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ASSESSING MECHANICAL DEMAND IMPOSED ON THE UPPER EXTREMITY DURING MANUAL WHEELCHAIR PROPULSION IN REALISTIC CONTEXTS

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SUMMARY
Individuals with spinal cord injury (SCI) use their upper extremity for mobility and activities of daily living. This study investigates the use of low cost wearable technology as a means of assessing repetitive mechanical demand imposed on the upper extremity during manual WC propulsion in realistic conditions outside of the lab. Segment 3D kinematics and hand rim reaction forces acquired using wearable technology were used to determine mechanical demand imposed on the shoulder (NJF, NJM) during repeated propulsive cycles under self-selected free and fast conditions. The joint kinetics results confirm that the mechanical demand imposed on the shoulder can vary considerably between cycles, particularly when the mechanical objective of the propulsion phase changes (e.g. speed up, maintain speed, slow down). Monitoring load exposure in the field together with other forms of wearable technology may assist in determining causal relationships between mechanical load exposure and shoulder pathology.

INTRODUCTION
Repetitive mechanical loading of the shoulder during manual wheelchair (WC) propulsion has been associated with disabling shoulder pain that can significantly affect health and active community participation[1,2]. Previous experimental research and model simulation results indicate that WC propulsion technique and propulsion speeds can affect the distribution of mechanical load imposed on the upper extremity[2-4]. Observed variation in shoulder joint kinetics stem in part from the complex interaction between an individual's upper extremity kinematics and reaction forces (RF) generated during WC propulsion. The relative distribution of NJMs across the extremities is affected by RF magnitude as well as the orientation relative to the upper extremity segments. For example, a 3-fold increase in RF magnitude may only result in minimal changes in shoulder net joint moment (NJM) magnitude[4]. Therefore, to assess the distribution of mechanical load imposed on the upper extremity knowledge of both segment kinematics and reaction forces at the handrim are required.

With the emergence of low-cost wearable sensors upper extremity kinematics can now be measured along with RF at the handrim in realistic contexts outside of a motion capture laboratory environment. The purpose of this study was to determine the feasibility of integrating wearable sensors with an existing instrumented wheel system to estimate shoulder joint kinetics during manual WC propulsion as performed as part of activities of daily living.

METHODS
An individual with paraplegia volunteered to participate in accordance with the Institutional Review Board at the Rancho Los Amigos National Rehabilitation Center, Downey, CA. Upper extremity kinematics and reaction forces at the hand-rim interface were quantified as the participant propelled their own WC outside of the seating center on a flat cement sidewalk and ramp using their self-selected technique at two speeds (self-selected free and fast). Each sequence involved acceleration, maintenance of speed, and deceleration of the WC. Upper extremity 3D segment kinematics were acquired by using two wearable sensors (gyro, accelerometer, magnetometer, 240Hz, AMM3D, Tuscon, AZ) secured to the upper arm and forearm. Simultaneously, pushrim reaction forces were collected using an instrumented wheel (SmartWheel, 250Hz, Three Rivers Holdings, Mesa, AZ). Sagittal plane video (240Hz) was also acquired and served to verify that segment kinematics derived from the wearable sensors were comparable to those obtained via manual digitizing of wrist, elbow, and shoulder joint centers. Shoulder Net Joint Forces (NJF) and NJMs were calculated for each cycle using inverse dynamics (custom code using MatLab). Upper extremity NJFs and NJMs served as indicators of

Figure 1. Wearable sensors secured to the upper arm, forearm, and WC were used to monitor segment and WC kinematics. Sensor signals were transmitted via Bluetooth to portable laptop computers.

mechanical load distribution and multijoint control requirements imposed on the upper extremity system during manual WC propulsion under each condition.

RESULTS AND DISCUSSION

Experimental results confirm that upper extremity joint kinetics vary considerably from cycle to cycle and the that the magnitudes of RF, NJF, and NJM are highly dependent upon technique as well as the mechanical objective of the task.

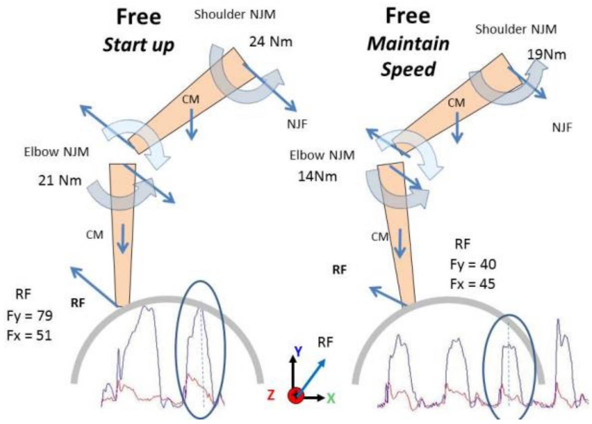

Figure 2 Free body diagrams reflecting the orientation of the reaction force relative to the upper extremity segments at the time of peak push (vertical line) during the free condition during start up and when maintaining speed. Exemplar reaction forces resultant RF_{xy},(blue), RF_z (red) time curves during different cycles are also provided to illustrate the variability between cycles and phases.

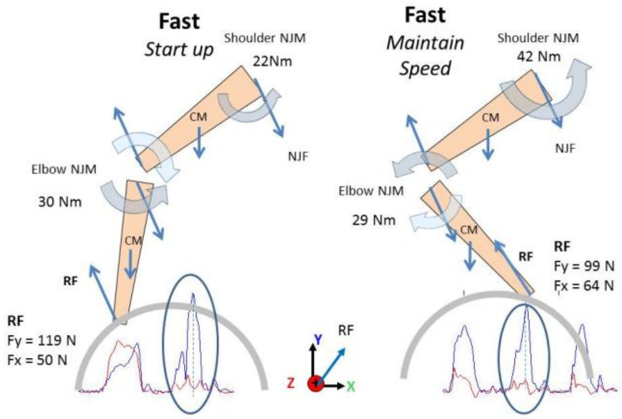

Figure 3. Free body diagrams reflecting the orientation of the reaction force relative to the upper extremity segments at the time of peak push (vertical line) during the fast condition during start up and maintaining speed. Exemplar reaction forces resultant RF_{xy},(blue), RF_z (red) time curves during different cycles are also provided to illustrate the variability between cycles and phases.

Obtaining segment kinematics using wearable sensors does have limitations as do motion capture systems. The source of measurement error includes that introduced by relative

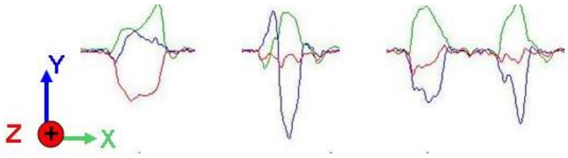

Figure 4. Variation in reaction force-time curves during different WC propulsion cycles also serve to characterize aspects hand/rim interaction including pull up on the rim (+blue), inward push on hand rim (-red), push (+green).

motion between the sensor and the arm after calibration, and estimation of joints centers between two adjacent segments.

In addition, angles output by the associated software often involve filtering and calculations typically not shared with the end user. To overcome these potential limitations in estimating mechanical load exposure, simulation results, generated using subject-specific modeling[5] can assist by determining the sensitivity of NJF and NJM estimates in relation to error associated with detecting segment orientation relative to the RF direction.

CONCLUSIONS

Incorporation of wearable technology to capture 3D segment kinematics during activities of daily living in realistic context shows promise for assessing and characterizing the mechanical demand imposed on the upper extremity. A more personalized assessment of mechanical load exposure in more realistic conditions affords the ability to better assess an individual's capabilities in relation to the mechanical demand imposed over time and in contextually relevant contexts imposed by their environment. As this emerging technology develops, additional measurements, longitudinal monitoring, and even interactive features involving mobile communication devices can provide potential pathways for improving performance and reducing risk, and assessing outcomes of clinical interventions that aim to preserve shoulder function.

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REFERENCES

1. Finley, MA et al. (2004). *J RehabResDev,* 41(3), 395-402.
2. Consortium for SCI Medicine (2005), *J SCI Med.* 28(5).
3. Mulroy, SJ et al. (2005). *J Spinal Coard Med*. 28:214-221.
4. Raina, S. et al. (2011). *Human Movement Science*.
5. Munaretto, JM et al. (2011).*Clinical Biomech*.27(3):255-62.
6. Rao, SS et al. (1996). *IEEE Trans Rehabil Eng*, 4:152-60.