Impact of Electromagnetic Magnetic Fields on Human Vestibular System and Standing Balance: Pilot Results and Future Developments

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***Abstract*—Studies have found that extremely low-frequency (ELF, < 300 Hz) magnetic fields (MF) can modulate standing balance. However, acute effects of ELF MF on standing balance have not been systematically investigated yet. We aim to establish the threshold for standing balance modulation during ELF MF exposure. 80 subjects will be exposed to an ELF MF (0 to 100 mT) and transcranial electric stimulation (DC and AC, 1 mA). The displacement of their center of pressure will be collected and analyzed using validated sway characteristics in order to detect modulations of vestibular system function. These results will contribute to the literature informing exposure guidelines aiming to protect power-line workers and the general public.**

I. Introduction

Power frequency magnetic fields (MF) result from electricity generation and distribution and from the use of electrical household appliances. We can be exposed to levels of up to 2000 µT using certain household appliances and power-line workers can be exposed to MF over 1000 µT [1, 2].

In order to protect workers and the general public being exposed to MF, guideline agencies, such as the Institute of Electrical and Electronics Engineers (IEEE), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), are providing exposure recommendations to protect the public and workers from potential MF exposure adverse effects [3,4].

Interestingly, there are several studies illustrating the impact of ELF MF on standing balance, which is mediated by the vestibular system [5—8]. However, these studies used low MF exposures and did not study the acute effects of ELF MF on standing balance (i.e. occurring within seconds), which is what we will be addressing in this study. Galvanic vestibular stimulation (GVS) (a direct current stimulation technique – on the order of 1 mA - applied to the vestibular system via 2 electrodes) is well known as a reliable method to induce acute vestibular perturbations translating into loss of balance in humans [5]. It leads the subject to tilt toward the anodal side, an effect mediated by the hair cells of the vestibular system (in the inner ear). Changes in the resting firing rate of the vestibular nerve (90 Hz at rest) causes a perceived accelerated movement, which is spontaneously corrected with a tilt in the opposing direction [5]. A technique related to galvanic stimulation is transcranial alternating current stimulation (tACS), which consists of externally applying an alternating current (on the order of 1 mA) in order to obtain a functional or even a clinical effect [9]. This technique applied to the vestibular system will allow testing of whether an in situ oscillating electric field can achieve the same affect as with galvanic stimulation. This is of critical interest since electric fields generated at the level of the vestibular system with this technology are on the order of 0.1 V/m, which is equivalent to the level of an in situ electric field achieved with a 60 Hz MF between 50 and 100 mT [10,11].

Therefore, our objective is to evaluate the threshold for an acute vestibular function modulation due to ELF MF exposure, and confirm that the effect is mediated by the endogenous induced electric field. Standing balance will be used as an indicator of vestibular system performance, since standing balance is mediated by the vestibular system [5].

II. Methods

A. Subjects

100 healthy subjects (aged 18-55) will be recruited and tested. Exclusion criteria include history of vestibular-related pathology or dysfunction, chronic illnesses (e.g., cardiovascular diseases such as hypertension, ischemia, and cerebrovascular disease) and neurological diseases that affect normal body movement (e.g., Parkinson's disease or Multiple Sclerosis).

B. Experimental Devices

We will be using a force plate (OR6-7-1000, AMTI, USA) recording postural sway (displacement of the Center Of Pressure, COP), using an A/D module (NI USB-6251), driven by LabView 8.6 (National Instruments, USA). MF exposure will be delivered via a headset exposure system (two 375 turn-coils of 5.2 cm diameter, with a 2 cm diameter laminated core of 2705M alloy – Metglas Inc, Conway, SC, USA). Galvanic vestibular stimulation (DC stimulation) and tACS (AC stimulation) will be delivered using the StarStim system (Neuroelectrics, Spain). Exposure will be directed at the mastoid level in order to target the vestibular system.

C. Experimental Design

5 groups of subjects will be tested at different frequencies (20, 60, 90, 120 and 160 Hz, 20 subjects per group, 100 subjects total - protocol approved by the Health Sciences Research Ethics Board (#106122) at Western University). These frequencies correspond to the vestibular nerve resting firing rate (90 Hz) ±30 Hz and ±70 Hz. There will be a total of three exposure modalities (MF, direct current (DC) galvanic stimulation (positive control), and tACS). Exposure modality order will be randomly selected for each subject.

The MF exposure modality will consist of eleven 10-s exposure sequences (ranging from 0 to 100 mT, 10 mT increments), given in a random order (managed automatically by the dedicated LabView script). There will be a 30-second rest in between, allowing subjects to sit and rest. The exposure will then be repeated on the opposite side of the head.

The second exposure modality (DC stimulation) will deliver a current of 1 mA. Similar to the first modality, each exposure will last 10 seconds with a 30-second rest in between and will be repeated on each side of the head. For the tACS exposure modality, we will be using the same frequencies used in the MF modality, however using a single intensity of 1 mA. During the experiment, subjects will be standing (feet together) eyes closed on a force plate covered in a foam layer to maximize vestibular system contribution [9]. Note that this protocol is still in its pilot phase and that minor adaptations may still be considered.

III. RESULTS

Validated sway characteristics (transverse and sagittal mean sway (cm), sway velocity (X and Y, cm/s), sway path (cm), and sway area (cm2)), calculated from COP data will be used for statistical analysis [8, 12]. The Statistical analysis will consist of within-subjects ANOVA (2 factors: flux densities and side of exposure) with a between-subjects factor (1 factor: frequency groups). This experiment is currently in its early phase, with pilot data currently being collected and analyzed.

IV. DISCUSSION

Our objective is to establish a threshold for human standing balance and vestibular modulation in response to ELF MF exposure up to 100 mT. We will do this by recording displacement of the COP while subjects are exposed to an ELF MF and we expect to detect a threshold for standing balance modulation that is flux density dependent (a higher dB/dT will have a greater effect). This study will contribute to the literature supporting the rationale for exposure guidelines protecting public and worker safety, developed by international agencies such as ICNIRP and IEEE. Another future direction of research will consist of exploring the possible impact of high frequency induction mechanisms using radio-frequencies (3kHz) and cell phone frequencies (900 MHz) on hair cells. This is studying the possibility of a "caloric-like" effect, which is described as a nystagmus or rapid eye movement effect in response to irrigation of hot or cold liquid through the external auditory canal. Caloric testing is used for vestibulo-ocular reflex testing [13]. Therefore, a potential thermal threshold effect could be integrated with the understanding of the vestibulo-ocular reflex.

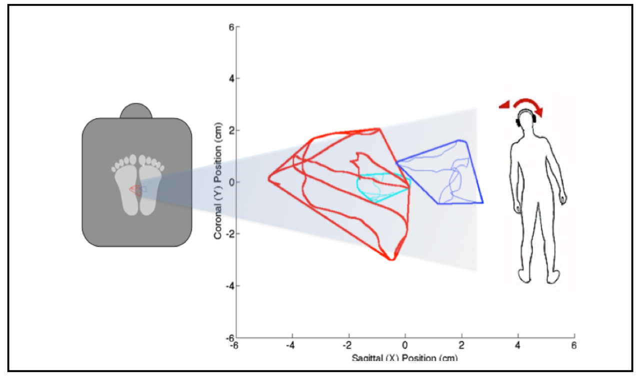

Fig. 1. Horizontal sway patterns from left 5 second GVS exposure in red (1 mA, 1 sec ramp up and down), 5 sec pre exposure period (light blue) and 5 sec post (dark blue).

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