A proposed method to study the effect of time-varying electric and magnetic stimulations on the vestibular function

Sebastien Villard[1, 2], Alicia Allen[1, 3], Michael Corbacio[1, 2], Daniel Goulet[4], Michel Plante[4], Martine Souques[5], François Deschamps[6], Genevieve Ostiguy[4], Jacques Lambrozo[5], Michel Guerraz[7], Alex Thomas[1, 8] & Alexandre Legros[1, 2, 3, 8]

[1]*Human Threshold Research Group, Lawson Health Research Institute, London, Ontario, Canada*
[2]*Medical Biophysics, University of Western Ontario, London, Ontario, Canada*
[3]*School of Kinesiology, University of Western Ontario, London, Ontario, Canada*
[4]*Hydro-Québec, Montréal, Québec, Canada*
[5]*Service de Études Médicales, EDF, Paris, France*
[6]*Service Environnement Réseaux, RTE, Paris, France*
[7]*Laboratoire de Psychologie et Neurocognition, Université de Chambéry, Chambéry, France*
[8]*Medical Imaging, University of Western Ontario, London, Ontario, Canada*

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Presented by: Sebastien Villard
Senior Corresponding Author: Alexandre Legros

Extremely low-frequency (ELF <300Hz) magnetic fields (MF) acute effects in humans are still mostly described as visual flickering perception called magnetophosphenes. Yet, postural control modulations in the presence of MF suggest the interaction between magnetic induction and vestibular sensory organs. This work propose to investigate the impact of 100 µT MF at 20, 60, 90, 120, and 160 Hz on the vestibular function by analyzing center of pressure (COP) displacement modulations and subjective visual vertical (SVV) measurements. The sensitivity of both COP and SVV to galvanic vestibular stimulation (GVS) will be used as positive control to evaluate the impact of transcranial alternating current stimulation (tACS) and ELF MF.

Introduction

In their modern daily life, humans are surrounded by natural and artificial sources of magnetic fields (MF), from the static earth geomagnetic field to the time-varying electricity-induced power-frequency MF (60 Hz in North America, 50 Hz in Europe). Since a time-varying MF has the property to induce electric fields and currents in conductors, the question of its potential impact on living systems is crucial from a human health and safety perspective. Although the average domestic exposure to MFs is low (around 0.01 µT) in general public [1], some situations can lead to higher levels at close vicinity of high power electrical devices (e.g. hair dryers can produce up to 2000 µT) or power-lines where workers can be exposed up to 1000 µT on regular basis [2,3].

In order to protect the general public and workers from potential MF exposure related adverse effects, it is particularly important to establish thresholds for acute neurophysiological effects in humans. International organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) or the Institute of Electrical and Electronics Engineers (IEEE) provide guidelines and recommendations [4,5] for safe exposure to extremely low frequency (ELF, <300 Hz time-varying MF. Thresholds of MF exposure are proposed based on the level for which faint flickering lights are perceived in presence of the exposure. This phenomenon, called magnetic phosphenes (or magnetophosphenes), is the most robust acute biomarker of MF exposure. This visual effect is presented as the result from the interaction between induced electric fields and currents, and electrically sensitive cells of the retina [5].

Similarities between information processing (afferent pathways convergence) and sensors structure (graded potential cells) involved in both vestibular and optical sensory systems [6,7] suggest that acute effects could also be observed when the vestibular system is exposed to a critical level of time-varying MF. Interestingly, Nausea, dizziness, vertigo or postural sway velocity modulations with MF exposure have been reported and suggest the implication of the vestibular system [8–10].

The purpose of this work will be to establish a time-varying MF threshold, in the ELF range, for which acute effects on the vestibular function can be observed. Since the expected mechanism of action at play is based on induced-current from time-varying MF to the vestibular electrically sensitive cells, we are expecting to trigger similar effects with an electric stimulation directly applied using skin electrodes. This technology is called transcranial alternating current stimulation (tACS).

In order to characterize the reliability of our vestibular biomarker metric, and its capability to discriminate an acute effect when it exists, we are using galvanic vestibular stimulation (GVS) as a positive control. Indeed, GVS induces a well-documented experimental acute modulation of standing balance. This direct current stimulation of the vestibular system is able to exhibit a deviation of the postural sway toward the side of the anode [6] but also alteration in the perception of verticality [11]. The judgment of verticality is greatly impacted by the perception of linear accelerations provided by the otolith function of the vestibular system. The subjective visual vertical (SVV) can be used as a psychophysical measure of the angle between perceptual vertical and true (gravitational vertical). SVV is well documented in healthy subjects but is also known to be sensitive to various vestibular disorders [12–14], and to GVS [11].

Therefore, this work is investigating whether tACS and time-varying MF show acute effect to the vestibular function similar to the GVS on postural sway and SVV.

Materials and Methods

Subjects and apparatus.

This project is in is pilot phase and only 2 participants have been tested to tune-up the experimental settings. 40 participants will be recruited. GVS and tACS stimulation will be delivered by a StarSim system (Neuroelectrics, Spain). MF exposure will be delivered via a custom headset exposure system (under development). Current and magnetic stimulation will be delivered behind the ear targeting the vestibular system. A force plate (OR6-7-1000, AMTI, USA) will be recording the center of pressure displacement (COP) to assess postural stability. A white line on black background with a random angle between -40° and +40° from the true vertical (0°) will be presented to the participant on a screen at eye level. The participant will control the rotation of this white line, and will be asked to stop its rotation when aligned with the perceived gravitational vertical. The angle between the perceived and the true vertical will be recorded as the subjective visual vertical (SVV).

Experimental protocol.
Participants will be asked to stand still, arms by their sides and feet together on the force plate. After 10 s of baseline, participants will receive 10 s of experimental stimulation. Three sources of stimulation will be testes: GVS (1.5 mA), tACS (1.5 mA) and MF (100 mT). For tACS and MF stimulations, 5 frequencies will be tested: 20, 60, 90, 120, and 160 Hz. Both right and left vestibular system will be tested. COP displacement data will be recorded continuously before, during and after stimulation. SVV evaluation will be performed before, during and after stimulation.
Each condition will be separated by 30 s of rest and randomly presented to the participants.

Results

Only preliminary data have been collected at this stage, only in the electrical stimulation conditions. First data collection shows a clear tilt toward the left (anode) for the GVS (Figure1, top left panel). No clear effect of the tACS has been exhibited in this first pilot subject.
Data collected on the SVV before and after the stimulation are presented in Figure 2. This figure represent the adjustement from the initial angle to the perceived vertical before (dashed line) and after stimulation (solid line) for one participant. No effect of the source of stimulation or the frequency can be suggested by these pilot data.
The MF stimulation device is still under develpomen and corresponding data will be presented at the conference.

Discussion and Summary

Preliminary data regarding the GVS on the postural stability are similar to the findings of Fitzpatrick and Day [6]. Further data are required to compare difference between direct and alternating current and to discuss the potential mechanisms of action on the vestibular system.
The limited amount of data on SVV does not allow us to suggest any impact of source of exposition and frequency on the vestibular function at this stage. Note that in this preliminary phase, the SVV was recorded during and after stimulation periods, but not during. SVV measurements during stimulation have been shown be more sensitive to GVS [11] and therefore will be conducted in further evaluation, and results will be presented at the conference. It is also known that the initial presentation of the line before adjustment tends to bias the SVV toward this initial direction [14]. Such effect will be better controlled in the final experiment. As presented earlier, SVV is a macroscopic psychophysical assessment of the vestibular function. Future works will

required a more specific evaluation of the different vestibular reflexes (i.e Vestibulo-Spinal Reflex and Vestibulo-Ocular reflex), by analyzing in particular the nystagmus in different rotation of the head in presence of ELF MF.

Any acute effect, or absence of effect, of alternating electric and magnetic stimulations on the vestibular system will be discussed comparatively to what is known about magnetophosphenes. Indeed, both the retinal photoreceptors and the vestibular hair cells are graded potential cells, which are more susceptible to be impacted by small modulations of their membrane potential [15,16].

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Figures

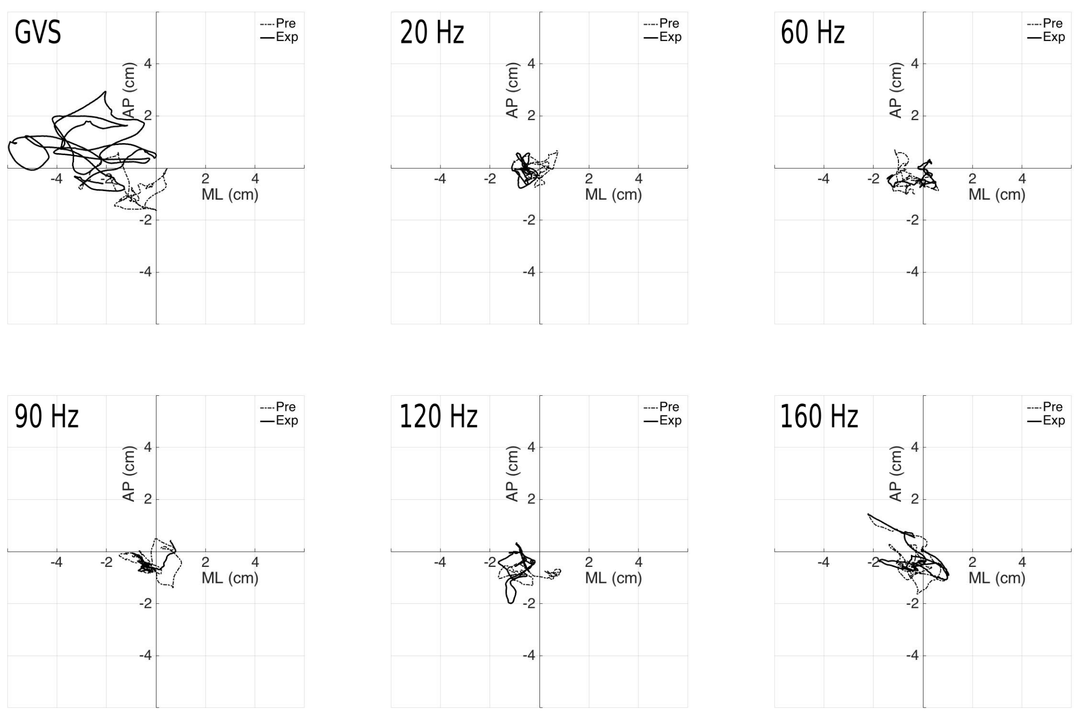

Figure 1. COP displacement of one pilot subject along medio-lateral axis (ML) and antero-posterior axis (AP) for GVS (top left), tACS at 20 Hz (top middle), 60 Hz (top right), 90 Hz (bottom left), 120 Hz (bottom middle) and 160 Hz (bottom right). Dashed line represent the baseline data collection and solid line represent the experimental stimulation.

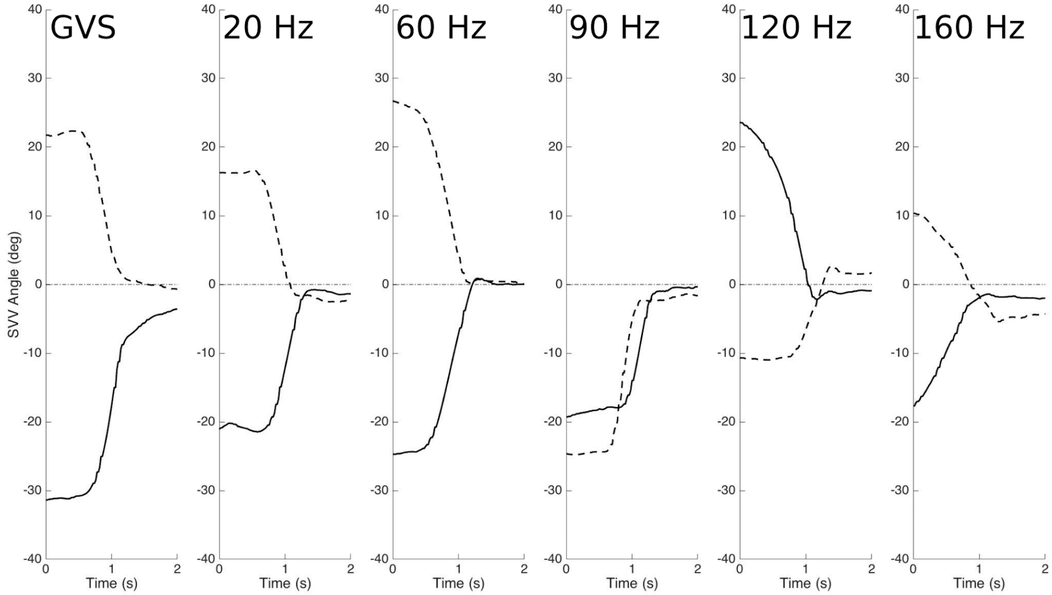

Figure 2. SVV angle before (dashed line) and after (solid line) exposure for GVS, tACS at 20, 60, 90, 120, and 160 Hz. Negative angle represent rotation to the left from the gravitational vertical.