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ABSTRACTS FROM CONFERENCE PRESENTATIONS (2003 – 2005)

The influence of stroke pattern on shoulder kinetics during wheelchair propulsion. Requejo PS, Bontrager EL, Gronley JK, Newsam CJ, Mulroy SJ, Perry J. Clinical Gait and Movement Analysis Society conference: May 2004; Lexington, KY

Introduction**:** Loss of lower extremity function with spinal cord injury (SCI) places the entire burden of locomotion on the upper extremities; contributing to high incidence of shoulder injury among manual wheelchair users. Specifically, the vertical component of the shoulder force creates greater potential for subacromial impingement [1]. Shimada and colleagues identified three patterns of the hand trajectory that characterize an individual's propulsion technique [2]. They hypothesized that the semicircular pattern was the most biomechanically efficient because these subjects had lower accelerations of the shoulder and elbow joints and spent a greater percentage of time in the push phase. However, they did not document whether the shoulder joint forces differed between stroke patterns. The purpose of this study was to characterize the mechanical relationship between the stroke patterns and shoulder forces and moments during wheelchair propulsion.

Statement of Clinical Significance**:** Identification of factors relating propulsion stroke patterns and upper extremity loading can be used in the development of individualized prescription guidelines to optimize propulsion techniques and lower the incidence of shoulder injury among wheelchair users.

Methods**:** *Experimentation:* Thirteen subjects with complete SCI (C6 to L3) propelled an instrumented wheelchair positioned on a stationary ergometer at a self-selected velocity. The seat was positioned such that the wheel axle was aligned 4 cm. anterior to the shoulder joint center. The right push-rim was instrumented (SmartWheel) to measure the magnitude and direction of the forces exerted by the hand on the pushrim. Three-dimensional motion of the right upper extremity was recorded (Vicon). Kinematics and hand force data from multiple propulsion cycles were used as model inputs. *Modeling:* The human right upper extremity was modeled as a collection of rigid segments (Figure A). Using Lagrange's formulation, the system dynamics were formulated as a set of second-order differential equations of the form:

$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{V}(\mathbf{q},\dot{\mathbf{q}}) + \mathbf{G}(\mathbf{q}) = \mathbf{Q} + \left[\partial P_f / \partial \mathbf{q}\right]^T \boldsymbol{\lambda} \qquad (1)$$

where $\mathbf{q}$ are the generalized coordinates, $\mathbf{M}(\mathbf{q})$ is an N x N mass matrix, $\mathbf{V}(\mathbf{q},\dot{\mathbf{q}})$ is an N x 1 vector of Centrifugal and Coriolis terms, $\mathbf{G}(\mathbf{q})$ is an N x 1 vector of Gravity terms, $\mathbf{Q}$ is an N x 1 vector of generalized forces, $\boldsymbol{\lambda}$ is the reaction force at the hand/push-rim interface, $\left[\partial P_f / \partial \mathbf{q}\right]^T$ expresses the location of the reaction force in terms of the generalized coordinates. In the sagittal plane, the hand center of mass trajectory relative to the shoulder joint center is a function of the generalized coordinates $\mathbf{q}$ as follow:

$$x_{hand} = q_1 + \sum_{5}^{i=1} L_i \cos(q_3 + .. + q_n), \;\; y_{hand} = q_2 + \sum_{5}^{i=1} L_i \cos(q_3 + .. + q_n) \qquad (2)$$

where x_{hand} and y_{hand} are the horizontal and vertical positions of the hand, L_i is the length of the ith segment. Eq. (1) and (2) were used in an inverse dynamics and forward kinematics simulation, respectively. Inputs to the inverse dynamics were segment lengths, masses, centers of mass, moments of inertia and generalized coordinates ($\mathbf{q}$) and their first and second derivatives. Hand reaction forces (λ) from experimental data were used as inputs. Inputs to the forward kinematics simulation were the generalized coordinates and segment lengths. Stroke patterns were averaged from multiple cycles of the hand segment position relative to the shoulder joint center. Shoulder net joint reaction forces and moments were determined from Eq. (1).

Results**:** Similar to Shimada's findings, three distinct stroke patterns were exhibited (Figure B): double loop (DL) (n=7), semicircular (SC) (n=5), and single-loop (SL) (n=1). In the DL pattern, the subjects lifted their hand above the propulsion path with a distinct crossover point. In the SC pattern, 4 subjects dropped their hands below the propulsion path during the recovery while 1 subject lifted his hand above the propulsion path. In the SL pattern, the subject dropped his hand below the propulsion path with no distinct crossover point.

During the push phase, greater peak superior forces were seen in the SC pattern than the DL and SL patterns. The peak posterior forces were the same in the SC and DL patterns and less in the SL pattern. The flexor net joint moments at the time of peak vertical force were greater in the SC than both the DL and SL patterns. At hand release, all stroke patterns had anterior and inferior forces and extensor moments.

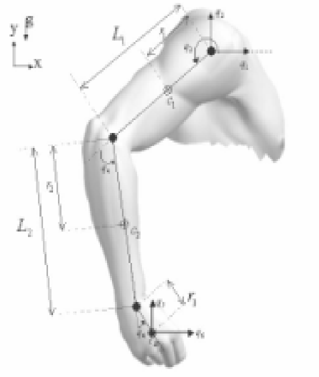

Figure A: Model description

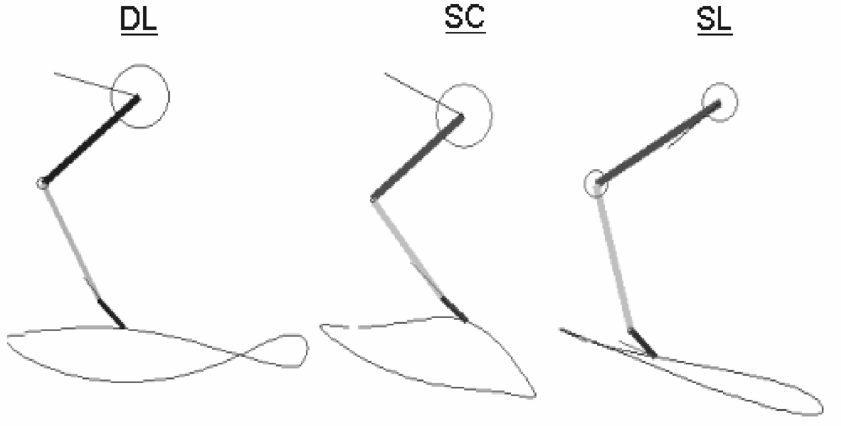

Figure B: Stroke patterns, force vectors (lines) and moments (circles)

Discussion: The hand stroke pattern reflects the outcome of the ongoing interaction between musculoskeletal control and dynamics and is a convenient means of assessing an individual's propulsion technique during clinical evaluation. Although Shimada hypothesized that the SC pattern was the most biomechanically efficient, we found that pattern to have higher, potentially damaging shoulder forces. Clearly, a study of all the factors that affect the relationship between stroke patterns and loading is needed. These include arm strength, limb length, propulsion velocity, and segment and joint orientation. Future research studies will examine the effects of the above variables as well as test modified propulsion techniques via forward dynamics simulation and optimization.

References**:**

1. Perry, J. (1993), in *F.A. Matsen III, F.H. Fu, and R.J. Hawkins, Editors. 1993, American Academy of Orthopaedic Surgeons: Rosemont, IL.* 185-191.
2. Shimada, S.D., et al. (1998). *J. of Rehab. Res. & Dev.* 35(2): 210-218.

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