Methods for Interpreting Wheelchair Propulsion Biomechanics in Tetraplegia

Yarossi, Kwarciak, Forrest, Dyson-Hudson, Ramanujam, Kirshblum, Boninger, Sisto, Cole

The purpose of the paper is to describe wheelchair propulsion biomechanics in tetraplegia relative to propulsion efficiency and push frequency considering important aspects of wheelchair configuration.

Four male participants with C6/C7 motor complete tetraplegia propelled their own wheelchair on a two-drum roller system at a self-selected speed. The rear wheels were replaced with a pair of 3D force sensing wheels and reflective markers were placed following International Society of Biomechanics recommendations. Fine wire EMG electrodes were placed in 13 muscles of the right shoulder. Anthropomorphic measures and wheelchair configuration were recorded. All data were averaged over ten consecutive push cycles (PC). 3D angles, forces and moments were calculated at the wrist, elbow and shoulder. Propulsion efficiency was calculated as the ratio of tangential force to total force on the pushrim. Push frequency per meter was derived from the average PC time and velocity. EMG data was normalized to MVC.

Participant self-selected speeds ranged from .57m/s to 1.20 m/s. Mean push efficiency ranged from 47% to 52% and push frequency/meter ranged from .71 PC/m to 1.86 PC/m. Seat plane angle ranged from 5 to 19 degrees. Trunk flexion/extension ranged from 18° flexion to 13.5° extension, however only one participant's trunk moved in both flexion and extension. Cessation of the anterior deltoid and pectoralis (shoulder flexors) activity ranged 21% to 49% and 24% to 47% of the PC respectively.

The participant with the greatest mean efficiency (52%) also displayed the lowest push frequency (.71 PC/m). This subject had the greatest seat plane angle (19.2 deg). Seat plane angle offers increased stability. The increased stability allowed the participants to exhibit a more optimal range of motion at the trunk putting the arm in a mechanical advantage. This is reflected in the comparatively lower EMG activity of the shoulder flexors during early push phase.

06-3054

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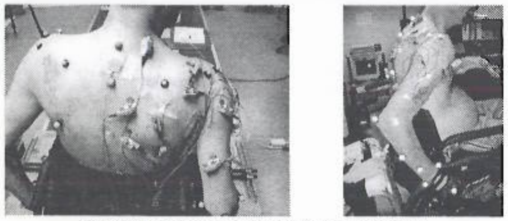
INTRODUCTION

Numerous studies have evaluated shoulder biomechanics during wheelchair propulsion in individuals with paraplegia[1,2,3,4,5]. Comparatively few studies exploring the upper limb biomechanics during wheelchair propulsion have included individuals with tetraplegia (IWT). Compared to paraplegia, tetraplegics exhibit greater superior forces[6] and EMG activity[7] at the shoulder. Differences in wheelchair propulsion biomechanics in individuals with tetraplegia versus those with paraplegia have been attributed to upper extremity weakness as well as an inability to grasp the push rim during propulsion. The primary objective of this study is to examine simultaneously, kinematics, kinetics and EMG of the shoulder during wheelchair propulsion relative to propulsion efficiency and push frequency considering important aspects of wheelchair configuration for IWT.

DATA COLLECTION & ANALYSIS

Four male participants with C5/C7 motor complete tetraplegia (see below) propelled their own wheelchair on a two-drum roller system at 2mph. The rear wheels were replaced with a pair of 3D force sensing wheels (SmartWheels, Three Rivers, LLC. Mesa AZ) and reflective markers were placed following International Society of Biomechanics recommendations. 3D angles, forces and moments were calculated at the wrist, elbow and shoulder using a Newton-Euler inverse dynamic approach. Fine wire EMG was recorded from 13 muscles of the right shoulder and data were normalized to maximum voluntary contraction. Propulsion efficiency was calculated as the ratio of tangential force to total force on the pushrim. Stroke frequency per meter was derived from the average push cycle (PC) time and velocity. All data were averaged over ten consecutive PCs. Anthropomorphic of the upper limbs measures and wheelchair configuration were recorded.



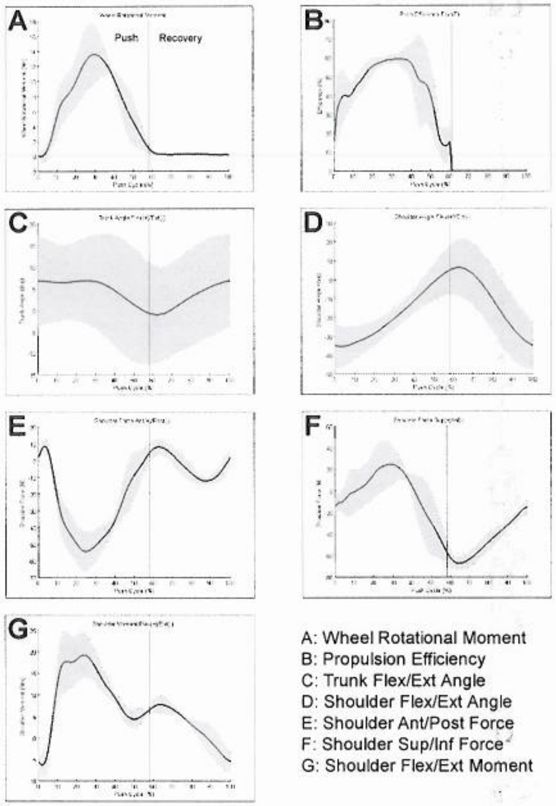
Fine wire EMG and kinematic marker setup

Participant Characteristics

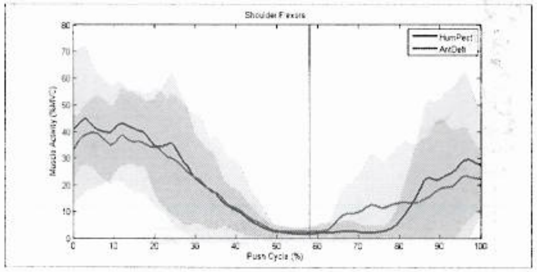
	Arm Length (cm)	Seat Height (cm)	Seat Plane Angle (°)	Horizontal Axle Pos. (cm)	Vertical Axle Pos. (cm)	Resting Trunk Position (°)
P1	62	47.6	19.2	3.5	8.1	1.44 flex
P2	60	48	9.5	9	5.3	5.59 flex
P3	64	46	5	4	13	11.26 ext
P4	69	47.5	7.9	8	9.5	7.34 flex

Temporal and Spatial Characteristics

SC Time (s)	Top Dead Center (% PC)	Release (% PC)	Stroke Freq (PC/m)	Contact Angle (°)	Release Angle (°)	Push Angle (°)
0.94 (.11)	29.62 (12.62)	56.18 (5.48)	1.26 (.15)	58.45 (21.95)	133.37 (12.02)	75.03 (22.98)

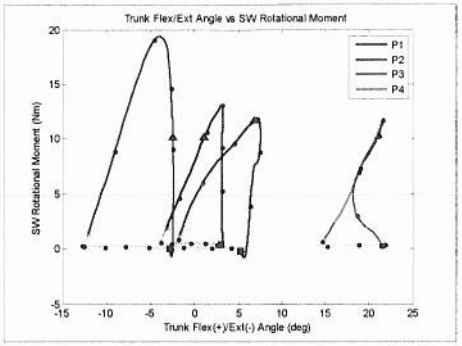


A: Wheel Rotational Moment
B: Propulsion Efficiency
C: Trunk Flex/Ext Angle
D: Shoulder Flex/Ext Angle
E: Shoulder Ant/Post Force
F: Shoulder Sup/Inf Force
G: Shoulder Flex/Ext Moment



Mean EMG activity of the shoulder flexor muscles.

Funding for this study was provided by the New Jersey Commission on Spinal Cord Injury (06-3054-SCR-EO) and the Henry H. Kessler Foundation



Relationship between trunk angle and SW rotational moment
Squares: Contact; Triangles: TDC; Stars: Release; Dots at every 10% of PC

RESULTS

Mean push efficiency ranged from 40.47%(P3) to 48.57%(P1). Mean push frequency/meter ranged from 1.08 PC/m (P1) to 1.46 PC/m (P2). A forward trunk position was recorded at contact and maintained throughout the first 20-40% of the stroke cycle. Trunk extension occurred throughout the remainder of the push phase. During push phase shoulder flexion moments were largest. Both shoulder flexors were active at contact with cessation of anterior deltoid and pectoralis activity occurring between 21% to 49% and 24% to 47% of the push cycle, respectively.

DISCUSSION

For each participant, the onset of trunk extension at mid push phase was found to be coincidental with shoulder peak flexion moment and peak rotational moment at the wheel. At this time point there was also a decrease in activity of the shoulder flexion muscles. Data from the four participants indicate that a shoulder flexion moment can more effectively be generated when the trunk is stationary. Shoulder flexion moment is the primary generator of rotational moment at the wheel.

Increased seat plane angle provides greater trunk stability and, not surprisingly, the participant with the greatest seat plane angle had the greatest efficiency and lowest push frequency and the subject with the least seat plane angle had the smallest efficiency and second greatest push frequency. Several studies have concluded that high push frequency and poor efficiency are main contributor to shoulder pain. Our pilot data suggests trunk stability influences push frequency and push efficiency.

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