Shoulder Biomechanics of Pushrim Impact during Wheelchair Propulsion in Tetraplegia: A Case Report

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Biomechanical Predictors of Shoulder Pain and Pathology During Manual Wheelchair Propulsion in Tetraplegia

- Identify relationships between upper limb kinematics, kinetics and muscle activation during wheelchair propulsion as predictors to pain and pathology
- First study to combine kinetics, kinematics and EMG

Upper Limb Overuse in Wheelchair Propulsion

- Overall, 51% of SCI patients have shoulder pain (Lee, 2002)
- Prevalence of shoulder pain increases with chronicity of injury and wheelchair use
- Individuals with tetraplegia (IWT) are at great risk of secondary disability due to shoulder pain that may be due to reduced muscle stability around the shoulder complex, leading to loss of control of joint motion.
- Weakness around a joint can lead to increased unwanted motion at that joint during propulsion and greater extremes of motion can lead to an increased incidence of injury.
- If the pain is severe, an IWT may lose the ability to transfer and thus require assistance with many ADLs or have to convert to a power wheelchair
- Campbell et al. (1996) reported increase capsular shortening in tetraplegia potentially leading to improper biomechanics

Previous Studies Discussing Wheelchair Propulsion in Tetraplegia

- Kulig et al. (2001) found an increased superiorly directed force at the shoulder in tetraplegia after controlling for differences in velocity
- Newsam et al. (1999) reported approx a 60 degree flexion angle and a 45 degree rotation angle from IC to HO.

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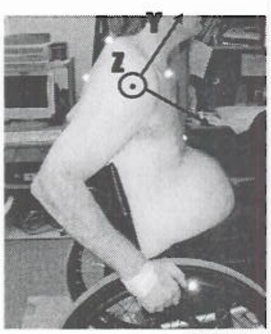
Pushrim Impact

- Previous Literature
  - Robertson et al. hypothesized that pushrim impact could cause rapid loading of the joint structures possibly producing joint trauma.
  - Add boninger paper

Maintaining Pushrim Contact with Limited Hand Function

- Lack the hand function to grab and pull the rim
- Lack the triceps innervation to push by extending the elbow
- Must produce radial and axial force of greater magnitude than tangential to maintain adequate contact
- Radial directed force on the pushrim translates to compressive force at the shoulder

Kinematic Setup and Analysis



Set position (0° for all angles) was defined as:

- **Arms at sides**
- **Forearms at 90°s to humerus**
- **Palms facing medially**

Shoulder angles found by rotating humeral coordinate system into the ISB trunk coordinate system.

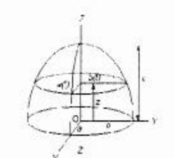
Rotation about X = ABD/ADD

Rotation about Y = INTROT/EXTROT

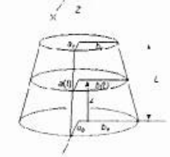
Rotation about Z = FLEX/EXT

Modeling the Upper Limb

- Modeling the asymmetrical upper limb common in tetraplegia poses a problem when using traditional methods of calculating segment mass, center of mass and moment of inertia (Dempster, Clauser etc.).

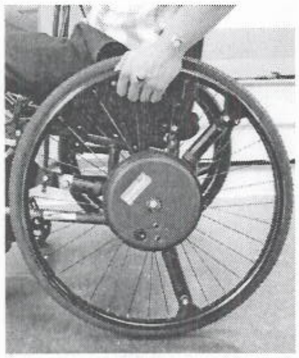


- These values were obtained using the body segment parameter equations established by Hanavan and Yeadon. The hand was modeled as a semi-ellipsoid and the forearm and upper arm were both modeled as truncated circular cones.



Kinetics – SmartWheel

Wheelchair wheels were removed and replaced with wheels equipped with force sensitive pushrims that measure the magnitude and direction of forces and moments exerted on the pushrim



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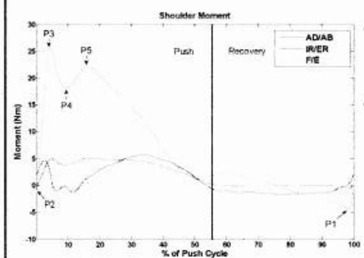
Inverse Dynamics



- Directional forces obtained at the pushrim were projected up the limb.
- Moments about 7 axes of rotation of the arm were found using a Newton-Euler approach (Requejo et al, 2004, Med. Eng. And Physics)
  - 2 moments at the wrist
  - 2 at the elbow
  - 3 at the shoulder

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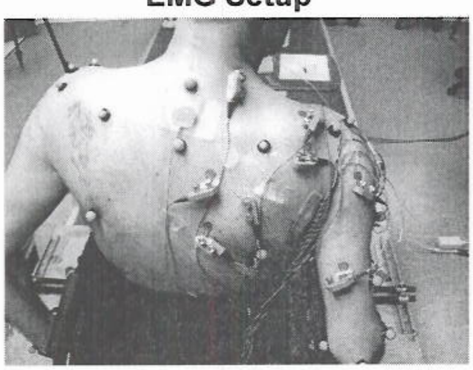
EMG Setup



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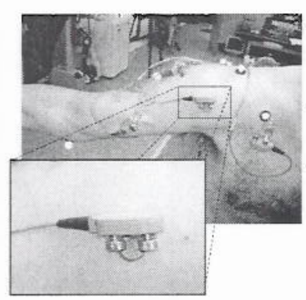
EMG Setup



- **Stainless steel nickel alloy insulated fine wire electrodes were inserted into 13 muscles of the right upper arm and trunk**
- **One pole of 13 pre amplified electrodes attached to fine wires The**
- **Second pole was attached to Ag/AgCl surface electrodes placed over the surface of the muscle, with the exception of the subscapularis for which a second intramuscular needle electrode was attached.**

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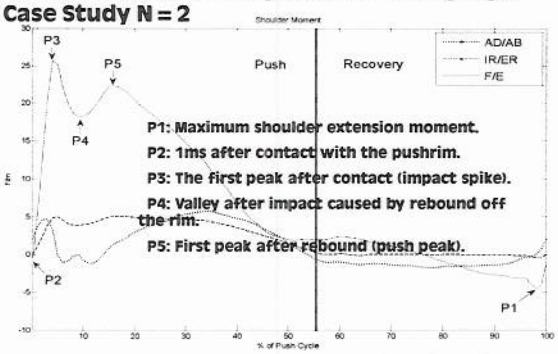
Shoulder Biomechanics of Pushrim Impact During Wheelchair Propulsion in Tetraplegia Case Study N = 2



P1: Maximum shoulder extension moment.

P2: 1ms after contact with the pushrim.

P3: The first peak after contact (impact spike).

P4: Valley after impact caused by rebound off the rim.

P5: First peak after rebound (push peak).

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Propulsion

- Functional Level: C6
- Age: 41
- Self selected speed: 1.2 m/s
- Makes contact with the rim for 76°

- Functional Level: C6
- Age: 46
- Self selected speed: 0.71 m/s
- Makes contact with the rim for 67°

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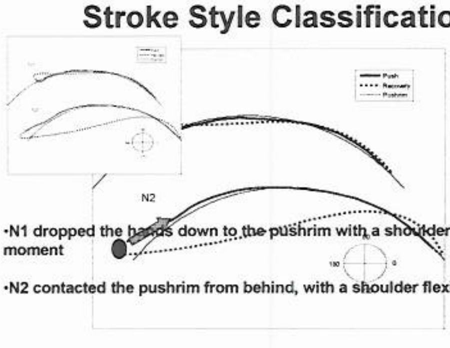
Stroke Style Classification



- N1 dropped the hands down to the pushrim with a shoulder extension moment
- N2 contacted the pushrim from behind, with a shoulder flexion moment

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Key Subject Differences

	P2 Initial Contact	P3 Impact Spike	P4 Rebound	P5 Push Peak	P2 Initial Contact	P3 Impact Spike	P4 Rebound	P5 Push Peak
	Participant 1				Participant 2			
	Pushrim				Pushrim			
Hand angle (°)	119.4	117.4	112.0	103.5	128.9	119.0	114.4	104.7
F_{total} (N)	19.6	105.7 <	87.3	112.6	25.9	110.9 ≈	108.7	147.3
F_{tan} (N)	0.2	22.7 <	20.3	35.0	0.3	31.8 >	34.1	50.3
F_{rad} (N)	14.7	77.8	61.0	72.1	19.1	70.6	70.5	79.8
F_{ax} (N)	-4.8	1.4	5.9	5.5	-6.5	-8.5	-4.0	-17.1
Eff (F_{tan}/F_{total})*	0.9	21.5	23.3	31.1	1.1	28.7	31.4	34.2
	Shoulder				Shoulder			
F_x (N) ant/post	-2.8	-53.2	-41.1	-53.2	-11.2	-63.4	-62.4	-75.2
F_y (N) sup/inf	-22.9	23.7	12.2	22.7	-23.7	5.3	8.3	17.9
F_z (N) med/lat	4.8	-1.4	-5.9	-5.5	6.5	8.5	4.0	17.1
M_x (Nm) flex/ext	-1.1	25.6	18.2	22.3	2.2	27.7	26.2	29.0
M_y (Nm) IR/ER	0.0	4.9	3.8	5.0	0.2	5.6	6.0	7.4
M_z (Nm) add/abd	2.0	3.3	0.0	1.4	3.1	6.8	4.9	11.0

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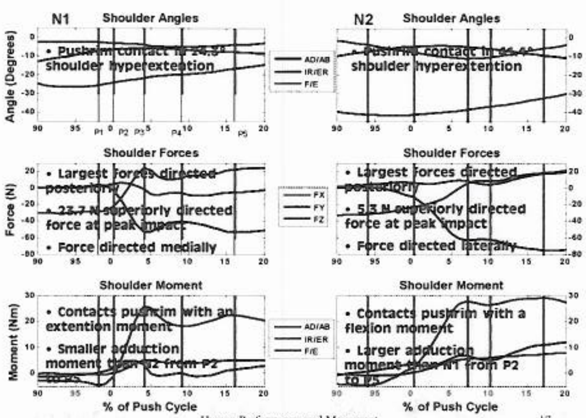

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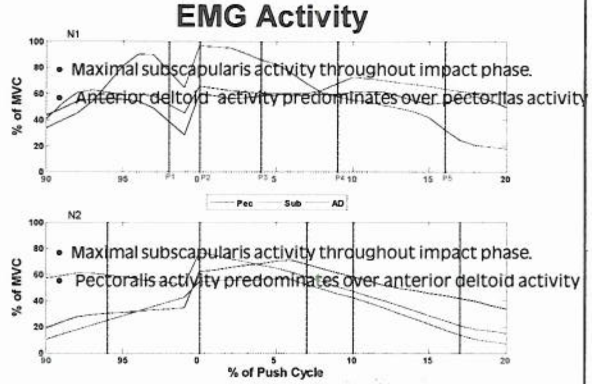
EMG Activity



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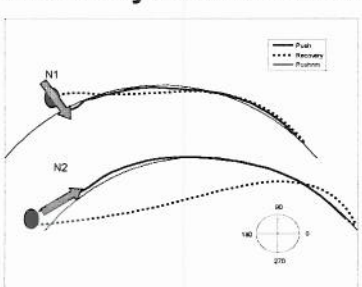
Stroke Style Classification



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Preliminary Conclusions

- Striking the rim from behind and using adductive force:
  - Reduces the compressive forces on the shoulder at impact.
  - Minimizes the loss of tangential force during rebound.
  - Favors the use of the pectoralis over the anterior deltoid.

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Limitations

- The use of the acromion to represent the glenohumeral joint center
- The use of a "zxy" rotation order at the shoulder differs from ISB recommendations
- The use of T3 instead of T8 differs from ISB recommendations
- Model does not include scapula

Future Goals

- Analyze the motion of the elbow and wrist.
- Expand the model to analyze the entire push cycle.
- Add motion of the scapula to the model.

Study Team

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Thank you

Questions??