Control Systems for Stimulated Pronation with the Stimulated Grasp of Persons with Tetraplegia.

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Abstract

The pronated posture is used often in relationship to grasp for the acquisition of objects. Subsequent to this, the arm is often moved, whilst maintaining grasp, into the supinated posture for improved stability of grasp. People with tetraplegia having impaired hand grasp and release usually have impaired ability to pronate their arm. Active supination is usually available to them via flexion of the biceps muscle. Electrical stimulation has been incorporated in this study in the provision of three possible methods of control of pronosupination in concert with stimulated hand grasp. Stimulated pronation has been provided to two subjects with tetraplegia secondary to spinal cord injury for the purpose of augmenting stimulated hand grasp and release. Grasp and release has been provided using fully implanted stimulators and stimulation of the pronator musculature provided using surface stimulation. Initially, the instrumented arm has been held in a custom splint with the hand being free to grasp and the degree of pronation held but adjustable. The ability of stimulated grasp to hold an object at varying degrees of pronosupination has been measured and has verified the dependency of grasp stability on the degree of pronosupination and the increased stability of the supinated posture. Subsequently, the three methods integrating the use of pronation during object acquisition and supination for increased grasp stability were examined. These are based on (i) actively controlled stimulation; (ii) touch controlled stimulation; and (iii) constant stimulation of the pronator musculature. Each of the three control methods were assessed during a standardised test involving object acquisition in the pronated posture followed by stable grasp in the supinated posture and completion time was measured. The touch-controlled method, although perhaps the most technically complex, was the significantly fastest ($P < 0.02$) method of the three in both subjects.

1. Introduction

Electrical stimulation has been applied to the upper extremity of persons with a spinal cord injury in the cervical region for the restoration of hand grasp and release [1, 2]. To assist with hand function, it has been proposed that stimulated control of pronosupination be used [3]. Pronosupination is used primarily in object acquisition and subsequent maintenance of stable grasp. To produce effective pronation without stimulation, a cervically spinal cord injured individual will often use substitution patterns of movement (such as shoulder abduction) to complete a task. Such substitution patterns may be disruptive to the individual and their performance of the task.

In this study, we first examined the grasp stability for varying degrees of pronosupination. This was to investigate the possible benefit to grasp stability of object acquisition occurring in pronation and maintenance of grasp occurring in the supinated posture. Subsequently, the paralysed pronator muscles (*pronator teres* and/or *pronator quadratus*) in two complete C5/6 spinal cord injured individuals were activated in concert with hand grasp. The aim was to improve the overall function of the grasp whilst providing an efficient control method. Three pronosupination control methods are proposed in this paper and compared with respect to each other.

2. Methods

Stimulation was applied to two C5/C6 spinal cord injured men using an eight channel fully implanted stimulation system (NeuroControl Corp, USA) providing hand grasp and release. Pronation was achieved through the use of a surface stimulator (Respond Select, EMPI Inc). Both men had paralysed, but stimulatable, pronation muscles (pronator quadratus and/or pronator teres). The study and its experimental trials were conducted in two stages. The first stage involved a quantitative analysis of the relationship between grasp strength and the degree of forearm rotation. The second stage involved the implementation and comparison of a number of pronosupination controllers.

The first experimental stage examined the relationship between an individuals ability to grip an object at varying degrees of pronosupination rotation. A splint was designed so that the wrist joint could be secured in a neutral position and the forearm fixed horizontally in one of five different pronosupination angles of rotation. The degrees of supination assessed were from -90 to +90. At the specific angle of pronosupination, stimulated hand grasp (palmar prehension) was activated to hold an aluminium cylinder of 5 cm diameter (instrumented with strain gauges for grasp force measurement). Once stable grasp was established, a vertical downward force was applied to the cylinder by an attached cord which was connected to a motor (Baldor Inc.) controlled by our computer system [Apple Power PC 9500 with data acquisition/controller boards driven by Labview software (National Instruments)]. The motor force was slowly increased in a linear fashion at a rate of 2 N/s until the motor displaced the cylinder out of the subjects stimulated grasp. In cases where the object was not displaced from the grasp when the applied force approached 25 N, the trial was stopped and the maximal force applied was recorded. The applied force of the motor was thereby limited in order to avoid a compromise of subject safety.

The second experimental stage investigated the use of stimulated hand grasp acquiring the cylinder (as in the first stage) in concert with stimulated pronation control. Three methods of pronosupination control were developed. Biomechanical parameters during these trials were recorded using our computer system using a sampling rate of 50 Hz. The pronator stimulator was controlled by the computer system via a relay circuit. The three methods of pronosupination control used are as follows:

Position-Controlled Stimulation

The first method of control evaluated was position controlled stimulation. In this case, the arm was stimulated into pronation for object acquisition. The stimulated hand could then perform grasp to acquire the object. Subsequently, the active biceps muscle supinated the forearm. An accelerometer instrument (utilising the Analog Devices component, ADXL50) was built to be placed upon the wrist to detect the angle of pronosupination. As the biceps muscle produced supination, by overcoming the stimulated pronator muscle, beyond a preset degree, the stimulation to the pronator muscle was stopped. Unresisted supination was subsequently enabled.

Touch-Controlled Stimulation

The second method of pronosupination control used a touch sensor (Interlink) to estimate when the stimulated hand acquired the cylinder. The cylinder was instrumented with the touch sensor, the on/off output of which was controlled by a force threshold circuit. In this method, pronation stimulation was applied and the user began the object acquisition. When the user grasped the object with sufficient force to activate the touch sensors, the pronation stimulation was stopped and unresisted supination, under the control of the active biceps muscle was allowed to occur.

Constant Stimulation

In the third method of pronosupination control the pronator muscle was continually stimulated. Supination was achieved by the biceps muscle overcoming the pronator muscle.

The three different cases were compared by measuring the time for completion of an acquisition sequence using the respective pronosupination control methods. The basic test sequence, while beginning in full pronation (stimulated), was for the subjects to acquire in their grasp the test object (the cylinder as described in the first stage of experimentation) and then complete the sequence by moving the forearm into complete supination. The results, unless otherwise indicated, are expressed as mean ± standard error of the mean.

3. Results

Figure 1 and Figure 2 indicate, for Subject 1 and Subject 2 respectively, the force required to remove the cylinder from the stimulated grasp plotted for varying degrees of forearm supination. The figures show that for increased forearm supination it is increasingly difficult to remove the object from the grasp. This indicates that the fully supinated posture (90 degrees) is the most stable one for grasping this object in such a situation. In fact, the grasp did not fail in the tests where the forearm was fully supinated and the test was stopped as the force on the forearm reached our safe upper limit.

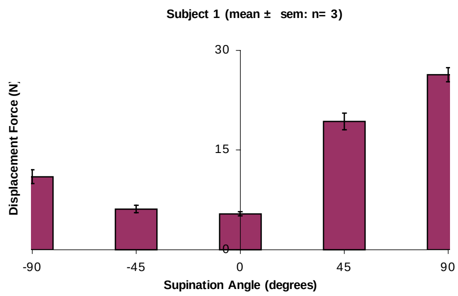

Figure 1. The force required to remove the cylinder from the stimulated grasp of Subject 1 for varying angles of forearm supination.

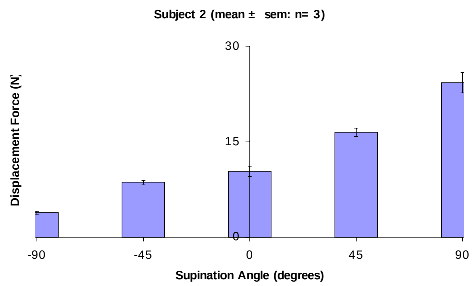

Figure 2. The force required to remove the cylinder from the stimulated grasp of Subject 1 for varying angles of forearm supination.

The three pronosupination control systems were implemented successfully in accordance with their description in the Methods. The three control methods were compared using a standardised test involving object acquisition in the pronated posture moving to a stable grasp in the supinated posture. Completion time was measured and the results indicated that the touch controlled method was the fastest ($P < 0.02$) of the three methods for both subjects.

4. Discussion

It has been demonstrated that the supinated posture is beneficial for increasing the stability of stimulated grasp against gravity while the ability to pronate the forearm is often necessary for object acquisition. The marriage of forearm pronosupination control and hand grasp in the systems proposed is likely allow the spinal cord injured user improved overall function in the use of their hand as pronosupination rarely is used without regard to hand function.

Of the three methods of control, the touch control method was shown to provide the fastest in completion of the experimental task. This method is also the most technically complex as in clinical use it would require monitoring of touch from the afferent nerves (as proposed by [4]). The least technologically complex solution proposed was the use of constant activation of the pronator muscles (also suggested by [3]). Although this method of control was slower, perhaps the ease of implementation recommends it. Nonetheless, the question of whether continuous activation is healthy for the muscle and the tendons and joints through which it acts is yet to be addressed. Between the two methods with respect to speed and complexity is the active control method which requires the use of an accelerometer. Clinical implantation of this method would require the development of instrumentation, incorporating such an accelerometer, for implantation in order to effectively support the implanted grasp system.

5. References

[1] Keith MW, Peckham PH, Thrope GB, Buckett JR, Stroh KC & Menger V (1988) Functional neuromuscular stimulation neuroprostheses for the tetraplegic hand. *Clin. Orthop. Rel. Res*. 233, pp.25-33.

[2] Hoshimiya N, Naito A, Yajima M & Handa Y (1989) A multichannel FES system for the restoration of motor functions in high spinal cord injury patients: a respiration-controlled system for multijoint upper extremity. *IEEE Trans. Biomed. Eng*. 36, pp.754-760.

[3] Lemay MA, Crago PE & Keith MW (1996) Restoration of pronosupination control by FNS in tetraplegia – experimental and biomechanical evaluation of feasibility. *J. Biomechanics* 29(4), pp.435-442.

[4] Haugland MK, Hoffer JA & Sinkjaer T (1994) Skin contact force information in sensory nerve signals recorded by implanted cuff electrodes. *IEEE Trans. Rehab Eng* 2(1), pp.18-28.

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