DIGITAL EARPLUG FOR BRAIN PLASTICITY RESEARCH

Marc Schönwiesner[1], Jérémie Voix[2], and Philippe Pango[3]
[1]International Laboratory for Brain, Music and Sound Research (BRAMS), University of Montreal, 90 av. Vincent d'Indy, Montreal, QC, Canada, H2V2S9, marc.schoenwiesner@umontreal.ca
[2]Sonomax Hearing Healthcare Inc, 8375 Mayrand, Montreal, QC, Canada, H4P 2E2, jvoix@sonomax.com
[3]Vitasound Audio Inc., 14 Connie Crescent (19-20), Concord, ON, Canada L4K 2W8, ppango@vitasound.com

1. ABSTRACT

This paper will present the feasibility of utilizing a miniaturized, real-time, in-ear, digital signal processing devices to investigate experience-dependent brain plasticity in the humans. An important component of this trial is the use of a recently developed digital hearing protector (from Sonomax, Montreal, QC) made with a custom earpiece that is instantly fitted to the user's ear, tested for attenuation and then equipped with a miniaturized set of microphone, receiver and Digital Signal Processor. The DSP is a versatile audio platform, originally designed for hearing aid applications, but that has also been successfully programmed for several other applications like a non-linear earplug (offering more attenuation when the ambient noise is higher) and as a musician's earplug (offering a constant attenuation over a wide frequency range together with a loudness correction). The central idea of the current study is to use such digital earplugs to change a person's sound perception, in real-time, in- and outside of the laboratory. Various time and frequency manipulations will be performed on the signal pick-up by the microphone and transmitted to the subject's ear by the receiver, while monitoring the brain plasticity with neuroimaging techniques. Preliminary results using a notch filter demonstrate tonotopic reorganization following sensory modification in the human auditory cortex.

2. INTRODUCTION

On the basis of a previous study (Pantev et al., 1999) we hypothesize that the removal of a frequency band from auditory input to both ears for one week may result in a reduction of the cortical surface responding to that band within tonotopically organized auditory cortex, and possibly an enlargement of the representation of neighboring frequency bands. We additionally predict that behavioral frequency discrimination thresholds will increase for the neighboring bands, in correspondence with the increased cortical representation.

3. METHOD

Figure 1 shows a photograph of a pair of digital ear plugs. The DSP utilized is a "Voyager", a versatile programmable audio processing platform originally designed by Gennum Corporation (and now distributed by Sound Design Technologies, Burlington, ON) featuring 2 audio inputs (32 kHz, 20 bit ADC), 2 amplified audio outputs (16 kHz, 20 bit DAC) and 4 specialized audio processing units (Input, Output, Time domain and Frequency domain clusters) with a 2.048 MHz clock rate.

The steps of the experiment were: 1) fitting of the ear plugs, 2) programming the processor of the plugs, 3) validating that the earplugs transform incoming sound as intended, and 4) wearing the earplugs and acquiring several fMRI scans and behavioral data from the participant to measure changes in sound perception and cortical mapping of the acoustic parameter that is studied.

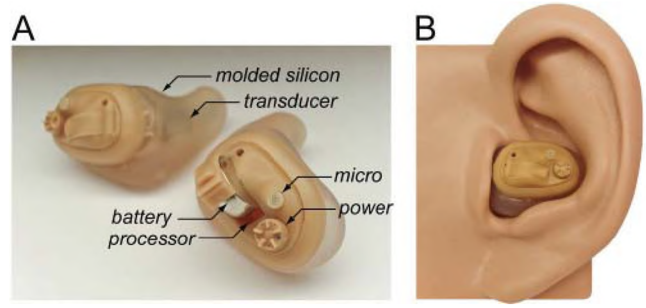

Figure 1: A) Components of a pair of digital earplugs custom-molded to a research participant. The signal processor is located in the center of the plug and programs can be uploaded through the opening of the battery enclosure with a small cable. B) Position of the plug in the pinna. The plug fits comfortably behind the tragus within the concha. The ear is part of an acoustic mannequin (KEMAR, Grass Inc., Denmark) used to measure and validate the frequency response and transfer function of the earplug.

For the present experiment the earplugs were programmed to run a simple notch filter with a center frequency of 1 kHz (Fig 2A). The function of the earplugs was verified by measuring the in-ear frequency response. In addition, standard clinical audiometry was performed with the participant, with and without the earplugs, to evaluate the effect of the earplugs on pure tone detection thresholds. The participant wore the earplugs over the day continuously for a period of 8 days (average 14 hours per day, 112 hours in total). The participant underwent two identical fMRI sessions, one before and one after the period of wearing the earplugs. In each session, high-resolution tonotopic maps of the participant's auditory cortices were acquired with a protocol one of us developed and verified previously (Schönwiesner et al., 2007). Briefly, responses to 5 frequencies are measured at an in-plane resolution of 1.5 x 1.5 mm. The responses are combined to a tonotopic map by finding the frequency that evoked that largest response (best frequency) at every voxel. This map is superimposed onto extracted temporal lobe surfaces, resulting in an accurate visualization of the frequency representation across the cortical surface of the auditory cortex.

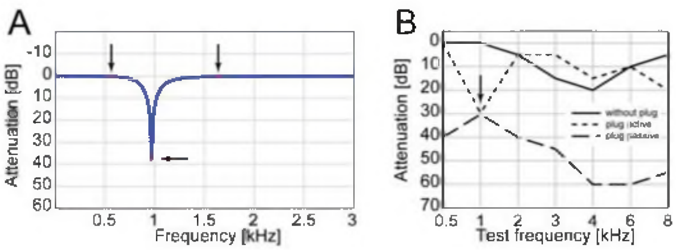

Figure 2: A) Frequency response of the notch filter implemented on the ear plugs. The notch is centered at 970 Hz, with a center rejection of 38 dB and a 3 db-bandwidth of 300 Hz. This design is based on the 5 frequencies tested during fMRI scanning to map the tonotopic organization of the auditory cortex (350, 590, 970, 1670, and 2800 Hz). The middle test frequency is effectively removed by the filter, while the neighboring frequencies are unattenuated (arrows). B) Hearing thresholds were measured from the participant to verify the performance of the earplugs. The plug achieves a passive attenuation of about 30 dB (difference between the solid and the dashed lines). When the plug is switched on, the filter described in (A) becomes active and hearing thresholds return to approximately normal levels, except around 1000 Hz, where the full 30 dB attenuation is maintained.

4. RESULTS AND DISCUSSION

The participant reported that about two days were needed to get completely used to wearing the earplugs, and that after this initial period, use became second nature and did not interfere with daily activities. Audiometric measurement confirmed an attenuation of the target frequency of about 30 dB (Fig. 2B). We compared histograms of the number of voxels responding at each frequency and tonotopic surface maps from the 'before' and 'after' sessions to identify changes in the cortical representation caused by the removal of a frequency band from the sound input. The number of voxels that respond to the frequency that was removed from the auditory input for 8 days is clearly reduced, whereas the neighboring frequencies show an increase (Fig. 3A). This corresponds to the expected pattern of results for a reorganization of a tonotopic map. There was no change at the highest frequency. The lowest frequency also shows a reduction, but we think that this is a result of the non-linear attenuation properties. In this pilot experiment, no attempt was made to correct the earplugs' frequency response electronically, but this will be done in the future studies.

We overlaid color-coded best frequency maps onto the cortical surface of the temporal lobes extracted from the participant's structural scan to find regions of auditory cortex that exhibit a change in the best frequency between the before and after scans. The most prominent difference is visible in the planum temporale where a strip of cortex (Fig. 3B, between arrows) changes its frequency preference from the removed band to neighboring bands.

CONCLUSIONS

These preliminary results are a direct demonstration of short-term tonotopic reorganization in the human auditory cortex. They illustrate the power of using miniature signal processing devices that can be worn in the ear canal to change a person's sound perception in real-time, in- and outside of the laboratory. In light of these initial findings, further research is warranted utilizing a larger group of subjects. Future experiments should also take advantage of the implementation of other filtering schemes onboard the digital earplug's DSP.

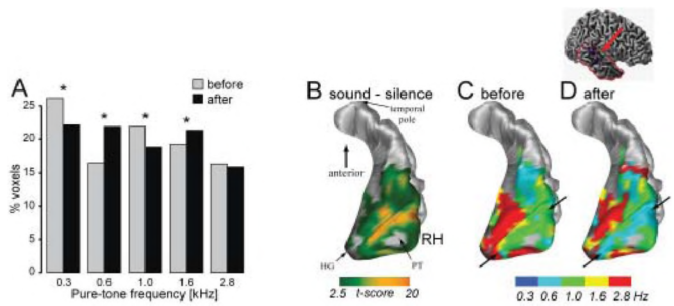

Figure 3: A) Histograms of the percentage of voxels responding maximally to each tested frequency, before and after removal of the frequency band around 1 kHz with digital earplugs. Asterisks indicate a significant difference ($p<0.05$, permutation test, Bonferroni-corrected for 5 comparisons) between the 'before' and 'after' session for each frequency. B) Surface of the right superior temporal plane (the inset illustrates the point of view), extracted from the participant's structural scan using software developed at the Montreal Neurological Institute, with the color-coded statistical significance of the response to all frequencies vs. a silent baseline superimposed. This illustrates the area of cortex that responds to sounds. Within this area, for each patch of cortex, the frequency condition that elicits the maximal response is color-coded for the session before (C) and after (D) wearing the earplugs.

REFERENCES

Pantev C, Wollbrink A, Roberts LE, Engelien A, Lütkenhöner B (1999) Short-term plasticity of the human auditory cortex. Brain Res. 18;842(1):192-9.

Schönwiesner M, Dechent P, Krumbholz K (2007) Basic coding mechanisms in the human auditory cortex: a view through high-resolution fMRI. Proc. 8th HBM, NeuroImage 36, suppl. 1.