Chapter

The Influence of Electromagnetic Fields on the Behavior of Mice

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Abstract

At the present, the development of life has led animals to have different behaviors in their evolutionary cycle, especially mice. For this reason, when mice are expose to physical agents such as electromagnetic fields, different behaviors can be found within their habitat and diet. Therefore, the analysis based on observation of the behavior of mice exposed to electromagnetic fields of different frequencies have been developed in the city of Potosí, Bolivia, which is located at an altitude of 3950 MASL. The methodology applied is the explanatory and longitudinal research. It is concluded that the influence of electromagnetic fields on the behavior of the mice generates a high stress index, influencing the change in the social behavior of the mice.

Keywords: electromagnetic fields, mice, mouse stress, mobile phones, mouse hyperactivity

1. Introduction

At the end of the twentieth century, humanity had great scientific advances, one of the main ones being the development of telecommunications. Today they have become particularly important since these technologies have allowed globalization and thereby improve both life in general and business life. Year after year, telecommunications technology evolves and with it, different applications have been created, which spread rapidly in all regions of the planet. Together with this communication phenomenon, electromagnetic signals, which have a certain influence on the environment, have increased due to the power of electromagnetic irradiation. This is how the electromagnetic spectrum for its irradiation depends on its wavelength and its frequency, concentrating a certain amount of propagated energy in the form of packages called quanta, postulated by Max Planck (1858–1947).

$$E = h\nu \tag{1}$$

where h is the Planck's constant (6.626×10^{-34} J × s^{-1}) and ν is the wave frequency (Hz).

In consideration of this Planck's postulate, the propagation of the energy of the irradiation of the electromagnetic field has an influence of interaction with matter; in addition, the living organisms of the planet are considered to be biochemical and bioelectric, which adapt to different conditions of the environment where it is evident that today pollution has increased compared to previous times. For this

reason, the propagation analysis of electromagnetic waves must be based on the optical properties of interaction with matter that, depending on the distance to the source and the time of exposure, more electromagnetic energy can be concentrated.

Consequently, it is important to consider that the electromagnetic force is composed of electric and magnetic fields, which are intrinsic properties of matter and can be presented statically and/or dynamically, where the emission of these variables is known as "electromagnetic radiation." The moving electric charges produce electric currents of different intensity, giving rise to the propagation of electromagnetic waves in the medium. **Figure 1** shows the schematic distribution of the electromagnetic spectrum.

It is important to note that electromagnetic waves are transverse, between the intensities of the magnetic field E and the magnetic field H, generating an irradiation called the Poynting S vector, in honor of John Henry Poynting [1].

$$S = E \times H \tag{2}$$

Electromagnetic radiation does not need a medium to propagate; however, air is known as a propagation medium which has certain conduction impedance, defined by the following equation:

$$Z = \sqrt{\frac{K\mu_0}{K\varepsilon_0}} = 377[\Omega] \tag{3}$$

where Z is the air impedance, μ_0 is the magnetic permeability, ε_0 is the electric permittivity, and K is the dielectric constant. According to Milford et al., K is 1.00059 [2].

The air impedance must be quasi-constant. Additionally, the interaction of electromagnetic fields with matter must be considered, where different behaviors are expected, which is due to the different electromagnetic optical properties. According to Kraus and Fleisch, other properties of electromagnetic radiation emission are attenuation, which consists of the interaction of the electromagnetic

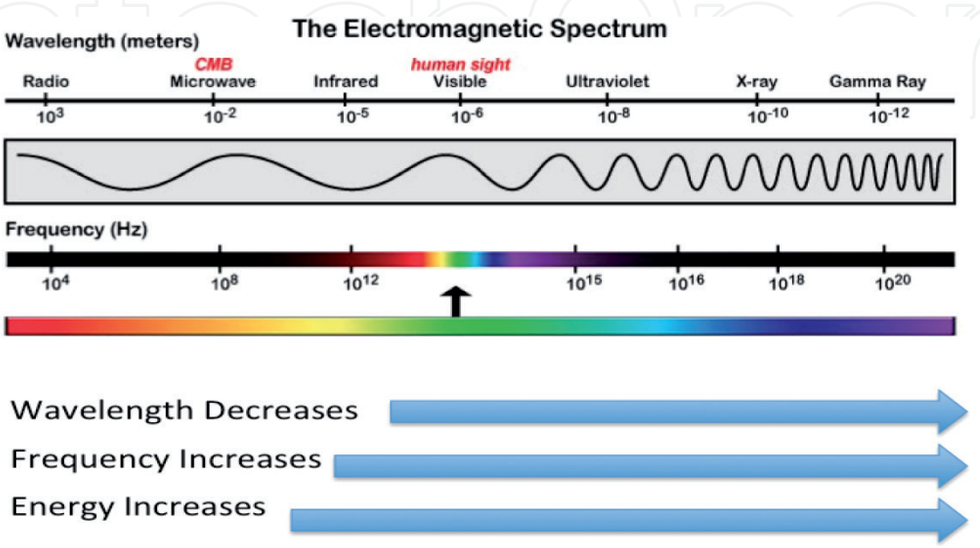

Figure 1.
Schematic presentation of electromagnetic spectrum (source: http://emc2-igcse-help.blogspot.com/2017/02/311-identify-order-of-electromagnetic.html).

field with some material, which has the property of exponentially decreasing its initial value and is given by the following equation:

$$\propto = \sqrt{\frac{\omega\mu\sigma}{2}} \tag{4}$$

where $\propto$ is the attenuation constant ($Np \times m^{-1}$), μ is the permeability of the medium ($H \times m^{-1}$), σ is the conductivity of the medium ($\Omega^{-1} \times m^{-1}$), and ω is the frequency ($rad \times s^{-1}$).

The wave penetration consists of a damping of the incident waves, since it is inversely proportional to the thickness of the material, which dissipates its energy as it travels. This energy is transformed into heat, which occurs by incidence of the wave that when crossing causes the molecules to vibrate causing molecular movements [3]. It is given by the following equation:

$$\delta = \frac{1}{\sqrt{\pi\mu\sigma}} \tag{5}$$

where δ is the penetration constant (m), μ is the permeability of the medium ($H \times m^{-1}$), σ is the conductivity of the medium ($\Omega^{-1} \times m^{-1}$), and π is number pi.

It is noted that these forms of communication have reached the general public, thanks to the constant innovations in systems and infrastructures introduced by mobile phone companies. Despite the fact that a large part of the current terminals belong to the second generation of mobile telephony, the current and future new developments are focused on the evolution of the third and even the fourth generation (3.5G, 3.75G, and 4G) [4]. However, we must consider in the last 2 years, there has been a great technological advance in 5G technology. Although it is still under development and testing, it will be implemented very soon (**Figure 2**).

Given this description, it clarifies that information and communication technology (ICT) is applied today, which facilitate new roles to work efficiently. For this reason, the work carried out by Ruiz-Palmeros and his collaborators in this technology concludes with the following context: "The first factor, excessive or inappropriate use of the mobile phone, included the difficulty in controlling behavior and impulses. The second factor was abstinence and the grouped elements in which concern was expressed about the possibility of not having a telephone. The third factor, by elements, referred to the difficulty of stopping the use of the telephone and family problems. The fourth factor explains the increase in data consumption" [5]. This situation leads to raise a critical and reflective

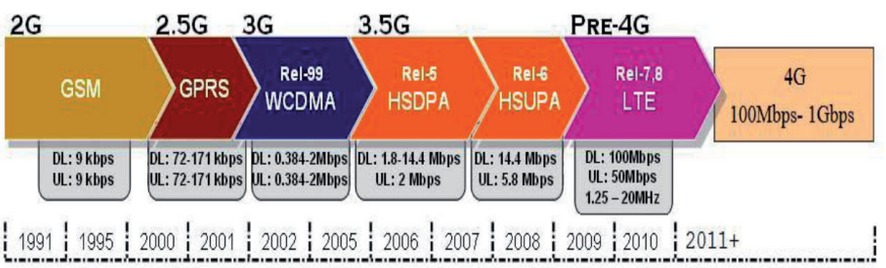

Figure 2.
Cell phone evolution timeline (source: https://cienciaysociedad/documentos/doc/El_Telefono_Movil_ETSIT-UPM.pdf).

aspect of the gravity or influence that communication technology has on biological bodies; so, the interest of this work focuses on observing the behavior of the direct and indirect influence of the emission of electromagnetic fields with a thorough analysis of experimentation in laboratory organisms, such as mice.

Mice are one of the most fertile and numerous groups of mammals on Earth due to the extraordinary ability of their populations to reproduce. They have large numbers of offspring, which is one of the primary reasons they make up the largest group of mammals; the second is that they have a short gestation (pregnancy) period. They are grouped in the Rodentia order and are characterized by very sharp and curved teeth like a chisel that is used to gnaw hard objects.

Rodents are the order with the most species within the group of mammals; there are more than 400 genera and some 2000 species. Among the best known species are mice, rats, chinchillas, and squirrels. Rodents that are closely related to humans (commensal rodents) such as the brown, Norwegian, or water rat (*Rattus norvegicus*), the black or roof rat (*Rattus rattus*), and the house mouse (*Mus domesticus* and *M. musculus*), which have spread throughout the world, taking advantage of their simple body designs, a high reproductive rate, a general diet, and a sophisticated behavior pattern that allowed them to avoid the most cunning attempts at eradication. Knowledge of the response of rodents to their environment can help explain their behavior patterns and allow us to propose or establish control methods [6]. Based on these considerations, it is important to note Mary Johnson's manuscript: "*Genetically defined and genetically modified mice and rats are widely used in research to analyze the function of specific genes, and to serve as experimental models for different human diseases. Thousands of these strains are available, with infinity of genetic alterations, selection of the strain and several applications*" [7].

Given these described aspects, the interest of this document focuses on verifying in a qualitative and quantitative way the real behavior of the exposure of mice to non-ionizing electromagnetic fields. Additionally, it is important to take the main biological aspects of mice according to the laboratory animal management guide. These groups mark their vital areas with urine, forming a network of odors that then allows them to overcome narrow bridges in total darkness. Dominant males and reproductive females create 3-cm-high olfactory stalagmites that announce the presence of their territories to animals nearby. In addition, it is important to take note of the sensory characteristics that they have, which are as follows:

- Smell: used to guide their movements around vital areas where feces, urine, and genital secretions contribute to leaving traces of odor. Traces are detected and can be followed or avoided by other individuals.

- Touch: their main action is the whiskers; this is because the mice and rats have the ability to control their position; they are in constant movement during the exploration, contacting the ground, walls, and any nearby object; in addition, they are the ones that announce the changes of the climate in the environment.

- Hearing: they have a keen sense of hearing, in addition to listening in the range audible to humans, they can capture ultrasonic sounds including those emitted by themselves in that range (between 22 kHz and 90 kHz), and these are used for social communications between them.

- Sight: they are specialized for night vision; they have high sensitivity to light, but poor visual acuity. Rodents have good depth perception and are able to correctly assess the effort required to perform any type of jump; apparently

they do not detect colors, capturing them as gray variants; yellow and green are probably the most attractive colors being perceived as light gray.

- Taste: the sense of taste is highly developed; they have a great ability to detect minimum amounts of bitter, acidic, toxic, or unpleasant substances, which complicates control with toxic baits.

It is also important to consider the predominant physical abilities: digging, climbing, jumping, and mainly gnawing, where their upper and lower incisors constantly grow, being worn away by this action [6]. This is how these conditions set the characteristics for experimentation and development of executed work.

2. Materials and methods

Based on the statements described above, it is important to consider the main behavioral characteristics that developed when mice exposed to electromagnetic fields. For this situation, it is important to reflect on the geographical place where it was made, the city of Potosí, with an average altitude of 3950 m above sea level, with temperatures ranging from 18°C in spring and summer to less than 5°C in the autumn and winter seasons.

The procedure carried out in this quasi-experimental evaluation starts from an exhaustive analysis in the control and observation of mice before and after irradiation to electromagnetic fields generated by mobile phones and signals that exist in the environment. For this reason, the evaluation is carried out in stages or phases, the selection of samples in an organized and equitable manner in each glass box. The first phase consisting of the time of adaptation and acclimatization to the environmental conditions of the region; in this, the metabolic data that the mouse undergoes and its behavior within its habit are registered before being affected by electromagnetic fields, learn about the different abilities particular of mice. Also, at this stage, it is important to record the levels of non-ionizing radiations, for its analysis and to subsequently observe the increase that is made with mobile sources such as cellular sources. In the second phase, it analyzes the characteristics of the cell phones, where the irradiation power must not exceed the permissible limits established in the ICNIRP. Subsequently, the phones are introduced gradually, observing and recording the behavior of the mice within their habit, applying the Likert scale method to demonstrate the level of behavior that each mouse has and thus, demonstrate the influence caused by the fields electromagnetic on mice.

Thus, the mice are housed in glass boxes with appropriate dimensions which are designed to facilitate their behavior since they:

- have adequate, safe space and protect them from external threats;
- provide adequate ventilation;
- provide ease of cleaning and are resistant to frequent disinfection and sterilization;
- allow the observation of the animal;
- facilitate the access or extraction of animals to verify their increase or decrease in body mass;

- there are no sharp edges or projections that can cause injury to the animal; and
- a running wheel is incorporated for their development.

In consideration of these aspects, it is also important to consider the instruments for analyzing the irradiation of electromagnetic fields. For this, three radiofrequency spectrum analyzers were used to observe the level of concentration of concentrated electromagnetic energy in the environment where the rats are located. These instruments are Spectran NF5030, HF2025E, and HF6040, from the German industry, with calibration certification; they analyze electromagnetic pollution with a margin of error of 0.7%, at 2.5% based on the standards established by the ICNIRP [8]. These regulations allow us to establish the real situation in a quasi-experimental environment, where the interest is focused on observing the behavior of animals exposed to these electromagnetic fields that are not noticeable.

With all these aspects, a rodent laboratory (bioterium) was implemented, considering the main aspects of hygiene, safety, and size control in the intrinsic metabolism of each mouse. It is also important to mention that the biosecurity elements are particularly important, where they can ensure control against any pest and/or disease that may be emitted while cleaning or controlling the dwellings where the experimental mice are located (**Figure 3**).

Once the environment is adequate, we proceed with the applied research methodological principles [9], seeking to generate knowledge on the topic developed. Therefore, this is fundamentally based on the findings that the use of wireless communication technology used in our environment implies addressing the issue of the current situation of settlement and/or proliferation of telecommunication antennas. For this reason, the study of this work concentrates on an explanatory methodology; it is used in order to try to determine the causes and consequences of the aforementioned phenomenon, giving the survey of why in some regions of the planet, there is so much problem of settlement or exposure to electromagnetic fields that are generated by the antennas of telecommunication and/or by the latest generation cell phones based on a coherent state of the question and without manipulation of information. We use of the logical tools of research centered on the inductive method this is focused on the observation and analysis of the situation, allowing conclusions to be drawn from the events that occurred in mice exposed to electromagnetic fields, considering that this is quasi-experimental, in the fact that it is intended to manipulate some specific variables, such as the density of mobile phones, which emit a certain amount of electromagnetic radiation, taking into account that there is no full control over all variables. Finally, longitudinal monitoring is assumed, which characterized the monitoring of the behavior of mice exposed to electromagnetic fields considering a specific observation period (**Figure 4**).

Figure 3.
Implementation of the Mice Lab at the Physics Department, "Tomás Frías Autonomous University."

Figure 4.
Laboratory instrumentation (bioterium), Physic Department, "Tomás Frías Autonomous University."

3. Results and discussions

Based on the established methodologies, we start with the climatic variables of the laboratory such as temperature and relative humidity (RH) in the environment. For this cold weather situation, the mice gradually adapt according to their habit of developing in glass cages, where they present concerns for their immunological and psychological development. Initially, the mouse has a social characteristic and is kept in groups without any problem; these groups form quickly once they are introduced to the glass cage. However, the males of both strains (boxes) begin to show their aggressiveness on the 15th day, even though these groups have not fully established themselves in their habitat. Low temperatures in the laboratory cause a death of 15% of the samples, which causes a controlled heat system to be introduced at certain hours of the night, in order to avoid the loss of the samples. Once these environmental conditions of temperature and humidity were established, the mice showed greater social activity among themselves. At the time of providing the corresponding food, there should have been a procedure for an adequate food balance, such as composition, meeting growth needs, and coat maintenance, the latter being a main aspect of observation, which thanks to this I show some allergies and/or poor digestion in gnawing some cereals.

Therefore, the feeding that is supplied to the mice must have the necessary amounts in fiber and nutrients; in addition, it must be considered that these animals always seek to gnaw some food; that is why much of the diet is concentrated in cereals such as wheat and corn. However, their diet is also concentrated on green foods and nuts in addition to proportions of potatoes, carrots, and other foods that help in growth. It is evident that balanced food that exists for domestic animals such as cats and dogs are attractive to the mouse, the same that causes the fur of the mouse to increase and be much finer. This leads us to have two affirmations: the first is that the food has enough vitamins and they consume in greater quantity in addition to having the corresponding hardness to gnaw. The second is that the taste sensation in some mice causes the bowel movements to be inconsistent but rather causes foul smelling diarrhea that is not favorable to the mouse. Therefore, the nutrition of the mice had processes through which the biological body transforms and uses the nutrients to obtain enough energy, as well as to maintain and repair the tissues since the organism needs to acquire an external contribution of matter, essential for getting the substances that regulate the metabolic processes of the mouse.

It is important to consider the feeding for cold places should be a maximum of 5.7 to 7.5 g of food per mouse; the above is subject to consideration depending on the climate of the region. It should also be considered that the water supply should never be missing in either of the two sample boxes, in a quantity of 250 ml per day. The adaptation time of the mice in the climatic conditions of the city of Potosí

Box 1			Box 2		
Mouse ID	Initial mass (g)	Final mass at the end of adaptation time (g)	Mouse ID	Initial mass (g)	Final mass at the end of adaptation time (g)
1	11.54	19.45	1	10.45	20.71
2	13.45	20.45	2	9.25	—
3	11.23	23.81	3	10.33	24.56
4	10.45	—	4	12.31	24.67
5	12.25	29.83	5	11.37	20.12
6	12.64	29.68	6	12.15	31.84
7	11.34	—	7	11.57	22.64
8	10.57	—	8	10.28	—
9	12.52	24.67	9	9.92	27.37
10	9.89	23.58	10	9.72	—
11	10.29	—	11	10.84	25.36
12	11.64	23.37	12	11.71	23.37

Source: U.A. "T.F."—FAUTAPO—Physic Department, Investigation Roberto Vera.

Table 1.
Body mass control at adaptation time.

was 33 days; currently, there was the loss of samples due to the climate conditions, where the extreme coldest temperature was −4°C. Despite the fact that the environment is controlled, it is important to consider that carbohydrate feeding increases between 10 and 15% on these cold days, since the body of the mice needs to create a greater amount of fat for their protection from weather conditions. In the laboratory, there is a heat regulator so that the temperature does not drop abruptly in the implemented environment (**Table 1**).

Once the adaptation of the mice has been achieved, parallel to this and for a time of 70 days, the accumulated average values of the power density of electromagnetic radiation are shown; according to the density of users, these levels of power increase during daylight hours, especially in the periods from 12:00 to 13:00 and approximately 18:30 to 20:00. This action is because many people today use the mobile phone, for immediate communication, which causes the concentration of power in some parts of the city to increase; so it is right where there is a telecommunication antenna, especially mobile telephony, will have a quasi-similar behavior to that of the following graph.

Although the graph in **Figure 5** shows high peaks, it must be considered that the irradiation activity was continuous; this means that the levels of electromagnetic radiation increased progressively, making use of commercial mobile phones. Where the power density generated by each of the cell phones does not exceed the value of 5 (mW/cm^2), this is based on the ICNIRP international standards, giving certainty of compliance with this.

In knowledge of these aspects, it is important to explain the behavior of mice exposed to these electromagnetic fields. It should be considered that the irradiation was progressive, considering that adaptation to the environmental conditions of the city of Potosí, also influence mice, which influences the behavior of hyperactivity, feeding, and growth. For the analysis of the irradiation of electromagnetic fields on the mice, a detailed control was carried out, starting with the division and marking of each mouse, with great care, where it identifies individually the behavior of feeding (appetite), thirst (water consumption), sleep, aggressiveness, hyperactivity,

irritability of the eyes, and bedding (mouse nest). Each of these aspects is considered as a variable, the same that is registered in a Likert table; this evaluation allows describing the physiological conditions, that is, the stress level of each mouse in the adaptation period, as well as in the gradual exposure to concentrated electromagnetic field levels in the experimental environment. The Likert levels adopted for this situation were as follows: normal level: 1 to 21; medium or moderate level: 22 to 42; and high or acute level: 43 to 63. Based on these considerations, **Figure 6** shows the behavior of the mice in general.

These last two graphs show admirable considerations at the level of the behavior of mice, especially on stress, generated by electromagnetic fields. It is interesting to discuss why this exposure to electromagnetic fields influences the behavior of mice, taking the following explanatory points of observation that are evident in experimentation.

Adaptation aspect and without exposure to electromagnetic fields: mice in the adaptation period show conflicting behavior in the first week, and in some cases, the isolation of some of the samples is evident, causing the normal level of stress to be high; however, over time, this decreased in this period. Despite having an extensive controlled diet of fibers, minerals, and others, some of the mice were unable to adapt to the environment; this is due to the low temperatures recorded. The death of the mice was not only due to the climate but also due to the fight between the dominant males of the herd; there was also the fight between some females and some males; this is due to the desire for reproduction which produced the death of some samples. Between the second and fourth weeks, it is evident that the mice begin to have an organizational system with respect to their habitat. From the third week on,

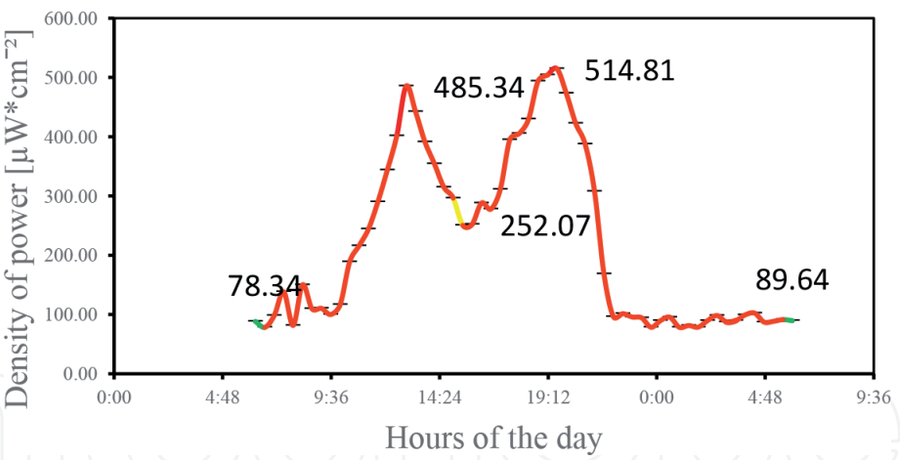

Figure 5.
Temporal behavior of the power density of non-ionizing radiation.

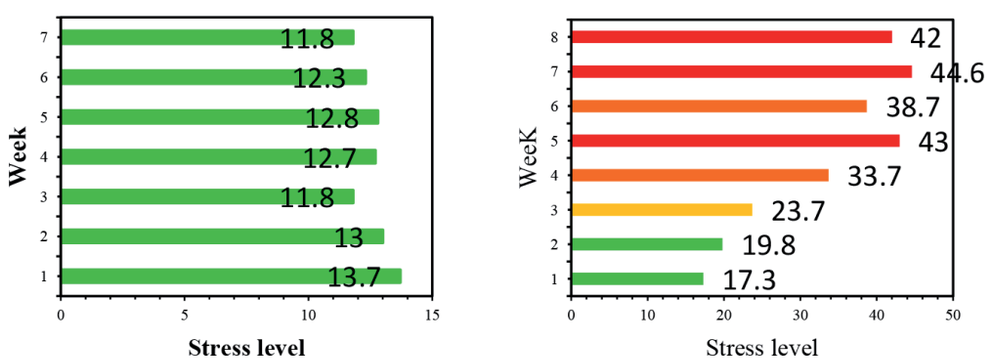

Figure 6.
Chart of stress levels without exposure (left) and with exposure (right) to EMF.

the mice show permanent exploration activity within their vital areas or domains they constantly explore in their environment, both the known and new elements or objects, whether sniffing, gnawing (biting), and tasting food and liquids found in the glass cage. We consider the organization and the exploratory activities carried out by the mice as relevant, however it is important to highlight that, at the time of periodically cleaning the cages, it is evident that urine stools defecation, frequently they are positioned in the same place away from the power supply and water.

Aspect of behavior of mice with exposure to electromagnetic fields: it is evident that in the second graph (right) of **Figure 6**, it shows that the behavior of mice in their stress levels gradually increases, from the lowest (tranquility), going through the moderate level to the level of watery aggressiveness. It is evident that the influence of electromagnetic field or radiation has a great direct influence on the behavior of mice exposed to these physical agents; despite the fact that the average energy accumulated per minute does not exceed 350 mJ, it is the same as it is a very low energy, compared to the molecular resonance that occurs for the ionization of the molecules. However, considering the physical principles of electromagnetic wave interaction with matter and its penetration on these biological bodies, we affirm that energy can accumulate according to the principle of wave superposition for certain time. This aspect causes an invisible concentrated field of energy to exist in the cages and the experimental environment, the same that increases the temperature level that is perceptible to mice; so, the behavioral changes in their habitat and physiology are very noticeable and progressive. The influence of electromagnetic radiation, emanating from different sources, causes a natural and necessary response for survival in the mouse; so, these actions give rise to the following aspects:

- In their habitat: a disordering in the path of their health needs, compared to the situation adaptive clutter in your shelter is more evident, foods are scattered everywhere. The presence of mobile phones in operation (without sound, vibration, or light emission) triggers a restless response in mice, where they try to gnaw and tear the object with greater force; in addition, they work on more than two subjects, trying to hide the equipment; for this action, they use the parts and other extremities, carrying small debris to cover said object, even though the mice avoid approaching the point where the mobile terminal is located. This aspect not only occurs with the cell phone but also with other electrical and electronic instruments, such as coils, radios, and current extenders.

- In their diet

- In the liquid consumption: they present a higher consumption which causes some fights and aggressiveness between them, noticing that we provide more water to avoid fights. Despite dividing the proportions of water into three different containers, the aggressiveness persists. In addition, it is important to mention that one of the water sources is close to the cell phone where the mice avoid going to it, with some of the samples approaching this source.

- Within their hyperactivity: a low performance is observed, since there is greater aggressiveness among the mice, which at the time of getting on the spinning wheel, some of them approach and push it, causing the fall of this.

- In their physiology: within the last 3 weeks of irradiation with electromagnetic fields, the mice have great irritation in the eyes, which when approaching to

the activated source of electromagnetic radiation (mobile phone) avoid being close to it. The mice feel discomfort in the whiskers more frequently when the active electromagnetic signal is increased (when the cell phone is switched on); the frictions that are made in the presence of this physical agent develop irritation in the mouse's snout.

All these exposed aspects show an explanation of how the influence of electromagnetic fields in prolonged periods influence the behavior of mice both in their stress levels and in their physiology.

4. Conclusions

The presence of electromagnetic fields within the environmental environment has grown progressively according to the human population density. The direct or indirect influence of these fields generates an uncomfortable presence in the habitat of an animal, especially for those animals that are sensitive to the variation of the intensities of static or dynamic electromagnetic fields, proof of this is the behavior of the mice within this study which are sensitive to the increase in the levels of electromagnetic fields.

Mice, without the influence of electromagnetic fields, present an organization within their habitat, which demonstrate dynamic hyperactivity in their life cycle. On the other hand, if the conditions of their habitat are abiotic due to the influence of electromagnetic fields, the mice present different levels of behavior, raising their stress conditions, for example, in aggressiveness and irritation of the eyes.

In an epilog, it can be concluded that the action of the electromagnetic fields generated by mobile phones directly influences mice on their level of behavior and their habitat. Furthermore, when the presence of this signal exists, the mice avoid proximity by activating intrinsic prevention in each one of them.

Acknowledgements

The authors are grateful to the FAUTAPO foundation, for making possible the purchase of equipment for the investigation of electromagnetic fields in the non-ionizing spectrum.

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