EFFECT OF STIMULATION LEVEL ON SENSATION DURING CONTINUOUS 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. In the framework of this optimization the effect of different stimulation levels on the course of adaptation during fifteen minutes of continuous electrocutaneous stimulation was studied. Important parameters during this study were Sensation Threshold ST, Uncomfortable Threshold (UT) and Dynamic Range (DR). Whereby DR was defined as the difference between UT and ST. The level of sensation during the experiments was judged using a Visual Analog Scale. The stimulation levels were adjusted at three different levels respectively 20%, 50% and 80% of the DR. The course of adaptation was recorded three times for each level. The conclusion, which can be draw from the results, is that stimulating at 80% of the Dynamic Range (DR) is less prone to adaptation than stimulating at 20% and 50% of the DR.

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 over come first before application of a tactile-display becomes generally accepted.

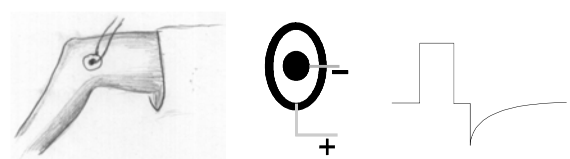
The possible cause of pain and adaptation was studied in several papers [4,5,6]. From these studies it became clear that by creating a good electrode-skin interface in combination with charge-balanced electric signals it is possible to stimulate painlessly for a long period. Others [7,8] argue about 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. The influence of stimulation level on adaptation is currently not well known. This abstract reports on a study 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.

From pilot studies and few publications [10,11] we believe that there is a significant difference in the course of adaptation for different continuous stimulation levels. However a good insight in the effect of different stimulation levels on the sensation during prolonged stimulation is lacking.

Methods

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



a b c

Figure 1: *a)* Place of attachment, *b)* the surface electrode and *c)* the stimulation pulse.

Ten (5 female and 5 male) subjects participated in this study regarding different levels during continuous stimulation. 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 uncomfortable threshold (UT). Prior to the actual experiments a warming up procedure was carried out. From that point the experiments began. ST and UT were determined three times such that the subject could not see the settings of the stimulator, but only gave feedback about the level of stimulation relative to ST and UT, below or above. From the two averaged thresholds three stimulation levels were calculated. Level 1 (L1) was 20% of the DR plus the ST, L2 was 50% of the DR plus the ST and L3 was 80% of the DR plus the ST. During subsequent adaptation test of 15 minutes the stimulation level stayed fixed (at L1, L2 or L3). Three trials per level were done, which yielded a total of nine trials to be carried out randomly.

During each trial the subject heard every forty seconds an auditory sign at which he had to scale the strength of sensation by putting a cross on a line. Both ends of this line were marked and labeled as *sensation level* and *not tolerable level*. 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 22 marks, judgements, during the fifteen minutes. If there was no sensation before the fifteen minutes had passed than the trial was stopped if the subject had marked zero sensation three times in a row.

At the end of every trial the computer generated a time between 20 [s] and 5 [min] randomly before shutting of the stimulator. The subject had to push a knob when he felt the stimulation was shut-off. In this way it was tested objectively on the basis of the reaction time and evaluation of the reaction if the judgement of the sensation was right.

To evaluate the Reaction Time (RT) the following classification was used; Very Clear (VC, 0s<RT≤2s), Clear (C, 2s<RT≤5s), Moderate (M, 5s<RT≤15s), Very Unclear (VU, 15s< RT ≤20s) and Did Not Detect (DND, RT >20s).

After each trial the dynamic range was determined again.

Results

In this section we present results of ten persons

Thresholds

The results, presented in figure 2, reveals that the sensation level during the experiments were approximately 4-5 mA. The average uncomfortable level was about 18-20 mA. What also could be observed from this graph is that the standard variation of the UT was much higher than that of the ST.

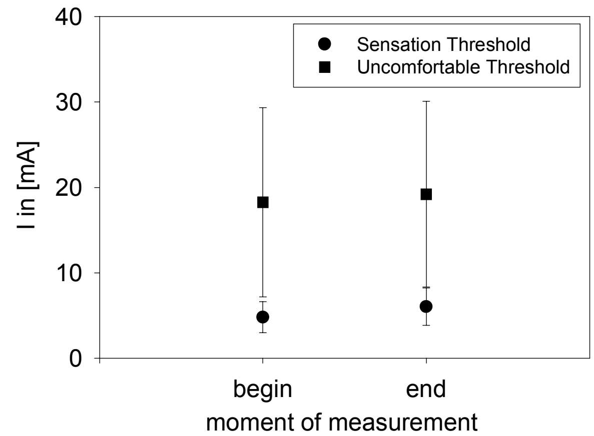


Figure 2: The average Thresholds at the beginning and at the end of the experiments.

Adaptation course in time

The curves reveal very obviously that the stimulation level at 80% is less prone to full adaptation than the other levels. If the *half-life* (HL) is considered than figure 3 shows an average-HL for 20% at 1 minute and 20 seconds, for 50% at 2 minutes and for 80% at 5 minutes and 20 seconds. Further, figure 3 tells us that full adaptation, when using continuous stimulation, is reached at two levels approximately after 15 minutes.

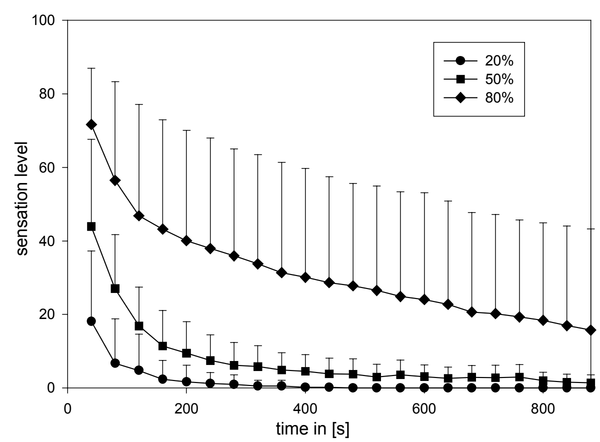


Figure 3: The average adaptation and standard deviation course in time at three different levels.

Reaction time

Table 1 shows that the reaction time in detecting the end of stimulation. Two cases were distinguished. Case one concerned the situation at which the subject indicated that there was still sensation and made an attempted to detect the moment of shutting-off the stimulator. Second case was that the subject tried to detect the shutting-off of the stimulator although the subject judged the sensation as being zero. This could be the case for instance when the subject had marked no sensation three times in a row.

Shutting of during sensation	VC 0-2 s	C 2-5 s	M 5-15 s	VU 15-20	DND >20 s
I1					
I2	4	3	1		1
I3	10	4	2	1	3
Shutting of during no sensation					
I1	2	2	1	2	23
I2	2	4	3	1	10
I3	1	5			4

Table 1: Overview of how many times a specific response occurred after shutting-off the stimulator.

Discussion and conclusion

Because of the fact that there was a rest period of 3-4 minutes after each trial and given the results shown in figure 2, it can be stated that 3-4 minutes of rest is enough for the skin to recover almost full from adaptation. Further, it can be hypothesized that the dynamic range of the persons has not being reached fully owing to the fact that the upper boundary (UT) has a large standard deviation whereas the lower boundary (ST) is well defined with a little standard deviation.

Effect of stimulation level to adaptation

The results reveals that 80% stimulation level is preferred when applying electrocutaneous stimulation for prolonged periods (>15 min.). But in fact, considerable adaptation was found at all levels.

Important suggestion which can be obtained from the results presented in Figure 2 and table 1 is that the Visual analog Scale is a proper method in evaluating the trajectory of sensation without disturbing the experiment.

Even if sensation was three times successively judged zero, shutting-off stimulation was detected within 5 s; this confirms the fact that sensors are especially sensitive to change.

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