전기 펄스의 주파수와 너비가 감각 유발에 미치는 영향
Effects of Different Pulse Frequencies and Pulse Widths on Electrically-Elicited Sensations

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1. Introduction

Characterizing the behavior of Electrically-elicited tactile sensation is the precondition to develop an artificial sensory feedback system. This study was designed to investigate the effects of 1) the pulse frequency modulation, and 2) different pulse frequencies and pulse widths on electrically-elicited tactile sensations. In our previous work, we discussed the effects of the polarities and waveforms and different types of intensity modulation of the electrical stimulus pulse train on the electrically-elicited tactile sensation in terms of the sensory activation threshold[1-2]. Our previous and current works together provide adequate understanding how different pulse parameters affect the electrically-elicited tactile sensations.

2. Experimental procedure

We did experiments on 20 healthy subjects. All the subjects participated in the experiment with a written consent that they were fully informed about the experimental procedure and any potential risk that might occur during the experiment.

We followed one common experimental protocol for every subject in order to ensure consistency in the experimental condition. The participant's finger pad was cleansed with an alcohol swap and water. Then water was removed with a tissue and a thin film of electrolytic gel was applied on the finger pad. Finally the subject's finger pad was placed on the two electrodes in such a way that the center of the swirl of the fingerprint was just over the active electrode. We took a 10-minute break between two consecutive experiments.

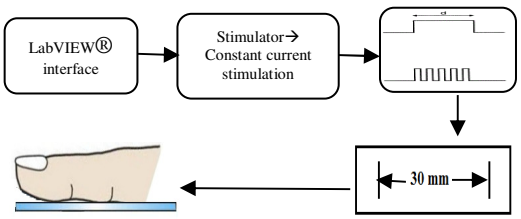

Fig. 1 Schematic diagram of system framework

An electrical stimulation interface was programmed with LabVIEW® to create the electrical pulse waveform and the related stimulation parameters. The rectangular pulse train was employed throughout the experiment. The LabVIEW® output was transmitted to the electrical stimulator developed in our laboratory specifically for this research. The stimulator provided constant-current pulse trains to the electrode. One source-sink line-electrode pair was used for the experiment. The electrode size was 0.5 mm x 10 mm, and the distance between the source and the sink was 30 mm. The index finger pad of hand was selected as the experimental site.

We performed the experiments in two steps. The objective of the first step was to observe the effect of pulse frequency modulation (PFM) on electrically-elicited tactile sensations. We modulated the frequency from 0 to 300 Hz (increment step size was

2 Hz in every 1 sec interval) keeping stimulation intensity constant at -7 mA with 200 μs pulse width. In the second step, the stimulation intensity was increased by 70nC charge per pulse (CPP) in every 2.5 seconds interval by modulating the pulse amplitude. Table 1 shows the frequencies and pulse widths used in this step.

Table 1 Experimental parameters of 2nd step of experiments

Frequency	20 Hz		200 Hz	
Pulse width	200 μs	500 μs	200 μs	500 μs

3. Results

In pulse frequency modulation experiment, we have found 4 qualitatively different types of vibration followed by pin-pricking pain. Frequency dependent sensations changed sequentially with the change of frequency of the stimulating pulse (Table 2).

Table 2 Order of frequency dependent sensations

Pulse frequency	1-10 Hz	10-50 Hz	30-80 Hz	100-150 Hz	150-300 Hz
Sensation name	Tapping	Fluttering	Vibration	Buzzing	Pinpricking pain

In our second step of experiment, we obtained Table 3 and Table 4 which suggest that electrically-elicited tactile sensations are heavily affected by the stimulating pulse widths and frequencies simultaneously.

Table 3 Percentage of subjects who perceived 4 major sensations

Pulse Frequency	Tickling	Pressure	Low Frequency Vibration	High Frequency Vibration
20 Hz	90%	95%	92.5%	52.5%
200 Hz	85%	85%	30%	75%

Table 4 Percentage of subjects who perceived clear sensations

Frequency	20 Hz		200 Hz	
Pulse width	200 μs	500 μs	200 μs	500 μs
Percentage of subjects	100%	75%	80%	45%

4. Conclusion

Our previous and current works show that increasing stimulation intensity increases the perceived sensation intensity and also changes the sensations from one to another. In contrast, increasing pulse frequency affects the frequency dependent sensations only, usually do not increase the perceived sensation intensity. Stimulating pulse with high frequency and high pulse width elicits not clearly perceivable sensations. Finally, as we observed in our previous experiments, biphasic pulse requires higher stimulation intensity to elicit tactile sensations in comparison to the monophasic pulses. We can conclude that each of the four major pulse parameters – amplitude, pulse width, frequency, and pulse waveform – affects the electrically-elicited tactile sensations.

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References

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