The Impact of Extremely Low Frequency (< 300 Hz) Magnetic Fields (up to 100 mT) on Human Standing Balance

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Keywords: Standing Balance, Vestibular Performance, Extremely Low Frequency Magnetic Fields, 100 mT, Human exposure.

SUMMARY

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 participants 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 further document the rationale of exposure guidelines aiming to protect power-line workers and the general public.

ABSTRACT

Introduction

Power frequency magnetic fields (MF) result from electricity generation and distribution, (60 Hz in North America and 50 Hz in Europe), and from the use of electrical household appliances, such as hair dryers or electric hair clippers. Although average level of exposure for the general public is low, on the order of 0.1 µT at power-line frequencies [1], we are occasionally exposed to higher levels of up to 2000 µT using certain household appliances [2, 3]. Additionally, power-line workers can be exposed to MF over 1000 µT [2, 3].

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 [4-7].

Interestingly, there are studies illustrating the impact of ELF MF on standing balance, which is mediated by the vestibular system [8]. Van Nierop et al. [9] found increased standing balance oscillations when exposed to induced ELF MF within a 7T MRI. Legros et al. [10] found reduced standing balance oscillations after a 1-hour exposure to a 60 Hz (1.8 mT) MF. Thomas et al. [11] also found reduced standing balance oscillations upon exposure to a pulsed MF (0.2 mT). 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 stimulation (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 [8]. More specifically, it leads the tested subject to lean or tilt toward the anodal side. This effect is mediated by the hair cells, located in the semicircular canals and otolith organs of the vestibular system (in the inner ear). Changes in the resting firing rate of these hair cells (90 Hz at rest) causes a perceived accelerated movement, which is spontaneously corrected with the initiation of an acceleration in the opposite direction by the subject [8,

12]. 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 [13]. 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 [14-16].

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. For this study, standing balance will be used as an indicator of vestibular system performance, since standing balance is mediated by the vestibular system [8]. Since we hypothesize that induced currents mediate this effect, we predict that a higher dB/dt (temporal rate of MF flux density variation, T/s) will have a greater effect (i.e. standing balance modulations are flux density dependent at a given frequency, with higher flux densities having a greater effect on sanding balance).

Methods

Participants

For this experiment, a total of 80 healthy participants will be recruited *via* poster advertisements placed around Western University campus. Participants will be tested in the Human Threshold Research Facility at St. Joseph's Hospital in London, Ontario, Canada. Inclusion criteria include healthy participants (males and females), aged 18-55. Exclusion criteria for the study 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). Also, people with self-reported permanent metal devices or piercings above the neck region will be excluded. Participants will have to refrain from alcohol, caffeine or nicotine intake 24 hours prior to the study.

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.

Experimental Procedure

The experimental design will consist of 4 groups of participants, each tested at a different frequency (20, 60, 120 and 160 Hz, 20 participants per group, 80 participants total - protocol approved by the Health Sciences Research Ethics Board (#106122) at Western University). These frequencies have been selected to be corresponding to the hair cells 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). The order of the exposure modalities will be randomly selected for each participant.

The MF exposure modality will consist of eleven 10-s exposure sequences (ranging from 0 to 100 mT, 10 mT increments), each repeated 5 times (36 minutes total), given in a random order (managed automatically by the dedicated LabView script). There will be a 30-second rest in between, allowing participants to sit and rest. The exposure will then be repeated on the opposite side of the head, which will take another 36 minutes.

The second exposure modality (DC stimulation) will be similar in design to the MF exposure modality. For this modality, a current of 1 mA will be delivered. Similar to the first modality, each exposure will last 10 seconds with a 30-second rest in between. This will be repeated 5 times on each side of the head (7 minutes). 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 (7 minutes). During the experiment, participants will be standing (feet together) eyes closed on a force plate covered in a foam layer to maximize vestibular system contribution [9, 17, 18]. Note that this protocol is still in its pilot phase and that minor adaptations may still be considered.

Results

Validated sway characteristics (transverse and sagittal mean sway (cm), sway velocity (X and Y, cm/s), sway path (cm), and sway area (cm^2)), calculated from COP data will be used for statistical analysis [11, 19]. 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 (Figure 1). We will present an analysis of these pilot results during the conference.

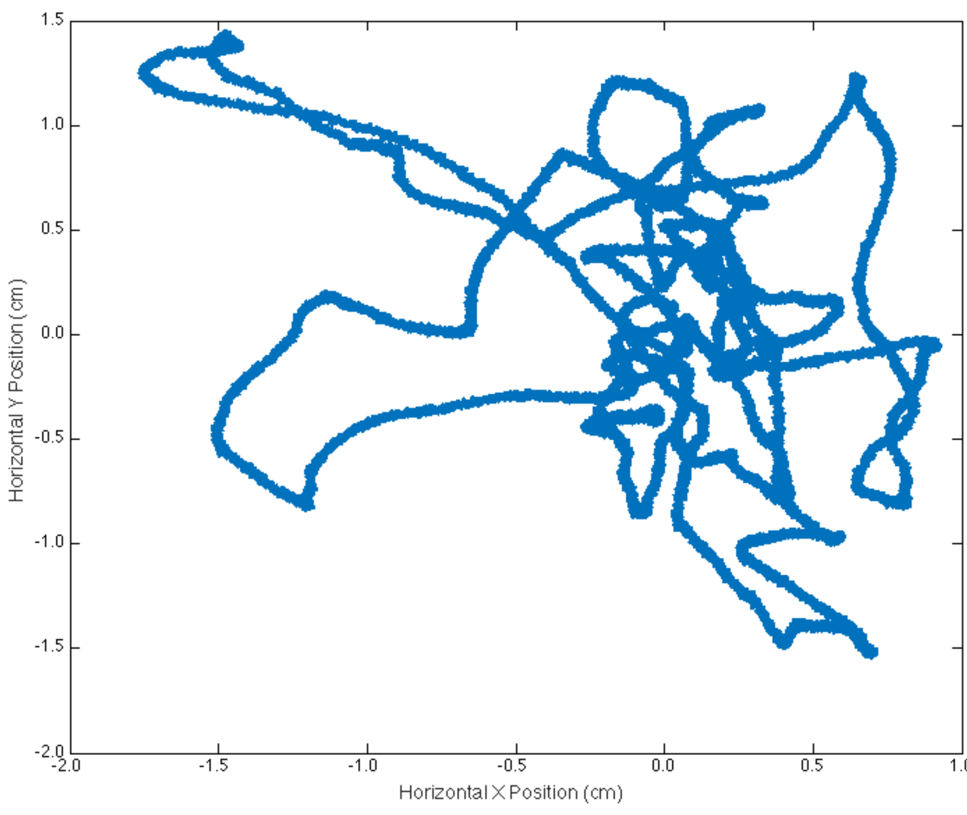

Figure 1. Example of two-dimensional COP displacement (in x and y) over a period of 30 s recorded in a control condition with eyes closed.

Discussion/Conclusion

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 participants 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 the public and worker safety, developed by international agencies such as ICNIRP and IEEE. Another future direction of research will consist of exploring direct measures of vestibular performance (such as oculomotor testing or vestibular evoked myogenic potentials) to further understand the impact of ELF MF on the human vestibular system.

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