Instrumented evaluation of myoelectric control in a bilateral percutaneous hand grasp neuroprosthesis for spinal cord injured persons with tetraplegia

TRD Scott, JM Heasman, VA Vare, JW Middleton, C Gschwind & SB Rutkowski
Spinal Injuries Unit and Biomedical Engineering for the NSAHS, Royal North Shore Hospital, St Leonards, 2065, NSW, Australia

I. Abstract
Stimulation was applied to both right and left hands to create simultaneous hand grasps using intramuscular percutaneous electrodes. It was controlled by myoelectric signals detected from both right and left sternocleidomastoid muscles in two persons with tetraplegia. The controller detected three levels of activation of the muscle: none, low and high; with the resulting hand movements being: no movement, close, and open respectively. Measurement of the effectiveness of this control method was made using grasp force and position sensors, which were applied to both hands simultaneously, with the output fed to a computer. In addition, visual feedback of hand position and force was provided. Tracking tasks were set up requiring the subjects to move their stimulated hands to predetermined levels of force and position. The sensitivity to the controller parameters in completion of these tracking tasks was measured in one of the two subjects. For proper adjustment of the controller parameters, the times with which the subjects could complete the precision tracking task suggested that errors resulting from the operator and the system were not sufficient to disrupt adequate control of the hands using bilateral sternocleidomastoids.

II. Introduction
The feasibility of using both sternocleidomastoid muscles as a control source for a bilateral hand grasp neuroprosthesis has been demonstrated [4]. Spinal cord-injured and non-spinal cord injured subjects were able to manipulate on-screen bar graphs to complete tracking tasks. In this study, this method of control has been applied directly to controlling both right and left stimulated hand grasps in two persons with C5 tetraplegia. Hand position and force has been detected in order that tracking tasks could be undertaken using actual hand parameters. This enabled the measurement of operator and system errors (as described by [3]) and their influence in the successful use of this method of control.

III. Method.
Intramuscular percutaneous electrodes (Neurocontrol Corp., Cleveland, OH) were placed in both the right and left hand in muscles identified to produce lateral and palmar prehension [1]. The recipients of the electrodes were two men with spinal cord injuries at the C5 level. The method of electrode placement was most similar to that described by Smith and colleagues [5]. Subjects were issued with a percutaneous stimulator (Neurocontrol Corp.) and exercised daily to condition muscles for functional use. The arms were splinted during stimulation to augment wrist extension where active wrist extension was insufficient to maintain a functional position for the wrist.

The skin surface above the sternocleidomastoid muscle was prepared by washing with soap and water. Redux paste (Hewlett Packard, CA) was then applied to reduce skin resistance and was then washed from the skin. Pre-gelled surface monitoring electrodes were applied to the skin and taped into place. A differential pair of electrodes were placed over the sternocleidomastoid muscle near the end of the muscle close to the sternum in order to reduce the amount of muscle movement under the skin during head turning. A third reference electrode was placed at the base of the neck at the shoulder, away from the sternocleidomastoid muscle, above the clavicle. The signals detected by these electrodes were amplified using an instrumentation amplifier (AD620: Analog Devices, CA) with a gain of 1000 and the amplified signal was band pass filtered with a pass band of 15 to 150 Hz. The signal was then sampled at 400 Hz using a dedicated data acquisition board (National Instruments, TX) and recorded on a computer using Labview Software (National Instruments, TX).

Subjects were presented with a computer screen which showed a vertical bar on the left and another on the right. These indicated to each subject the position and force of their left and right hands via grasp sensors applied to both hands (similar to those used by Memberg and Crago [2]. The hands could be controlled by the flexing of the left or the right sternocleidomastoid respectively. A strong flexing of the muscle (above a preset high threshold) would open the hand and a weak flexing of the muscle (above a preset low threshold, but below the high threshold) would close the hand. The experimental trials involved tracking tasks by the manipulation of the force and position of the left and right hands to match the on-screen position indicators. Only one side was allowed to be moved at a particular instant. The low and high thresholds incorporated hysteresis in order to reduce the occurrence of accidental state changes. These thresholds could be changed between trials via the computer keyboard.

IV. Results
The spinal cord-injured subjects were able to operate their hands using this controller. Sensitivity to the set up parameters of the controllers was measured in one subject. The time to complete the tracking task was found to change as the speed of the hand movement changed. Originally measured at (13.79*2.58s: mean*sem:n=6), the time to complete was maintained (11.72*4.88s:n=3) with reduction of hand speed by one-third. A further reduction of hand speed by
one-third showed the time to complete increase to (62.99 ± 17.04s: mean*variance:n=2). The integral of the error with respect to the target and the amount of errors made in completing the task were also assessed.

V. Discussion
Both subjects were able to operate the stimulation to their hands using the right and left sternocleidomastoids. The results indicated that, for proper adjustment of the controller parameters, operator and system errors did not disrupt adequate control of their own hands. The high degree of sensitivity to the controller set up parameters, measured here and in the prior study by Scott and colleagues [4], indicated that a customised set of parameters will need to be evaluated for each candidate. For the application of this method of controller to fully implantable applications, the problems of stimulation artifact and myoelectric electrode design and manufacture will need to be addressed.

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VII. References