Myo-Electrically Controlled Functional Electrical Stimulation

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The possibilities of using the myoelectric signals from a paretic muscle to control FES of the same muscle have been investigated. The controlling muscle is the extensor carpi radialis, ECR (wrist extensor) of C5/6 spinal cord lesioned tetraplegics. The aim is to establish a functional grasp by use of surface electrodes. Electronic hardware, denoted MeCFES (Myo-electrical Controlled Functional Electrical Stimulation), has been developed as a step towards forming a device that can be used in daily living. Tracking tests have proved that the MeCFES device enhances the force and range of movement of the paretic wrist extension. The MeCFES is battery powered and can be placed in a pocket. It comprises an artifact free fast recovery amplifier, power supply with a high voltage generator, current stimulator and a digital signal processor unit. The myoelectric signal is transformed into a control signal for the stimulation amplitude.

I. Introduction

Every year there are new cases of spinal cord lesions leading to paralysis of the body. A complete C6/7 spinal cord lesion can leave the person with no control of the hands (tetraplegia). The wrist extensors can be more or less paralysed as well. Such tetraplegics may have the possibility of using the tenodesis function for grasping objects. The tenodesis function is a passive grasp that requires some force of the wrist extending muscle (extensor carpi radialis). The force of the grip depends on the force of the extensor carpi radialis muscle. For some tetraplegics this muscle has a muscle force less than 3 (on a scale to 5) which is insufficient for a proper grip. In 1992 Haxthausen [1, 2] proved that it is possible to use the myoelectric signals from such a muscle to control functional electrical stimulation of the same muscle. The method requires dedicated hardware and signal processing [3-5]. Both recording and stimulation can be done by use of surface electrodes. It has been found [6] that the stimulation of the extensor carpi radialis might not be sufficient to establish a grasp. Stimulation of the flexor muscles controlled by the extensor carpi radialis [7] can provide the user with prehension as well.

II. Methods

A portable system for Myo-electrical Controlled Functional Electrical Stimulation (MeCFES), has been developed. The size is 7x11x3 cm with a weight of 200g. It is capable of recording myoelectrical signals from the same muscle as it stimulates. It comprises an amplifier, a digital signal processor and a stimulator. It is powered by a built-in rechargeable battery. The unit can be connected to a laptop computer for data acquisition. The myoelectrical signal is filtered by a comb filter to remove stimulation responses. Subsequent signal processing includes linear and non-linear filtering. The stimulation and recording electrodes are placed over the extensor carpi radialis by trial and error to find the best stimulation and recording configuration, Figure 1. A reference electrode is used for minimising common mode noise.

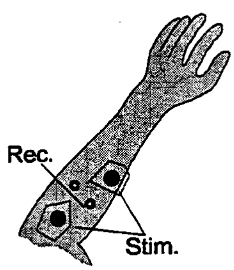

Figure 1. Electrode placement

To test the performance of the electrical part of the system, a tracking test has been used. The forearm is positioned with the palm down in a device connected to a computer. The device can be used for recording the angle of wrist extension against gravity or the isometric force of the wrist extension. A desired course of angle or force is shown on a computer screen together with the actual angle/force exerted by the wrist extension. A 10% of error boundary is permitted. The test shows the degree of control the subject has over the wrist extension and is performed with and without MeCFES assistance. The set-up is also used to record the recruitment curve for the muscle, which is the response to a given stimulation intensity. The stimulation frequency is fixed at 16.6 Hz and the amplitude of the bi-phasic stimulation pulse is variable.

III. Results

The system has been tested on tetraplegics. A systematic evaluation has been done on five complete C5 spinal cord lesioned subjects of different age and sex. The following results are from a complete C5 lesioned male tetraplegic with a very weak (muscle strength <3) extensor carpi radialis. This is the subject in the test panel with least muscle power. Figure 2 and Figure 3 show the difference in the angle tracking test without and with assistance of the MeCFES.

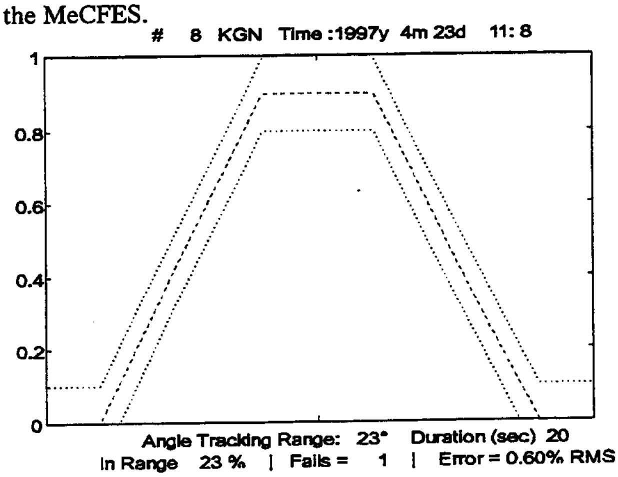

Figure 2. Unassisted angle tracking

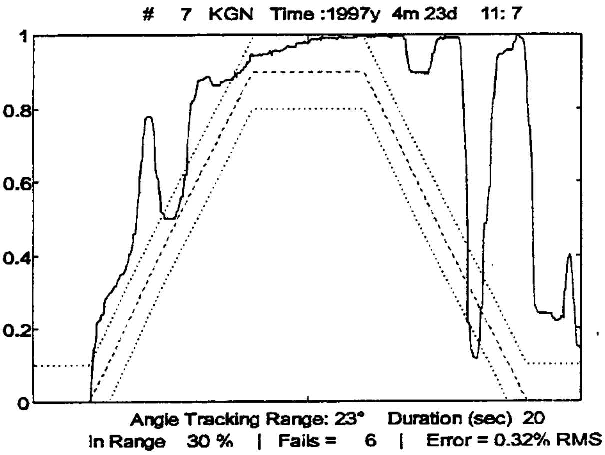

Figure 3. Angle tracking with MeCFES assistance

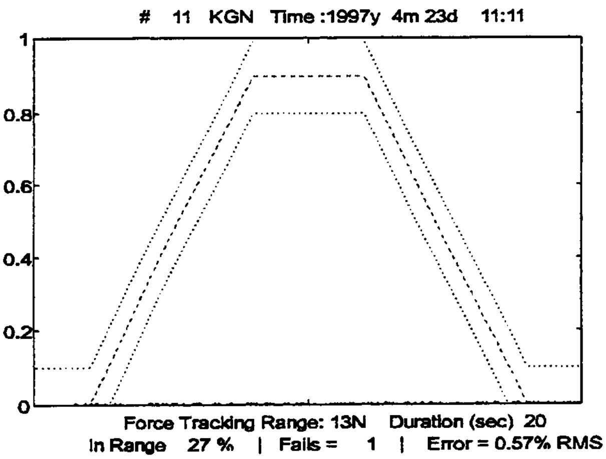

Figure 4. Unassisted force tracking

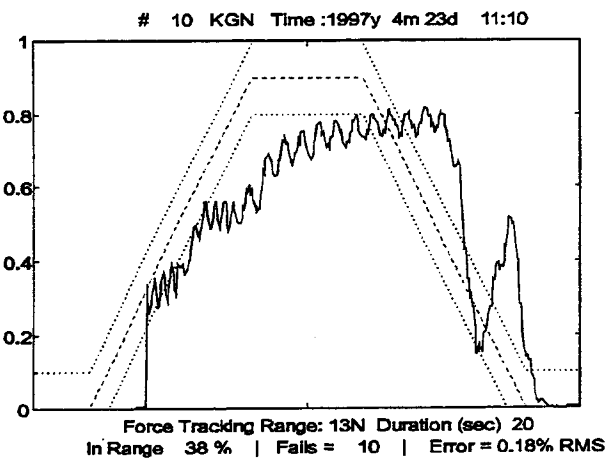

Figure 5. Force tracking with MeCFES assistance

Fixating the wrist in normal anatomical position and recording the isometric force gives the results shown in Figure 4 and Figure 5.

For a C5 spinal cord lesioned woman with a stronger extensor carpi radialis (force 3-4, voluntary contraction) the angle tracking tests are as in Figure 6,7. As it can be seen when comparing Figure 7 with Figure 3 the higher voluntary force gives better tracking accuracy. To determine the causes for the deviation from the target, recruitment curves

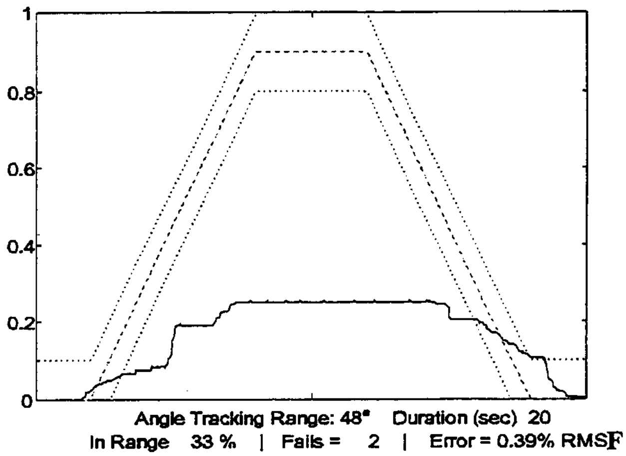

Figure 6. Unassisted angle tracking

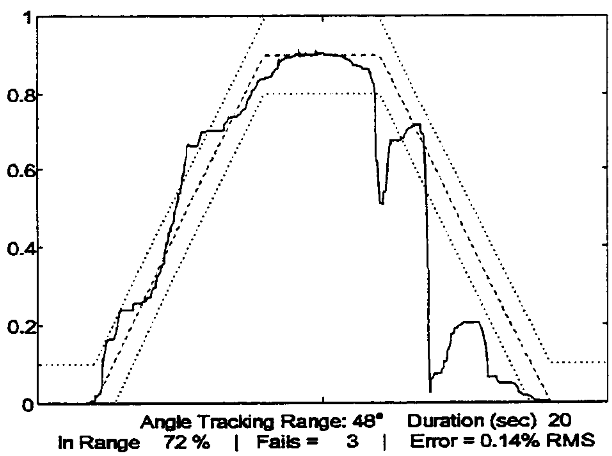

Figure 7. Angle tracking with MeCFES assistance

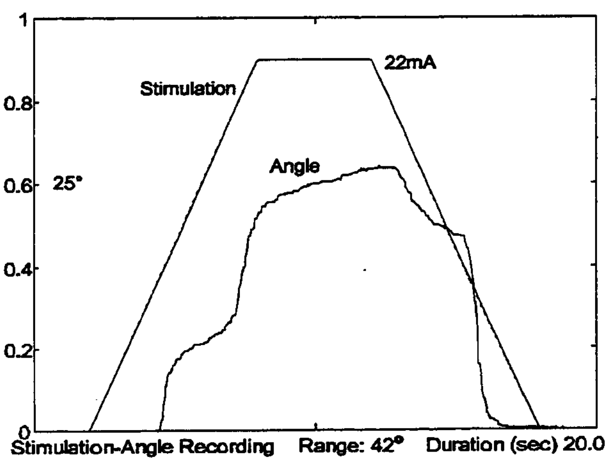

Figure 8. Time course of stimulation and angle

For the female tetraplegic the recruitment curves can be seen on Figure 8,9. The maximal stimulation is 22mA. The time course of stimulation and output is shown on Figure 8 and the output as a function of the stimulation is shown on Figure 9.

The hysteresis like shape is present for all recordings. Also in normal subjects this is found (3 subjects).

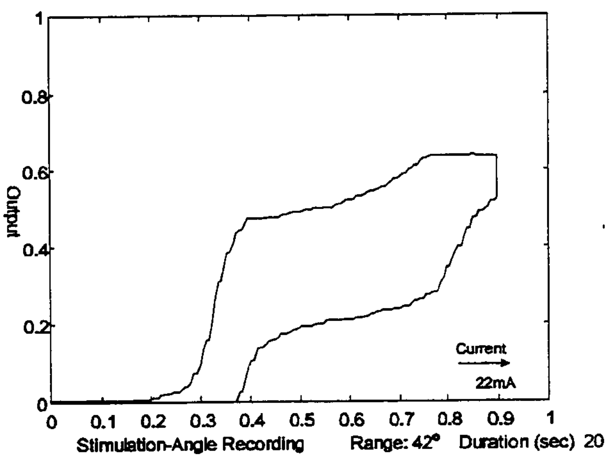

Figure 9. Stimulation-angle curve

IV. Discussion and Conclusion

The MeCFES is a device which is able to use myoelectric signals from a paretic muscle to control functional electrical stimulation of the same muscle. Using surface electrodes it is able to enhance both the force and angle of the joint on which the paretic muscle is acting. For muscles with a high degree of paralysis the amplification is highest. On the other hand the movement is best controlled by the subjects who have more voluntary muscle power. For all experiments there is a significant better control of an ascending force/angle than when it is descending. One of the reasons might be found in the nature of the recruitment of muscle fibres. Tests, examining the relation between stimulation amplitude and muscle output, have shown that the required current to obtain a certain output depends on whether the stimulation amplitude is rising or falling. This in conjunction with the fact that the antagonists are absent, results in a more inaccurate control of the movement than for non lesioned people. It has been found that the precision is increased, as the user learns to use the system. Only long term tests can show to what degree this habituation extends.

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Acknowledgement

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