INTRODUCTION
The ability to transfer safely to a variety of surfaces is a fundamental requirement of independent mobility for individuals who use a manual wheelchair (WC). Transportation and ability to drive independently are important determinants of employment status and quality of life for individuals with SCI\(^1\). However, independent driving also requires transferring oneself and lifting a WC in and out of the car. Curtis et al. (1999) reported that for long-term WC users, the greatest amount of shoulder pain was experienced when the functional activity required extremes of shoulder range of motion, overhead positioning, or a high level of upper extremity strength\(^2\). Since transferring into a car and loading a WC encompass all three of these, it is crucial to identify the specific biomechanical demands at the shoulder in order to develop strategies for prospectively preventing shoulder pathology and loss of functional independence.

The purpose of this study was to examine the biomechanical demands of independent WC-to-car transfer and lifting of the WC frame into and out of a car. We evaluated the shoulder joint kinematics, kinetics and muscle activities of these tasks in order to examine the shoulder joint and muscular demands experienced by individuals who transfer independently with various techniques from their personal manual WCs to vehicles of different heights.

METHODS
Participants: A total of 11 participants with paraplegia from SCI (SCI level thoracic or lower and American Spinal Injury Association Impairment Scale (AIS A, B, or C – either no motor function below the level of SCI or motor function that is less than 3/5 in key muscles) who use a manual wheelchair for community mobility and routinely transfer and drive independently were asked to participate. Prior to data collection, we provided each participant with a copy of the Bill of Rights of Human Subjects and they read and signed an informed consent form that had been approved by the Institutional Review Board. Instrumentation: We instrumented a Toyota Camry (Toyota Motors, Torrance CA) to measure 6-degree-of-freedom reaction forces exerted on the steering column, driver seat, and driver’s side overhead grab bar; further described in Requejo et al. 2013\(^3\). We used a sixteen-camera Optitrack® (Natural Points) motion capture system to track the positions (AMASS, C-Motion, Inc.) of the trunk and the bilateral upper limbs, wheelchair frame, and car positions. We recorded the electromyography (EMG) of key shoulder muscles (2000Hz) using indwelling fine-wire electrodes. Data Collection: Laboratory testing began with the subjects sitting in their personal WC, ready to lift their body into the car. Subjects were then instructed to place their right hand either on the instrumented seat, grab bar, or steering wheel, to assist in pulling or pushing themselves into the car. After subjects had transferred into the car, they were instructed to lift the WC frame from the ground to the passenger seat or rear seat. The order of hand placement and WC frame placement testing was randomized prior to data collection. The car transfer task was conducted twice; once with the instrumented vehicle set up to simulate the height from ground to the seat of an average sedan (~22”) and again at a height simulating an SUV (~28”). Three wheelchair frames of varying configurations and weights were evaluated; 1) ultra-lightweight L-shaped Ti-lite Ti (3.8kg.), lightweight box frame Quickie GPV (5.9kg.), and lightweight L-shaped Colours Razorblade (4.5kg.). Data Processing and Analysis: Force, EMG, and motion data were combined using custom software (C3D Server, MLS, Inc.) and Visual3D (C-Motion Inc., Rockville, MD) was used to implement...
the three-dimensional model of the upper body and calculate the upper extremity kinematics and kinetics during the transfer and loading tasks. Motion and load-cell trajectory data were smoothed with a 6-Hz and 14-Hz zero-phase fourth-order digital Butterworth low-pass filter, respectively. Upper limb segments were defined following the description of Rao et al. Joint kinematics was calculated using Euler/Cardan rotation sequence with the proximal segment defined as the reference frame (i.e. upper arm relative to torso, etc.). The shoulder net joint forces and moments during each phase of the transfer and lifting task were determined using inverse dynamics. The EMG activity recorded during transfer and loading tasks was processed using the International Society of Electrophysiology and Kinesiology (ISEK) recommendations. The duration and median intensity of each muscle were determined for each phase of each trial.

RESULTS AND DISCUSSION
Results: We examined the influences of varying car height, WC frame (weight and dimensions) and right hand placement during car transfer on the shoulder joint kinetics and muscle activities during independent transfers and WC frame loading. Kinematic and kinetic data from an individual with T12 paraplegia (ASIA A) transferring (Figure 1) into the sedan height vehicle and EMG when lifting (Figure 2) an L-Shaped ultra-lightweight WC frame shown as exemplary data. During the loading task, he lifted the frame from the ground with the left arm in a slight external rotation, while holding onto the steering wheel with the right arm. During placement of the frame onto the rear seat, both hands were used but the right shoulder was in maximum external rotation and abduction; an external rotation moment was observed during this time. Muscle activities were highest in right Infraspinatus (INFRA), Subscapularis (SUBSCAP), right Supraspinatus (SUPRA) during this time. The shoulder joint kinematics, kinetics, and muscle activities showed variations between test conditions.

Discussion: The current investigation documented the large forces and extreme position of the shoulder during the body lift of the transfer and release of the WC frame into the rear seat; which may predispose the shoulder joint to high stresses that lead to injury. Information from this research is critical to the development of a comprehensive shoulder pain prevention program that is crucial for preserving independence and community participation for individuals with SCI.

CONCLUSIONS
Quantitative biomechanical analysis of the car transfer and WC loading allowed the identification of the demands associated with high-stress activity that can contribute to the development of shoulder pain in manual WC users.

REFERENCES
Requejo, P., et al. (2012). RESNA.

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