

PAPER • OPEN ACCESS

Impact of electromagnetic fields on human vestibular system and standing balance: pilot results and future developments

To cite this article: A Allen *et al* 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **120** 012018

View the [article online](#) for updates and enhancements.

You may also like

- [Identifying the Symmetry of an Object Based on Orbital Angular Momentum through a Few-Mode Fiber](#)
Zhou-Xiang Wang, , Yu-Chen Xie et al.
- [Design and numerical optimization of a mode multiplexer based on few-mode fiber couplers](#)
Yiwei Xie, Songnian Fu, Hai Liu et al.
- [Enhancing pulse energy in a mode-locked thulium-doped figure 9 fiber laser by incorporating a few-mode fiber saturable absorber](#)
Xinhao Zhou, Zhenkun Hong, Huanhuan Li et al.

Impact of electromagnetic fields on human vestibular system and standing balance: pilot results and future developments

A Allen^{1,4}, S Villard^{1,2}, M Corbacio^{1,2}, D Goulet⁵, M Plante⁵, M Souques⁶, F Deschamps⁷, G Ostiguy⁵, J Lambrozo⁶, A W Thomas^{1,3} and A Legros^{1,2,3,4,8}

¹ Human Threshold Research Group - Bioelectromagnetics, Imaging Program, Lawson Health Research Institute, London, ON, N6A 4V2, Canada

² Department of Medical Biophysics, Western University, London, ON, N6A 3K7, Canada

³ Department of Medical Imaging, Western University, London, ON, N6A 3K7, Canada

⁴ School of Kinesiology, Western University, London, ON, N6A 3K7, Canada

⁵ Hydro-Québec, Montreal, QC, H2Z 1A4, Canada

⁶ Service des études médicales, EDF, Paris, France

⁷ Service Environnement Réseaux, RTE, Paris, France

Abstract. Although studies have found that extremely low-frequency (ELF, < 300 Hz) magnetic fields (MF) can modulate human standing balance, the acute effects of electromagnetic fields on standing balance have not been systematically investigated. This work aims to establish the threshold for acute standing balance modulation during ELFMF exposure. One hundred volunteers will be exposed to transcranial electric stimulations (Direct Current - DC and Alternating Current - AC, 1 mA) and ELFMF (0 to 160 Hz, 0 to 100 mT). The displacement of their center of pressure will be collected and analyzed as an indicator of vestibular performance. During pilot testing (n=6), we found increased lateral sway with DC, and to a lesser extent, AC exposure. The ELFMF exposure system still needs to be adapted to allow meaningful results. Future protocol design will test for possible effects due to exposures in the radiofrequency range (i.e. above 3 kHz). These results will contribute to the literature documenting exposure guidelines aiming to protect workers and the general public.

1. Introduction

Power frequency magnetic fields (MF – 50 and 60 Hz) result from electricity generation and distribution and from the use of electrical household appliances. MF levels up to 2mT can occur near certain household appliances [1, 2]. These time-varying MF induce electric fields and currents in conductors, including exposed biological systems. From a public health perspective, it is crucial to know the thresholds at which ELFMF and the corresponding induced internal electric fields and currents have an acute biological effect. More specifically, at what exposure threshold does the MF acutely modulate neurophysiological processes

⁸ To whom any correspondence should be addressed.



in humans? International agencies, such as the Institute of Electrical and Electronics Engineers (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), provide exposure recommendations and guidelines protecting the public and workers from MF exposure and its potential adverse effects resulting from induced electric fields [3, 4]. Human balance control, and its modulation under EMF exposure conditions, is one of the meaningful neurophysiological outcomes reviewed in these guidelines. Indeed, standing balance is shown to be particularly responsive to Extremely Low Frequency (ELF, < 300 Hz) MF exposure [5, 6, 7]. Interestingly, standing balance is a complex process involving vestibular, visual, and sensory-motor signals. Glover et al. hypothesized that observed sway pattern perturbations were due to forces on the vestibular organ and induced currents in the vestibular nerve [8]. Nevertheless, these previous studies used low MF exposure levels (below 1 mT) and did not focus on establishing an acute threshold response to higher (up to 100mT) MF exposure levels.

Acute vestibular perturbations translating to a loss of balance in humans have, however, been well documented for a direct current stimulation (DC) called galvanic vestibular stimulation (GVS). Indeed, GVS at 1mA leads to an acute standing balance effect [9]. Interestingly, it has been reported that a 60Hz MF stimulation at 100mT should induce current intensity of such order [10, 11]. Our first hypothesis is that a 60Hz MF stimulation at 100mT will acutely impact standing balance in a similar fashion to a 1mA DC exposure with GVS. Therefore, the main goal of this study is to find the threshold for an acute standing balance response somewhere between 0 and 100mT (tested in 10mT increments).

The most documented physiological biomarker of ELFMF stimulation is the magnetophosphenes, a flickering visual perception. Magnetophosphenes perception serves as a threshold detection reference for IEEE recommendations and ICNIRP guidelines. Research has shown that magnetophosphenes are more easily detected at 20Hz [12]. This finding suggests that magnetic flux density threshold for an acute response might be dependent on the frequency of the MF stimulation. Therefore, the second objective of this study is to evaluate the effect of different frequencies of ELFMF (20Hz, 60Hz, 90Hz, 120Hz, and 160Hz). Since changing the MF stimulation frequency for a given flux density also changes the induced current intensity, we also tested the same frequencies with a fixed 1mA transcranial Alternating Current Stimulation (tACS). tACS consists of externally applying an alternating current and has been used in order to obtain a functional or even a clinical effect. Specifically, it has been shown to reduce resting tremor in Parkinson's patients, however vestibular effects have not yet been explored [13].

2. Methods

2.1. Subjects

One hundred healthy volunteers (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). Participants will have their eyes closed during the data collection portion of the protocol and so participants with visual impairments are eligible.

2.2. 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 14.0.1 (National Instruments, USA). Galvanic vestibular stimulation (DC stimulation, 1 mA) and tACS (AC stimulation, 1 mA, 20-160 Hz) will be delivered using the StarStim system (Neuroelectrics, Spain). Exposure will be directed at the mastoid level in order to target the vestibular system. 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 permendur-49 – The Goodfellow Group, Coraopolis, PA, USA). The exposure will be delivered behind the

ear (just above the mastoid process of the temporal bone), targeting the vestibular system, located 2.5 cm deep from the external auditory canal.

2.3. Experimental Design

Five groups of 20 participants will be tested. Each group will be assigned to a specific stimulation frequency: 20Hz, 60Hz, 90Hz, 120Hz, and 160Hz. Participants will be standing (feet together, eyes closed) on a force plate covered in a foam layer to maximize vestibular contribution and will be exposed to three stimulation modalities: direct current (DC), tACS and MF.

Each exposure will last 5 seconds followed by a 30-second rest and will be repeated on the right and left side of the head. Thus, for each group, DC stimulations will consist of 2 exposures (Right and Left), tACS at the assigned frequency will consist of 2 exposures (Right and Left), and MF stimulation at the assigned frequency will consist of 22 exposures (0 to 100mT in 10mT increments for Right and Left). Exposures will be presented in a random order.

This protocol was approved by Western University's Health Sciences Research Ethics Board (#106122).

3. Results

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 [6, 14]. The statistical analysis will consist of a within-subjects ANOVA (flux densities x side of exposure) with a between-subjects factor (frequency groups). Six pilot subjects have been tested so far. Based on preliminary inspection of these data, DC stimulation seemed to affect sway patterns and demonstrated a clear responsive tilt towards the side of the head containing the stimulation anode (Fig. 1 and 2). Similar acute effects appear to result from tACS, however, the MF condition (pilot tested at a single flux density of 100mT) showed minimal effects on standing balance (Fig. 2). This was expected since the pilot exposure device was stationary and therefore could not allow for much participant movement while maintaining exposure. The use of an ambulatory unilateral exposure device currently being developed should improve this result.

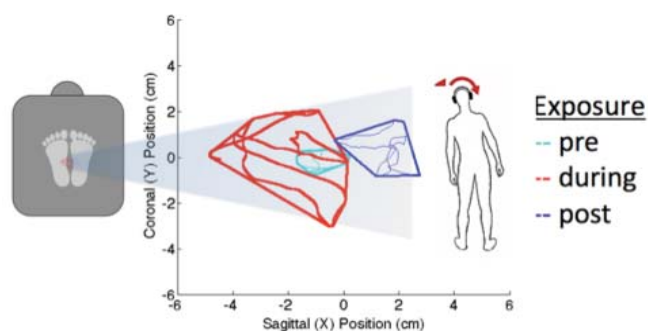


Figure 1. Horizontal sway patterns from left 5s GVS exposure in red (1mA, 1s ramp), 5s pre exposure period (light blue) and 5s post (dark blue).

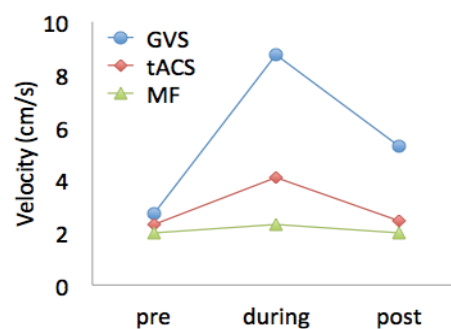


Figure 2. Subject average sway velocity of oscillation for 5s right exposure to GVS (1mA), tACS (1mA, 120Hz) and MF (120Hz, 100mT).

4. Discussion

The main aim of this study is to establish a flux density threshold at which acute postural responses are detected for a 60 Hz MF exposure. The second aim of this study is to identify how this threshold is influenced by the frequency of the stimulation.

So far, with six pilot subjects tested, data appears to be promising in demonstrating an acute effect of DC and tACS on human standing balance. Higher frequencies appeared to show a greater effect in the tACS condition. Regarding the MF condition, different flux density effects have not been tested yet, however the future protocol will use a newly developed MF exposure device allowing for free movement of the participants and therefore a more thorough exploration of the MF effects on standing balance. Data from 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.

Considered future developments could question the possible direct impact of radiofrequencies on the vestibular system via electrophysiological mechanisms (in the kHz range) or via a thermal effect (at cell phone frequencies - 900MHz and above). A thermal effect could indeed trigger a possible vestibular caloric response, which is described as a rapid eye movement due to an acute temperature change in the external auditory canal [15]. The vestibular system could therefore be an interesting biological target adapted to test for a thermal effect in humans.

5. References

- [1] Gauger J R 1985 Household appliance magnetic field survey *Power Eng.* **5** 2436
- [2] Gandhi O P, Kang G, Wu D and Lazzi G 2001 Currents induced in anatomic models of the human for uniform and nonuniform power frequency magnetic fields *Bioelectromagnetics.* **22** 112
- [3] ICNIRP 1998 Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) *Health Phys.* **74** 494
- [4] IEEE 2002 *IEEE Standard for safety levels with respect to human exposure to electromagnetic fields, 0-3 kHz* (New York: IEEE)
- [5] Legros A, Corbacio M, Beuter A, Modolo J, Goulet D, Prato F S and Thomas A W 2012 Neurophysiological and behavioral effects of a 60 Hz, 1,800 μ T magnetic field in humans *Eur J Appl Physiol.* **112** 1751
- [6] Thomas A W, Drost D J and Prato F S 2001 Human subjects exposed to a specific pulsed (200 microT) magnetic field: effects on normal standing balance *Neurosci Lett.* **297** 121
- [7] van Nierop L E, Slottje P, Kingma H and Kromhout H 2013 MRI-related static magnetic stray fields and postural body sway: a double-blind randomized crossover study *Magn Reson Med.* **70** 232
- [8] Glover P M, Cavin I, Qian W, Bowtell R and Gowland P A 2007 Magnetic-field-induced vertigo: A theoretical and experimental investigation *Bioelectromagnetics.* **28** 349
- [9] Fitzpatrick R C and Day B L 2004 Probing the human vestibular system with galvanic stimulation *J Appl Physiol.* **96** 2301
- [10] Merlet I, Birot G, Salvador R, Ardekani B, Mekonnen A, Frish A, Ruffini G, Miranda P C and Wendling F 2013 From oscillatory transcranial current stimulation to scalp EEG changes: a biophysical and physiological modeling study *PLoS One.* **8** e57330
- [11] Salvador R, Ramirez F, V'yacheslavovna M and Miranda P C 2012 Effects of tissue dielectric properties on the electric field induced in tDCS: a sensitivity analysis *Conf Proc IEEE Eng Med Biol Soc.* 787
- [12] Lovsund P, Oberg P A, Nilsson S E and Reuter T 1980 Magnetophosphenes: a quantitative analysis of thresholds *Med Biol Eng Comput.* **18** 326
- [13] Brittain J S, Probert-Smith P, Aziz T Z and Brown P 2013 Tremor suppression by rhythmic transcranial current stimulation *Curr Biol.* **23** 436
- [14] Despres C, Lamoureux D and Beuter A 2000 Standardization of a neuromotor test battery: the CATSYS system *Neurotoxicology.* **21** 725
- [15] Hain T C 2012 Vestibular testing. American Hearing Research Foundation