EARtrodes: Towards a Wireless In-Ear Custom-Fitted Brain Computer Interface

Olivier Valentin*[1, 2], Guilhem Viallet†[1] and Jérémie Voix‡[1, 2]
[1]École de technologie supérieure, Montréal, Québec, Canada.
[2]Centre for Interdisciplinary Research in Music Media and Technology, Montréal, Québec, Canada.

1 Introduction and objectives

Brain-computer interfaces (BCI) can directly translate human intentions into discrete commands, bypassing the motor system. Most non-invasive BCI systems currently in use are based on electroencephalography (EEG) recording technology, thanks to recent developments toward mobile EEG solutions. However these systems are currently facing important limitations. In addition to be robust to motions, sensors of mobile EEG-based BCI systems should also be as inconspicuous as possible to be adequate for social settings. The present study evaluates the signal quality of auditory steady state responses (ASSRs) obtained with an unobtrusive earpiece, dubbed "EARtrodes", incorporating in- and around-the-ear electrodes and compared to those obtained with well-established gold-plated electrodes.

2 Material and method

2.1 Overview the ASSRs

ASSRs are electrophysiological responses, recorded from the human scalp, and often evoked by one or more carrier frequencies (Fc) that are amplitude-modulated at a specific frequency (Fm). In practice, when a subject is exposed to such a stimulus, spectral power of the EEG frequency spectrum of the subject that is related to the stimulus will be manifest at Fm, and may also appear at its harmonics [1]. ASSR recordings and stimuli generations were conducted by using the LabVIEW™ based "MASTER SYSTEM™" Rotman Research software.

2.2 Overview of the MASTER SYSTEM

The MASTER SYSTEM is a data acquisition system designed by Michael S. John & Terrence W. Picton [2] to assess human hearing by recording auditory steady-state responses. This LabVIEW based environment simultaneously generates multiple amplitude-modulated and/or frequency-modulated auditory stimuli, acquires electrophysiological responses to these stimuli, displays these responses in the frequency-domain, and determines whether or not the responses are significantly larger than background physiological activity. Typical hardware of the MASTER SYSTEM (Fig. 1) includes a PC, an acquisition board, a variable gain amplifier, an audiometer, a transducer (usually, earphones or headphones), an EEG amplifier, BNC and audio cables, and a set of gold-plated electrodes placed at vertex (Cz), on the back of the neck (reference) and on the clavicle (ground).

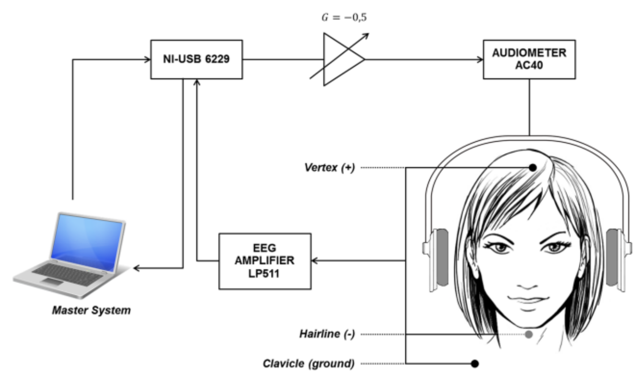

Figure 1: Overview of the MASTER system. All components are monitored by a single PC. The stimulation signals from the analogue output of the NI-USB 6229 board are attenuated by an operational amplifier with a gain of -0.5, so that they may be delivered to the "tape input" of the audiometer, which enables the operator to adjust the levels of stimuli delivered by the transducer. In parallel, ASSRs are scalp-recorded on the electrodes (placed between vertex (+) and hairline (ref), with clavicle as a ground) and are then amplified by an EEG amplifier, before reaching the analogue input of the data acquisition board. Data is processed online through the LabVIEW based software.

2.3 Overview of the EARtrodes

The EARtrodes (Fig. 2) consist of a custom-fitted earpiece which incorporates a custom-fitted earplug coupled with a behind-the-ear piece forming a 7 miniaturized wet electrodes interface. The shape of the behind-the-ear piece was designed by the authors with the help of outer ear impressions made on ten subjects in order to optimize a good contact quality.

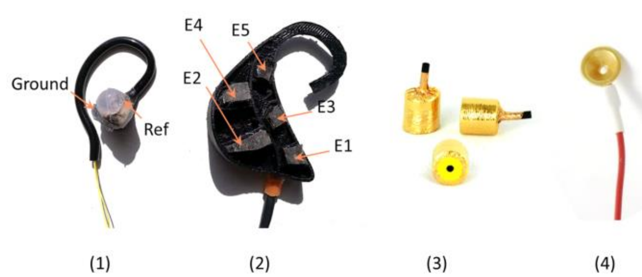

Figure 2: Electrodes used for this study: EARtrodes' custom-fitted earplug (1) and behind-the ear piece (2), gold foil electrodes (3) and gold-plated cup electrodes (4).

* m.olivier.valentin@gmail.com
† guilhem.viallet@etsmtl.ca
‡ jeremie.voix@etsmtl.ca

Additive manufacturing and casting techniques has been used to build the custom-fitted earplug with electrodes. All electrodes were made of silicone filled with carbon chopper.

2.4 Participants

Five men with ages from 19 to 29 and hearing thresholds below 20 dB HL (from 125 Hz to 8 kHz) were assessed. The study was reviewed and approved by the "Comité d'éthique de la recherche", the internal review board (IRB) of the École de technologie supérieure.

2.5 Experimental procedure

A typical experiment procedure included two recording sessions whose purpose was to compare ASSRs scalp-recorded with the EARtrodes' behind-the-ear piece and custom-fitted earpiece to those obtain with gold foil or gold-plated cup electrodes. For both experiment, the stimuli consisted of four pure tones (500, 1000, 2000 and 4000 Hz) amplitude modulated at 40 Hz with a depth of 100 %. The different placements used for each experiment are reported in Table 1.

3 Results and discussion

Although EARtrodes' signals show lower amplitudes, corresponding signal-to-noise ratios of ASSRs recorded with EARtrodes were similar to those of ASSRs recorded with gold electrodes (Fig. 3 and 4). As a consequence, the proposed EARtrodes seems to be a promising candidate for future small, mobile, and unobtrusive BCI platforms. Further research is still needed to investigate event-related potentials, such as the one obtained from an auditory oddball or a mismatch negativity paradigm, to further validate the proposed system. In the long term ear-EEG systems like EARtrodes could be merged with other audio devices, such as hearing aids and headphones, to build next-generation devices that dynamically adapt to the listener's intentions and cognitive state changes.

Acknowledgments

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References

[1] M.S. John, A. Dimitrijevic, T.W. Picton. Efficient stimuli for evoking auditory steady-state responses. *Ear & Hearing*. 24, 406–423, 2003.

[2] M.S. John, A. Dimitrijevic, T.W. Picton. MASTER: a Windows program for recording multiple auditory steady state responses. *Computer Methods and Programs in Biomedicine*. 61, 125–150, 2000.

Table 1: Electrodes' placements used for the two experiments. «G.P.C» refers to gold-plated cup electrodes, «G.F» refers to gold-foil electrodes and «EAR» refers to EARtrodes' electrodes.

<table>
<tr><th></th><th></th><th>Reference</th><th>Ground</th><th>+</th></tr>
<tr><td rowspan="3">Exp. #1</td><td>Control condition #1</td><td>Hairline (G.P.C)</td><td rowspan="3">Clavicle (G.P)</td><td rowspan="2">Vertex (G.P.C)</td></tr>
<tr><td>Control condition #2</td><td rowspan="2">Wet In-ear (G.F)</td></tr>
<tr><td>Measurements #1 to #5</td><td>Around-the-ear (EAR)</td></tr>
<tr><td rowspan="5">Exp. #2</td><td>Control condition #1</td><td>Hairline (G.P.C)</td><td rowspan="4">Clavicle (G.P.C)</td><td rowspan="5">Vertex (G.P.C)</td></tr>
<tr><td>Control condition #2</td><td>Wet In-ear (G.F)</td></tr>
<tr><td>Measurements #1</td><td>Dry In-ear (EAR)</td></tr>
<tr><td>Measurements #2</td><td>Wet In-ear (EAR)</td></tr>
<tr><td>Measurements #3</td><td>Wet In-ear (EAR)</td><td>Wet In-ear (EAR)</td></tr>
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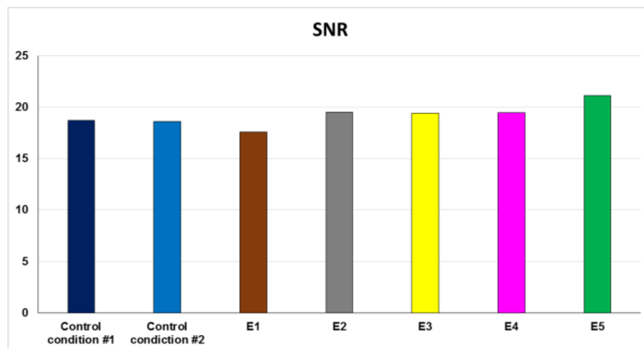

Figure 3: Signal-to-noise ratio, in dB, of ASSRs scalp-recorded on subject #1 using gold electrodes (control condition #1 and #2) and EARtrodes' behind-the-ear piece (E1 to E5). Electrodes placements are detailed in Table 1.

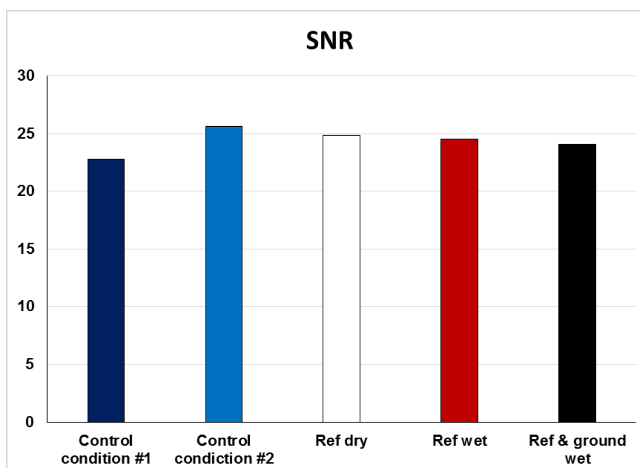

Figure 4: Signal-to-noise ratio, in dB, of ASSRs scalp-recorded on subject #3 using gold electrodes (control condition #1 and #2) and EARtrodes' custom-fitted earpiece.