EFFECT OF INTERMITTENT STIMULATION PATTERNS ON THE SENSATION DURING ELECTROCUTANEOUS STIMULATION

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Abstract
For electrotactile displays to become useful for supplementary sensory feedback for transfemoral prosthesis users the interface needs to be optimized. A closer look is taken at the nature of adaptation during electrocutaneous stimulation. In this portion the effect of intermittent stimulation patterns on the sensation is investigated. Seven different intermittent stimulation signals and two continuous signals were applied to the subjects skin in random order. Each of the nine trials lasted for about fifteen minutes and during these trials the stimulation current was adjusted at 80% of the dynamic range, as recommended in a previous study. The Visual Analog Scale was used to record the course of sensation during the period of stimulation. Results suggest two things. One, a minimal stimulation time \( T_{on} \) of 0.5 seconds is required to reach a maximal sensation. Two, a minimal rest period of about 0.3 seconds is required in order to postpone the occurrence of full adaptation \( T_{off} \).

Introduction
The application of an electrotactile–display to transfemoral prostheses is currently not considered acceptable although its usefulness for improved motor performance has been demonstrated [1,2]. The prolonged stimulation of skin, which is typical for the use of transfemoral prosthesis, is accompanied by pain sensation and adaptation during electrocutaneous stimulation [1,2]. These drawbacks have to be overcome first before application of a tactile-display becomes generally accepted.

The possible cause of pain and adaptation was studied in several papers [4,5,6]. From these studies it became clear that by creating a good electrode-skin interface in combination with charge-balanced electric signals it is possible to stimulate painlessly for a long period. Others [7,8] argue about whether or not the surface area has a significant influence on a comfortable sensation, but this has hardly been investigated. Besides these investigations, little has been done to study adaptation in electrocutaneous stimulation [9,10,11].

How to avoid the adaptation phenomenon during electrocutaneous stimulation without losing its utility for prostheses remains unanswered. According to the principles of neural science [12] the adaptation characteristics reside more or less in all sensors in the human nervous system. Adaptation will especially occur if continuous stimulation is applied to the skin. Therefore other types of stimulation than continuous stimulation have to be found. This abstract reports on a study on adaptation during intermittent stimulating aimed at initiating the design of an acceptable electrotactile-display. The Objective in the long run is to apply an electrotactile-display to people using a transfemoral prosthesis or who suffer from other insufficiencies regarding mobility.

In this abstract the results are given of the effect of stimulating intermittently. We believe that by putting dynamics in the stimulating signal, the occurrence of adaptation will be postponed.

Methods
Tests were carried out on the medial-distal side of the upper leg just above the knee.

![Figure 1: Place of attachment, b) the surface electrode and c) the stimulation pulse.](image)

Three (1 female and 2 male) subjects participated in the study regarding different continuous stimulation levels. All test last for a period of 15 minutes. The electrodes used in this study were BioStim pre-wired self-glue electrodes from BioMedical Life System, BV. The electrodes were cut to oval concentric bipolar arrangement, see figure 1b. A skin-stimulator designed at our department is capable of producing a charge-balanced bi-phasic signal, see figure 1c. A computer could control the stimulators on and off period.

Experimental protocol
First the skin was prepared and subsequently the electrode was placed as shown in figure 1a. Stimulation signals as shown in figure 1c were used during the experiments. The pulse-width (40μs) and frequency (30 Hz) of the stimulator signal were fixed.
Only the amplitude could be changed, by steps of 0.1 [mA], during the determination of the Dynamic Range. The Dynamic Range is the difference between sensation threshold (ST) and the uncomfortability threshold (UT). Prior to the actual experiments a warming up procedure was carried out. From that point the experiments began. Not the subject but somebody else adjusted the amplitude at the subjects ST and UT three times. From the two averaged thresholds one level at 80% of the DR was calculated.

![Figure 2](image)

**Figure 2**: The intermitting signal with its on and off period.

Seven different intermittent patterns were used. With the computer we were able to adjust the $T_{on}$ and $T_{off}$ periods. The seven intermittent signals were; C1 (continuous), C2 ($T_{on}=0.5$ s & $T_{off}=0.1$ s), C3 ($T_{on}=0.5$ s & $T_{off}=0.3$ s), C4 ($T_{on}=0.5$ s & $T_{off}=0.5$ s), C5 ($T_{on}=0.3$ s & $T_{off}=0.3$ s), C6 ($T_{on}=0.3$ s & $T_{off}=0.5$ s), C7 ($T_{on}=0.1$ s & $T_{off}=0.1$ s) and C8 ($T_{on}=0.1$ s & $T_{off}=0.5$ s). Those currents were chosen such that signals could be compared with one parameter staying the same. For instance same $T_{on}$, same $T_{off}$, same duty-cycle (same number of pulses per time-period) and same cycle time.

During each trial the subject heard every forty seconds a sound at which he had to judge the strength of sensation by putting a cross on a line. Both ends of this line were marked and labeled as *sensation threshold* and *not tolerable threshold*. This type of scale is named Visual Analog Scale [3]. Every time the subject had put a cross on the scale, he turned the page and waited for the next sound. The subject put a total of 23 marks, judgements, during the fifteen minutes. If there was no sensation before the fifteen minutes had passed than the subject had to mark three times in a row zero before that trial ended.

**Results**
In this section preliminary results of three persons are presented. Experimental testing in another seven persons and statistical evaluation over the whole population is being performed.

**Intermittent stimulation**
In the following section the continuous stimulation is compared with three different types of intermittent signals. Figure 3 shows that the intermittent signals with a $T_{on}$ of 0.5 [s] and $T_{off}$ of 0.3 or 0.5 reaches almost a constant plateau during 15 minutes of stimulation. Also, the signal with a $T_{off}$ of 0.1 [s] still adapted.

![Figure 3](image)

**Figure 3**: Comparison between continuous signals and intermittent signals with equal $T_{on}$.

That $T_{on}$ is an important feature is shown in figure 4. Although all currents reached a certain plateau, the level of this plateau is lower for the pattern with shorter on time.

![Figure 4](image)

**Figure 4**: Comparison between continuous signals and intermittent signals with equal $T_{off}$.

When the duty-cycle is kept the same, as shown in figure 5, two things can be seen. First, the signal with the shortest on and off period (C7) tend to adapt almost completely although it started from a higher level than the others did. Second, both signals C4 and C5 reached a plateau in the sensation but the level of the plateau of C4 is a bit higher.
Discussion and conclusion

Effect intermittent signals

Figures 4 up to 6 suggest that some intermittent stimulation signals are superior to continuous stimulation in postponing full adaptation. We hypothesize that the level of constant sensation, using sufficient T_{off} time, is determined by the stimulation time (T_{on}) if the intermittent patterns are compared mutually. Furthermore a minimal T_{off} should be used otherwise the skin will still tend to adapt to the applied intermittent signal.

If the criterion of choosing a signal is based on its ability to give a constant clear sensation than two types are to be recommended. Those are C3 (T_{on}=0.5 s & T_{off}=0.3 s), C4 (T_{on}=0.5 s & T_{off}=0.5 s). At this moment it is a bit too early to draw conclusions from the result because only three persons have been measured. We planned to measure seven more subjects and evaluate the results statistically before we state final conclusions.

References


