Neuroprosthetic haptic interface and haptic stimulation: neuromorphic microtransduction and EEG alpha variations

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Abstract — **According to the recent studies on the psychophysiology of touch, a haptic effector designed in a neuromorphic way was projected, designing an electronic card as to be able to deliver variable signals over time and in intensity. The two-dimensional arrays of micro-actuators were made either with planar geometry or with three-dimensional, semi-spherical or "dome" geometry. Subsequently, on both the behavioral and the electrophysiological level the haptic sensation received by the effector was evaluated on 6 subjects and compared to real stimulations of different grains (Paper). During the various stimulations the subject was in a state of Resting State (RS). Each stimulation had a frequency range ranging from 2 to 500 Hz on 2 and 5 seconds. Analysis of behavioral responses and the alpha in RS showed significant differences for low frequencies vs Paper. RS highlighted differences in ROIs on the various frequency distributions, especially low frequencies in Frontal ROI. Conclusion of this pilot study indicates that the best frequencies for a haptic simulation are between a range from 20 Hz to 166 Hz.**

I. Introduction

Haptic sensation is linked to tactile sensation, and is elicited by the pressure receptors and thermoreceptors in the skin [1], [2].

To date, numerous studies have been conducted on haptic interfaces applied to neuroprosthetics, and this work fits into this innovative view [3]–[6]. Following this topic of research we set out to create a simulator of haptic perceptions through sensory nano-transductions. The effector was constructed with neuro-morphological assumptions [7]. On the basis of our studies on the physiology of touch, an electronic card has been designed so as to be able to deliver signals that vary over time, with an independent input on the 8 contacts of the two-dimensional matrices.

Recall that the matrices are made of two types:

1. matrix 64 pads (8x8, 500 x 500 μm2, period 1 mm) The 8 columns can be electrically activated independently by the 8 electric connection islands
2. 256 pads matrix (16x16, 250 x 250 μm2, period 500 μm). The 16 columns are connected in 8 pairs (2 columns in parallel) to be electrically connected to the 8 connecting islands, as in the case of the 8x8 matrix. The two-dimensional micro-actuator arrays were made either with planar (two-dimensional) geometry or with three-dimensional, semispherical or "dome" geometry.

The latter were designed to allow the signals sent to penetrate deeper into the stratum corneum. In order to simulate a "grain" effect in tactile stimulation, on each column of pads, connected to one of the eight input contacts, a square wave electric signal was applied with a duration varying from one second to five seconds (Figure 2). The pulse train frequency has been varied in the range between 2 and 500 Hz. The electronics have been designed and built to deliver square wave pulse trains of predetermined duration and frequency, in rastering sequence from left to right on the eight input contacts, so that the signal was applied on the columns of adjacent pads sequentially and continuously, without delays between one another. The signal amplitude has been changed in the 5-20mA range.

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II. Material and Methods

A. Behavioral and Psychophysiological Testing Sessions

The subjects were subjected to EEG recording while they were invited to touch with a fingertip of the left hand of the cards with different degree of roughness. Subsequently, the same subjects were subjected to EEG recording while signals were applied at different frequencies, by means of the realized tactile actuator device.

The purpose of this experimentation is to identify a set of values for the frequencies of the signal delivered by the actuator. Subjects: Six subjects were recruited (4 women and 2 men, university students, average age 25, standard deviation ± 9.8).

EEG instrumentation: Brain Vision Recorder; Brain Vision Analyzer, BrainAmp 16 Channels (Brain Products GmhB)

Method: The subject was sitting in a comfortable chair in the laboratory during an EEG recording. The subject was asked to use the dominant hand, with the elbow resting comfortably on the table and the wrist still, to move only the index finger to the right and left touching real surfaces that were proposed or the Pad with various frequencies of Stimulation and with various seconds of stimulation intensity (i.e, 2 sec. and 5 sec.). The 'Paper' Session (4) consisted of 5 haptic training related to 5 different grain stimulations (from a 'shiny and uniform' grain, to a very rough grain grit 400 sandpaper pattern). Pad stimulation frequencies had frequency ranges of 2-50 Hz (1) on 2 or 5 seconds; 80-166 Hz (2) on 2 and 5 seconds and 250-500 Hz (3) on 2 and 5 seconds. Sessions were performed in pseudo-random order.

During the various stimulations the subject was in Resting State [8]. Each stimulation had a duration of 1000 ms. After the stimulation session, the subject was asked to judge, subjectively, the value of haptic stimulation intensity, which ranged from a minimum of 0 to a maximum of 10.

B. *Statistical Data Analysis*

Descriptive analyzes and inferential analysis were carried out on behavioral and psychophysiological variables (T-Test with single sample and Anova).

III. RESULTS

Behavioral ANOVA showed significant results (F=45.782; alpha=0.000). Anova's Post Hoc (Bonferroni Test) indicates significant differences between Value 3 (250-500Hz) with Value 1 (2-50 Hz) and Value 4 (Paper Variable) with all other values (see Fig.1)

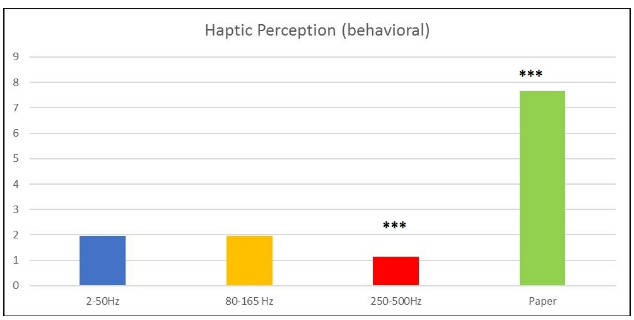

Fig. 1. Behavioral Haptic perception showed in a graphical way. It indicates the subjective values attributed to the intensity of stimulation as a function of the received haptic stimuli.

For the EEG Recordings, 4 ROIs are identified (Frontal, Central, Parietal and Occipital) extracted from the 16 recorded channels.

Results on the Resting State, carried out with the single-sample T-Test comparison, are described in Table 1. Each ROI is associated with each range of the stimulation (i.e, Hz 2-50=1; Hz 80-166=2; Hz 250-500=3; Paper=4)

As described before, the different stimulations were compared with the results alpha variations during the application of the actuator with 20mA signals on variable frequencies in ranges 250Hz, 80-166Hz and 250-200Hz.

IV. DISCUSSION AND CONCLUSION

The response of the subjects to the stimuli-induced with the device is always comparable or slightly higher than that perceived during the actual sensation, especially at the lower frequencies (i.e., 2-50 Hz). The same type of comparison was applied with the frequencies recorded in the central, parietal and occipital localization. The order of magnitude of the measured intensities is always comparable. At the conclusion of this experimental pilot study can be observed

TABLE I
ROIS T-TEST FOR EACH STIMULATION

ROI and Stimulation	T Value and Sign.(2 Tails)
Frontal1	3.516 – 0.017
Frontal2	3.440 – 0.018
Frontal3	3.108 – 0.027
Frontal4	3.773 – 0.013
Central1	2.644 – 0.046
Central2	2.618 – 0.047
Central3	2.565 – 0.050
Central4	2.827 – 0.037
Parietal1	3.125 – 0.026
Parietal2	3.236 – 0.023
Parietal3	2.433 – 0.059
Parietal4	3.342 – 0.021
Occipital1	4.100 – 0.009
Occipital2	3.898 – 0.011
Occipital3	3.752 – 0.013
Occipital4	4.249 – 0.008

that the most suitable frequencies to represent a haptic virtual simulation are the lower frequencies, included in a range between 20 Hz and 166 Hz. Main considerations can be related to the possibility to apply 'micro-transduced' stimulations to the haptics receptors. These stimulations are able to enhance sensorial activations and perceptions, investigated in a behavioural (i.e., haptic perception questionnaire) and in a psychophysiological way (i.e., alpha in resting state). Future applications of the neuromorphic device could be related to understand in a more controlled way, the cortical response to haptic stimulation. A trigger temporal-linked to the onset of stimulation will be allow to investigate haptic event related potentials (H-ERP). At the moment this research methodology is not available on the market, but it would be extremely useful for both basic research and applied clinical research.

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