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On the modeling and analysis of the RF exposure on biological systems: A potential treatment strategy for neurodegenerative diseases ☆

Fabio Mesiti [a,*], Pål Anders Floor [b,c], Anna Na Kim [a,b,c], Ilangko Balasingham [a,b,c]

[a] Department of Electronics and Telecommunications, Norwegian University of Science and Technology (NTNU), Norway

[b] Intervention Centre, Oslo University Hospital, Norway

[c] Institute of Clinical Medicine, University of Oslo, Norway

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ABSTRACT

Mobile communication devices, body area networks, monitoring systems, and diagnostic and therapeutic tools are based on radio frequency emissions, raising the public concern on the possible negative effects on the human health. The future is also oriented towards the use of in-body (nano) sensors for medical applications. Biological alterations caused by non-thermal induced effects have currently been under investigation and experimental results on long-term effects are often discordant. To this end, recent experiments on transgenic Alzheimer mice revealed a progressive regression of the neurodegenerative disease after controlled exposure to mobile phone radiations. Therefore, the importance of understanding the RF-induced effects on the neuronal activity is twofold. Future wireless devices can be designed minimizing unhealthy effects whereas novel RF-based diagnostic and treatment devices for neurodegenerative diseases can be envisaged (in-body micro and nano-sensors and non-invasive techniques). In this paper, we propose an alternative approach in the investigation of such hidden biological mechanisms, where traditional concepts from radio communications are applied to neuroscience. The interaction of RF sources with the neuronal activity is the key point as well as the information exchanged in neuronal networks and the small-world topology of such network, heavily altered in Alzheimer patients.

1. Introduction

Electromagnetic (EM) fields generated by electronic devices are common in many fields of human activities. Even though in most scenarios the transmission energy is relatively low, we are continuously exposed to the presence of numerous EM fields operating in a wide range of frequencies, with particular interest to Radio Frequency (RF) devices for remote communication purposes. Hence, there is an increasing attention in investigating whether the continuous exposure to low-power RF signals could generate undesired effects on biological living tissues and in particular human organs. In the recent past, several efforts focused on the possible effects on the human health as a consequence of continuous exposure to EM fields generated by portable devices such as cellular phones, cordless indoor phones, wireless LANs transceiver and similar RF equipment [20,35]. Extensive experiments have been carried out in the recent past to examine the possible relationship between cause (RF) and effects (biological alterations), but results are often discordant. On the contrary, the heretic possibility, recently advanced in [5], that the RF exposure could induce *positive* and *healthy* effects on neuronal systems when affected by neurodegenerative diseases like Alzheimer,

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* Corresponding author.
E-mail address: fabio.mesiti@iet.ntnu.no (F. Mesiti).

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is enlightening the scientific debate on the effectiveness of this non-invasive treatment of the disease. To this end, our contribution can offer an alternative point of view of the problem, exploiting possible similarities between the response of simple neuronal systems under RF exposure and classical radio communication systems. In this paper, a concise review of existing experimental and theoretical studies will be proposed. First, the fundamental definitions at the basis of this interdisciplinary analysis are defined. Second, we will describe our analytic approach in understanding the RF-induced alterations on the neuronal activity. Possible strategies for envisioned treatments for neurodegenerative diseases based on RF exposure will also be presented.

The paper is structured as follows. Section 2 reviews related works and describes the motivations, while in Section 3, a brief review of common RF sources is provided. In Sections 4 and 5, the neuronal structure is described at different levels. Section 6 reviews the most significant effects on the brain and Alzheimer's disease. In Section 6.2, the key points of the proposed research approach are described with respect to possible treatments of neurodegenerative diseases. Finally, Section 7 draws the conclusions.

2. Related works and motivations

In the past two decades, several international organizations, as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2009 [20] and the US National Council for Radiation Protection (NCRP) (http://www.ncrponline.org/) in 2003, published detailed technical reports with the aim of regulating the maximum allowed energy of EM fields emitted by electronic devices. The most important operating range of frequency for RF devices is the Industrial, Scientific and Medical band (ISM) from 6.78 MHz up to 245 GHz. Many aspects of the impact of EMF exposure on living systems have been considered. For example, physiological alterations, cancer development and genotoxicity have been tested with experiments characterized by the following key-points.

- Exposure setup: definition of EMF sources (mobile phone, medical instruments, body networks), exposure duration, distance from the source and transmitting power.
- Exposed subject: human volunteers, animals or *in-vitro* cultured cells.
- Effects evaluation: biological alterations, direct and indirect effects on non-exposed organs and tissue.

In our research approach, a particular focus is given to the neurocognitive system, which is perhaps one of the most complex and fascinating biological structure in nature. Such analysis could not be carried out without a *reductionist* approach, where the whole *biological machine* is described by fundamental layers representing both structural and functional mechanisms. To this end, we can consider the following layering, inspired by [9], which preserves a parallelism with the typical abstractions of neuroscience.

Table 1
Communication functions for each biological level.

Molecular–cellular	Ionic channels, neuronal signal generators, propagation of electro-chemical signals, neurotransmitters messengers and synaptic transceiver
System	Neuronal networking between cells, optimal routing for signal propagation
Behavior–cognitive	Information processing, message evaluation, feedback to cellular levels, system response

1. *Molecular neuroscience*. This is the most elementary biological level in the neuronal system. Synaptic transmission between neuronal cells is carried out with flows of molecules. Molecular ionic channels regulate the neuronal activity.
2. *Cellular neuroscience*. The basic complex components in a neuronal network are represented by neurons of different types. Neuronal structure, membrane potential, action potential spiking and signaling mechanisms are studied in this level of analysis.
3. *System neuroscience*. Each neuron plays a role in a global neuronal network which interconnects different areas and functions of the brain. External inputs coming from visual processes, world perception and movements, continuously interact with several neuronal networks in the brain. The analysis of the whole system and the macro interactions therein is the main aim of this level.
4. *Behavioral and cognitive neuroscience*. Psychological, cognitive and behavioral functions are included in this level, representing the final separation between the biological *brain* and the highest abstraction level of the human being, the *mind*, where emotions, self cognition and advanced mental functions arise (*cognitive neuroscience*).

Moreover, in Table 1, a parallelism between concepts from communications and neuroscience is proposed, useful to exploit interesting information processing properties behind biological mechanisms. In order to provide the reader with the basic knowledge, a brief review of general effects induced by EM exposure and which are currently under debate, is provided.

2.1. Thermal and non-thermal effects

Microwave RF exposure can induce two main categories of biological effects: *thermal* and *non-thermal*. In short, thermal effects concern acute alterations on the living tissue induced by heating, where the *Specific Absorption Rate* (SAR) quantifies the level of energy absorbed by the human body per unit of mass:

$$\mathrm{SAR} = \frac{\delta}{\delta t}\left(\frac{\delta W}{\delta m}\right) = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho \delta V}\right) \ (\mathrm{W\,kg^{-1}}) \qquad (1)$$

where δW is the energy dissipated in a unit of mass δm evaluated for a volume δV with density ρ. It is usually averaged over the entire body or part of it. Non-thermal effects include all those consequences where the temperature increase is negligible and long-term interactions are expected. Hence, the SAR concept is not sufficient to characterize the exposure and the signal