

BIOMECHANICS OF UPPER EXTREMITY DURING WHEELCHAIR PROPULSION

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INTRODUCTION

Of the 1.6 million wheelchair users in the US, only 150,000 use an electric wheelchair (NHIS-D, 1994). A large percentage of wheelchair users are individuals with spinal cord injury. Wheelchairs are the primary means of mobility and for such individuals and hence an essential component of their daily life. Depending on the level of the injury the user possesses varying degree of strength and control of the upper body.

Wheelchair propulsion is a highly repetitive task which is primarily controlled by the upper extremity. This places excessive demands on the shoulder joint which is anatomically not designed to handle such loads for an extended period of time. This causes wear and tear at the shoulder and other joints of the upper limb and can eventually lead to debilitating secondary injuries. There is a need for new designs to lower these loads and consequently reduce the likelihood of injuries. Previous investigations have tried to quantify forces and moments at the shoulder under varying conditions of propulsion (Kulig et al., 1998). The aim of this study is to determine how mechanical loads are distributed among the wrist, elbow, and shoulder under two conditions, which are self-selected fast and slow propulsion. We hypothesized that the distribution of mechanical load across the wrist, elbow, and shoulder joints will be the same across speeds.

METHODS

Participants in this study exhibited various levels of spinal injury and provided informed consent in accordance with the Institutional Review Board at the Rancho Los Amigos Medical Center, Downey, California. Reflective markers were placed on the hand, forearm, upper arm and the trunk segments, and the right wheel to track segment and wheel kinematics during self-selected fast and slow wheelchair propulsion (six camera Vicon® 3D tracking system). The force applied to the wheelchair by the hand while propelling was measured using SMART^{WHEEL} pushrim force collecting system. A four segment 3D upper extremity model (Visual 3D) was used to calculate the joint forces and moments in the upper extremity during the propulsion of the wheelchair. Fine wire EMG was also recorded from eight shoulder and scapular muscles (lower and middle trapezius, anterior and middle deltoids, pectoralis major, subscapularis, supraspinatus and the rhomboids). EMG data was used to determine the role of the upper extremity muscles in controlling the shoulder girdle and joint during fast and slow propulsion.

RESULTS AND DISCUSSION

The distribution of the mechanical demand imposed on the wrist, elbow, and shoulder was found to be different between tasks at the time of the first (Z_1) and second (Z_2)

peaks in the vertical component of the reaction force (Figure 1).

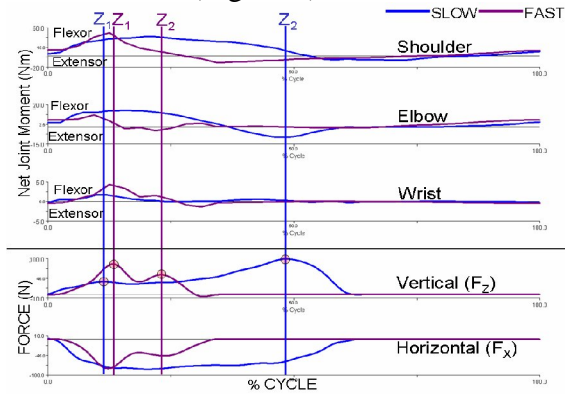


Figure 1: The Net Joint Moments (NJM) at the wrist, elbow and shoulder during one propulsion cycle for an exemplar participant: 37 year old male with a T12 spinal injury, 57kg, 1.78m, 15 years post injury.

In the case of the exemplar participant, fast propulsion imposed greater relative demand on the shoulder whereas slow propulsion a more equal distribution between the shoulder and elbow (Figure 2). Wheelchair users with cervical levels of spinal cord injury exhibited different segment kinematics in conjunction with less trunk control. In general, the NJMs were dependent on the magnitude of the reaction forces and Net Joint Forces (NJF) in relation to the segment orientation and the adjacent NJMs. As the segments became more aligned with the reaction and NJFs the magnitude of the NJMs declined. During fast propulsion, the relative angles between the segments and the joint forces were large as compared to slow propulsion. This between-task difference in segment orientation at the time of peak vertical reaction forces contributed to higher wrist and shoulder NJMs during fast propulsion and higher elbow NJMs during slow propulsion. Increase in muscle force requirements increases the potential for muscle fatigue and detrimental loading overtime.

During both the fast and slow propulsion trials, a flexor NJM was required at the elbow and shoulder at Z_1 . In contrast, at Z_2 , a flexor NJM was required at the shoulder whereas an extensor NJM was required at the elbow. This shift in NJM requirements between Z_1 and Z_2 indicates a different set of upper extremity muscles may have been used during the early and late phases of propulsion.

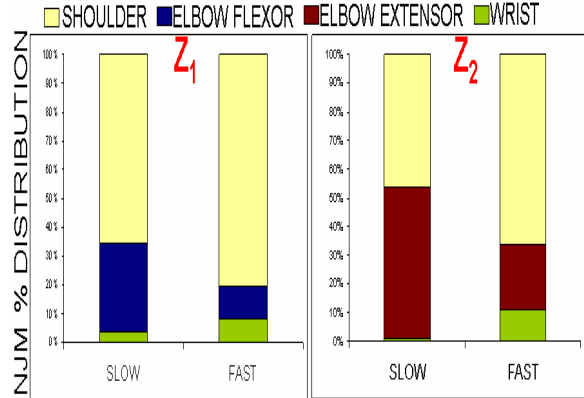


Figure 2: Distribution of the NJMs as a percentage of the sum total of wrist, elbow and shoulder moments at Z_1 and Z_2 . Elbow NJM at Z_1 is a flexor; at Z_2 is an extensor).

During fast propulsion, the upper extremity NJMs were sustained for a shorter duration than during slow propulsion. These between task differences in impulse duration may influence the set of muscles used to generate the NJMs required to perform the task.

By understanding how individual patient populations distribute mechanical load during wheelchair propulsion, wheelchair designs can be customized so that individual users can better utilize their muscle force generating capabilities without sustaining an injury.

REFERENCES

- National Health Interview Survey on Disability, (1994-95) National Center for Health Statistics.
- Kulig, K. et al., (1998) Clinical Orthopedics and Related Research, **354**, 132-143.