Acute impact of extremely low frequency (< 300 Hz) magnetic fields up to 100 mT on human standing balance

A. Allen [1,4], S. Villard[1,2], M. Corbacio[1,2], D. Goulet[5], M. Plante[5], M. Souques[6], F. Deschamps[7], G. Ostiguy[5], J. Lambrozo[6], M. Guerraz[8], A. W. Thomas[1,3], A. Legros,[1,2,3,4]

[1]Human Threshold Research Group, Lawson Health Research Institute, London (ON) Canada
[2]Department of Medical Biophysics, Western University, London (ON) Canada
[3]Department of Medical Imaging, Western University, London (ON) Canada
[4]School of Kinesiology, Western University, London (ON) Canada
[5]Hydro-Québec, Montréal (Qc) Canada
[6]Service des Études Médicales, EDF, Paris, France
[7]Service Environnement Réseaux, RTE, Paris, France
[8]Laboratoire de psychologie et neurocognition, Université de Chambéry, France

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SUMMARY

Studies have found that extremely low-frequency (ELF, <300Hz) magnetic fields (MF) can modulate standing balance, however acute balance effects of high flux densities in this frequency range have not been systematically investigated yet. This pilot study explores acute human standing balance responses to magnetic induction and to alternating currents (AC) directly applied with skin electrodes. The study uses direct current (DC) stimulation, or galvanic vestibular stimulation (GVS), as a positive control. The center of pressure displacement was collected and analyzed using validated sway characteristics. This work aims to explore MF exposure thresholds for inducing acute standing balance modulations at various ELFs.

ABSTRACT

Introduction

Power frequency magnetic fields (MF – 50 and 60Hz) result from electricity generation and distribution and from the use of electrical household appliances. These MF are falling under the so-called extremely low frequency range (ELF - <300Hz). Although the average daily level of exposure for the general public is low, on the order of 0.0001mT at power-line frequencies [1], we are occasionally exposed to higher levels of up to 2mT using certain household appliances, such as hair dryers or electric razors [1-3]. Additionally, power-line workers can be exposed to MF as high as 1mT [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), provide exposure recommendations [4-7].

Recent studies have shown that ELF MF can modulate human standing balance [8-11]. It is possible that MF-induced currents in the vestibular system can cause these effects [12]. However, these studies used MF exposures levels that were too low to trigger acute responses on standing balance (i.e. occurring within seconds). Therefore, the remaining questions are 1. what is the threshold at which acute standing balance modulations occur as a result of ELF MF exposure, and 2. what are the possible mechanisms of action involved?

In order to address these questions, this pilot study explores the acute effects of MF-induced electric fields and currents, and of directly applied alternating current (AC) on human standing balance. This second technique is called transcranial alternating current stimulation (tACS), and it consists of directly applying an AC externally via 2 electrodes (up to 2mA). tACS will allow us to determine how an *in situ* oscillating electric field impacts vestibular control.

In addition, direct current (DC) stimulation, also known as galvanic vestibular stimulation (GVS), will be used as positive control. GVS is a type of transcranial direct current stimulation technique (tDCS - typically up to 2mA) where 2 electrodes are placed bilaterally on the mastoids to target the vestibular systems. tDCS is a reliable, well known

method inducing acute vestibular perturbations translating into loss of balance in humans [11, 12].

We hypothesize that standing balance will be modulated by ELF MF and by tACS (increased transverse mean sway, increased sway path, increased sway velocity, and a peak frequency in the 0.1-0.5Hz range) above a threshold to be determined. This effect will be frequency dependent.

Methods

Participants

This experiment is currently ongoing. Participants are 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 exercise, and alcohol, caffeine or nicotine intake 24 hours prior to the study.

Experimental Devices

We use a force plate (OR6-7-1000, AMTI, USA) to record postural sway (displacement of the Center Of Pressure, COP), using an A/D module (NI USB-6251), driven by LabView 14.0.1 (National Instruments, USA). MF exposure will be delivered using a newly developed, freely moving headset exposure system (two 375 turn-coils of 5.2cm diameter, with a 2cm diameter laminated core of permendur-49 – The Goodfellow Group, Coraopolis, PA, USA), suspended on a pulley system to allow for free movement of the participant's head and body. Galvanic vestibular stimulation (DC stimulation) and tACS (AC stimulation) is delivered using the StarStim system (Neuroelectrics, Spain). Exposure is directed at the mastoid level in order to target the vestibular system.

Experimental Procedure

The experimental design for the pilot subjects tested to date consisted of MF and electrical stimulation conditions. MF, DC, and AC exposures were delivered at the mastoid (5 seconds per exposure, 1mA for DC and AC exposure, up to 100mT for MF exposure) at randomized frequencies (DC, 20, 60, 90, 120, and 160Hz). GVS and tACS intensities have been chosen to match the estimated induced electric field at 100mT [13-15].

In the presented data, each exposure was delivered on the left side of the head (anode on the left for DC and AC conditions). The MF exposure condition was delivered using a newly developed portable coil, which was manually held by the experimenter in this initial experimental stage. During the experiment, participants stood (feet together, eyes closed) on a force plate covered in a foam layer to maximize vestibular system contribution [8]. Thirty-second postural sway recordings were taken with a one-minute rest between each exposure to avoid participant fatigue. This protocol was approved by the Health Sciences Research Ethics Board (#106122) at Western University.

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 [10, 16]. We are also performing Fourier transform analysis in order to distinguish peaks in the frequency range indicative of vestibular stress and disturbance (0.1-0.5Hz) [17, 18].

Based on preliminary inspection of pilot data, DC stimulation seemed to affect sway patterns and demonstrated a clear responsive tilt towards the stimulation anode side of the head (Figures 1 and 2). Effects from AC exposure are less clear, however testing at higher intensities may increase this effect. The MF condition showed minimal effects on standing balance, however this was expected since the positioning of the device provided the participant with tactile positional cues. The use of a pulley system to suspend the coil should improve this result. Further pilot data collected using this new exposure system will be presented at the conference.

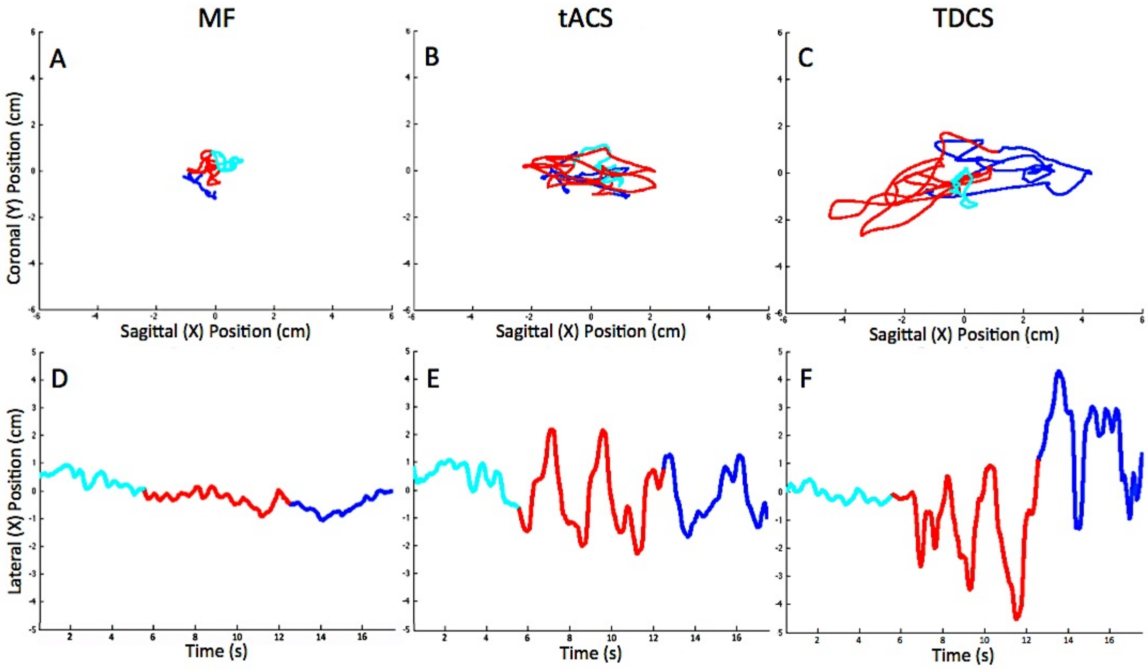

Figure 1. Subject COP movements (A, B, and C) and lateral displacement (D, E, and F) for a five-second exposure (in red) to MF (A and D, left side exposure, 50 mT, 160Hz), tACS (B and E, stimulation anode on the left, 1mA, 160Hz), and TDCS (C and F, stimulation anode on the left, 1mA). Five-second pre and post exposure periods are shown in light and dark blue respectively.

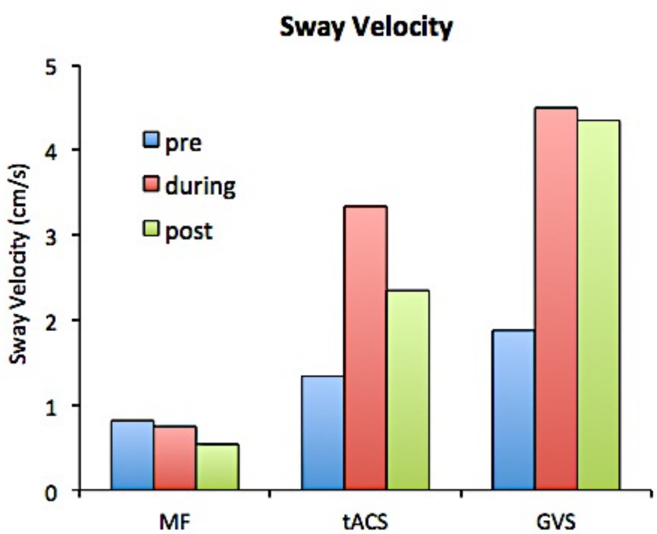

Figure 2. Subject average transverse sway velocity (cm/s) for a five-second exposure to a MF exposure (left side exposure, 50mT, 160Hz), a 1mA tACS exposure (stimulation anode on the left, 160Hz), and a 1mA GVS exposure (stimulation anode on the left).

Discussion/Conclusion

This pilot study explores the effects of MF and AC exposure on human standing balance at different frequencies. As expected, data confirm an acute effect of GVS on human standing balance. Although not as spectacular, the AC shows a destabilization effect that we will present in detail at the conference. The MF exposure apparatus still needs to be finalized to allow proper experimental results. It is currently being adapted to allow for coil suspension using a pulley system. The experiment phase testing 10 subjects in the finalized protocol is about to start and the full results will be presented at the conference. Based on our tACS results and on previous studies on magnetophosphene perception [19-21] and on the similar properties between the retinal photoreceptors (graded potential cells transducing light into electrical signaling) and vestibular hair cells (graded potential cells transducing accelerations into electrical signaling, see for example [22]), we are anticipating to observe acute ELF MF modulations occurring between 50 and 100mT.

This work will further explore MF exposure thresholds capable of inducing acute neurophysiological responses in humans, and aims to contribute to the literature supporting MF safety exposure guidelines for workers and the general public.

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