

EFFECTS OF FUNCTIONAL ELECTRICAL STIMULATION ON MANUAL WHEELCHAIR PROPULSION

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INTRODUCTION

Functional electrical stimulation (FES) can facilitate many activities of daily living for individuals paralyzed by spinal cord injuries [1]. Bilateral activation of the paraspinal muscles via implanted electrodes can improve the seated posture of FES users [2], and may also improve manual wheelchair propulsion efficiency. The goal of this preliminary study was to investigate the effect of stimulating the lumbar trunk extensors via an implanted FES system on propulsion biomechanics. The results may provide insight into the benefit of FES during manual wheelchair propulsion.

METHODS

Subjects: Three long-time (>12 months) recipients of the CWRU/VA implanted standing neuroprosthesis [1] with motor complete paraplegia participated in this study. The age, height and years of wheelchair use of the two male and one female volunteers were 40.5 ± 9.3 years, 1.72 ± 0.05 meters, and 5.8 ± 0.7 years respectively.

Experimental protocol: Subjects' own wheelchairs were fitted bilaterally with SMART^{Wheels}TM instrumented pushrims (Three Rivers Holdings, ILL., Mesa, AZ), and secured to a dynamometer with a four-point tie down system. An OPTOTRAK motion analysis system (Northern Digital Inc., Ontario, Canada) was synchronized with the kinetic system to record kinematic data. Subjects were asked to propel their wheelchairs at a steady-state speed of 0.9, and 1.8 m/s for one minute while real time propulsion speed was displayed on a monitor. All propulsion trials were repeated three times: two with electrical stimulation to the erector spinae ON at 50% and 25% maximal recruitment, and one with electrical stimulation OFF. The order of stimulation condition was randomly assigned. To minimize fatigue, at least one-minute of rest was provided between trials.

Data analysis: For each stroke, the start and end of the push phase were determined by the presence/absence of forces detected by SMART^{Wheels}TM. The kinetic data were collected at 240 Hz and linearly interpolated for synchronization with the 60 Hz kinematic data. Since data from both sides were highly correlated ($r = 0.68$; $p < 0.01$), average values of both sides were obtained on all biomechanical variables over ten continuous strokes. Descriptive analyses were reported for each speed condition separately. Since one subject was unable to reach the target speed at 1.8 m/s, only data from two subjects are reported under this speed condition.

RESULTS AND DISCUSSION

Table 1 summarizes the biomechanical variables while propelling with and without FES. Continuous activation of the paraspinal muscles appears to improve propulsion performance. The mechanical effective force (MEF), the percentage of the resultant force leading to forward propulsion, is generally higher with FES for all speed conditions. Higher propulsive forces and longer stroke cadences were generally observed with stimulation ON. Mean trunk angles increased with FES under all conditions. This ability to lean the trunk forward and return facilitated with FES may help the subjects to transfer power from the upper extremities to the pushrim, thereby increasing MEF [3,4]. Although the low level (25%) stimulation showed less advantage than the high level (50%), it may be less fatiguing with prolonged use and allow a greater degree of trunk mobility. The potential benefit of low activation warrants further investigation.

The generalizability of these results is limited by the small sample size due to the limited availability of the CWRU/VA implanted standing neuroprosthesis. Future studies using a non-invasive surface FES system may be needed to further explore the phenomenon and determine benefits of FES on wheelchair propulsion in the larger SCI population.

CONCLUSIONS

Stabilizing the trunk by continuous stimulation of the lumbar erector spinae appears to improve manual wheelchair propulsion. With activation of back muscles, implanted FES users were able to lean forward and thereby increase mechanical effective forces. A future study with a larger sample size is needed to verify these findings.

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Speed Condition	0.9m/s (n=3)					1.8m/s (n=2)				
	Cadence (stroke/sec)	Max force (N)	Moments (N-M)	MEF (%)	Trunk angle (°)	Cadence (stroke/sec)	Max force (N)	Moments (N-M)	MEF (%)	Trunk angle (°)
OFF	1.20±0.20	68.0±3.3	6.85±0.63	0.59±0.04	1.9±1.2	1.32±0.01	90.4±3.7	8.24±2.40	0.51±0.06	4.03±10.5
25 %	1.26±0.19	68.4±3.2	6.33±0.46	0.55±0.02	19.9±14.5	1.40±0.07	89.5±6.1	8.22±2.46	0.55±0.04	18.4±9.7
50 %	1.20±0.20	70.1±3.2	6.98±0.86	0.62±0.05	16.2±9.9	1.39±0.13	97.8±4.7	8.47±2.97	0.55±0.07	18.0±15.7

Table 1: Summary of the effects of trunk stimulation on manual wheelchair propulsion.