Demodulation Effect is Observed in Neurones by Exposure to Low Frequency Modulated Microwaves

R N Pérez-Bruzón¹, T Figols¹, M J Azanza¹ and A del Moral²

¹ Laboratorio de Magnetobiología, Departamento de Anatomía e Histología Humanas, Facultad de Medicina, Universidad de Zaragoza, Spain.
² Laboratorio de Magnetismo de Sólidos, Departamento de Física de Materia Condensada and Instituto de Ciencia de Materiales de Aragón, Universidad de Zaragoza and CSIC, Spain.

E-mail: naogit@yahoo.com

Abstract. Neurones exposure to a microwave (carrier \( f_c = 13.6 \) GHz; power \( P \approx 5 \) mW; \( H_\circ \approx 0.10 \) Am\(^{-1}\) = 1.25 mOe; \( E_0 \approx 3.5 \) V/m; \( \Delta T \approx 0.01^\circ\)C; SAR: \( 3.1 \times 10^{-3} - 5.8 \times 10^{-3} \) W/Kg) EMF amplitude modulated by ELF-AC field (frequency, \( f_m = 0-100 \) Hz) shows no electrophysiological effect under the carrier MF alone, but “frequency resonances” at 2, 4, 8, 12, 16, 50, 100 Hz: demodulation effect. Resonances appear when applied ELF-MF is close to a dominant characteristic frequency of the neurone impulse Fourier spectrum. This is an interesting result considering that ELF-MF modulating RF or MW in the range of human EEG could induce frequency-resonant effects on exposed human brain.

1. Introduction

We have experimentally shown in molluscan brain single neurones that as the frequency of the applied magnetic field (MF), \( f_M \), was coincident with the main frequency, \( f_0 \) of the Fourier decomposition of the spontaneous bioelectric activity voltage impulse, the neurone firing frequency showed a maximum, an effect so called frequency resonance [1]. The exposure of neurones to microwaves (MW) of 13.6 GHz amplitude modulated by ELF-MF around 4 and 16 Hz have shown that are the ELF-MF the responsible for the elicited responses, a so called demodulation effect [2]. The purpose of our research by applying MW modulated by ELF-EMF was to separate out the possible effect of the MW from the one induced by modulated ELF-EMF within a wider range of frequencies, i.e. 2-100 Hz.

2. Experimental details and techniques

The experiments were carried out on neurones of the visceral and parietal ganglia of Helix aspersa. Brain ganglia (about 6mm\(^3\) of volume) were placed in a chamber of acrylic glass, immersed in 5 ml of Ringer solution specific for molluscs (NaCl 80mM, KCl 4mM, CaCl\(_2\) 7mM, MgCl\(_2\) 5mM, pyruvic acid 10mM, buffer TRIS-HCl 5 mM, pH=8). Neurones were viewed using a zoom binocular microscope. Intracellular recordings were made using glass micro-electrodes (tip diameter < 0.5 \( \mu\)m) filled with 1 M potassium acetate (pH 6.8) (tip resistance of 2-20 MΩ). The bioelectric impulses were Fourier spectrum analysed using computer standard methods (Chart v 4.1.2 program for Windows, ADInstruments).

EMF were applied putting the ganglia within a toroidal cavity with a delivered measured power \( P \approx 5 \) mW from a generator, through a 50 Ω coaxial cable and with a typical peak value of \( H_\circ \approx 0.10 \) Am\(^{-1}\) (=1.25 mOe) (the peak electric field (EF) was \( E_0 \approx 3.5 \) V/m) at the Helix brain position (cavity centre). The resonant cavity is made of a dielectric ring of 1mm thickness of FR4, metallized on both surfaces, which are in turn short-circuited in their external edge. The MW field of 13.6 GHz was generated by a home made Gunn diode oscillator, which modulates the high frequency voltage by an ELF frequency signal voltage between 0-100 Hz. The MW MF is homogeneous within a rectangle of 5 mm side about the centre (nervous sample volume \( \approx 6\)mm\(^3\)) and within the cavity plane. The MW EF is polarized along Z axis and is also homogeneous within the cavity height. The MW signal was extracted using a
rectangular waveguide, working in a dominant $TE_{10}$ mode, followed by a coaxial cable, so that the mode becomes TEM, the cable being connected to the cavity by BNC gold plated connector. Modulation depth was fixed at 90%. MW frequency and generator output power were measured using a MW spectrum analyzer. Typical Poynting vector at the cavity centre was $\approx 1 \text{W/m}^2$. Homogeneity and MF polarization were checked by performing numerical simulations of the EMF in the cavity hole. The measured temperature variation was smaller than $\Delta T \approx 0.01 \degree C$. Calculated mean SAR value was $3.1 \times 10^{-3} - 5.8 \times 10^{-3} \text{W/Kg}$, considering all possible configurations interposed to the MW plus the recording borosilicate microelectrode and reference silver microelectrode.

3. Results

Main observation is that application of a microwave EMF of carrier, $f_c=13.6 \ \text{GHz}$, amplitude modulated (90%) by ELF-AC field of frequency, $f_m=2-20 \ \text{Hz}$ shows: no effect under the carrier MF alone, but "frequency resonances" at low frequencies, 16 Hz (Figure 1a), similar to the case of only ELF application, i.e. also with Lorentzian profiles [1, 2]. The effect is a "frequency resonance" of Lorentzian shape, when the MF frequency matches the characteristic frequency (-ies) of the neurone impulse Fourier spectrum (Figure 1b).

The resonance effect seems to be neurone specific. In the experiment made on neurone V12 (Figure 2a), caffeine solution (3mM) did not induced any calcium-dependent metabolic activity [3], Ringer solution was added to remove caffeine decaying neurone bioelectric activity to 0.05 spikes/s. Plane wave (C) was applied and then the carrier modulated by ELF from 2, to 100 Hz frequencies. A resonance was observed at 8Hz. Fourier spectrum gives a maximum for 8 Hz and, interesting observation was that Fourier spectrum also gives a maximum for 3.9 Hz which is coincident with a minimum neurone frequency (2-4 Hz) (Figure 2b), a so called window effect or neurone inhibition.

In our opinion frequency in the main feature for looking at the mechanism responsible for the interaction of weak low frequency magnetic fields with neurone membranes [4]. Neurones plasma membrane seems to behave as a physical system able to resonate as the MF frequency matches some other one characteristic of the bioelectric impulse than the spontaneous neurone frequency we had so
far considered [1]. A new approach has been made for the interpretation of our actual resonance results consistent in a membrane depolarization due to the increase of cytosolic Ca\(^{2+}\) concentration. Ca\(^{2+}\) is detached from plasma neurone membrane through the superdiamagnetism (SD) and Ca\(^{2+}\) Coulomb explosion (CE) as explained elsewhere [5,6].

4. Discussion
We have observed that neurones bioelectric activity is highly sensitive to low frequency applied alternating magnetic fields. Our experiments on Helix neurones showed that for 56% of the studied neurones firing frequency decreases, for 26% spikes frequency increases while the remainder 18% of neurones either do give no response or responses progress very slowly in time [7]. Comparable behaviour has been observed in our actual experimental conditions. Neurones bioelectric activity is highly sensitive to low frequency applied alternating magnetic field modulating a MW carrier in the ten of GHz range. Extremely low frequency modulated MW radiation at non-thermal level of field power density (\(\Delta T\) increase in bath lower than 0.01\(^\circ\)C) modifies neurones bioelectric firing frequency, in a resonant way. The resonance appears when the ELF applied MF is close to a characteristic frequency of the impulse Fourier spectrum (not to the firing frequency, as formerly reported in our ELF experiments [1]).

Stimulatory effects by MW modulated by ELF- EMF have been described on human volunteers EEG. 400 MHz 100 % modulated in the EEG physiological spectrum, at frequencies of 7, 14 and 21 Hz showed increased alpha (8-13 Hz), and beta (13-30 Hz) rhythms. Alpha and beta rhythms were also activated by MW modulation at 40 Hz and 70 Hz [8]. This frequency band seems particularly susceptible to alteration subsequent to electromagnetic field exposure but this effect is not currently
understood. We have observed in our experiments that 13.6 GHz carrier did not induced any effect, being the bioelectric responses elicited by modulating ELF-MF. This effect could be considered as a demodulation effect, a singular capacity of neurone plasma membrane based on SD+CE. A model has been developed that will be published elsewhere [9]. Similarly to observations on humans EEG we have got resonances at frequencies in the alpha and beta rhythms, values much higher than spontaneous Helix neurones frequency. Our conclusion is that the frequency resonant effect must be the expression of an intrinsic biophysical property (0.1-8 spikes/s) common to molluscan and human neurones plasma membrane which appears when the ELF applied MF is close to a characteristic frequency of the bioelectric impulse Fourier spectrum, not to the firing frequency, as formerly reported for ELF-MF application [1]. These observations could explain the effects observed on humans EEG.

5. Acknowledgements

Authors are indebted to Spanish Ministry of Defence under Project EU-ERG 101.013 and to the Diputación General de Aragón, Spain, under Project B-43. Prof. R. Gómez and his group (Universidad de Granada) are acknowledged for simulation, numerical dosimetry calculation and characterization of field irradiated levels.

6. References

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