

## **Electromyographic Activities of Shoulder Muscles during Forward and Reverse Manual Wheelchair Propulsion**

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### **Abstract**

The repetitive nature and poor efficiency of the conventional manual wheelchair contribute to muscle fatigue and overuse in long term wheelchair users. An innovative wheel system, the Rowheel, was developed to address the concern of repetitive stress injuries related to wheelchair use. The Rowheel incorporates a planetary gear system that allows the user to pull on its hand rims to propel the wheelchair forward. This reverse wheeling technique is expected to translate loads to the stronger and more capable groups of muscles of the back, promotes balance of exercise, and increase overall efficiency of the user-wheelchair system.

The present study sought to compare the phasing and intensity of shoulder muscle activity during forward and reverse wheeling. Surface electromyography of nine muscles of the upper body, right shoulder and arm were analyzed. Parameters investigated include: (1) peak and average intensity of muscle activity measured as a percentage of MVC, and (2) timing of muscle activity (onset, cessation and duration) measured as percentage of cycle. In forward wheeling, the pectoralis major is the most active in the propulsion phase while the trapezius ascendens is the most active during recovery. The posterior and middle deltoids were found to be most active in reverse propulsion.

### **Keywords**

Electromyography, wheelchair, disabilities

### **1. Introduction**

Propelling a conventional manual wheelchair is physically demanding. Large number of manual wheelchair users complains of pain and injuries of their upper extremities from prolonged use of the wheelchair. As the life expectancy of persons with spinal cord injury (SCI) increased with improved health care, secondary health issues related to aging in this population have begun to surface. More

specifically, the effects of muscle overuse are becoming evident in the forms of muscle pain, torn rotor cuff, joint degeneration, and carpal tunnel syndrome.

Researchers and engineers have developed several mechanical device systems to resolve the many drawbacks of the conventional manual wheelchairs. More popular among these alternatives include levers, cranks or hand cycles, and hub-crank. In all cases, these alternative methods of propulsion have some advantages over the hand-rim propelled wheelchair. Either by alternating pushes and pulls (levers), or following a continuous circular motion (hand cycles, hub-crank), the waste of the recovery phase seen in the hand-rim wheelchair is eliminated. As a result, these devices are generally more efficient (Van der Woude, 2001) than the traditional wheelchair, requiring less exertion on the part of the user even while sustaining higher coasting speeds.

This study focused on another technique, reverse wheelchair propulsion. Reverse-wheeling is accomplished with the incorporation of a planetary gear system that accepts a pulling or reversed motion at the input hand rim and translates it into a forward motion at the wheels. A feasible and practical wheelchair wheel device has been proposed in previous work (Nasser et al. 2004). So far, two studies on healthy able young adults examined the merit of reverse-wheeling propulsion (RWP) (Linden et al. 1993; Salvi et al. 1998). As with most previous research on alternative wheelchair design evaluation, the two studies on RWP focused on the physiological demands on the user as compared to the FWP. The two studies arrived at contradicting conclusions. Linden et al. (1993) have concluded that, for all power outputs investigated, RWP required less physical exertion (in terms of cardio-respiratory responses) than that compared to FWP. Salvi et al. (1998) concluded the opposite. Salvi et al. (1998) noted the differences in range of motion (RoM) during the propulsion phase as the key factor contributing to the discrepancy in the results between the two studies.

The purpose of this study was to compare the phasing and intensity of human shoulder muscle activity during forward and reverse wheeling. The reverse-wheeling technique is expected to recruit larger and stronger muscles of the back and arms, thereby reducing the risk for repetitive stress injury to smaller, stabilizing muscles of the shoulders. Further, the user will experience improved stamina as these larger muscles are not likely to fatigue easily.

## **2. Methods**

Surface electromyography was used to examine the muscle activity of nine muscles around the shoulder region of able-bodied research participants as they propelled a wheelchair fixed on a roller system. The muscles investigated included the triceps, anterior deltoid, ascending trapezius, bicep, pectoralis major, posterior deltoid, middle deltoid, latissimus dorsi, and the middle trapezius.

### **2.1 Research Participants**

The study enlisted ten (10) able-bodied adults who have given informed consent. The mean age ( $\pm$ SD) of the participants was 23.6 years ( $\pm$ 3.6 years); all participants are right-handed, in good health and have no previous record of pathologies of the upper extremities. Manual wheelchair users were not chosen because they comprise a group with non-homogeneous abilities and were skilled in FWP. This would have introduced bias in the data.

### **2.2 Surface Electromyography**

The surface EMG was recorded using a data acquisition and communication unit MP30™ (Biopac Systems Inc.) and the collected data (sampled at 1000Hz) were processed using the Biopac Student Lab PRO software. The Biopac surface EMG electrodes (EL-503, Biopac Systems Inc.) are disposable, pre-

gelled and self-adhesive. Electrodes were placed on the participants according to guidelines by Delagi et al. (1980), Hermens et al. (2000), and the European Recommendations for Surface Electromyography (results of the SENIAM project). All electrodes are grounded to the bony landmark on the right ankle. Five seconds of rest EMG data were collected, followed by the measurement of MVC EMG. Manual muscle test techniques presented by Hislop et al. (1995) were modified for testing participants in a seated position. Three consecutive propulsion cycles of EMG data were full-wave rectified and integrated over 0.02s of data (20 points). The integrated EMG data were then subtracted from the rest EMG, and then normalized by the highest 0.1 sec of activity obtained in maximum voluntary exertion of each muscle. The normalized and integrated EMG data (expressed in %MVC) are average over 1% cycle time of the propulsion cycle (Mulroy, et al. 1996). Finally, the resulting EMG data for all participants were averaged to form a global assemblage of curves.

## 2.3 Motion Analysis

Three mini-DV digital cameras (JVC GR-DVL9800) are used to capture the kinematics of propulsion techniques in FWP and RWP. The velocity of the wheelchair wheels moving over the roller is determined by the motion of a reflective marker on a spoke with respect to another on the axle (inter-marker distance  $IMD=15.75cm$ ). Marker displacements are recorded at 60 fps. One marker is placed on the frame of the WC as a reference. Eight other markers are placed on the participant's body: 3rd and 5th right dorsal metacarpal heads, distal radial and ulnar processes (wrist), lateral epicondyle of the humerus (elbow), most lateral aspect of the acromion (shoulder), jugular notch (base of neck), and C-7 vertebrae (Rodgers et al. 1994). The video recordings are used to distinguish the propulsion and recovery phase. The propulsion phase begins when the hand first touches the wheelchair hand rim and continues until the hand loses contact with the hand rim. Digital videos are analyzed using the Ariel's Performance Analysis System™ (APAS, Ariel Dynamics Inc.).

## 2.4 Test Exercises

The research participants first practiced propelling the wheelchair/roller system both forward and in reverse. After sufficient rest, the participants propelled the wheelchair either forward or reversed (randomized to eliminate errors) at a self-selected, comfortable pace for three (3) minutes. The camera system recorded the motion of the reflective markers during the last 30 seconds of the exercise, while the EMG acquisition unit recording readings for 10 seconds (including at least five consecutive propulsion cycles). The participants are allowed ten (10) minutes of rest, and the experiment and data recording is repeated for the other propulsion technique.

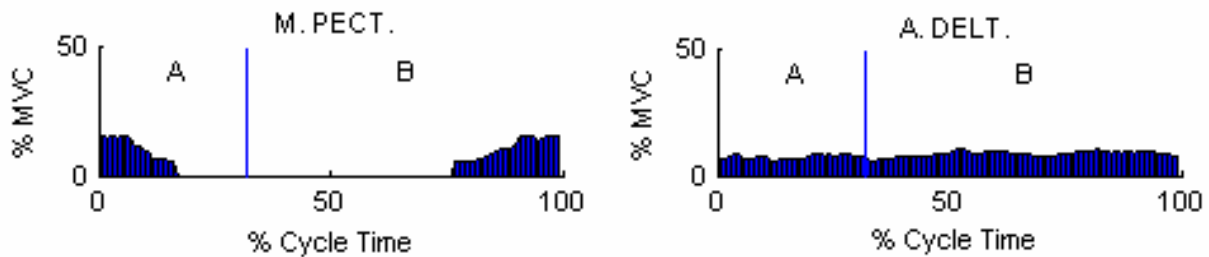
## 3. Results

Average wheelchair velocity for FWP (average= $0.64m/s$ ,  $\pm 0.122m/s$ ) was lower than that of RWP (average= $0.79m/s$ ,  $\pm 0.005m/s$ ). The average propulsion cycle time for FWP and RWP was  $1.09s \pm 0.23s$  and  $1.16s \pm 0.24s$  respectively. However, the percentage time spent during active propulsion was longer in RWP ( $40.8\% \pm 5.7\%$ ) than in FWP ( $32.0\% \pm 9.3\%$ ). Propulsion phases are distinguished in regions A and B in Figure 1-3.

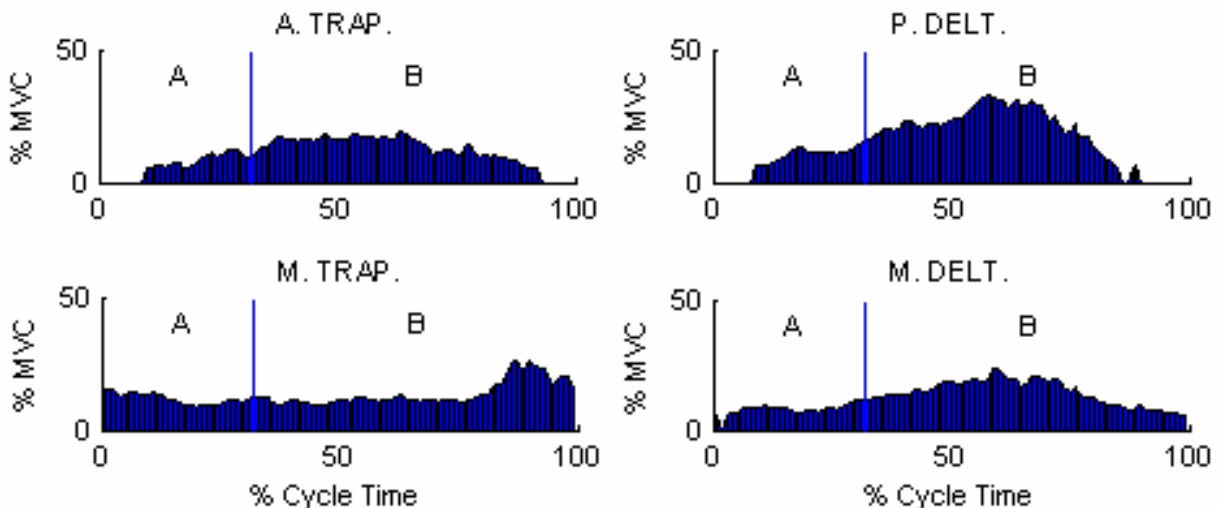
Table 1 below shows the peak EMG intensities in each muscle in FWP and RWP, as well as the corresponding time into the propulsion cycle when the peak intensities occurred. Muscles that activate and peak early in the propulsion cycle (region A) are considered propulsion phase muscles, while activation in region B is represented by recovery phase muscles. It must be noted that in some cases muscles activate very late in the cycle (85% or later), and such activities must be interpreted as muscle pre-contractions in preparation for the next propulsion phase.

**Table 1: Peak Intensity of Muscle Activity during FWP and RWP and the Corresponding Timing of Occurrence.**

	FWP		RWP	
	Peak Intensity (%MVC)	Percentage Cycle Time (%)	Peak Intensity (%MVC)	Percentage Cycle Time (%)
Tricep	14.4	62	22.7	8
A Delt	10.8	83	10.6	98
A Trap	18.8	64	21.3	88
Bicep	10.7	79	11.9	11
M Pect	16.3	1	11.2	11
P Delt	33.2	59	59.0	6
M Delt	24.0	60	28.6	17
Latt	12.8	86	24.8	3
M Trap	26.2	88	27.4	12



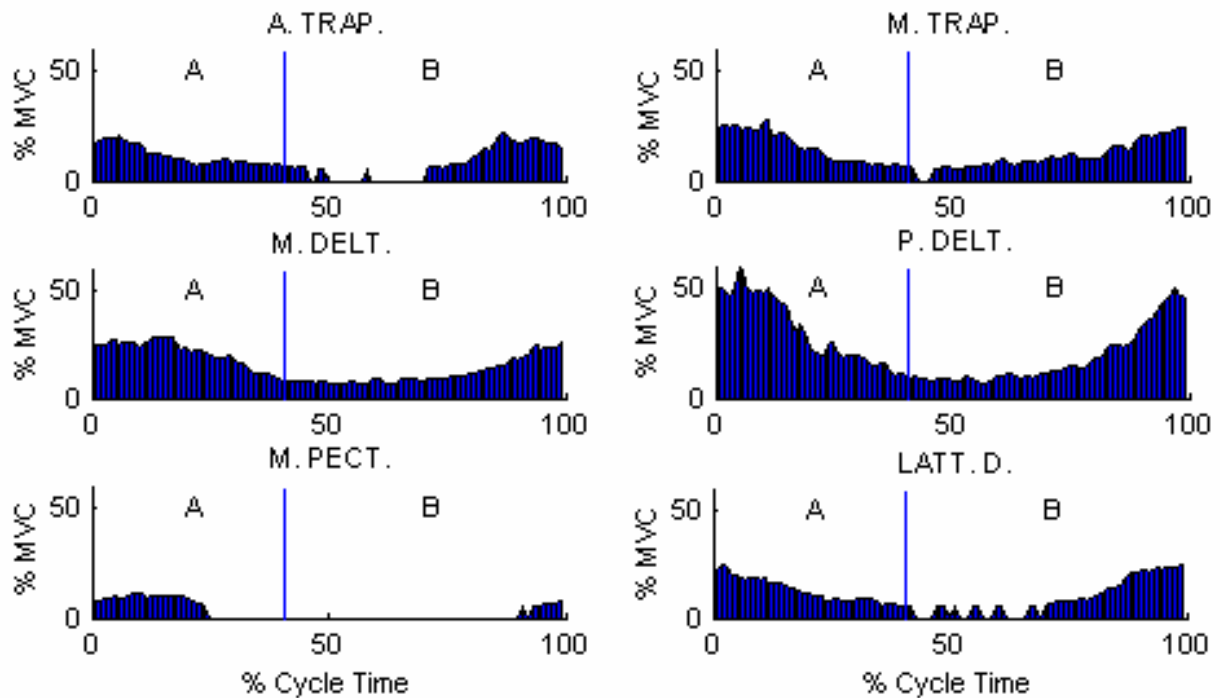
**Figure 1: Propulsion Phase Muscles in FWP**



**Figure 2: Recovery Phase Muscles in FWP**

In RWP, all muscles were active during the propulsion phase. As shown in Table 1, EMG activities peaked very early (3- 17% into the cycle) in RWP. Peak EMG of the anterior deltoid and trapezius

ascendens occurred at 98% and 88% respectively and are interpreted as activation in preparation for the next propulsion cycle.



**Figure 3: Propulsion Phase Muscles in RWP**

#### 4. Discussion

Healthy able-bodied young adults were selected for the experiment because their abilities were more homogeneous and they were equally inexperienced in both methods of wheelchair propulsion. Manual wheelchair users, on the other hand, are skilled in FWP, which would introduce bias in the data. The contradicting results obtained by Linden et al. (1993) and Salvi et al. (1998) may be attributed to the range of motion (RoM) employed by their research participants. Salvi allowed the participants to choose the RoM that was most comfortable to them. Linden et al. (1993) prescribed the RoM to be adopted by the subjects (FWP from  $-15^{\circ}$  Top Dead Center to  $120^{\circ}$  TDC; RWP from  $160^{\circ}$  TDC to  $-45^{\circ}$  TDC). The RoM prescribed by Linden et al. (1993) required large trunk motion that cannot be realistically performed by paraplegics or quadriplegics. As a result, participants in this study were allowed to propel the wheelchair using the range of motion that is most comfortable to them. The average RoM employed in FWP and RWP was  $70.3^{\circ} \pm 9.9^{\circ}$  and  $106.5^{\circ} \pm 22.8^{\circ}$  respectively.

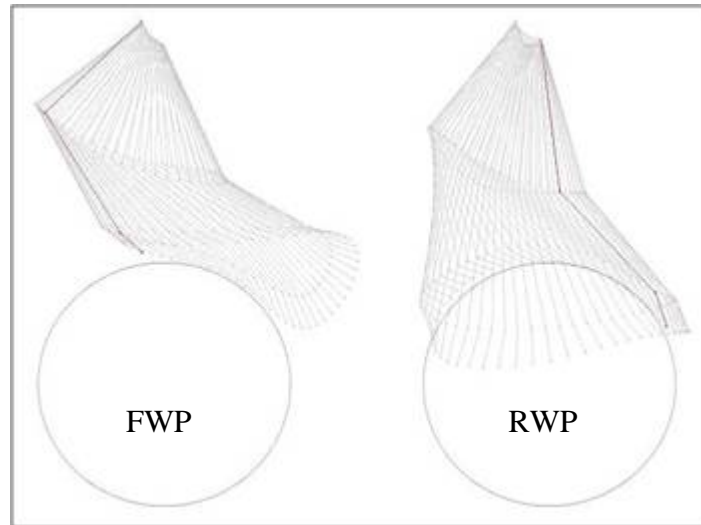
Average propulsion cycle times in FWP and RWP (1.09s and 1.16s respectively) compared well with the range report by Salvi et al. (1998) (0.83–1.09s and 1.07–1.20s) but were considerably lower than the Figures reported by Linden et al. (1993) (1.25–1.28s and 2.14–2.40s). Previous study on FWP by Rodgers et al. (1994) found similar average cycle times of 1.15-1.20s.

EMG data recorded for FWP compared well with previous research in terms of intensities (Mulroy et al. 1996) and timing (Rodgers et al.). Mulroy et al. (1996) used needle electromyography and reported somewhat higher intensities of EMG activity; Rodgers et al. (1994) used surface electromyography but did not report intensities in EMG measurements.

In FWP, the pectoralis major was found most active during the propulsion phase, although the actual %MVC were relatively low. The anterior deltoid was also expected to be most active during the propulsion phase (as seen in study by Mulroy et al. 1996), but this is not observed in Figure 1.

Eight out of nine muscles were active during the propulsion phase in RWP, indicating that the technique is highly efficient as most of the muscle work is translated into propulsion work. On the other hand, high muscle activities during the recovery phase in FWP suggest that the process is wasteful and unstable.

The triceps remained highly active during the propulsion phase in RWP (up to 50% into the propulsion cycle). This can be explained by the elbow extension that occurred when the hand passed over top-dead-center (TDC) of the wheel as seen in Figure 4.



**Figure 4: Kinematics of arms and shoulder motion in FWP and RWP**

Both posterior and middle deltoids are highly active during RWP. The posterior deltoid is seen to provide propulsion torque, while middle deltoid activity corresponds to humerus abduction (upward movement of the humerus to the side) as the hand crossed the TDC of the wheel. M. deltoid contraction provided for both useful propulsion work, as well as maintaining shoulder stability (Ozkaya et al. 1999). Deltoid contractions have been linked to possible impingement of the supraspinatus tendon due to the upward slipping of the humeral head (Mulroy et al. 1996). This effect is less pronounced in RWP since humeral abduction increases the stabilizing component of the M. deltoid muscle force (horizontal component, which presses the humeral head in place in the socket) while reducing the shearing component of the force. Further, fatigue in pectoralis major is less likely in RWP (by its low EMG activity); therefore, this large muscle can continue to act as an effective antagonistic to the middle and posterior deltoid contractions, and thus minimize the risk of joint slippage and tendon impingement.

The loads on shoulder muscle have been transferred from the pectoralis major and anterior deltoid (in FWP) to the middle and posterior deltoid and the trapezius (in RWP). The average velocity achieved by RWP is higher than that in FWP. This benefit, however, is paid for by an overall increase in muscle activity during RWP. Future work should focus on the design of a wheelchair device that permits both FWP and RWP to ensure overall balance of muscle exercise and usage.

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