - \Delta I) - g_L V_{th}](I_{mean} - g_L V_{reset}) < [(I_{mean} - \Delta I) - g_L V_{reset}](I_{mean} - g_L V_{th}) \; (11)$$

$$I' = I - \Delta I \rightarrow \frac{I' - g_L V_{reset}}{I' - g_L V_{th}} > \frac{I - g_L V_{reset}}{I - g_L V_{th}} \; (12)$$

$$T' > T \;\; \rightarrow \;\; f' < f \; (13)$$

The result of this process is a decrease in the activity of the cortex (13), which is in line with the decrease in the activity of the memory of the primate. Figure (7) shows the raster gram and the mean fire rate of the corresponding neurons and pools[58, 59]. In this simulation, the number of neurons in each pool was multiplied by 4 to clearly observe the effect of the NMDA receptors. As seen in Figure (7), the activity of the neuron populations decreased with a decrease in the activity of the NMDA receptors. Hence, the memory performance is expected to decrease in this state (As we expect from the experimental phase).

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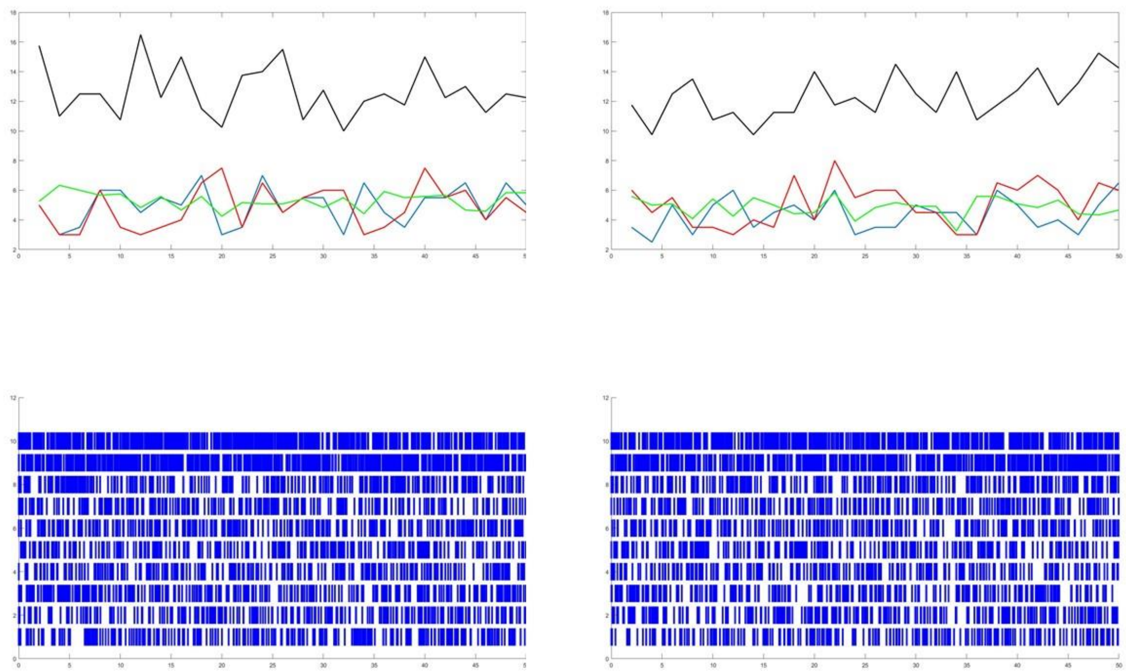

Figure (7) displays the top diagrams, which represent the fire rate diagrams, and the bottom diagrams, which show the raster-grams. The images on the left depict the raster-gram and fire rate diagrams of all neurons in the primary state without any changes and with zero electric field. The images on the right show the raster-gram and fire rate diagrams of all neurons exposed to a 3kV/m electric field, which resulted in a decrease in the NMDA conductivity.

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Based on the experimental phase, it was observed that exposure to high-voltage fields led to a reduction in the volumes of the hippocampus and amygdala, as well as a decrease in the concentration of NMDA. Furthermore, cognitive tests conducted on primates exposed to these fields revealed a decrease in visual working memory. Additionally, the concentrations of sodium and potassium also declined, which could result in the transmission of messages becoming difficult and the performance of the simulated neural networks model to decrease. On the other hand, a decrease in cortex activity may be indicative of cognitive, emotional, or sensory disorders depending on the region. For example, studies using applied magnetic resonance imaging (MRI) techniques have shown that a decrease in the activity of DLFPC impairs visual memory, while a decrease in the activity of DMPFC and the amygdala is associated with depression and a lack of reaction to negative emotional stimuli. The simulated model could also explain the impairment of memory, the decrease in emotional reactions, and the onset of depression (as shown in Figure 7).

It could be stated that the simulation results, as well as the cognitive, hormonal, blood, and genetic test results, are in accordance with the decrease in brain functionality, memory functions, and learning (In other words, the SNN model is evaluated by experiment results). Therefore, exposure to high-voltage towers (due to living or working conditions) and high-voltage electric fields may reduce brain performance, memory, and learning.

Discussion

The objective of the present research was to investigate the effect of high-voltage towers on the brain. To achieve this objective, a rhesus macaque was exposed to a 3kV/m high-voltage electric field for four hours a day for one month, and cognitive, blood, and anatomic variations (MRI) were recorded and analyzed. In this study, two male rhesus macaques were used. Additionally, a neural simulation model was created to investigate the performance of the hippocampus in the brain. Changes were made to the model depending on the conditions of certain elements in each state, and the results were obtained from the model. The SNN model results were evaluated based on the experimental results. [2, 60-62]

The results obtained using the cognitive elements of the rhesus macaque revealed that the 3kV/m high-voltage electric field impaired the visual memory of the samples and the duration of applying electric field simulations effectively contributed to this damage. This is because in the recovery phase, by distancing from applying the electric field simulations phase, the results of the cognitive tests improve. The exposure of the primate to 4 hours of treatment a day for a month caused this level of damage. Hence, if the hours of exposure to the high-voltage field increase, the impacts will be more severe and more difficult to reverse. Various studies have been carried out on this subject because different results are obtained depending on applying electric field simulations duration and the frequency, severity, and time of the experiment. Moreover, the Hippocampus and amygdala play primary and secondary roles in memory, respectively[17, 38, 63-65]. For example, when the hippocampus neurons are damaged, the patient develops Alzheimer's disease[66, 67]. In the titration examinations of the levels of Hippocampus and amygdala in the primate exposed to high-voltage electric fields a decreasing trend of variations was observed, which substantially contributes to the impairment of memory. Glutamate is an excitatory neurotransmitter and a vital source of other receptors. The effects of this neurotransmitter are exerted via membrane receptors known as the ionotropic and meta tropic receptors. The NMDA receptors provide a slow synaptic response and contribute to the genesis of the brain, learning, and memory. In addition, the potassium, sodium, and calcium ions properly travel through these receptors. The results of examining the primate exposed to the high-voltage field revealed a decrease in the expression of the NMDA receptor gene, which could be another cause of the decrease in visual memory and its performance. Furthermore, the decrease in the expression of the NMDA receptor gene reduces the flow of sodium and potassium ions. The sodium, potassium, and calcium ion elements substantially affect memory. Another result of this research was the decrease in the concentrations of sodium and potassium ions, which could be another cause of the decrease in visual memory and visual performance.

The NMDA neural receptors are among the important factors influencing the performance of the model in modeling cortex neural models. According to the research results, the variations of the NMDA element in the experimental group sample (i.e., the primate exposed to the high-voltage field) reduced the concentration of this element[4, 7, 50, 56, 68]. Similar results were obtained from the experimental model. In other words, a decrease was seen in the performance of the cortex

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neural network (impairment of visual memory). Hence, the results of the neural simulation model and the experimental model suggest that proximity to high-voltage fields reduces memory performance. Thus the performance of the SNN model is evaluated by experiment results.

The results of examining the primates can be generalized to humans. Moreover, it could be stated that by adopting some characteristics of the metrics of the resulting model, it is possible to obtain satisfactory results from examining the effects of high-voltage fields on humans.

Finally, the experimental results agree with the results of neural simulation modeling (SNN).

Conflict of Interests:
The authors have no potential conflict of interest pertaining to this journal submission.

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All ethical standards were met based on the international ir.bmsu.rec.1394.112

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