EMG-guided training for advanced rehabilitation of patients after selective nerve transfers

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Abstract

A special selective nerve transfer, called targeted muscle reinnervation (TMR) provides amputees with the possibility to control a prothesis with up to 6 myo-signals. In surgery, the nerves of the arm are rerouted to muscles of the stump region to gain additional myo-signals. Following the TMR-operation, "TechNeuroRehabilitation" starts which takes about 1.5 years, depending on the level of amputation. During this time, the patient has to learn how to control his new neuro-muscular interface. Within this rehabilitation process, the patients amongst others train with EMG-biofeedback. A measure to evaluate the EMG-biofeedback training for myo-signals is provided by our new sEMG-Testtool. It offers a good way for determining a patient's ability of generating myo-signals, which is essential for the controlling of a myo-prosthesis. First data was gained from healthy persons. Additionally, the sEMG-Testtool has been used successfully for non-healthy persons.

More data on able-bodied and amputees is needed, to test and document the validity and reliability of the measures gained by our software.

1 Introduction

Targeted Muscle Reinnervation (TMR) provides an opportunity to improve prosthesis control for patients with high amputations (transhumeral or glenohumeral). In surgery, the nerves of the arm are rerouted to muscles of the stump region to gain additional myo-signals that can be used to control a prosthesis more intuitively. Following the TMR-operation and nerve healing, the so-called "TechNeuroRehabilitation" starts which takes about 1.5 years, depending on the level of amputation. During this time, the patient has to learn how to control his new neuro-muscular interface.

1.1 The TechNeuroRehabilitation

The rehabilitation process can be divided into 4 stages as shown in the figure:

The first stage („**Reinnervation**") starts with the operation and takes about 3 months. The main goal here is to support wound healing. It is important to control the pain and have a look on body symmetry as well as trunk stability. In this stage the patient can start imaging hand movements, which may help him/her in the next stage, called „**Patterning**". It starts 3 months after the operation and takes approximately another 6 months. The first myo-signals (EMG-signals) appear and can be trained. The motor imagery should be continued and supplemented by gross movements of the whole upper extremity and precise pattern movements that refer to one single nerve (e.g wrist extension for the radial nerv).

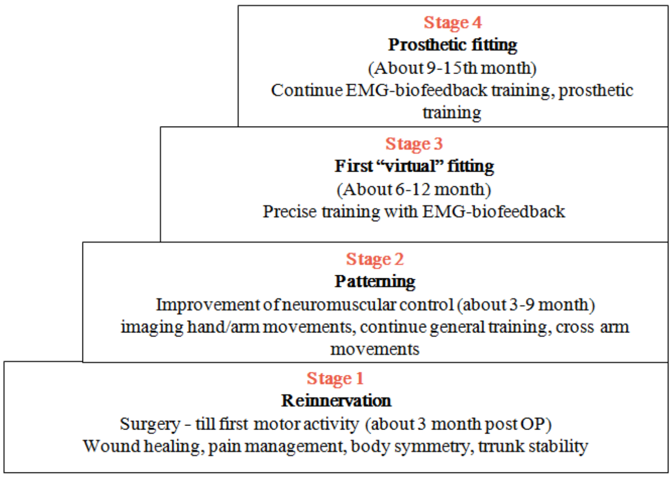

Figure 1: The 4 stages of TechNeuroRehabilitation after TMR

The next stage, called „**First virtual fitting**" lasts from about 6 months after TMR-operation to about 12 months after surgery. In this stage, a lot of specific therapeutical and technical support is needed. At this stage the patient has to learn how to separately activate the different signals and how to control the amount of activation. To perform this, the support of EMG biofeedback is needed. Usually, a software is used that shows the activation of different signals as graphs on the computer screen. Using this tool, the control of the signals increases.

The fourth stage of TMR-rehabilitation is called „**Prosthetic fitting**", which happens between 9 and 15 months after operation. The patient is now able to generate stable signals for prosthetic control. The final prosthesis can be fitted and manipulating with the prosthesis can be trained in therapy. After finishing this stage the patient should be able to use the prosthesis in daily life.

2. Methods:

Our sEMG test tool uses an interactive EMG biofeedback workstation, with an extra computer screen dedicated to the patient. Specific motor tasks are being recalled and presented to the patient, who needs to activate and control myo-signals according to a set of predesigned specific geometric profiles (see graphic).

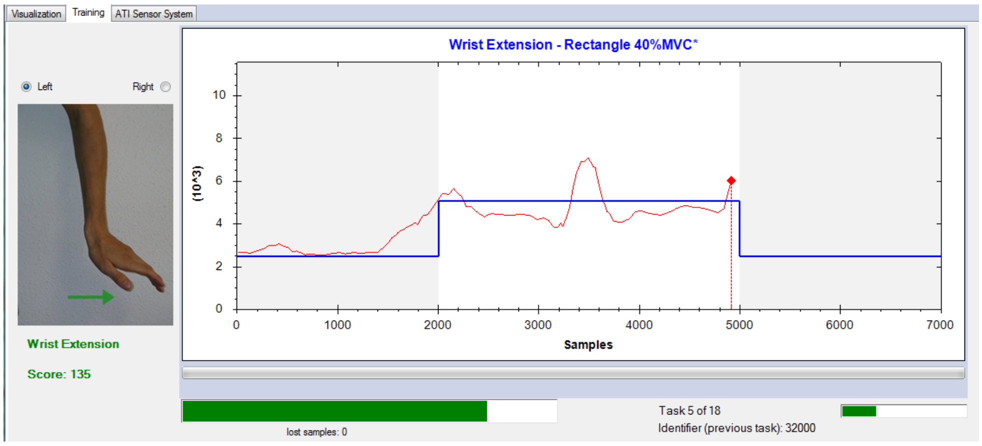

Figure 2: The sEMG test tool: The patient is asked to follow the profile (blue line) with his myo signal (red line).

The normalized root mean squared error (NRMSE) between the sEMG and the given targeted contraction task (i.e. rectangle, triangle, ramp, etc. with different levels of activation) produces a raw score of the subject's ability for mastering this given targeted contraction item. It activates both, cognitive and neurophysiologic motor functions. In the beginning of the training process, the control by the patient appears crude and imprecise, but improves with practice. This improvement can be quantified by calculating an ability-score, using the raw score. The ability score ranks each item in 5 different ability-classes (1-5; 1 is the best). Furthermore, an ability score for all movements in one can be generated. This allows comparing patient abilities of generating myo-signals at different time points, thus, helps selecting the kind of training that is needed by the individual amputee.

In order to prove the ability-score and to document true improvements in muscular activation, we did some testing on 5 healthy, able-bodied persons (2 male, 3 female, age 34,4 ± 9,7). They performed 3 testing-sessions with 4 movements (wrist flexion, wrist extension, finger flexion extension of the little finger) within 2 weeks. Additionally, the sEMG test tool was used for two non-healthy persons. This was done in order to find out, if it worked for persons who have to relearn how to activate their muscles as well. Two patients with peripherical nerve injury (plexus brachialis injury), were tested. Both of them showed a completely functionless hand, but nevertheless were able to produce 2 independent sEMG signals. The first patient has trained these signals for 9 months, while the second patient only started with the training recently.

3. Results:

The testing results for 5 healthy persons measured 3 times and for two patients with a periphical nerve injury are shown in Table 1. For the healthy persons there is a mean value of 1,86 for the first measurement, of 1,55 for the second measurement and of 1,54 for the third measurement.
This means a small increase in muscle coordination for the three measurements.

	Prob01 (40a)	**Prob02 (46a)**	**Prob03 (37a)**	**Prob04 (23a)**	**Prob05 (26a)**	**mean**	RMSD
1. measure	2,586	1,419	2,237	1,125	1,96	**1,865**	0,595
2. measure	1,167	1,448	2,863	1	1,278	**1,551**	0,751
3. measure	1,673	1,236	2,651	1	1,167	**1,545**	0,666

Table 1: Data for 5 healthy subjects measured 3 times within 2 weeks.

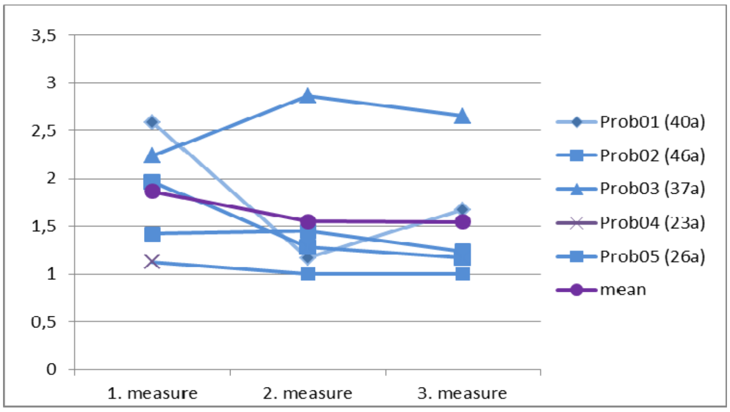

Figure 3: Data of 5 healthy subjects in 3 measurements

Within the two patients with plexus brachialis injury it was shown, that they were also able to use the tool. The patient, who did EMG biofeedback training for 9 months, was able to follow the profiles for the two muscles he was able to activate in the same way as healthy subjects. In contrast, the untrained patient did not reach a score equal to one of healthy, untrained subjects and he did also report that he felt muscle fatigue after the 40 minutes of testing.

4. Discussion:

The analysis of the data seems to detect an increase of muscular activation within each measure in general. Still, this increase was only shown for person 4 and 5 within each measurement. For the others, no such learning curve was shown. It seems that the day's form affected the performance of the healthy subjects a lot. So it might be a good idea to test a person for a least two times to get an idea of how he/she performs. Furthermore, due to the fact that all healthy subjects did well at the first testing, it was more difficult for them to improve within the next testings. Since we expect a score between 3 and 5 for patients who have to relearn their muscle activation, it might be easier to detect an improvement. This is supported by the findings, that there was a significant difference between two patients with a similar peripherical injury, but one after 9 months of biofeedback training and one at the beginning of his training. Nevertheless, it might also be important for patients to consider the day's form. To corroborate these hypotheses, more data of healthy persons and of patients is needed.

5. Conclusion:

In conclusion, this work has presented a new method for testing a patient's ability of generating myo signals. With the method applied, it should be possible to achieve data for measuring the outcome of EMG-biofeedback training used in TechNeuroRehabilitation after TMR-operation. It was shown that there was a significant difference in results for the two patients tested. They both had a similar peripherical nerve injury so that they could not move their affected hand any more, but the one who has trained his two remaining myo-signal for 9 months showed better results than the one who has been training for only one week.
In healthy persons, the day's form affected their performance. This effect overlapped the learning performance for 3 training sessions for 40 minutes each within 2 weeks.
Next, a comprehensive study with more subjects, able-bodied and amputees will follow.

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