A Review of the Mechanisms of Interaction Between the Extremely Low Frequency Electromagnetic Fields and Human Biology

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Abstract—Studies of the biological effects and any health related consequences of extremely low frequency (ELF) electromagnetic fields (EMF) have been going on for over half a century however with contradictory outcomes. Hence, it is now necessary to stress on standardizing the EMF-health research experiment procedures in order to enable such experiments become replicable and results comparable. In 1998, a review of several of the ELF EMF human biological interaction mechanisms regarding field intensities and frequencies was presented to the Australian Radiation Laboratory of Commonwealth Department of Community Services and Health in 1988 by Andrew W. Wood. Wood's 1988 assertion of the importance of understanding the interaction mechanisms did not alter even after a decade when the NIEHS RAPID (http://www.niehs.nih.gov/) gathering of world experts produced their statement, in which quoted, there have been experiments on possible mechanism/s in support or refutation of the various proposals however none were replicated. Valberg (Valberg et al., 1997) also summed up some but failed to include all the claimed proposed mechanisms at the time. This paper is to present a complete list of the allegedly possible interaction mechanisms to date.

This paper will also report on an academic research on computer modeling of biological effects of ELF EMF using one of the proposed mechanisms. The research reported here has generally aimed at modeling the proposals using computer. The initial phase of this effort has concentrated on Ca effect as the number of publications referencing that was considerable. Calcium is a key element in the biological performance of every organ in the human body. Thus it deemed imperative to study the effect of EMF on Ca channels of a living cell.

Furthermore, considerations for setting standards in EMF experimental research protocols are recommended. Developing a standard protocol allows results of future experiments to be comparable; and, the chance of replicability in EMF-health improve, which this aspect has indisputably been absent in EMF research projects thus far. Replication is desirable mainly because it eliminates bias, artifact and systematic errors. Replication is almost impossible in the case of epidemiological studies however in experimentation is possible if the details are specified in full. To authenticate any effect of MF, it is not satisfactory to present experimental results without reporting the experimental settings in their entirety.

1. Introduction

Allegations of the biological effects and health hazards of extremely low frequency (ELF) electromagnetic fields (EMF) have been debated for over fifty years. The epidemiological and experimental studies and clarification of conclusions of both research methods have been contradictory. Hence, stipulations have arisen for standardizing EMF-health research experiment procedures so that results of various experiments can be replicated and compared. This paper is to present a list of interaction mechanisms suggested thus far followed by a discussion on setting standard protocols in EMF experimental research. Using a standard protocol allows outcomes of experiments become comparable and replicable. The replicability attribute has undeniably been missing in EMF research projects to date [35].

2. Introducing the Proposed Interaction Mechanisms

Non-ionising radiations are those EMF with frequencies less than 2×10^{16} Hz. They can be grouped into: (i) frequencies over 1 GHz e.g., microwave, infrared and visible light; (ii) frequencies over 3 kHz but below 1 GHz e.g., those in communication systems; and, (iii) frequencies less than 3 kHz known as extremely low frequency or ELF.

The higher frequency exposure can cause dielectric heating by enforcing intra-molecular friction via vibrating momentum increase in water molecules as happens in a kitchen microwave cooking oven. Radiation in this domain can primarily affect the human superficially e. g., skin, cranium, eyes etc and the heat generated can subsequently move deeper onto the body and effectively heat all the internal human organs. Radiation in the GHz range, e. g., mobile phone handsets, antenna and towers' exposure can cause a heating effect penetrating more inside the human body. In the ELF range ($< 3\,\text{kHz}$) for instance. when one is exposed to power-line frequencies and/or home appliances, the effects are not yet well clarified. In other words, the jury is still out on what the interaction mechanism is. Unlike the higher frequency radiations stated above, the electric and magnetic fields in the ELF range can be considered de-coupled. The electric component may barely diffuse in the human body. A widespread observation is via skin hair and only for high flux EMF. But, magnetic component may well penetrate the body nearly un-attenuated.

A review [41] of some of the ELF EMF human biological interaction mechanisms with respect to field intensities and frequencies was presented to the Australian Radiation Laboratory of Commonwealth Department of Community Services and Health in 1988. Wood's 1988 affirmation of the importance of understanding the interaction mechanisms did not alter even after a decade years when the NIEHS RAPID [27] gathering of world experts released their report, in which cited, there have been experiments on possible mechanism/s in support or refutation of the various proposals[3] however none were replicatedThe interaction mechanisms proposed to date are:

(1) **Magnetite**;
(2) **Free radical**;
(3) **Cell membrane**;
(4) **Cell nuclei**;
(5) **Heat shock proteins**;
(6) **Resonance**;
(7) **Blood-brain barrier**;
(8) **Spatial summation**;
(9) **Field induction**;
(10) **Energy**; **and**,
(11) **Corona**.

Describing all the above require a book to be written. However, we will endeavour to introduce these in layman terms briefly in the presentation. The suggested references in support and/or refutation and for better understanding each of the proposed mechanisms are as listed below [35].

Magnetite: Kirschvink et al. [2001], Phillips [1996] and NIEHS [1997].

Free radical: Valberg et al. [1997], Adair [1994] and NIEHS [1997].

Cell membrane: Miles [1969], Cotman and McGaugh [1980], McLeod [1995], Kavaliers et al. [1996], Adey [1981], Blackman et al. [1988], Wood [1988], Ueno [1996], Manni et al. [2002] and Szabo et al. [2001].

Cell nuclei: Lai and Singh [1997], Goodman and Blank [2002], Adair [1998], Ruiz-Gmez et al. [2002], Yomori et al. [2002] and Blank and Goodman [1998].

Heat shock proteins: Zryd et al. [2000].

Resonance: Blackman et al. [1985], Liboff et al. [1987], Lednev [1991], NIEHS [1997], Prato et al. [1996], Prato et al. [1997], Hendee et al. [1996] and Prato et al. [2000].

Blood-brain barrier: Andreassi [1995], Salford et al. [1994] and Lai [1992].

Spatial summation: Valberg et al., [1997] and Astumian et al. [995].

Field induction: Gailey et al. [997], Dimbylow [1998], Baraton and Hutzler [1996], Sagan [1996] and Kaune et al. [2002].

Energy: Valberg et al. [1997].

Corona: Fews et al. [1999], Hopwood [1992], Wood [1993].

Any experimental design to authenticate our theoretical model needs to be replicable. Replication is desirable mainly because it eliminates bias, artifact and systematic errors[4]. Replication is almost impossible in the case of epidemiological studies however in experimentation is possible if the details are specified in full. To substantiate any effect of MF, it is not adequate to present experimental results without reporting the experimental settings in their entirety.

A research has begun by our team using computer simulation of the proposed mechanisms starting with modeling the effect of ELF EMF on the calcium channels. The research project team preparing this paper has also aimed at modeling the proposals using computer. The initial phase of this study concentrated on Ca effect.

Calcium is a crucial element in the biological functioning of every organ in human body. Thus it is important to study the effect of EMF on Ca channels of a living cell.

3. Replication in EMF Research

Replication in EMF research is advantageous since it eradicates bias, artefact and systematic errors [35]. Replication is almost impossible in the case of epidemiological studies but in laboratory experimentation is achievable if the details are specified completely. To validate any biological effect of EMF, it is inadequate to present experimental results without reporting the settings fully. This would make certain the effects are replicable. A proper EMF replication necessitates applying excellent quality assurance measures to ensure matching exposure parameters [34]. These include the human biological endpoint of interest, field characteristics, exposure timing, physical dimensions of the exposure (local or whole body), field strength, DC or AC (sinusoidal or pulsating) frequency, harmonics, field alignment, field direction (linear vs. polarised), instrumentation, laboratory temperature, air-conditioning, light quantity, quality and intensity, background and environmental EMF, time of day, subject's history of exposure, subject's prior to experiment exposure, subject's adaptability to environmental factors, food intake and many others. Obviously, one has limited control over the subject's individual biological condition prior to the experiment [35].

Range of some of the parameters listed above may be controlled using correctly planned, designed and executed protocols. In planning a laboratory research project on the human health effects of EMF, biological measures chosen for the study need to be relevant.

4. Results and Discussion

The ELF bioelectromagnetics biological effects research has entrapped the scientists and the public in a maze since 1960's; no one has yet rescued the concerned community by provision of replicable proof [35]. Besides, a synthesis of the above-listed mechanisms may have to be considered if reasonable in an endeavor to formulate an indisputable interaction mechanism theory verifiable by experimental work.

This area of science is widely accepted as an area of controversial results. The proposed interaction mechanisms were: Magnetite; Free radical; Cell membrane; Cell nuclei; Heat shock proteins; Resonance; Blood-brain barrier; *Spatial summation; Field induction; Energy; and, Corona.* Acceptance or rejection of the proposals is impossible due to lack of independently replicable experiment. The parameters to be considered in a replication include the biological endpoint, field characteristics, strength, signal waveform, frequency, harmonics, alignment, direction, exposure timing, physical dimensions, instrumentation, laboratory temperature, air-conditioning, light quantity, quality and intensity, background and environmental EMF, time of day, subject's history of exposure, subject's prior to experiment exposure, subject's adaptability to environmental factors, food intake and many others. Obviously, one has limited control over the subject's individual biological condition prior to the experiment.

5. Conclusions

None of the alleged interaction mechanisms were proven with replication. Hence, it was concluded that, there was vividly a need for future experimental research in this field using a standard set of experimental research protocols.

Finally, experimental design efforts for testing the interaction mechanism/s theories in our research group are currently tending to focus on protein folding and Ca channels which are slow biological processes. Any experimental design to verify our theoretical model must be replicable. A replication necessitates applying excellent quality assurance measures to match exposure parameters and conditions.

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