RECONFIGURATION OF THE UPPER EXTREMITY RELATIVE TO THE PUSHRIM AFFECTS LOAD DISTRIBUTION DURING WHEELCHAIR PROPULSION

Joseph M. Munaretto, 1, 2, 3 Jill L. McNitt-Gray, 4 Henryk Flashner, and 1, 5 Philip S. Requejo

1 Department of Biomedical Engineering, 2 Kinesiology, 3 Biological Sciences
4 Aerospace and Mechanical Engineering, University of Southern California, Los Angeles, CA
5 Rehabilitation Engineering, Rancho Los Amigos National Rehabilitation Center, Downey, CA
University of Southern California, Los Angeles, CA, USA
munarett@usc.edu

INTRODUCTION

Repetitive loading during manual wheelchair propulsion (WCP) is associated with overuse-related injury of upper extremity (UE) [1]. Redirection of the hand / rim reaction force (RF) relative to the upper extremity segments provides a means to redistribute mechanical load across joints away from areas at risk [2,3]. Reconfiguration of the UE relative to the pushrim was hypothesized to influence how redirection of the RF redistributes load without a decrement in performance.

METHODS

One wheelchair user with spinal cord injury (SCI) volunteered to participate in this study in accordance with the Institutional Review Board at the Ranchos Los Amigos National Rehabilitation Center, Downey, CA. The participant performed self-selected speed wheelchair propulsions for 10 seconds. Reflective markers were used to monitor the 3D motion of the hand, forearm, upper arm, trunk, and wheel segments (VICON, 50 Hz) and 3D hand / pushrim force was collected (SmartWheel 2500 Hz). The markers and upper extremity model to estimate wrist, elbow, and shoulder joint centers followed methods described in [4].

A 2D inverse dynamic model, incorporating subject-specific experimental tangential force and kinematic data, was used to determine the sensitivity of UE loading to shoulder/pushrim distance and wrist placement during WCP. We assume the shoulder is in a constant position as determined by its average position during the push cycle. Forearm and upper arm lengths are determined as averages of the distances between elbow / wrist and shoulder / elbow centers of rotation in 3D during the push phase. The model is then restricted to 2D by assuming shoulder, elbow, and wrist are in sagittal plane. Given the shoulder/axle distance and wrist angle at time t, configuration of the forearm and upper arm can be determined (using the law of Cosines) at time t that agrees with the static constraints of forearm and upper arm segment length (Equation 1&2, Figure 1).

\[
\theta_E = \cos^{-1}\left(\frac{L_{SW}^2 - L_U^2 - L_F^2}{-2L_U L_F}\right)
\]

(1)

\[
\theta_F = \tan^{-1}\left(\frac{y_s - y_w}{x_s - x_w}\right) + \theta_E
\]

(2)

Mechanical loading was characterized by elbow net joint moment (NJM) and shoulder NJM over a range of RF directions. RF direction was systematically varied by maintaining the tangential component of the RF and varying the magnitude of the radial component.

![Figure 1: 2D model of modifications in UE configurations associated with changes in shoulder distance relative to wheel axle. Distance between shoulder and wheel axle (r_s) and push range (θ_p) are modified to give shoulder and wrist coordinates. Law of Cosines is used to determine UE segment orientations](image-url)
RESULTS AND DISCUSSION

As forearm angle increases, minimum elbow and shoulder NJMs will occur at increasingly tangential RF directions (Figure 2). Minimum shoulder NJMs occur at more radial RF directions than minimum elbow NJMS. At low forearm angles, RFs that keep moment arms small on the forearm and upper arm are more radially directed and have relatively large magnitudes. As forearm angle relative to pushrim increases, RF directions shift more tangentially and have lower force magnitudes which can allow NJMs of both joints to decrease.

![Figure 2: Elbow, shoulder, and total NJM and axial shoulder NJF (at time of peak force) in relation to RF direction \( \theta_R \) and forearm angle \( \theta_F \) relative to pushrim when elbow angle \( \theta_E \) is kept constant. The effect of RF direction is dependent on forearm angle. Larger forearm angles shift low moment areas (blue) to more tangential RF directions. Black dot represents location of experimental results within solution space.]

As elbow angle increases, there is no change in effect of RF redirection on elbow NJM. RF direction associated with minimal shoulder NJM shifted from 15° to 40° relative to the radial direction (Figure 3). The difference in RF directions which minimize elbow and shoulder NJM decreases with increasing elbow angle. Since forearm orientation relative to the pushrim did not change, there were no changes in how \( r \times RF \) alters elbow NJM. Increasing elbow angle rotates the upper arm into closer alignment with the forearm. RFs directed through or close to the forearm reduce the moment arm when acting on the upper arm.

CONCLUSIONS

These simulation results provide mechanically based information to guide clinical interventions that aim to maintain WCP performance and redistribute load by modifying RF direction, seat configuration and hand/rim interaction.

![Figure 3: Elbow, shoulder, total NJM, and axial shoulder NJF at the time of peak force in relation to RF direction \( \theta_R \) and elbow angle \( \theta_E \) when the forearm angle \( \theta_F \) relative to pushrim is kept constant. The effect of RF direction is dependent on elbow angle. Larger elbow angles shift low shoulder moment areas to more tangential RF directions. Black dot represents location of experimental results within solution space.]

REFERENCES

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