Experience with a hand grasp neuroprosthesis incorporating natural sensory feedback

A. Inmann, M. Haugland, T. Sinkjær

Center for Sensory-Motor Interaction
Aalborg University
Fredrik Bajers Vej 7 D-3, DK-9220 Aalborg, Denmark
ai@smi.auc.dk

Abstract
This paper presents experience with a hand grasp neuroprosthesis that is controlled by means of signals from natural sensors in the skin. The signals from the natural sensors were recorded with a cuff electrode implanted around the palmar digital nerve innervating the radial aspect of the index finger. The implanted muscle stimulator is part of the commercial FREEHAND® System. A data-recording unit allowed storage and off-line analysis of the stimulator command and the recorded nerve signal. The system was used by a tetraplegic volunteer to test the feasibility of including natural sensors in a hand grasp neuroprosthesis for activities of daily living.

1. Introduction
Injury to the spinal cord at the cervical level results in loss of sensory and motor functions in both upper and lower extremities leading to tetraplegia. To restore basic hand function and enable individuals with tetraplegia to grasp and manipulate objects, several hand grasp systems based on functional electrical stimulation (FES) have been developed [1, 3, 11, 12]. These systems usually control the grasp without any grasp-specific feedback information such as finger position or grasp force, so that the user has to rely on vision and experience to perform grasping safely.

At the Center for Sensory-Motor Interaction, a new technique was developed to provide a hand grasp system with feedback information by incorporating signals from natural sensors readily present in the skin of the index finger [4]. These signals can be recorded with a nerve cuff electrode around the palmar digital nerve that innervates the radial aspect of the index finger. The recorded nerve signal provides information about skin contact, force changes, and slips across the skin [4, 6, 7].

To obtain information for optimizing such a complex system and to gain knowledge about the performance of the hand grasp neuroprosthesis outside the laboratory, a portable system was built [9]. The portable system allows test and evaluation on a daily basis, while the user is performing activities of daily living such as eating with a fork or drinking from a cup.

This paper presents experience with the FES hand grasp neuroprosthesis incorporating natural sensory feedback. A data-recording unit has been used for long-term recording of important information about the neuroprosthesis during daily use. The system was used over nine consecutive days and we analyzed the occurrence and the duration of tasks that were performed with the neuroprosthesis.

2. Materials and Methods
The hand grasp neuroprosthesis incorporating natural sensory feedback was described in detail in [9]. Briefly, to restore grasp function in the left hand, a tetraplegic volunteer was instrumented with an eight-channel muscle stimulator, which is part of the FREEHAND® System (NeuroControl Corp., Cleveland, OH, USA). In addition, a tripolar nerve cuff electrode was implanted on a branch of the palmar digital nerve deriving from the median nerve. The cuff electrode recorded activity from skin mechanoreceptors innervating the radial aspect of the index finger [4]. Informed consent was obtained from the volunteer, and the local ethics committee approved the implantations.
The nerve signal was amplified, bandpass-filtered, sampled at 10 kHz, rectified, and bin-integrated in blocks of samples in the last 5 ms of each stimulation interval [5]. The bin-integrated nerve signal was then further processed to remove interference from slow changes in background activity and to enhance peaks in the signal [6]. Mechanical events on the skin of the index finger were detected by comparing the processed nerve signal (P-ENG) to a fixed threshold.

The muscles were stimulated at 20 Hz and modulation of the pulse duration between 0 and 200 µs was used to control the stimulation intensity. Individual muscles were controlled with a single command that was translated into specific stimulation intensities for each stimulation channel by using a predetermined activation scheme (grasp template) [10]. The grasp was directly controlled by the command ranging from 0 (fully open hand) to 100 (fully closed hand).

A push button in the armrest of the wheelchair was used to switch the entire system on and off. Additionally, two push buttons, mounted on the headrest of the wheelchair, were used to control the neuroprosthesis. With these control buttons, the neuroprosthesis user could activate and deactivate the system and could control opening and closing of the hand by ramping the stimulator command up/down. When the user had adjusted the grasp with the control buttons, the system took over and the stimulator command was automatically regulated to a level that produced sufficient grasp force to hold an object securely [8]. A piezoelectric audio transducer provided feedback to the user such as indication of system state and stimulation ramp up/down.

For long-term data recording, we implemented an exchangeable 64 MB flash memory card, fully compatible with the ATA PC-card standard. The control software, the control parameters, and the grasp template were stored on the memory card. For later off-line analysis, the processed nerve signal and the stimulator command were recorded with a rate of 40 Hz, resulting in 844 kB of data per hour. Additionally, start and stop times of the use of the neuroprosthesis were recorded. When the capacity of the memory card was reached, the card could be easily removed from the system and sent by regular mail to the laboratory.

3. Results
The hand grasp neuroprosthesis was set up at the user’s home, and the first day of use was supervised to accustom the user to the new system. The stimulator command, the P-ENG, and the time of usage were stored on the memory card. Additionally, the user’s caretaker filled out a form reporting the activity for which the neuroprosthesis was used.
The system was used over nine consecutive days (Fig. 1A) without interference from the investigators. Most of the activities were concentrated in the second half of a day. Long activity periods mainly occurred for dinner (between 18:00 and 22:00), and short activity periods mainly occurred for picking up objects throughout the day. Fig. 1B shows sample data from a three-minute sequence of one activity (dinner) of day four. The variation of the command during this activity indicated a succession of active and inactive periods during the task, illustrating the details of the automatic control of the command. The pattern of activity and breaks was similar to the pattern seen in data recorded while the tetraplegic volunteer was eating a meal in the laboratory [8]. Peaks in the P-ENG indicated mechanical activity on the skin of the index finger such as force changes or slips of the held object. Depending on detected events in the P-ENG (i.e. crossing the threshold), the stimulator command was automatically regulated between a minimum level (65), necessary for keeping an object in the grasp, and the maximum level (100). A high activity in the P-ENG led to a high average of the stimulator command was automatically regulated on the basis of events in the P-ENG (i.e. crossing the threshold), the stimulator command was automatically regulated between a minimum level (65), necessary for keeping an object in the grasp, and the maximum level (100). A high activity in the P-ENG led to a high average of the stimulator command. This produced a sufficiently high grasp force to counteract the increased mechanical activity and to secure the held object in the grasp.

The average stimulator command during the active periods over the nine days was 80.3 ± 13.5 (mean ± std). The system was used for 26 ± 16.6 minutes (mean ± std) per day. The use pattern of the neuroprosthesis was the same as for the original FREEHAND® System, and the sensory feedback did not influence the performance of the volunteer during the tasks.

4. Conclusion

We analyzed the performance of an FES hand grasp neuroprosthesis incorporating natural sensory feedback. Automatic regulation of the stimulator command based on mechanical activity on the skin of the index finger showed that less stimulator command was used on average compared to a system without feedback [8]. In a hand grasp neuroprosthesis without feedback, the stimulator command is usually held constant and locked at the maximum level to ensure safe grasping [2].

The control of the neuroprosthesis with push buttons that were permanently mounted on the headrest of the wheelchair provided a simple and intuitive interface and was highly accepted by the user. Donning and doffing of the system was only comprised of attaching the transmitter coil of the stimulator and connecting the cuff electrode. We will further analyze the performance of the FES hand grasp neuroprosthesis at the user’s home by using the signals stored with the data-recording unit. The main question to be answered is whether the idea of natural sensory feedback for hand grasp control is beneficial and acceptable for the user in everyday tasks such as eating with a fork or drinking from a cup.

Acknowledgements

This work was supported by the Danish National Research Foundation.

References