Instrumented Evaluation Of Control Of Bilateral Stimulated Hand Grasp And Release In Persons With Tetraplegia By Monitoring Ipsilateral Wrist Joint Angle Compared With Ipsilateral Myoelectric Signals From Sternocleidomastoid Muscles

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Abstract--Bilateral grasps using intramuscular and fully implantable electrodes in a C5/C6 tetraplegic retaining active wrist extension in both hands but without active hand grasp or release were achieved. Control of these grasps were compared using two methods. These were the monitoring of the myoelectric signal from ipsilateral sternocleidomastoid muscles (SCMs: used as a statae controller) and the monitoring of joint angle from the ipsilateral wrists (used as a proportional controller). Electrogoniometers monitored wrist angle and surface electrodes detected SCMs to control grasps in separate trials. The hands were instrumented for force and position and were controlled to complete tracking tasks. It was demonstrated the SCMs control had directional preference (and therefore favoured one side), an effect that may reduce with training. The wrist did not demonstrate such a preference, performed well without training.

I. INTRODUCTION

Electrical stimulation has been used for activation of paralysed muscles to provide hand grasp and release in persons with tetraplegia [1]. It is necessary that, in order to provide useful function, the recipient of such stimulation have control over their own hand. A number of different types of control methods utilising remnant muscle activity above the spinal lesion have been used to allow the user to operate their own hand (see for [2] review). The activation of bilateral hands using electrical stimulation has been achieved [3] and control has been demonstrated using the sternocleidomastoid muscles in the neck [4]. The use of wrist extensor muscles for the control of bilateral stimulated hand grasp and release is illustrated here and compared with that using the myoelectric signal of sternocleidomastoid muscles. The comparison is made by the performing of tracking tasks where the hands are instrumented to measure their degree of opening and force applied.

II. METHODS

Electrical stimulation was applied to both hands of a spinal cord injured individual using an eight channel fully-implantable stimulator in the right hand and percutaneous intramuscular electrodes in the left hand musculature (Neurocontrol Corp., OH) producing lateral and palmar prehension [1] in each hand. The subject was injured in the C5/C6 region of the spinal cord and retained some active wrist extension in both hands but was without active hand grasp or release. The method of percutaneous electrode placement was most similar to that described by Smith and colleagues [8]. The subject was issued with a percutaneous stimulator (Neurocontrol Corp.) and exercised daily to condition muscles for functional use.

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).

The subject was presented with a computer screen which showed a vertical bar on the left and another on the right. These were to be matched by the user with predefined target bars to complete each trial. These indicated to the 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 [5]. For the myoelectric trials, 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 (as is [6]). 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.

For those experiments using wrist control, the wrist joint angle of both hands was monitored using electrogoniometers (Penny & Giles, UK) and this was measured by a computer (Macintosh Power PC9500) with data acquisition boards within controlled with Labview software (National Instruments, TX). The computer sent a control signal to the hand grasp stimulators to create a degree of hand opening corresponding proportionally to the input wrist joint angle.

Record of commands issued, the time at which they occurred and the position of the tracking bars was made during the experimental trials onto the computers hard disk by the software. These recordings were analysed after the experiment in order to determine the time that was taken to complete the task, the integral of the position error with respect to the target position and also the percentage of commands made that were errors. The time taken to complete the task was the final time recorded in the data file before the tracking task was stopped. Integral of position error was calculated using the following formula:

\[ \text{Integral Position Error} = \left\{ \sum |P_n - P_{trag}| \times (t_n - t_{n-1}) \right\}_{\text{right + left}} \]

where \( P_n \) is the position of the tracking bar as controlled by the subject, \( P_{trag} \) is the position of the target bar to which the subject is aiming to reach with the tracking bar, \( t_n \) is the time from when the trial began to the end of the \( n \)th segment and \( \text{coef} \) is the number of time segments recorded in the trial. The integral of the error was calculated to combine the position error and the time taken to complete the task in order to provide a performance index. It would be expected, for example where the speed of the tracking bar was varied, in the slower speed, higher accuracy trials, time dominates this integral whereas for the higher speed, lower accuracy trials the position error dominates.

The percentage error is calculated by the following formula:

\[ \% \text{Error} = \frac{100 \times n(\text{commands}_{\text{error}})}{n(\text{commands}_{\text{error}}) + n(\text{commands}_{\text{correct}})} \]

where \( n(\text{commands})_{\text{error}} \) and \( n(\text{commands})_{\text{correct}} \) are the number of erroneous commands and the number of correct commands made during the trial. An erroneous command consisted of a time window where the tracking bar, on either the right or left side, was moved in the direction away from the target bar.

Data is expressed as mean±SEM: n=3.

III. Results

Use of the wrist extensors as controllers for the stimulated hands did not require training and the subject was able to complete all the tracking tasks asked of him. Using myoelectric control, the user was able to complete all tracking tasks asked of him after a brief training period of half an hour.

In performing tracking tasks, results (test 1) using the wrist controller were a completion time (CT) of 31.2±11.8s, integral of the error (IE) of 3102±1437unit.s and percentage errors(PCT) of 49.2±0.4%. Reversing the target positions (test 2) for both hands, a CT of 27.0±1.4s, IE of 2055±232unit.s and PCT of 49.6±0.9% resulted. Using the SCMs (test1) resulted in a CT of 16.8±5.6s, IE of 2055±939unit.s and PCT of 239.9±17.6%. Again reversing the target positions (test 2) here resulted in a CT of 198.0±68.8s, an IE of 39052±1645unit.s and 52.3±22% PCT.

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\begin{array}{|c|c|}
\hline
\text{SCM and Wrist Control of Tracking} & \text{Students t-test} \\
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\text{Test 1: NSD between methods} & P(T<=t) > 0.45 \\
\text{Test 2 Vs Test 1: NSD in wrist control} & P(T<=t) > 0.34 \\
\text{SCM control worsened} & P(T<=t) < 0.05 \\
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\end{array}
\]

IV. Discussion

The subject was able to operate the stimulation to their hands using the right and left sternocleidomastoids. The wrist joint angle as a controller for bilateral stimulated hand grasp offers the user the benefit of proportional control and extended physiological proprioception (EPP: [7]). To use this wrist controller active wrist extension is required, with gravity being sufficient to provide wrist flexion motion. This requirement limits its use to persons with spinal injury at the C6 level or lower.

The ease of use with which the user adapted to the control most likely lies with the fact that its operation copies the action of the natural weak tenodesis grasp.

Wrist joint angle control of the ipsilateral stimulated hand grasp for both right and left hands simultaneously has been demonstrated herewith. A low sensitivity to the parameters of moderate target size and target position suggests that this control methodology will be functionally useful in actuating the stimulated hand in qualifying persons with tetraplegia following spinal cord injury.
For a specific tracking task there was little difference (see Table 1) between the performance of the two controllers (P>0.45). Whilst changing target position did not influence tracking in the wrist controller (P>0.34), the results for the SCMs were significantly worsened (P<0.05). This suggested the SCMs control had directional preference (and therefore favoured one side), an effect that may reduce with training. The wrist did not demonstrate such a preference, performed well without training and, therefore, may prove more beneficial for qualifying users.

V. CONCLUSIONS

Control of bilateral, concurrently stimulated hands using myoelectric signals from sternocleidomastoid muscles was compared with that from joint angle commands from the ipsilateral wrists. For a specific tracking task there was no significant difference between wrist and SCM control. SCM Control indicated some directional preference for hand opening and closing. Wrist control did not indicate a directional preference.

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VII. REFERENCES


7. Simpson DC (1973) The choice of control system for the multimovement prosthesis: extended physiological proprioception (e.p.p.). In The Control of Upper-Extremity Prostheses and Orthoses Ch 15, pp146-150.