주파수변조 전기자극에 의한 감각현상의 특성화
PERCEPTION CAUSED BY FREQUENCY VARIATION IN ELECTRO-TACTILE STIMULATION

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1. INTRODUCTION

Tactile perception added to a prosthetic hand device augments its functionalities. *Current electro-tactile displays* are feasible alternatives for this since they directly activate the nerve fibers. Improvement is needed in the characterization of the elicited sensations and the detailed contribution of each electrical stimulation parameter, as current amplitude and frequency, has to be derived. The discrimination ability, in relation to these parameters, should be further analyzed.

This study reports a set of experiments issuing the characterization of the electro-tactile stimulation parameters. We investigated the upper and lower limits of the *frequency interval* to use (defined as *Frequency Activation Threshold (FAT)* and *Frequency Pain Threshold (FPT)* respectively). A *Discrimination Ability Test (DAT)* was conducted to define how much the frequency should be changed to elicit a differentiable sensation. A set of questions for the description of the electrically-elicited tactile sensations were asked.

2. MATERIALS AND METHODS

Four mechanoreceptors are embedded in the layered structure of the skin. We focus on the Meissner's Corpuscle Receptors encoding the velocity of skin deformation and vibration, both related to roughness signaling. The axons attached to these are vertically oriented, and have a diameter around 7 to 12 nm [2].

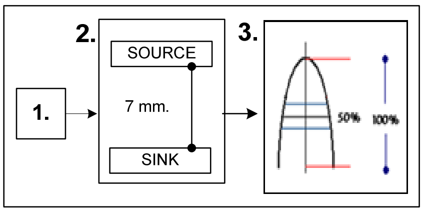

Fig. 1 Schematic diagram of the *electrical stimulation system* and the *source-sink electrode pair*. (1) Software application in LabVIEW 2009, DAQ and voltage-to-current converter. (2) Source-sink electrode pair, 10 x 0.5 mm electrodes. (3) Testing site: index finger pad of the dominant hand.

An anodic, monophasic, and constant-current rectangular 200 μs pulse train was applied to stimulate vertically oriented nerve fibers [1, 3]. A personalized current amplitude value, between the activation and pain current thresholds, acquired in a previous experiment was used. The frequency was varied between 10 to 100 Hz [1].

Ten subjects participated in the experiment with five trials each. Their finger pad was treated to homogenize the skin conditions among subjects. Two lines were drawn on the finger pad, equally separated from the middle, such that the distance between them was 7 mm (Box (3) in Fig. 1), appropriate according to a preliminary experiment. The finger pad was positioned on the electrode using the drawn lines as guidelines. The starting frequency was of 10 Hz increasing it by 5 Hz every 5 seconds until reaching 100 Hz or until an uncomfortable sensation was reported. FAT and FPT were measured and recorded. For DAT, the subjects clicked the computer mouse button, using the non-dominant hand, every time a different sensation was perceived. The time and frequency value at each click were recorded. A set of questions regarding the perceived sensation were asked to describe it using human-defined tactile descriptors [4] and to verify the perception consistency.

3. RESULTS AND CONCLUSIONS

The median FAT and FPT values were between 10–100 Hz for 90% of the participants, supportin g previous studies [1] while eliciting perceptible and comfortable sensations.

The relationship between the stimulus frequency and the number of elicited sensations was analyzed through a linear regression model per subject, as the one in Fig. 2.

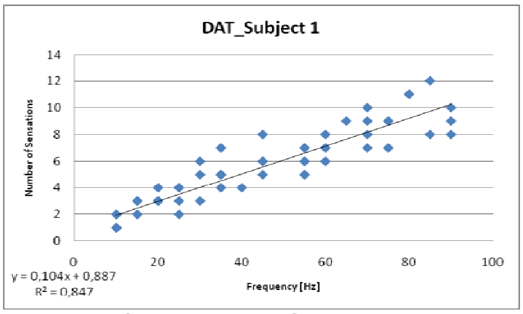

Fig. 2 Typical DAT regression line.

The *Discrimination Ability Value (DAV)*, indicating how much the stimulus frequency should change to elicit a new sensation, was acquired from the inverse of the slope. Six DAVs were found (5, 10, 15, 20, 25 and 30) Hz/sensation, reported by (2, 2, 1, 3, 1 and 1) subjects respectively. A *runs test* validated each linear model. In80% of the models, there was no significant deviation from linearity (high P-value, >0.3475). The remaining 20%, had significantly fewer runs than expected (low P-value, <0.05), implicating a significant deviation fromlinearity. This 20% coincide with the subjects whose DAV is of 5 Hz/sensation, meaning that the most sensitive subjects' discrimination ability might be better described by a curve than by a straight line. The correlation coefficient between the frequency and the number of elicited sensations was strong (0.69-0.97), regardless of the model.

In relation with the descriptions, the sensation type was *pulsing* in 48% of the cases, *vibratory* in 48% and both in 4%. The surface was *sharp and prickly* in 52% cases and *dull* in 48%. A *pressure* like sensation was reported in 58% of the cases. These non-definite percentages show that a mechanical reference would be useful to standardize the descriptors among the subjects. Also, the sensation varies as the stimulus frequency is being changed, and it is difficult to choose a single descriptor for the overall set of elicited sensations. The sensation was 100% *localized* and 90% *well defined*, suggesting the feasibility of generating tactile sensations through electrical stimulation. In 96% of the cases, the sensation was located near the upper electrode and between the electrodes, making the *sensation spot* controllable through the positioning of the source-sink electrode pair.

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