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Evaluation of Transfer Technologies to Preserve Shoulder Function in SCI

Karen Michelle Mann

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Evaluation of Transfer Technologies to Preserve Shoulder Function in SCI

by

Karen Michelle Mann

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering
Department of Chemical and Biomedical Engineering
College of Engineering
University of South Florida

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March 19, 2012

Keywords: Activities of Daily Living (ADLs), Biomechanics, Electromyography (EMG), Spinal Cord Injury, Veterans, Wheelchair Transfers

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Dedication

I would like to dedicate this thesis to my parents, Barry and Susan Mann, who have lent their unconditional support. I love both of you very much even though I have trouble saying the words. I am very grateful for all you have given me especially during the past couple years while I have been tackling this project.

Now I can buy you dinner.
Acknowledgements

I’d like to thank all who have helped me through this process, especially:

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Dr. Lloyd for taking a chance on me and for allowing me to take over this project for use as my thesis. For helping me stay afloat, making terrible jokes and consistently throwing me into the deep-end.

Dr. Brian Schulz for being a brilliant lab mentor. For helping me find answers to my many questions and exposing me to new concepts and equipment.

The late Shawn Applegarth for design and fabrication of lab equipment, without which I would have had a model that would have been distinctly less functional.

Dr. Nathan Gallant for agreeing to be a part of my thesis committee.

Mike Kerrigan for his vital assistance in the lab during set-up and data collection.

All those at the COE who I have worked closely with over the years: Ron Olney, Dr. Jan “Dad” Jasiewicz, Dr. Jeff Craighead and “Uncle” Alan Barlow.

Lastly, I’d like to thank all my supporters, manuscript reviewers and editors.

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Abstract

This study investigated a series of independent unassisted and device-assisted transfers from a wheelchair to vehicle mock-up and vice versa while simultaneously capturing kinematic, kinetic and electromyographic (EMG) data of impaired volunteers. The study provides a venue for observation and evaluation of upper extremity (UE) joint stresses, muscular force and functional demands associated with transfers in persons with spinal cord injury (SCI) to ultimately prevent UE injury, minimize excessive stress, preserve functionality and limit pain. If people with SCI lose function of their UEs, due to pain and/or degeneration, they must then rely on others for everyday tasks.

Five paraplegic males from the Tampa Bay area were recruited to take part in the study. Participants were asked to perform a series of transfers using 4 commercially available devices or mock-ups of that device as well as an unassisted transfer, which permitted the use of no assistive device. Three data types were captured: kinematic data using motion capture, kinetic data using force transducers which were integrated into the vehicle mock-up and EMG of 5 bilateral muscle groups. Data collection took approximately 4 hours per subject.

Forces occurring during the unassisted transfers were found to be the highest. This is also supported by the EMG data. Performing level transfers lessened stresses at the UE versus non-level transfers. The highest moments of the UEs were found at the shoulders with high variability between subjects. It was also found that body mass index (BMI) had an affect on a subjects ability to perform transfers.

Ultimately this study found that using an assistive device is better than not using an assistive device. This is proven by EMG and force data, which were both found to be
less with the use of an assistive device as opposed to transferring independently with no assistance. Performing level transfers, maintaining ones body mass and staying active are all factors that will limit stresses at the UEs during wheelchair transfers to and from a vehicle.
Chapter 1 – Introduction

1.1 Background

Individuals with SCI that render them paraplegics face a variety of challenges post-injury. Typically, people with SCI perform activities of daily living (ADLs) such as mobility, dressing, transferring and repositioning, without the functional use of their lower extremities. Since most persons with SCI are young when injured and are living longer,\textsuperscript{1,2} concerns are justified about maintaining independence during ADLs over time. Increase in knowledge of SCI has helped improved post-injury care, which in-turn increases the need for secondary injury prevention.

For persons with SCI, many years of overuse of the UEs leads to an increased incidence of cumulative trauma to the shoulders, elbows and wrists. Over 50% of persons with SCI have UE pain;\textsuperscript{3} rotator cuff tears have been reported in 59-73%;\textsuperscript{4} and 40% have clinical evidence of carpal tunnel syndrome.\textsuperscript{5} UE deterioration following years of compensating for the lack of functional lower extremities reduces quality of life, function, independence and even life expectancy following SCI.\textsuperscript{6-8} To minimize the adverse effects of SCI as people age there is a need to examine wheelchair transfer safety, UE joint injury prevention and preservation of function.

Investigators have conducted comprehensive evaluations of UE kinematics,\textsuperscript{7,9-14} kinetics\textsuperscript{15,16} and muscle activity as determined by EMG\textsuperscript{3,16} among individuals with SCI during numerous ADLs. However, few studies were identified, that specifically address transfers from a wheelchair to vehicle while capturing these three data types.\textsuperscript{17-19}
1.2 Objectives of the Study

This study evaluated at a series of independent unassisted and device-assisted transfers from a wheelchair to vehicle mock-up and vice versa while simultaneously capturing kinematic, kinetic and EMG data, facilitating observation and evaluation of UE joint stresses, muscular force and functional demands associated with transfers in persons with SCI to ultimately prevent UE injury, preserve functionality and limit pain. One general objective of this research was to explore whether any assistive devices are in fact beneficial to people with SCI.

1.3 Significance of Work

This study was performed following a pilot study that analyzed SCI patients transferring from a wheelchair to and from a hospital bed, commode mock-up and vehicle mock-up. It was found that transfers from wheelchair to vehicle and vice versa were distinctly the most difficult with respect to the stresses generated at the UEs. The study also found that capturing wheelchair to vehicle transfers is quite difficult, which is likely one reason there are few studies that have taken on the challenge.

This previous study was conducted as part of the larger research efforts of the Tampa Patient Safety Center. The current study continues the research previously conducted and expands upon it by solely evaluating wheelchair to vehicle transfers and updating data acquisition methods. The pilot study conducted made use of a vehicle mock-up, which was an assembly of 2x4’s. The large cross-section was found to severely occlude markers. The new vehicle design adopted a more streamlined appearance, utilizing 2.54cm (1in) steel tubing, painted in a matte black to minimize reflections. Biomechanical models utilizing inverse dynamics from the previous study were also utilized for this current study to determine reaction forces at the UEs. The
current study will additionally look at the demands of stowing and retrieving a wheelchair, a necessary task if full independence is desired.

This research adds to the understanding and knowledge that aims to improve how those with SCI can remain independent and mobile. Without the functional use of their UEs they must rely on others for the simplest of everyday tasks. It is important to discover and learn how SCI patients can continue to function independently. With the technology available today and technology to be developed in the future, SCI patients will have the ability to live longer, healthier lives.

The study was approved by the University of South Florida Institutional Review Board (IRB) and the James A. Haley Research and Development Committee.

1.4 General Limitations

During the process of conducting this study a number of limitations may have hindered the acquisition of the best possible data.

For one, mock-up devices were utilized for data collection. The vehicle used for this study was a model essentially comprised of a steel frame. The seat of the vehicle may not have been properly adjusted for both a car and a truck or van and therefore could have affected the transfer height for the Ryno Lift mock-up transfers. The Glide ‘n’ Go mock-up also created non-level transfers, but to a lesser degree than those during the use of the Ryno Lift mock-up.

Data acquisition also presented some difficulties. Major challenges include markers and electrodes falling off during data collection, marker occlusions and marker labeling. In some cases EMG voltages were higher during the transfer trials than during the MVC trials and therefore % MVC values exceed 100%.
Participant recruitment also proved to be a challenge. In the span of approximately 18 months, data from only 5 subjects meeting the inclusion/exclusion criteria was able to be later processed and analyzed.

1.5 Anatomy and Physiology

The focus of this study is the UEs, so for a complete understanding a brief background of the anatomy is provided.

The shoulder joint is a ball-and-socket joint which is designed for a wide range of motion (ROM). Movements of the shoulder include adduction/abduction, protraction/retraction and internal/external rotation. While the shoulder joint has the ability to move in all three planes, it is not a stable joint as is endemic of the lower extremities. This lack of stability increases the risk of injury such as dislocation and rotator cuff tears. The rotator cuff is the soft tissue which encapsulates the articulation of the humerus and glenoid surface of the scapula. Impingement, sprains, strains, arthritis and fracture are other common injuries of the shoulder.

The elbow joint acts as a hinge providing movement in a single plane (flexion/extension). The decreased ROM allows the elbow to have greater stability than that of the shoulder, also protecting it from a high risk of injury.

The wrist, a condyloid joint, also allows for a wide ROM. The condyloid joint is similar to a ball-and-socket, but with an elliptical pathway. Movements of the wrist include flexion/extension, circumduction and pronation/supination. The latter occurs specifically at the distal radioulnar joint, which is a pivot joint formed by the articulation of the distal radius and ulna.
Chapter 2 – Literature Review

Across the globe there is an incidence of 15 to 40 cases per million of spinal cord injuries per year. Approximately 12,000 cases of paraplegia and quadriplegia occur each year in the United States alone, with almost 60 percent surviving their injuries.\(^2\)

People with SCI rely on their UEs to perform everyday activities, such as wheelchair propulsion and transfers. Their ability to lead independent lives is directly influenced by the integrity of their UEs.\(^{21}\) Unlike the joints of the lower extremities, which are comprised of stable structures designed for load bearing and locomotion, the joints of the UEs are characterized by unstable structures specialized for ROM, but limited mechanical stress.\(^7\) Consequently, functions performed by the UEs that are typically performed by the lower extremities, may lead to musculoskeletal degeneration.\(^3,7\)

Multiple factors may contribute to UE joint degeneration and/or loss of function following SCI. These factors include age and length of time from SCI onset,\(^9,22-25\) pain,\(^3,12,22,26-29\) UE joint and muscle strength deficiencies or imbalances,\(^22,26,28,30-32\) exercise capacity and tolerance for the physical strain of ADLs,\(^33-36\) body mass and composition,\(^14,16,37\) previous UE injury or disease history,\(^23\) wheelchair-to-user interface,\(^38-40\) and transfer techniques.\(^6,39,41,42\)

2.1 Incidence of Pain

Studies of manual wheelchair users indicate that UE pain is most common in the shoulders, wrists, hands and elbows.\(^9,21,23,29,43,44\) Within the SCI population, a reported 1/3 to 1/2 suffer from UE pain and deterioration caused by the stresses of overuse.\(^6\)\(^9,12,23-26\) Respondents to a questionnaire administered by Gironda et al,\(^44\) reported 58.5%
had UE pain; 71% reported shoulder pain, 53% wrist pain, 43% hand pain and 35% elbow pain. Their study also reports veterans with paraplegia suffer from at least a minimal level of ongoing unspecified pain (81%) and/or current UE pain (69%).

Subbarao et al also indicated high instances of wrist and shoulder pain, with nearly 73% of respondents reporting some degree of chronic pain in one or both of these areas. The investigators concluded that alternative methods for transfers need to be developed for persons with SCI to lessen stress and cumulative trauma and thereby diminish the incidence of chronic UE pain.

Several epidemiological studies have been conducted for the purpose of investigating the prevalence and intensity of UE pain and its association with functional activities in individuals with SCI. Studies have found that incidence of UE pain is greatly increased during performance of ADLs. According to Dalyan et al, pain frequency and intensity of functional activities performed by SCI patients, it was found that pain interfered most during pressure reliefs, ambulation, transfers, upper body dressing and wheelchair mobility, indicating that UE pain may have a significant impact on functional independence.

A study by Gellman et al concluded that pain increased with time from the onset of SCI. This is supported by Lal’s finding that shoulder dysfunction appears to increase with time since onset of injury as well as age. Lal also reported a correlation between age and a higher level of wheelchair activity. While age has been found to be a common factor in shoulder pain, Pentland and Twomey concluded that shoulder pain was related to duration of wheelchair use, exclusive of age. Surprisingly, in a study by Fullerton et al, that compared athletes to non-athletes, it was found that there was no difference in duration of wheelchair use between the two groups. Gironda et al found that the duration of wheelchair use only modestly predicted shoulder pain.
prevalence and intensity, while Wylie et al\textsuperscript{46} found that moderate joint activity protects the shoulders against degeneration.

To measure the effect of rehabilitation on UE pain, strength and function, investigators have measured changes in physical capacity and performance during ADLs following rehabilitation.\textsuperscript{33,47} Van Drongelen et al\textsuperscript{47} evaluated persons with SCI and found that tetraplegics have more pain than paraplegics, UE pain was inversely related to function, and strength was inversely related to shoulder pain. Dallmeijer et al\textsuperscript{33} found that after rehabilitation it is important to continue activities to maintain and even improve physical performance. In general, better strength and function were related to reduced UE pain. This is supported by previous findings that protection of the joints is directly related to the strength of the surrounding muscles.\textsuperscript{21}

In an effort to determine the effects of UE pain, studies investigating the prevalence and intensity of pain during ADLs have reported high incidences of wrist and shoulder pain, which effectively leads to a loss of mobility and therefore independence. It is important to continue performing daily tasks to maintain or improve physical performance and to discover the biomechanically effective methods of these tasks to help prevent degeneration and UE pain.

\section*{2.2 Biomechanics Studies}

Those with SCI are at considerable risk for injury to their UE, which is why studying how they perform various activities of daily living is critical for understanding and preventing injury so that patients can maintain their independence. Biomechanical models have been used to measure and predict UE kinematics and kinetics,\textsuperscript{48-51} glenohumeral joint contact forces\textsuperscript{52,53} or pressure,\textsuperscript{5} and upper extremity muscle forces\textsuperscript{52,53} or activations\textsuperscript{48-50} with varying complexity and methodology.
Numerous studies evaluating the biomechanics of ADLs performed by SCI subjects address the effects on key muscle groups surrounding the glenohumeral joint. Typically, investigators used surface EMG to obtain muscle activation measurements. The main objective for those with SCI is to develop and maintain the ability to independently transfer and maneuver when performing ADLs.

2.2.1 Glenohumeral Contact Forces

The glenohumeral joint is the most mobile articulation of the body, supported by the surrounding muscles to provide dynamic balance and stability. The calculation of glenohumeral contact forces has been modeled in various studies involving persons with paraplegia, tetraplegia and able-bodied persons for comparison. These studies provide insight into the effects of lesion level, ADL performance, BMI and anthropometric measurements on forces and moments produced at the joints of the UEs.

Transfers are among the most demanding ADLs likely due to the asymmetry of tasks and the awkward postures required. Gagnon et al. assessed sitting pivot transfers (SPTs) to compute joint forces and moments acting at the shoulders and elbows. For analysis, the transfer was divided into 3 phases: pre-lift, lift-pivot and post-lift. Resultant joint forces show that more weight is being supported by the trailing UE at the beginning of the transfer in the pre-lift phase. The weight progressively shifts to the leading UE producing increasing resultant forces at the elbow and shoulder during the lift-pivot phase. The investigators found that peak resultant forces occurred at the trailing UE during transfers to a raised seat.

During a transfer, the weight of the body is transferred from the trunk through the clavicle and scapula across the glenohumeral joint to the humerus. Bayley et al. used an arthrographically-placed catheter at the subacromial area of the shoulder joint to continuously measure arterial pressure during six different ADLs. They reported that
persons with paraplegia having a lower lesion level may be able to partially support their body weight during transfers using functional abdominal or spinal muscles, which may be vital to relieving excessive transfer forces imposed on the shoulders.\textsuperscript{6} The pressure in the shoulder joints during transfers usually exceeds mean arterial pressure by more than 250\%. The belief is that this high pressure in conjunction with abnormal stress across the subacromial area during a transfer contributes to the high rate of shoulder injuries in persons with SCI.

\textbf{2.2.2 Transfers}

Persons with SCI typically perform numerous transfers, potentially averaging 19 transfers each day\textsuperscript{60} and as many as 35 daily.\textsuperscript{67} Since transfers require a high muscular demand it is necessary to understand task mechanics to minimize any adverse effects.

The SPT method is defined by two seating surfaces angled anywhere from 25\textsuperscript{69} to 65 degrees\textsuperscript{69} from each other, depending on patient preference, and is commonly performed unassisted by SCI persons with strong UEs. This setup requires a patient to place the leading arm on the target seat, or other support surface, with the trailing arm on the initial seat. Next they must lift their body weight by extending the elbows, depressing the shoulders, lifting the buttocks\textsuperscript{70} off the initial seat, then rotating their body in order to move to the target seat. This maneuver generates high mechanical loading at the UE\textsuperscript{69}.

The position of the UE during transferring is crucial to preventing injury. Koontz et al\textsuperscript{71} noted that when the arm is internally rotated and abducted it is in a position of impingement, but the severity of this can be avoided with the use of an assistive device.

Perry et al\textsuperscript{50} found that the lift phase of a SPT required the greatest muscular effort by the lead arm. Gagnon et al\textsuperscript{55} evaluated SPTs at three different target seat heights; high, low and level. At the raised seat height it was found that the trailing UE
was affected by having to progressively increase elbow extension and angular velocity, while the leading UE reached peak extension angular displacement and velocity.\textsuperscript{64}

A number of studies have done further research into whether the leading or trailing arm is required to exert greater muscular exertion during transferring.\textsuperscript{67,72,73} In a study conducted by Cooper et al\textsuperscript{73} it was found that the trailing arm, in comparison, supported a higher percent body weight than the leading arm. Gagnon et al\textsuperscript{67} found only limited support that muscular demand is higher for the trailing UE. Upon further study they also found that muscular demand is similar in the preferred and non-preferred direction.

In a similar study Finley et al\textsuperscript{56} compared scapular kinematics and muscle function of manual wheelchair users with and without shoulder impingement. They found that those with impingement performed transfers with significantly less thoracic flexion, increased scapular upward rotation, and reduced humeral internal rotation as compared to those without the pathology.

Wang et al\textsuperscript{54} explored how reaction force and muscle activity change when transferring from a wheelchair to three different heights. Their study found that transfers to a higher surface resulted in a shift of the “friction force” from primarily anterior-posterior to more medial-lateral and required a greater muscular contribution from the biceps brachii muscle. Ideally, seat height should be level with the individual’s wheelchair when performing a SPT due to less muscular effort required than transferring to an elevated or lowered target seat. Perry et al\textsuperscript{50} concluded that assessment of SPT skill should not be based on the ability to lift body weight alone, due to the need for stabilization and lateral movements.

These studies demonstrate the exceptional demands placed upon the UEs of persons with SCI, but little attention has been given to the evaluation of techniques\textsuperscript{71} and
assistive devices to reduce these demands and thereby reduce pain and extend function.
Chapter 3 – Methods and Procedures

3.1 Screening and Selection Criteria

5 males with paraplegia who use a manual wheelchair for mobility were recruited from the James A. Haley VA Hospital in Tampa, as well as the surrounding community. Respondents were pre-screened in person or by telephone. Qualifying participants were also screened in the lab, prior to informed consent, to assure they met inclusion/exclusion criteria.

3.1.1 Inclusion Criteria

1. Level of SCI will be limited to ASIA A classification at T2 through L5 level to standardize physical capabilities;
2. SCI for at least 2 years (neurologically stable);
3. Use a rigid manual wheelchair as a means of primary transportation;
4. Able to self-propel wheelchair;
5. Able to independently transfer between wheelchair and vehicle;
6. Between the ages of 18-65;
7. Able to follow simple instructions;
8. Free from acute upper extremity injury for at least six months (determined by history review) to minimize risk of injury during task performance;
9. Comparable bilateral functional range of motion and strength of the shoulders, elbows and wrists (determined by physical evaluation) to minimize risk of injury during task performance.
3.1.2 Exclusion Criteria

Candidates who present:

1. Extended bed-rest within the past 30 days;
2. Ventilator-dependent;
3. Any cardiac or respiratory condition that would limit subject’s physical performance;
4. Unstable medical conditions;
5. Clinical evidence of severe musculoskeletal disorders of the upper extremity were precluded from participating in this study.

3.1.3 Participants

An initial questionnaire to obtain demographic and anthropomorphic data was administered. Previous injuries and experience of pain were recorded, as were daily activities performed recreationally and professionally. Table 3.1 shows anthropometry and demographics of the 5 participating subjects. Most subjects also participated in recreational activities including swimming, weight training, horseback riding, golf and rugby.

A board-certified physician, who practices Spinal Cord Injury Medicine, performed a physical evaluation of each candidate to verify upper extremity and spine integrity in order to determine their eligibility for the study. This evaluation included a review of the candidate’s historical file, a functional strength test and ROM.

Some possible anomalies amongst the study participants were noted, including: Subject 1 was the only subject with an incomplete injury; he has some motor function and is receiving ambulatory training, but lacks sensory function. Subject 2 was the only subject who did not report performing any physical activities. Subject 4 was the victim of a traumatic brain injury (TBI), which occurred in conjunction with his spinal cord injury.
Table 3.1: Subject Anthropometry and Demographics.

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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Smoker</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TBI</td>
</tr>
<tr>
<td>Mean</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Data Acquisition and Processing

Kinematic data was collected using a Vicon Motion Analysis system\textsuperscript{74}. This lab’s system has 13 MX40 cameras, which emit infrared light, to capture a full-body marker set of 63 spherical 9mm diameter reflective markers (Figure 3.1). This system captures 3D real-time information; the smallest measurable movement is 0.1 mm. The system is calibrated statically and dynamically prior to data collection using a specifically designed static calibration frame and dynamic wand each with integrated reflective markers (Figure 3.2). Data was captured at 30 frames per second. All peripheral components, including force transducers, EMG and a digital video camera, are interfaced using Vicon’s MX Control, MX Link and MX Net to allow all data to be captured simultaneously.

Data was initially processed using Vicon Nexus. An auto-label function was used to label all markers. The auto-label function is defined by a template of the marker configuration that was utilized for this study. Due to marker occlusions and in some cases mis-labeling, all kinematic trials were viewed frame by frame to manually label and re-label markers.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{motion_capture_components.png}
\caption{Motion Capture Components. A. Reflective markers including (from top right clockwise) individual markers, as well as gloves, triads, and a headband each with integrated markers. B. Vicon MX40 infrared camera.}
\end{figure}
The vehicle mock-up (Figures 3.3 and 3.4) is composed of a frame of 2.54cm (1in) steel tubing painted a matte black to minimize marker occlusion and excessive reflection, respectively. The base of the vehicle is wood, supported by a steel grid. Wheels were attached for ease of movement and height. The vehicle mock-up was designed with 7 integrated AMTI\textsuperscript{75} 6 degrees-of-freedom (DOF) force transducers, 4 in each corner of the base of the vehicle as well as one in the steering wheel, grab handle and vehicle door (Figure 3.5). The analog signal via the force transducers was amplified and conditioned before being converted to a digital signal. In Vicon Nexus, force transducers were imported as AMTI OR6 force plates. Calibration matrices, location and orientation of force transducers were defined in the software. Only data for the force transducers located at the wheel, handle and door were processed. Data will only be analyzed when a single segment (e.g. hand) is applying a load to the transducer. Forces were verified using a Chatillon manual force gage.\textsuperscript{76}
Figure 3.3: Vehicle Model without Platform. This represents a truck or other raised chasse vehicle. The floor of the vehicle measures 60cm from the ground. The base of the car measures 168cm width by 186cm depth. This truck model was used for transfers utilizing the Easy Reach and Glide ‘n’ Go mock-up.
Figure 3.4: Vehicle Model with Platform. This represents a vehicle mock-up with platform to represent a car. The vertical distance from the platform to the vehicle measures 25cm. The platform was designed with a ramp for easy wheelchair access with a slope of ~8 degrees. This model was utilized for the unassisted transfer and when using the transfer board.

EMG data was collected using a Delsys Bagnoli™ Desktop System utilizing 10 channels to collect bilateral data of 5 muscles (Table 3.2). Each electrode has 2 1mm by 1cm Silver (99.9% Ag) bar sensors spaced 1cm apart (Figure 3.6). Placement of each electrode is detailed in Table 3.2. After the area was cleaned with alcohol Delsys electrodes were placed perpendicular to muscle fibers with a reference sensor placed on the bony prominence at C7. Maximum voluntary contraction (MVC) data was collected as well as muscle activity during each trial.
Figure 3.5: Integrated Force Transducers. A. Steering wheel. B. Grab handle. C. Vehicle door support.

Figure 3.6: EMG Electrodes. Surface EMG sensor and reference sensor.
Table 3.2: EMG Electrode Location.\textsuperscript{79}

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Location of EMG electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Deltoid</td>
<td>in neutral position, measure 3 fingerbreadths below the bony prominence of the acromion, anteriorly</td>
</tr>
<tr>
<td>Latissimus Dorsi</td>
<td>in neutral position, measure 3 fingerbreadths below the posterior axillary fold</td>
</tr>
<tr>
<td>Pectoralis Major</td>
<td>in neutral position, anterior position just below the axillary fold</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>angle of neck and shoulder</td>
</tr>
<tr>
<td>Long Head Triceps</td>
<td>with arm abducted 90°, measure 4 fingerbreadths distal from the posterior axillary fold</td>
</tr>
</tbody>
</table>

Subjects were measured for their MVC using the equipment shown in Figure 3.7. After EMG electrodes were applied bilaterally to the anterior deltoids, latissimus dorsi, pectoralis major, upper trapezius and long head of triceps, participants were asked to perform weight lifting exercises in best attempt to isolate each of these muscles. A single exercise was chosen for each muscle group. An arm raise for the anterior deltoids, a lat pull-down for the latissimus dorsi, a pec fly for the pectoralis major, a shoulder shrug for the upper trapezius and a push-bar with tucked arms for the triceps. The data collected during each exercise provided a maximum voltage output or maximum muscle exertion for each muscle measured, which will be used in comparison to the EMG readings captured during the wheelchair transfer trials. EMG readings will be presented as a percentage of the MVC measurements.
Figure 3.7: MVC Equipment. Equipment used in measuring maximum muscle activity at each muscle group. This equipment has numerous fixture settings for appropriate positioning for each exercise to stimulate each of the 5 muscle groups. The volunteer shown is performing an exercise to measure the MVC of the pectoralis major.

After MVC data was collected, 63 reflective markers were placed on the subject for collection of kinematic data. Figure 3.8 shows full-body marker placement. The Vicon motion capture system was then calibrated and force transducers zeroed prior to data collection.

Before wheelchair transfer trials a static kinematic trial of ~3 seconds was captured. This data was then used to calibrate the subject to a marker template that was previously created. This template created in Vicon Nexus defines each marker, the relative location of all markers to one another and defines bodily segments, which are characterized by a minimum of 3 markers.
Subjects were asked to perform transfers from their wheelchair to and from a vehicle mock-up, which was versatile in that it could represent a truck (Figure 3.3: Vehicle Model without Platform) or a car with the addition of a platform (Figure 3.4: Vehicle Model with Platform). Five tasks were designated for data capture, but subjects were asked to only perform at their ability to prevent injury. In the event of a fall, a ceiling lift was in place that could traverse the entire lab. The transfer tasks included the use of 4 different commercially available devices, or mock-up of the device, as well as an unassisted independent transfer. These devices were chosen to explore user independence as well as offer a full range of transfer difficulty. Participants were also asked to stow and remove a standard wheelchair (Figure 3.9) once at each height. This
rigid frame Quickie GT\textsuperscript{81} has an aluminum frame, 40.6cm x 40.6cm (16in x 16in) seat, 61cm (24in) wheels and a weight of 91.2 N (20.5 lbs.). The seat back was set at a height of 28cm (11in), measured from the height of the uncompressed 5cm (2in) removable cushion. The wheelchair was stripped of armrests and anti-tip assembly. Data collection took approximately four hours per subject.

![Figure 3.9: Standardized Wheelchair. Used for trials requiring the stowage and removal of a wheelchair.](image)

Between tasks, subjects were asked to rate their level of pain and how safe they felt during the task (Table 4.6: Pain Questionnaire and Table 4.7: Transfer Device Questionnaire). A period of rest and recovery was also permitted between tasks. The order of task performance was randomized between and within car and truck model as shown in Table 3.4.
### Table 3.3: Task Randomization Table.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Task</th>
<th>Task</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Transfer Board</td>
<td>Unassisted</td>
<td>Glide 'n' Go</td>
</tr>
<tr>
<td>2</td>
<td>Ryno Lift</td>
<td>Easy Reach</td>
<td>Glide 'n' Go</td>
</tr>
<tr>
<td>3</td>
<td>Easy Reach</td>
<td>Glide 'n' Go</td>
<td>Ryno Lift</td>
</tr>
<tr>
<td>4</td>
<td>Unassisted</td>
<td>Transfer Board</td>
<td>Ryno Lift</td>
</tr>
<tr>
<td>5</td>
<td>Unassisted</td>
<td>Transfer Board</td>
<td>Glide 'n' Go</td>
</tr>
</tbody>
</table>

### 3.3 Wheelchair Transfers

Transfer studies among SCI subjects should consider factors including age, overall medical status, length of time since disability, wheelchair transfer strategies, muscular strength, physical strain of daily activities, body mass and composition, and UE injury history. This SCI subject transfer study utilized kinematic, kinetic and EMG data. Combined, these data sets allow for a complete look at the demands placed on the UE, particularly at the shoulder joint, during wheelchair transfers.

The following five transfer methods from wheelchair to vehicle are described in detail. They include Glide ‘n’ Go mock-up, Ryno Lift mock-up, Easy Reach, transfer board and an unassisted independent transfer, which used no device for assistance. Subjects performed transfers from their personal wheelchair.

Prior to data collection subjects were given a thorough explanation of the transfer tasks including the use of each device. Subjects were also shown a video of a researcher performing each task. This was done as a safety precaution and not with cause to influence the subject. All transfers were performed at the subjects own pace.
3.3.1 Glide ‘n’ Go Mock-up

The Glide ‘n’ Go (Figure 3.10 – 3.12) was designed for persons who are semi-ambulatory to able-bodied. It may also be acceptable for use by high functioning paraplegics. A mock-up model was used for testing, as the actual device was not acquired. The seat measured 41cm with a 39cm depth. The commercial device is designed to fold away into the vehicle for easy storage. This device required the subject to perform 4 separate transfers: wheelchair to Glide ‘n’ Go, Glide ‘n’ Go to vehicle seat, vehicle seat to Glide ‘n’ Go, and Glide ‘n’ Go back to wheelchair. Transfers between the Glide ‘n’ Go and vehicle seat were level transfers, while the transfer from the wheelchair to the Glide ‘n’ Go mock-up was a raised transfer. On the return, the wheelchair was lower than the Glide ‘n’ Go seat. The manufactured device would ideally allow each transfer to be level.

![Image A and B]

**Figure 3.10: Glide ‘n’ Go Mock-up.** The Glide ‘n’ Go mock-up was designed with a ceiling lift for subject controlled vertical height. Image A. shows device in lowest position and B. shows the higher transfer position.
Figure 3.11: Glide ‘n’ Go Transfer In. Subject transferring from wheelchair to Glide ‘n’ Go. A. Captured video from the trial. B. Screen capture from Vicon Nexus.

Figure 3.12: Glide ‘n’ Go Transfer Out. Snapshot of subject transferring from Glide ‘n’ Go to vehicle seat. A. Captured video from the trial. B. Screen capture from Vicon Nexus.

3.3.2 Ryno Lift Mock-up

The Ryno Lift\textsuperscript{83} (Figure 3.13 – 3.14) is a commercially available device designed as an under-chassis lift that can be used with a van, truck or sports utility vehicle. A hydraulic scissor lift table\textsuperscript{84} with a capacity of 4,448N (1,000lbs) was used to model the original device. Once the subject was on the lift they locked their wheels and were then lifted by researchers to the height of the vehicle floor. Data collection started once the subject was in the passenger area of the vehicle. As the subject transferred to the
vehicle seat from their wheelchair they performed a downward transfer and a raised transfer as they transferred back to their wheelchair. Ideally, when installed in a patient’s vehicle a level transfer could be performed.

Figure 3.13: Ryno Lift Mock-up. Image of device in the raised position, level with the base of the vehicle.

Figure 3.14: Ryno Lift Transfer In. Snapshot of subject transferring from their wheelchair to vehicle seat. A. Captured video from the trial. B. Screen capture from Vicon Nexus.
3.3.3 Easy Reach

The Easy Reach\(^2\) (Figure 3.15 – 3.16) was designed for those with disability range between quadriplegic and semi-ambulatory. This device allows the vehicle manufacturer’s seat to be modified to swivel out of the vehicle without compromising the safety of the seat itself. This device has a user-operated switch, which adjusts the seat to the desired vertical height; therefore a level transfer can always be performed.

![Easy Reach](image)

**Figure 3.15: Easy Reach.** Image of Easy Reach in the lowered position.

![Easy Reach Transfer Out](image)

**Figure 3.16: Easy Reach Transfer Out.** Snapshot of subject transferring from Easy Reach to their wheelchair. A. Captured video from the trial. B. Screen capture from Vicon Nexus.
3.3.4 Transfer Board

The transfer board (Figure 3.17 – 3.18) is a device commonly introduced during rehabilitation to aid in transferring. It is used for a wide range of transfers and allows a person with SCI to use the device as a bridge to maneuver from one seat to another. The transfer board is also very portable for easy use in any environment. The transfer board used for the study measured 71cm by 21cm.

Figure 3.17: Transfer Board. Image of transfer board between wheelchair and vehicle seat.
3.3.5 Unassisted

An unassisted transfer was also performed (Figure 3.19). This transfer did not permit the use of any assistive devices. The transfers were performed with the platform in place and therefore allowed the transfers into and out of the vehicle to each be level transfers.

Figure 3.18: Transfer Board Transfer In. Snapshot of subject transferring from wheelchair to vehicle with use of transfer board. A. Captured video from the trial. B. Screen capture from Vicon Nexus.

Figure 3.19: Unassisted Transfer In. Snapshot of subject transferring from their wheelchair to the vehicle seat with no assistive device. A. Captured video from the trial. B. Screen capture from Vicon Nexus.
3.4 Data Analysis

After data processing, which included manually labeling markers, and replacing missing and occluded markers via BodyBuilder\textsuperscript{74} using a custom BodyLanguage\textsuperscript{74} code, data was also analyzed using BodyBuilder. Analysis outputs provided include anthropometry of all body segments, joint centers of the shoulder, elbows and wrists, as well as tri-axial kinematics and kinetics of the joints. After data was run through BodyBuilder, a custom MATLAB\textsuperscript{85} code was utilized for data reduction. Microsoft Excel was used for further data reduction and graphic analysis.

3.4.1 Kinetics

After kinetic data was exported from BodyBuilder, MATLAB was utilized for data reduction. A custom code was utilized to calculate fast Fourier transforms (FFTs) to determine the frequency range of the data (Figure 3.20). Based on the FFT plot this data was then filtered using a recursive 4\textsuperscript{th} order Butterworth low-pass filter with a cutoff frequency of 5Hz. The root mean square (RMS) max and mean values of each joint’s X, Y and Z components were calculated. Resultant max and mean forces and moments were then saved as comma separated variable (CSV) files to be further manipulated in Excel. Kinetic data was grouped by task and transducer location and then averaged across subjects.
Figure 3.20: FFT of Force Data. Shows frequency range of force data to determine which filter and filter parameters to apply.

After the filter was applied to the kinetic data a plot (Figure 3.21) of the effect of the filter was generated to validate the use the filter parameters.

Figure 3.21: Force Filter Effect. After kinetic data was filtered, the original and filtered data were graphed to assure proper filtering.

External forces at the joints of the UE were calculated using inverse dynamics, specifically at the wrists, elbows and shoulders. Scalars and vectors to consider include
the mass and weight of body segments, center of mass (COM), anthropometry of body segments and external forces and moments generated by the hands. A free body diagram shows a general description of the forces acting on the UE (Figure 3.22).

![Free Body Diagram](image)

**Figure 3.22: Free Body Diagram.**

### 3.4.2 Kinematics

After kinematic data was exported from BodyBuilder, MATLAB was utilized for data reduction. A custom code was utilized to calculate FFTs. This data was then filtered using a recursive 4\(^{th}\) order Butterworth low-pass filter with a cutoff frequency of 5Hz. Mean values were then saved into their positive and negative X, Y and Z components to CSV files. Figure 3.23 and Table 3.4 show the tri-axial definitions used for the UEs.
## Table 3.4: Definition of Upper Extremity Joint Rotation References.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Axis of Rotation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>X</td>
<td>Adduction/Abduction&lt;br&gt;Movement of the arm at the shoulder, towards or away from the body, respectively, with respect to the sagittal plane</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>Protraction/Retraction&lt;br&gt;Movement of the arm, at the shoulder, anterior or posterior, respectively, with respect to the coronal plane</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>Internal/External Rotation&lt;br&gt;Movement of the arm, at the shoulder, rotated medial or laterally, respectively, to the midline</td>
</tr>
<tr>
<td>Elbow</td>
<td>Y</td>
<td>Flexion/Extension&lt;br&gt;Flexion is a bending at the joint that decreases the angle between two bodies. Extension increases this angle</td>
</tr>
<tr>
<td>Wrist</td>
<td>Y</td>
<td>Flexion/Extension&lt;br&gt;Flexion is a bending at the joint that decreases the space between the palm and the forearm. Extension increases this angle</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>Pronation/Supination&lt;br&gt;Movement of the palm from anterior to posterior and reverse, respectively</td>
</tr>
</tbody>
</table>
Figure 3.23: Upper Extremity Joint Definitions. Defines X, Y and Z of each joint of the upper extremities.

Figure 3.24 shows an issue that arose with the kinematic data. While graphically it appeared that there was a distinct change in the angle about the X-axis (abduction/adduction) the motion capture data (left) shows essentially no change in the movement of the left arm. At this time the problem, which is thought to be software related, has yet to be resolved. Consequently, this will be the extent of the kinematic data presented.
Figure 3.24: Kinematic Error. The left shows an angular shift of approximately 180 degrees, while the right shows no visible changes to the left shoulder joint.

3.4.3 EMG

EMG data was first exported directly from Vicon Nexus. A custom MATLAB code was utilized to calculate FFTs to determine the frequency range of the data (Figure 3.25). EMG data was sampled at 960Hz. This data was then filtered using a recursive 4th order Butterworth band-pass filter with cutoff frequencies of 50 and 479Hz. Next a
moving average, with an epoch of 40 milliseconds, was applied with full wave rectified data to create a linear envelope. Epoch was determined based on the speed of bodily motion within the trial. A longer epoch is used for a slower trial. The max value of each muscle group per trial was then saved to a CSV file. Microsoft Excel was then used for further data reduction.

Figure 3.25: FFT of EMG Data. Shows frequency range of EMG data to determine which filter and filter parameters to apply.

The artifact at ~60Hz can be attributed to power line noise being picked up by the EMG equipment. Filter effect plots were also generated. Figure 3.26 shows an EMG signal from the MVC trials in which the subject was trying to exert his maximum muscle exertion. Approximately 3 seconds of effort is seen before the subject relaxed as asked via the data collection protocol. The following, Figure 3.27, shows the filter effect for EMG captured during a wheelchair transfer trial.
Figure 3.26: MVC Calibration Filter Effect. After MVC data was filtered, the original and filtered data were graphed to assure proper filtering.

Figure 3.27: Wheelchair Transfer EMG Filter Effect. After EMG data was filtered, the original and filtered data were graphed to assure proper filtering.

3.5 Data Reduction and Statistical Analysis

A transfer is defined as the movement from the initial seat to the target seat (e.g. wheelchair to vehicle seat). Wheelchair transfer trials contained data prior to and post transfer; this was defined as a “full transfer trial”. Full transfer trials were further cropped
to define specific “events” that occurred during the transfer motion. This method was a product of the poor kinematic data and lessened the number of frames in which markers needed to be manually labeled. An “event” is a sequence during a transfer in which the left or right hand contacted a force transducer (steering wheel, grab handle or vehicle door) and generated a measurable force. The beginning and end of an “event” was based on visual inspection from motion capture data, a digital video camera and graphical force data.

Force data was normalized by the subject’s body weight and moments were normalized by the subject’s body weight and stature. Kinetic data reports results based solely on “event” trials. These trials were then grouped by task or transducer location (vehicle door, grab handle and steering wheel). Forces and moments for each UE joint location were averaged across the 5 subjects. Standard deviations for these values come from the variability across subjects.

Electromyographic % MVC data was grouped by subject, task, leading versus trailing arm, and vehicle height and further separated by trial type: wheelchair transfer or wheelchair stowage. With the transfer trials defined as full transfer trials and “event” trials. EMG data is all represented as % MVC (EMG/MVC*100). Data was average across subjects and muscle groups. % MVC data is presented as box plots with outliers defined as 1.5*IQR.

Statistical differences were determined though analysis of variance (ANOVA) at a 95% confidence interval. In some cases a 2-sided t-test with the assumption of unequal means was used to determine statistical significance. All statistically significant values are p≤0.05.
3.6 Equipment Uncertainty

3.6.1 Force Transducers

Table 3.5: MC3A Series AMTI Force/Torque Sensors Specifications.\textsuperscript{75}

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>Door/Handle</th>
<th>Wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>V/V</td>
<td>4000</td>
<td>1000</td>
</tr>
<tr>
<td>Capacity</td>
<td>N (lb)</td>
<td>2200 (500)</td>
<td>4400 (1000)</td>
</tr>
<tr>
<td>Fx, Fy Sensitivity</td>
<td>mV/(V*N)</td>
<td>0.67 (3.0)</td>
<td>1.35 (6.0)</td>
</tr>
<tr>
<td>Fz Sensitivity</td>
<td>mV/(V*lb)</td>
<td>0.17 (0.75)</td>
<td>0.34 (1.5)</td>
</tr>
<tr>
<td>Mx, My Sensitivity</td>
<td>mV/(V*Nm)</td>
<td>35.4 (4)</td>
<td>70.8 (8)</td>
</tr>
<tr>
<td>Mz Sensitivity</td>
<td>mV/(V*Nm)</td>
<td>26.5 (3.0)</td>
<td>53.1 (6.0)</td>
</tr>
</tbody>
</table>

3.6.2 Signal Amplifiers

Each AMTI amplifier has 6 channels each with an anti-aliasing low-pass filter with a 1000 Hz cutoff frequency.

Table 3.6: MSA-6 MiniAmp AMTI Amplifier Specifications.\textsuperscript{80}

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>1000, 4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>V/V</td>
<td></td>
</tr>
<tr>
<td>Excitation Voltage</td>
<td>V</td>
<td>2.5, 5, 10</td>
</tr>
<tr>
<td>Output Signal</td>
<td>V</td>
<td>10</td>
</tr>
</tbody>
</table>

3.6.3 EMG System

Table 3.7: Delsys System Specifications.\textsuperscript{77,78}

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface EMG Sensors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preamplifier Gain</td>
<td>V/V</td>
<td>10 ±1%</td>
</tr>
<tr>
<td>Noise</td>
<td>µV</td>
<td>1.2</td>
</tr>
<tr>
<td>Bagnoli Desktop EMG System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall EMG Amplification</td>
<td></td>
<td>1000 ±1%</td>
</tr>
<tr>
<td>EMG Bandwidth</td>
<td>Hz</td>
<td>20-450 ±10%</td>
</tr>
<tr>
<td>Noise</td>
<td>µV</td>
<td>≤1.2</td>
</tr>
</tbody>
</table>
Chapter 4 – Results

4.1 Kinetics

Two selections of data are presented to show dynamic force results from the wheelchair transfers. One from the right UE, during a transfer using the transfer board where the subject utilized the steering wheel to assist with their transfer (Figure 4.1) and the other from the left UE also during a transfer using the transfer board where the subject utilized the grab handle of the vehicle to assist with his transfer (Figure 4.2).

Figure 4.1: Forces of the Right Upper Extremity. Plot of force applied by the right hand to the steering wheel during a transfer trial, which utilized the transfer board.
Figure 4.2: Forces of the Left Upper Extremity. Plot of force applied by the left hand to the grab handle during a transfer trial, which utilized the transfer board.

Subjects were asked to perform up to 10 transfers in approximately 4 hours.

Table 4.1 shows a catalog of transfer trials and events that occurred during each trial. An “event” is a sequence during a transfer in which the left or right hand contacted a force transducer and generated a measurable force. The transfer is the time from when the subject left the initial seat and then moved to the target seat. The beginning and end of an event was based on visual inspection from motion capture data, a digital video camera and graphical force data.

Table 4.1: Wheelchair Transfer Trial Catalog.

<table>
<thead>
<tr>
<th>Trials</th>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer</td>
<td>Board</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>✓</td>
<td>1b</td>
<td>✓</td>
<td>2b</td>
<td>2b</td>
<td>✓</td>
<td>1b</td>
</tr>
<tr>
<td>B</td>
<td>✓</td>
<td>1a</td>
<td>n/a</td>
<td>✓</td>
<td>1a</td>
<td>✓</td>
<td>2a</td>
</tr>
<tr>
<td>Unassisted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>✓</td>
<td>n/a</td>
<td>✓</td>
<td>2b</td>
<td>✓</td>
<td>2a</td>
<td>✓</td>
</tr>
<tr>
<td>B</td>
<td>✓</td>
<td>2a</td>
<td>✓</td>
<td>2a</td>
<td>n/a</td>
<td>✓</td>
<td>2a</td>
</tr>
<tr>
<td>Table 4.1 (continued)</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Glide 'n' Go</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A ✓ ✓ ✓ ✓ 1b 3b n/a n/a ✓ ✓ ✓ ✓ 2a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B ✓ ✓ ✓ ✓ 1a 3b n/a n/a ✓ ✓ 2a ✓ ✓ 2a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ryno Lift</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A ✓ ✓ ✓ ✓ 1b ✓ ✓ 1a n/a ✓ ✓ 1a 2b ✓ ✓ 1b</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>B ✓ ✓ ✓ ✓ 1b n/a n/a ✓ ✓ 1b ✓ ✓ 1b</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Easy Reach</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A x ✓ n/a x x x x</td>
<td></td>
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<tr>
<td>B x x n/a x x x x</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.1: Legend:**

- A: Transfer into vehicle from wheelchair; B: Transfer from vehicle back to wheelchair.
- A check mark (✓) denotes a "good" trial. Data could be processed and events could be defined.
- An X (x) denotes that a trial was captured, but there were no events or the data could not be processed and therefore no events were defined.
- n/a denotes that no trial exists.
- 1: Event occurring on the steering wheel of the vehicle; 2: Event occurring on the grab handle of the vehicle; 3: Event occurring on the door of the vehicle.
  - a: Right hand; b: Left hand.

Force and moment data presented does not capture the Easy Reach as per Table 4.1. Subjects were not in the vicinity of the steering wheel, grab handle or vehicle door during the transfer and therefore no kinetic data was captured for these trials. Data for other device assisted transfers (transfer board, Glide 'n' Go, and Ryno Lift) as well as the unassisted transfer are presented.

Force has been normalized by body weight of each subject (Figures 4.3 and 4.4).\(^{87-89}\) The highest forces, across all joints, were seen during the unassisted wheelchair transfers followed by transfers using the Ryno Lift mock-up at the left arm (Figure 4.3). The Glide 'n' Go mock-up had the lowest forces when averaged across all joints. Two statistically significant groups were found for the joints of the left UE. The Glide 'n' Go and transfer board transfers were different from the unassisted and Ryno
Lift transfers. The joints of the right UE showed significant differences between only the unassisted and Ryno Lift transfers.

Mean data shows a similar trend to max data in that the unassisted wheelchair transfers generated the greatest forces across all joints while the Glide ‘n’ Go maintained the lowest average forces (Figure 4.4). Statistical significance was found only at the left UE. The Glide ‘n’ Go and transfer board transfers were found to be different from the unassisted and Ryno Lift transfers.

Figure 4.3: Max Forces per Transfer Task, Normalized.
Figure 4.4: Mean Forces per Transfer Task, Normalized.

Glide ‘n’ Go transfers were typically performed with the right arm generating force, except for on one occasion. Subject 1 was the only subject who generated any force with the left hand during a transfer. Therefore, forces of the left arm during the Glide ‘n’ Go task appear to have no variability, but actually the value is from a single trial and cannot be statistically tested.

Table 4.2 (mean (st. dev)) shows summarized absolute and normalized data averaged across all joints per each task. Further complimentary data that has not been normalized to body weight can be found in Appendix F.

Table 4.2: Mean Forces Across UE Joints per Task.

<table>
<thead>
<tr>
<th></th>
<th>Transfer Board</th>
<th>Unassisted</th>
<th>Glide ‘n’ Go</th>
<th>Ryno Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Force (N)</td>
<td>299 (6)</td>
<td>478 (15)</td>
<td>262 (92)</td>
<td>317 (128)</td>
</tr>
<tr>
<td>Max Force Normalized (N/N*100)</td>
<td>35.8 (2.4)</td>
<td>58.8 (4.7)</td>
<td>36.9 (9.1)</td>
<td>39.0 (21.0)</td>
</tr>
<tr>
<td>Mean Force (N)</td>
<td>118 (13)</td>
<td>202 (8)</td>
<td>100 (46)</td>
<td>135 (31)</td>
</tr>
<tr>
<td>Mean Force Normalized (N/N*100)</td>
<td>14.1 (1.9)</td>
<td>25.6 (0.7)</td>
<td>13.9 (5.1)</td>
<td>16.2 (6.2)</td>
</tr>
</tbody>
</table>
Figure 4.5 presents the max moments and Figure 4.6 mean moments that occurred at each joint per transfer task. Moments were normalized by body weight and stature to eliminate any bias based on these measures. Moment arms were calculated from the center of pressure (COP) where the hand applied force to the transducer.

There is a high degree of subject variability within this data especially at the shoulders and in the case of the max right wrist during the unassisted transfer. The high subject variability at the right wrist is due to subject 4 who generated a force at the grab handle that was ~10 times that of the other subjects (Figures 4.5 and 4.7). The highest moment was generated at the left shoulder during use of the Ryno Lift.

Statistically significant groups were found at the left and right elbows in Figure 4.5. At the left elbow the Ryno Lift and unassisted transfers were found to be different from the Glide ‘n’ Go and transfer board transfers. At the right elbow it was found that the Ryno Lift was different from the unassisted and Glide ‘n’ Go transfers.

In Figure 4.6 statistically significant groups were found at the left elbow and left wrist, with no differences found at the right UE. At the left elbow and left wrist the Ryno Lift and unassisted transfers were found to be different from the Glide ‘n’ Go and transfer board transfers. At the left wrist the same two groups were found.
Table 4.3 (mean (st. dev)) summarizes the moments of the absolute and normalized data averaged across all joints per each task. Further complimentary data that has not been normalized to body weight and stature can be found in Appendix F.
Across all joints the Ryno Lift transfer generated the highest moments while the Glide ‘n’ Go generated the lowest. The unassisted transfer, however, generated moments nearly as high as the Ryno Lift mock-up.

Table 4.3: Mean Moments Across UE Joints per Task.

<table>
<thead>
<tr>
<th></th>
<th>Transfer Board</th>
<th>Unassisted</th>
<th>Glide ‘n’ Go</th>
<th>Ryno Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Moment (Nmm)</td>
<td>64366 (35429)</td>
<td>76607 (41563)</td>
<td>46885 (32874)</td>
<td>76712 (69971)</td>
</tr>
<tr>
<td>Max Moment Normalized</td>
<td>4.6 (2.5)</td>
<td>5.4 (2.8)</td>
<td>3.9 (2.6)</td>
<td>5.5 (5.5)</td>
</tr>
<tr>
<td>Mean Moment (Nmm)</td>
<td>21871 (12995)</td>
<td>27809 (18852)</td>
<td>16736 (13320)</td>
<td>31431 (23855)</td>
</tr>
<tr>
<td>Mean Moment Normalized</td>
<td>1.5 (0.9)</td>
<td>2.0 (1.4)</td>
<td>1.4 (1.0)</td>
<td>2.1 (1.8)</td>
</tr>
</tbody>
</table>

Figures 4.7 and 4.8 show moments that occurred by transducer location without task consideration. When moments were averaged across all joints of the UE it was found that the highest moments occurred at the steering wheel, with the grab handle at a close second. Force was only applied to the door by the left hand, therefore moments are only presented for the left arm at the vehicle door.

Statistically significant differences were found at the left shoulder, right shoulder and right elbow (Figure 4.7). At the left shoulder the steering wheel was found to be different from the vehicle door and the grab handle. At the right shoulder and right elbow the steering wheel and grab handle were significantly different from each other.

In Figure 4.8 statistically significant differences were found at the left shoulder, right elbow and right wrist. At the left shoulder the steering wheel was different from the vehicle door and the grab handle. At both the right elbow and right wrist the steering wheel and grab handle were found to be significantly different.
The greatest variability was found at the steering wheel. The highest moment across all joints was found at the left shoulder while force was being applied to the steering wheel. When moment measures were averaged across all joints it was also found that the steering wheel had the highest max average while the grab handle had
the highest mean average (Table 4.4). The greatest variability continues to be seen at the shoulders and the right wrist.

Table 4.4: Mean Moments Across UE Joints per Transducer Location.

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Door</th>
<th>Grab Handle</th>
<th>Steering Wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Moment (Nmm)</td>
<td>20304</td>
<td>72316</td>
<td>76167</td>
</tr>
<tr>
<td></td>
<td>(18139)</td>
<td>(43908)</td>
<td>(58511)</td>
</tr>
<tr>
<td>Max Moment Normalized (Nmm/Nmm*100)</td>
<td>1.9</td>
<td>4.8</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>(1.7)</td>
<td>(2.8)</td>
<td>(4.4)</td>
</tr>
<tr>
<td>Mean Moment (Nmm)</td>
<td>5649.9</td>
<td>26282</td>
<td>25569</td>
</tr>
<tr>
<td></td>
<td>(3812)</td>
<td>(18108)</td>
<td>(20357)</td>
</tr>
<tr>
<td>Mean Moment Normalized (Nmm/Nmm*100)</td>
<td>0.5</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(1.2)</td>
<td>(1.5)</td>
</tr>
</tbody>
</table>

4.2 Wheelchair Stowage

![Number of Hand Positions per Subject](image)

Figure 4.9: Number of Hand Positions per Subject.

By visual inspection from motion capture data and digital video each subject was viewed to see how many hand grabs were performed (Figure 4.9). The stowage trials were selected since this task had the most variation in experience. It is clear that subject 4 had the highest number of hand grabs and also the longest trials of all subjects.
4.5 shows a summary of the data in Figure 4.9. Subject 4 was found to be significantly different from subject 1 and subject 5.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean</th>
<th>St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>6</td>
<td>±2</td>
</tr>
<tr>
<td>Subject 2</td>
<td>6</td>
<td>±2</td>
</tr>
<tr>
<td>Subject 3</td>
<td>7</td>
<td>±1</td>
</tr>
<tr>
<td>Subject 4</td>
<td>12</td>
<td>±3</td>
</tr>
<tr>
<td>Subject 5</td>
<td>5</td>
<td>±2</td>
</tr>
</tbody>
</table>

4.3 EMG

EMG data is presented as a percentage of MVC. In theory, this parameter should be between 0 and 100%. EMG during transfer trials was typically greater than that recorded during the MVC trials, therefore % MVC values reported exceed 100%. Theoretically, a subject will exert the maximum force possible during the MVC trials and any data captured during the transfers will be of a lesser value. Percent MVC data for this study was not ideal however and therefore EMG data will still be presented as % MVC, but is not necessarily capped at 100%.

EMG data for subject 1 will not be presented due to improper data collection.

4.3.1 Wheelchair Transfers

“Event” trials as stated earlier are those trials in which the left or right hand contacted a force transducer and generated a measurable force during a transfer. The beginning and end of an event was based on visual inspection from motion capture data, a digital video camera and graphical force data.

All subjects were right hand dominant. All transfers to the vehicle seat from the wheelchair moved the subject from left to right; except for the Ryno Lift transfers. Subjects then moved from right to left on their way back to the wheelchair.
Each subject appeared to have difficulties with the transfer tasks. In a comparison of % MVC of subjects 2 through 5, subject 5 had the highest mean % MVC across all muscle groups (Figure 4.10). Subject 4 had the greatest variability across all muscle groups. Subject 3 was found to be significantly different than subjects 2, 4 and 5.

![Figure 4.10: % MVC “Event” Trials per Subject.]

% MVC averaged across all muscle groups compared muscle exertion per task (Figure 4.11). The average % MVC generated during the unassisted transfers was the highest amongst all the transfer tasks, showing that it required the most muscle exertion across all subjects, with the greatest variability across muscle groups and subjects. The average for the unassisted transfers is in fact double that of the transfer board, which required the next highest muscle exertion. The unassisted transfer was found to be statistically significantly different from the transfer board, Glide ‘n’ Go and Ryno Lift transfers.
Figure 4.11: % MVC “Event” Trials per Task.

Figure 4.12 shows the average % MVC across all muscle groups is higher for the trailing arm versus the leading arm. There was no statistical difference found between the leading and trailing arms.

Figure 4.12: % MVC Full Transfer Trials – Leading vs. Trailing Arm.
Figure 4.13 shows a comparison of each of the transfer tasks during a full transfer trial. These trials include data before, during and after the transfer from initial to target seat took place. The mean % MVC for the transfer board was found to be the highest with the unassisted transfer following. The Glide ‘n’ Go had the most variability between muscle groups, but had the lowest average % MVC overall. Two different statistically significant groups were found between the full transfers tasks. The transfer board and unassisted transfers were found to be significantly different from the Easy Reach and Ryno Lift transfers. The Glide ‘n’ Go transfer was found to not be significantly different from the other transfers.

![Figure 4.13: % MVC Full Transfer Trials per Task.](image)

4.3.2 Wheelchair Stowage

During this time subjects were also asked to stow a wheelchair into the vehicle and vice versa, and if possible, once at the car height and once at the truck height.

All subjects performed stowage and removal of the wheelchair at both heights, except for subject 2 who was unable to perform this task at the truck height. Events were
not defined for the stowage and removal trials because it was found that the more
significant forces and moments occurred during the transfer trials. However, EMG data
for these trials was analyzed.

Figure 4.14 captures the difference in EMG activity between the car height and
the truck height. The average % MVC of the raised height is ~1.8 times higher than that
of the car height. In a 2-sided t-test the mean muscle exertion at the car height and truck
height were found to be significantly different.

![% MVC WC Stowage per Height](image)

**Figure 4.14: % MVC Wheelchair Stowage per Height.**

### 4.4 Pain and Questionnaires

Tables 4.6 and 4.7 are results from questionnaires administered before and
during data collection. Questionnaire forms can be found in Appendices C through E.

Table 4.6 specifically shows pain from the past week as well as a summary of the
pain experience during each transfer. The Glide ‘n’ Go received scores slightly higher
than the other tasks. It was also seen that pain experienced during performance of these
tasks did not exceed the usual level of pain the subjects were experiencing the week
before data collection.
Table 4.7 breaks down the subject’s impression of the device used to perform the transfer. From this table it is seen that subjects were most comfortable with the Ryno Lift and transfer board. Overall the Ryno Lift received the highest scores based on comfort, ease of use, efficiency and safety, while the Easy Reach received the lowest score overall. From most favorable to least across all factors, assistive devices were rated: Ryno Lift, transfer board, Glide ‘n’ Go, Easy Reach. The “overall comfort” of the Ryno Lift was found to be significantly different from the Easy Reach and Glide ‘n’ Go. It was also found that perceived safety of the transfer board was found to be significantly different from the Easy Reach and Glide ‘n’ Go, while the Glide ‘n’ Go was found to be significantly different from the Ryno Lift and the Ryno Lift was found to be significantly different from the Easy Reach.

**Table 4.6: Pain Questionnaire.**

<table>
<thead>
<tr>
<th>Scale: 0 – 10 Where 10 is the “worst pain ever” and 0 is “no pain”</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate you usual level or pain during the past week.</td>
<td>3.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Rate your pain at its best during the past week.</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Rate your pain at its worst during the past week.</td>
<td>5.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Rate the current level of pain you are now experiencing based on the current transfer method:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unassisted</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Transfer Board</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Glide ‘n’ Go</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Ryno Lift</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Easy Reach</td>
<td>1.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Table 4.7: Transfer Device Questionnaire.**

<table>
<thead>
<tr>
<th>Scale: 0 – 5 Where 5 is “very good” and 0 is “very poor”</th>
<th>Transfer Board</th>
<th>Glide ‘n’ Go</th>
<th>Ryno Lift</th>
<th>Easy Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>How would you rate your overall comfort during the use of this product?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4.2</td>
<td>2.7</td>
<td>4.8</td>
<td>2.8</td>
</tr>
<tr>
<td>St Dev</td>
<td>1.3</td>
<td>0.6</td>
<td>0.5</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Table 4.7 (continued)

<table>
<thead>
<tr>
<th>What is your impression of this product’s overall ease of use?</th>
<th>Mean</th>
<th>St Dev</th>
<th>Mean</th>
<th>St Dev</th>
<th>Mean</th>
<th>St Dev</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.0</td>
<td>1.2</td>
<td>3.0</td>
<td>1.0</td>
<td>4.3</td>
<td>1.0</td>
<td>2.7</td>
<td>1.2</td>
</tr>
<tr>
<td>How efficient do you feel this product will be in use of your time?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>1.3</td>
<td>3.3</td>
<td>1.2</td>
<td>4.3</td>
<td>1.0</td>
<td>3.0</td>
<td>1.6</td>
</tr>
<tr>
<td>How safe do you feel during use of this product?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>0.6</td>
<td>3.0</td>
<td>1.0</td>
<td>4.8</td>
<td>0.5</td>
<td>2.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Total</td>
<td>17.0</td>
<td>11.0</td>
<td>18.2</td>
<td>9.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 5 – Discussion

This study hypothesized that the use of an assistive device would eliminate some of the stresses posed on the UEs during wheelchair to vehicle transfers. It was also expected that these transfer events will generate high moments at the shoulders, which could be injurious over time.

The Easy Reach was found to be the least favored of all the devices (Table 4.7: Transfer Device Questionnaire). This can be attributed to a number of factors:

1. Subject’s inexperience with the device,
2. Height at which the subject was raised during the transfer into the vehicle (although this height was not unlike that required for the Glide ‘n’ Go transfer),
3. Appearance of instability of the device while being lowered,
4. Lack of rigidity of the vehicle seat when it was in the lowered (transfer) position,
5. Location of the transfer did not provide access to extra supports such as the steering wheel and grab handle.

The Ryno Lift was ranked highest in all categories (comfort, ease of use, efficiency and safety). This may be attributed to the ease at which the subjects entered the vehicle, although this particular device played no actual role in the transfer itself as the device aided in placing subjects in the passenger area before performing the transfer to the vehicle seat.

The transfer board was ranked second after the Ryno Lift, which is likely attributed to increased experience with this device as it is frequently introduced during rehabilitation after a spinal cord injury.
Transfers that utilized the transfer board and Easy Reach as well as the unassisted transfer were level transfers. The Glide 'n' Go mock-up and the Ryno Lift mock-up did not allow for level transfers. Previous research has determined that a level transfer is ideal.\textsuperscript{54} The height difference of these transfers was found to be significantly different (Figure 4.14).

Differences between all joints of the right and left UEs are more varied in these non-level transfers. Table 5.1 shows the forces averaged across the joints of each UE for each transfer task. All subjects were right hand dominant, but that does not appear to correlate with the subject’s ability to comfortably transfer and even apply more body weight with the left hand. Researchers have found that preference of transfer side, whether it is in the dominant or non-dominant hand direction, does not have a significant effect on the ability or effort required to transfer in either direction.\textsuperscript{72}

From Table 5.1 it is seen that the Ryno Lift transfers had the greatest variance between the right and left arms with the Glide ‘n’ Go following. The forces generated by the left and right hands were found to be significantly different for the Glide ‘n’ Go and Ryno Lift transfers when a 2-sided t-test was conducted with the assumption of unequal means.

<table>
<thead>
<tr>
<th>Transfer Type</th>
<th>Left UE</th>
<th>Right UE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Board</td>
<td>295</td>
<td>304</td>
<td>9</td>
</tr>
<tr>
<td>Unassisted</td>
<td>488</td>
<td>468</td>
<td>20</td>
</tr>
<tr>
<td>Glide ‘n’ Go</td>
<td>178</td>
<td>345</td>
<td>167</td>
</tr>
<tr>
<td>Ryno Lift</td>
<td>434</td>
<td>201</td>
<td>233</td>
</tr>
</tbody>
</table>

Transfers involving the Ryno Lift were typically led with the left UE. Figure 5.1 is a breakdown of all the Ryno Lift transfer “event” trials. This normalized data shows that subjects typically used the steering wheel to support their body weight during a transfer, but in one instance a subject utilized the grab handle. The forces generated at the grab
handle exceeded those seen at the steering wheel. There are two distinct groups (p≤0.0001), showing the differences between the loads applied by the left hand versus those applied by the right hand. Upon reviewing these trials again it was found that in the events in which the right hand generated force during a transfer, more of the subjects body weight was applied to another un-instrumented surface.

![Ryno Lift Transfers (Max Force Normalized)](image)

**Figure 5.1: Ryno Lift Transfers.** Trials are defined by: subject, transfer into or out of vehicle and transducer to which force was applied.

During testing it was found that a number of surfaces were used to assist in transferring, but were not instrumented and therefore not captured in this study. These surfaces included wheelchair armrests, wheelchair wheels, wheelchair seat, vehicle seat and the vehicle seat armrest.

As part of the inclusion criteria subjects were required to regularly perform transfers, yet they were not all previously subjected to each of the assistive devices used during the study. Some subjects had notably more difficulty during the transfer trials than others, which appeared to also correlate with their BMI (Figure 5.2). Subject 2 who had the highest BMI of all subjects also had the most difficulty during all phases of the study. He was also the only subject who did not perform some sort of regular exercise or
participate in recreational activities. Researchers have found that regular activity affects transfer ability.\textsuperscript{33,47}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{BMI_vs_Number_of_Transfers_Completed.png}
\caption{BMI vs. Number of Transfers Completed.}
\end{figure}

While traumatic brain injury (TBI) is outside the scope of this study, subject 4 reported suffering from a severe TBI at the time of his spinal cord injury. This was found to affect his cognitive function in the sense that it took him more time to process and complete all tasks. Yet it did not appear to interfere with his actual transfer ability. Figure 4.9 and Table 4.5 (Number of Hand Positions per Subject) provide quantitative results for these observations.

Figures 4.3 (Max Forces per Transfer Task), 4.4 (Mean Forces per Transfer Task) and 4.11 (% MVC “Event” Trials per Task), show that using a device, even one that is unfamiliar, can be beneficial in alleviating some of the stresses that are typically encountered at the UEs. In all cases, results for forces and EMG proved to be highest for the unassisted transfers. Based on observation alone it was typically seen that transfers requiring the use of an assistive device were less strenuous, even if the subject
had not previously used that device. In relation to difficulty of each task, it appeared to make no difference that the Ryno Lift and Glide ‘n’ Go were mock-ups.

Some difficulty was observed during the trials requiring the use of the Ryno Lift. Challenges during these transfers were dictated more by the height differences between the initial and target seats as well as the distance from one seat to another and less due to the device itself. In some instances the Ryno Lift may be used to assist with getting into the vehicle, but require no transfer, as some may drive from their wheelchair once locked in place. Note: The VA does not condone driving from ones wheelchair, as wheelchairs do not meet the safety standards to which vehicle seats are subjected to uphold.

Results show that overall the Glide ‘n’ Go generated the lowest forces and the lowest % MVC readings amongst all the devices. The transfer board proved to be the next best in terms of generating the lowest forces at the UEs during the transfer from initial to target seat.

Statistical significance of tasks was different for the forces of the right and left UE. This can be attributed to a number of factors. First, non-level transfers cause asymmetry in the transfer task, generating unequal stresses at each of the UEs. Unequal stresses may also be seen in leading versus trailing arms. Secondly, in some cases it was found that a higher percent body weight was typically applied by one hand over the other (Figure 5.1). This was not an affect of hand dominance as all subjects were right hand dominant and in the case of the Ryno Lift, greater forces were applied by the left hand. Lastly, force data found that there was no statistical difference between the unassisted and Ryno Lift transfers or between the transfer board and Glide ‘n’ Go transfers. However, these two groups were found to be statistically significant from one another at all joints of the left UE. At the right UE the only statistical difference was found between the unassisted and Ryno Lift transfers.
Hand position when applying load during a transfer had an impact on the forces and moments that were generated. It was found that some of the highest forces were found at the handle. Based on observations, this result is expected since subjects were able to more easily pull up a greater percent of their body weight as opposed to applying a push force to the steering wheel. The vehicle door was utilized by only subject 1 for minimal load bearing during the transfers and was found to be one of the least stable locations for support. The steering wheel however was expected to generate some of the highest moments due to the angle of the shoulder at which the force was applied.

Of all the joints of the UE, the shoulders appear to have the most sensitivity to force and position and also proved to be the most crucial joint in which to prevent injury and pain. This is largely seen in the amount of variability at this joint during the transfer trials. The greatest variability was seen at the left shoulder during the Ryno Lift transfers, which is an extension of the force results shown. While it was found that the unassisted transfers generated the highest forces, the lack of assistive device did not necessarily generate the highest moments.

Figure 5.3 compares the left and right shoulders for each task. A significant difference between these 2 joints during the Ryno Lift transfers.
Moments generated during the unassisted transfer task were always highest for the elbow and wrist for both the left and right UEs. At the right and left shoulders the highest moments were frequently found at the steering wheel. Statistically significant differences between the steering wheel and other force transducers occurred at both shoulders.

Significant differences between the unassisted transfers and the transfer board, Glide ‘n’ Go and Ryno Lift transfers can be attributed to the extra challenge that was observed when subjects did not have access to an assistive device (Figure 4.10: % MVC “Event” Trials per Task). While the primary goal of this study was to view the duration of the transfer tasks from initial to target seat, data was also captured prior to and post transfer. The unassisted and transfer board transfers were found to be different from the Easy Reach and Ryno Lift transfers, which is evidence that some transfers require more effort than others before and after the actual transfer takes place.

Complications surrounding the fact that percent MVC data exceeded 100% is unsolved, but not without speculation as to why:
1. MVC capture method. While the approach seemed logical and followed prior literature, it is possible that the method used during this study can be improved upon.

2. Subject inconsistency. Subjects did not exert as much force during the MVC trials as they did during the wheelchair transfer and wheelchair stowage trials.

3. EMG electrode contact. MVC trials were performed first allowing less time for electrode contact than for the other trials captured later. It is known that the longer the contact time for an EMG sensor, the greater chance there is for better contact due to perspiration and steadying of the signal. This leads to the conclusion that contact was better during the wheelchair transfer and wheelchair stowage trials.

4. Muscle signal. During MVC trials muscle exertion was slow with a steady increase as seen in Figure 3.25 (MVC Calibration Filter Effect). This is in contrast to some of the EMG signals seen during the transfer trials, especially those which generated high peaks during more strenuous movements.

The inclusion criteria had no requirement for subject to stow and remove their own wheelchairs. It was found that many of the subjects did not regularly stow their own wheelchairs. Based on observation alone wheelchair stowage appeared to be one of the more challenging aspects of data collection requiring trunk stability to help minimize forces at the shoulder, elbows and wrists.

Figure 5.4 shows the effect of transfer order on % MVC during an “event”. While there is seemingly a large difference between the means of tasks 1 and 2 this difference is not significant. The measure in this case is also misleading in that trials for task 1 were dominated by “events” that occurred during unassisted transfers. Unassisted transfers were previously shown to require the highest muscular exertion.
Figure 5.5 shows the effect of transfer order on % MVC during the full transfer trials, which contained the entire transfer from initial to target seat as well as some data prior and post transfer. It was expected to see the trend evidenced in Figure 5.4, but there is actually a significant difference between task 1 and task 2, which had the next highest mean. Of transfers that were completed and able to be processed, the second task is only represented by the transfer board, which was previously shown during the full transfer trials to have required the highest muscular exertion. While EMG frequency decrease as muscles become fatigued, it cannot necessarily be said that this data provides any insight into fatigue that may occur from performing multiple transfers in sequence.

Figure 5.4: % MVC “Event” Trials per Task Order.
Figure 5.5: % MVC Full Transfer Trials per Task Order.
Chapter 6 – Conclusions and Recommendations

6.1 Conclusions

It is well established in the literature that SPTs (sitting pivot transfers) are one of the most demanding of all wheelchair related ADLs and that of this type of transfer, vehicle transfers may be some of the most challenging. Prior to this study, there had been little attention paid to this important area of research. This study is a step forward in discovering how those with SCI can adapt as they age and are subjected to an increased risk of degenerative injuries, along with decreased recovery time and cumulative pain.

While many assistive devices are available, there is no measure concerning the effectiveness of these devices when it comes to comfort, efficiency and the feeling of safety. It is clear that there is a need for these types of devices simply based on the product market.

Ultimately this study found that using an assistive device is more effective than not using an assistive device. This is proven by EMG and force data, which were both found to be less with the use of an assistive device as, opposed to transferring independently with no assistance.

With this knowledge, a problem to overcome will be the stigma that comes with using an assistive device. Through conversation with the recruited male sample, it was found that many find the use of a device to make them less “macho” even if it is well known that using an assistive device can protect their UEs from injury and pain.

While it is difficult to make sweeping conclusions that will apply to everyone with SCI, a few recommendations can be made from the results of this study. First it is
recommended based on observations and quantitative data, that those with SCI use some sort of assistive device when performing a transfer. This will help to maintain function of their UE over a longer period of time. Second, it is recommended that those with SCI typically perform level, or close to level transfers, such as to a car versus a truck. Assistive devices can likely be even more beneficial with training and practice. Lastly, it is recommended that those with SCI try to keep healthy through exercise and training and carefully manage their body mass. Staying fit will help to make transferring easier and alleviate any extra stresses due to body mass on the UEs.

6.2 Limitations and Suggestions for Future Work

Numerous challenges arose during the course of this study. As a learning experience these challenges were necessary and have provided insight for conducting future studies.

6.2.1 Data Acquisition and Processing

Beginning with motion capture, insufficiencies were introduced into the data collection process. The smaller cross-sectional area of the frame of the vehicle model was a vast improvement over the previous version. Unfortunately there were still several issues that arose.

During trials subjects occluded the markers with other areas of their body. This is unavoidable and was worse during the trials in which subjects were asked to stow and remove a wheelchair from the car. Even though the wheelchair was broken down, it was carried across the front of the body occluding many markers at once. There was also a problem of markers falling off during the trials. Markers that fell off were not replaced until the trial was completed. This was also the case for EMG electrodes, which due to
their location could not be wrapped to the body. Although with less frequency than markers, electrodes also lost contact.

Camera placement may have also played a role in marker visibility. The motion capture system requires at least 2 cameras to resolve a marker. Placement of the vehicle was limited due to the lab’s arrangement and cameras were wall mounted, therefore data was not collected in the most ideal conditions.

Marker occlusions led to difficulty in marker labeling, which created the need to view each trial and manually label all occluded markers in each frame. Trials ranged from ~1000 up to ~10,000 frames, with an average of about 3000 frames. This was a very time consuming process. If a similar study is to be performed it is recommended that an active-marker motion capture system be used to completely eliminate the need for manual labeling. Additionally, for a study in which only the UEs are to be analyzed, no markers would be necessary for the lower extremities.

Trials were performed only once due to time constraints, patient fatigue and risk of injury. Transfer-in and transfer-out trials were used as a 2 trial series for statistical purposes when possible. As seen in Table 4.1 even this was not always possible.

6.2.2 Vehicle and Device Mock-up Designs

The mock-up designs and relative placement of devices was not completely accurate. This likely had no adverse effects on the study since all subjects used the same model, but design flaws are noted nonetheless.

The seat used in the vehicle was fairly low to the floor. This affected some of the transfer heights. Ideally all transfers would be level transfers. Level transfers put the least stress on the UE.54

There were also some major design differences in the mock-up models as compared to the commercial devices. The most dissimilar being the Glide ‘n’ Go mock-
up, which was very cumbersome and made stowing a wheelchair near impossible. Transfers to and from the Glide ‘n’ Go mock-up to the wheelchair were not level, but the actual device is designed to make all transfers level and does not create an extra obstacle when attempting to stow or remove a wheelchair.

6.2.3 Recruitment and Testing

Subject recruitment was a significant weakness in this study. Recruiting in the SCI population posed a challenge and took approximately 18 months to obtain 5 participants. VA Researchers are not allowed to solicit potential participants, therefore clinicians were asked to help. A modification was implemented later in the study, which allowed non-Veterans to also participate. Unfortunately, the proposed number of participants was not met, within an acceptable time frame.

It would have been beneficial to run multiple trials of each transfer task, but due to safety, fatigue and physical ability this was not possible. Some subjects were unable to perform all the tasks called for in the study, due to lack of ability, inexperience, body weight, and/or fatigue.

6.2.4 Variability

6.2.4.1 EMG

There was some variability in the EMG testing due to the fact that the researchers conducting data collection had no previous experience in EMG placement at the UE. Literature references were used to place electrodes as accurately as possible, but variability likely occurred between subjects and researchers.

Variability in EMG data also arose from having to replace sensors that lost contact during trials. After initial attachment of EMG sensors, the subject was asked to activate each muscle to assure proper contact. All sensors were then zeroed via
hardware and software. However, sensors were not zeroed or signal checked when replaced after loss of surface contact. The position of replaced electrodes was not found to be an issue since the skin was marked. Subjects were only asked to complete one MVC trial for each muscle group so as not to get fatigued prior to performing a series of transfers. With only one trial it is difficult to know the accuracy of the trial and may have been beneficial to conduct more than a single MVC trial.

6.2.4.2 Participants

Any study involving human subjects will exhibit variability within the population. Some disparities that made an observational difference were subject BMI and cognitive health. Within the SCI population there is much variability in injury level, which greatly affects their physical ability.

6.2.5 Future Work

In continuation of this study a few changes should be introduced. The marker set would be limited to just the trunk and UE and an active motion capture system would be used rather than a passive one to eliminate the need for manual marker labeling while increasing accuracy.

Many of the transfers that took place in this study were done for the first time by the subjects and were completed only once. With this limitation, it is difficult to know how well a person with SCI may perform if they had the opportunity to physically train with an assistive device. It could be hypothesized that there may be a learning curve associated with vehicle transfers and that over time the forces and moments acting on the joints of the UE could be minimized and muscle exertion decreased.
In the future studies related to wheelchair transfer can be expanded to include quadriplegics, as many are able to perform vehicle transfers and do so on a regular bases.

Kinetics and kinematics are a good measure for comparison when relative to each other, but no research has been found that has addressed what, if any, significant magnitudes may lead to injury of the UE. What combination of forces, moments and angles may be considered injurious?
List of References


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Appendices
Appendix A – Informed Consent for an Adult Form

University of South Florida, the IRB of record for the James A. Haley VA Hospital
Information to Consider Before Taking Part in this Research Study

IRB Study # 106564

Informed Consent to Participate in Research and Authorization to Collect, Use and Share your Health Information

Doctors and researchers at James A. Haley VA Hospital study diseases and other health problems people may have. Our goal is to try to find better ways to help treat these health problems. To do this, we need the help of people who are willing to take part in a research study.

We are asking you to take part in a research study that is called:

**Evaluation of Transfer Technologies to Preserve Shoulder Function in SCI**

The person who is in charge of this research study is Dr. John Lloyd. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. The person explaining the research to you may be someone other than the Principal Investigator. Other research personnel who may be involved with you include: Kevin White, MD; Jeffrey Harrow, MD, PhD; Ron Girona, Ph.D.; Steve Luther, Ph.D., Shawn Applegarth MSME, Ron Gironda, PhD, Shirley Fitzgerald PhD; Karen Mann, BSME; Mike Kerrigan, BSME and Ron Olney, PhD.

The research will be done at the Patient Safety Center/James A. Haley V.A Hospital

This research is being paid for by VA Rehabilitation Research and Development

**Should you take part in this study?**

This form tells you about this research study. After reading through this form and having the research explained to you by someone conducting this research, you can decide if you want to take part in it. **You do not have to take part in this research to receive medical care.** Reading this form should help you decide if you want to take part in the study. If, at any time, you have any questions, feel free to ask the person explaining this study to you.

**Before you decide:**

1. Read this form and make sure you know what the study is about.
2. Talk about this study with the study doctor or the person explaining the study. You can have someone with you when you talk about the research study.

**This form explains:**

1. Why this study is being done.
2. What will happen during this study and what you will need to do.
3. Whether there is any chance you **might** experience potential benefits from being in this study.
4. The risks of having problems because you are in this study.
Appendix A (continued)

You can ask questions:
You may have questions this form does not answer. If you do, ask the study doctor or study staff as you go along. You don’t have to guess at things you don’t understand. Ask the people doing the study to explain things in a way you can understand.

After you read this form, you can:
1. Take your time to think about the information that has been provided to you.
2. Have a friend or family member go over the form with you.
3. Talk it over with your regular doctor.

It’s up to you. If you choose to be in the study, then you can sign the form. If you do not want to take part in this study, you should not sign the form.

Why is this research being done?
The purpose of this study is to find out which wheelchair transfer device is easiest and safest for getting into and out of a vehicle. You will be asked to transfer in and out of a minivan and stow and retrieve a rigid wheelchair while using five commercially-available devices.

Why are you being asked to take part?
We are asking you to take part in this research study because you are treated at the Tampa VA for your spinal cord injury, are between the ages of 18 and 65 years, use a manual wheelchair, and transfer independently.

How long will you be asked to stay in the study?
Data collection, from start to finish, will last approximately 4 (four) hours. It may be on a single visit or in 2 visits, depending on scheduling needs of both the researchers and you.

How often will you need to come for study visits?
A research study visit is one you have with the study doctor or research personnel. This visit is different than the visits you make with your regular doctor. You will need to come for one study visit. The study visit will take about four hours.

How many other people will take part?
About 58 people will take part in this study at the Tampa VA.

Will your regular medical treatment change if you take part in this study?
The kind of medical treatment you now get from your regular doctor will not change because you take part in this study. You will keep seeing your regular doctor. Your regular doctor will give you the same kind of treatment you would get anyway, whether or not you take part in the study.
If you need to, you can:
1. Use medicines prescribed by your regular doctor.
2. Have surgery you need.

However, you should tell the study doctor about all the medicines you take and about any planned surgery you may have scheduled.
Appendix A (continued)

If you have an emergency, you can get emergency care. If possible, let the emergency caregiver know that you are participating in a research study. Also, let the study doctor know that you have had to seek emergency care as soon as possible.

What other choices do you have if you decide not to take part?
If you decide you do not want to take part in this study that is okay. If you decide not to participate in this research, there are no other choices similar to this research and so your other choice would be not to participate, but you can continue to see your regular doctor for management of your condition or disease.

How do you get started?
If you decide to take part in this study, you begin by signing this consent form. This form is also your agreement to allow us to use your personal health information as needed in the research study. Until you have agreed to take part in the study and have signed this form, no research actions or measures will take place.

If you decide to take part in the study, we will do a screening test. Screening tests are done to see if you are able to be in the study.

The following are screening tests:
3. The screening test will consist of a physical evaluation to determine if your range of motion and strength of shoulder, elbow and wrist are relatively equal. The screening test will take about five minutes and we will immediately know the results of this test and whether or not you should be in the study.

What will you need to do to get ready for this study?
To begin the study, you will need to bring or wear athletic shorts and a T-shirt.

What will happen during this study?

Your study visit will consist of the following:
A board certified SCI physician and an Ergonomist/Biomechanist will review your medical chart and perform a physical evaluation to make sure you can participate in this study. After the evaluation, you may be asked to return on another day for the testing, or you may go straight to testing, depending on the scheduling of both the researchers and you.

Next you will be shown how to use the different devices and asked to practice each step of the transfers, which involves transferring into the vehicle’s driver’s seat, stowing a manual chair in the passenger compartment, retrieving the wheelchair from the passenger compartment, then transferring from the vehicle to wheelchair.

When ready, we will gather information about how you transfer and what effect this has on your upper-body will be collected using a motion analysis system. You will need to dress in athletic shorts and T-shirt for this part of the study because a series of markers will be placed on your body using adhesive tape. After the markers are placed, we will also attach electrodes to the surface of your skin to capture the muscle activity during the transfer. You will also be asked to wear gloves during the transfer so we can measure the forces you exert with your hands.
Appendix A (continued)

We would like to video-tape and take still pictures of the testing to help us see how you conduct the transfers.

You will be shown a video of someone performing each transfer so that you know what it looks like. You will be asked to perform each of the five transfer tasks. Rest periods will be allowed as needed. After each transfer, a team member will ask you questions about how you feel, and what you thought about the different transfer devices. Once completed, we will remove the markers, electrodes and gloves. The data collection and the medical testing should take no more than 4 hours.

Will you be paid for taking part in this study?
We will pay you $75 for your time and transportation costs for being in this study.

What will it cost you to take part in this study?
It will not cost you anything to be part of the study.

If you are a VA patient, there may be co-payment costs for some of the procedures that occur during the research for which the VA may not pay. Some veterans are required to pay co-payments for medical care and services provided by the VA. These co-payment requirements will continue to apply to medical care and services provided by the VA that are not part of this study.

What are the potential benefits if you take part in this study?
We do not know if you will get any health benefits by taking part in this study. We do not know if this study will help spinal cord injury users with their transfers in and out of a car.

That is why we are doing this study. This research study should help us learn more about which assistive device will help prevent injuries.

What are the risks if you take part in this study?

The treatment might not help.
There is a possibility that you could become anxious, frustrated or otherwise upset during the evaluation sessions if you think that you are not performing as well as you expect. These feelings should be relatively brief and you will receive feedback about your performance when testing has been completed. It is possible that you may experience a wheelchair tip, fall, or upper extremity discomfort while you are performing the wheelchair transfers.

There may be side effects.
You may also discover some bruising or soreness from exertion after the testing is completed. We will monitor you carefully to avoid these adverse events.

There is always a chance that any medical treatment may cause you some discomfort or harm and the procedures in this study are no different. We will do everything possible to keep you from being harmed. There may be other risks or side effects that occur which we do not know about at this time. It is important for you to tell us when you experience such a side effect.
Appendix A (continued)

If you have any of these problems, tell the study doctor. If these side effects bother or worry you, or if you have other problems, call John Lloyd at (813) 558-3925 or Ron Olney at (813) 558-3968. It is uncommon for the medical treatment that you would receive as your standard care to also cause problems.

What if you get sick or hurt while you are in the study?
You are participating in a research project approved by a Research and Development Committee and conducted under the supervision of one or more VA employees. If you are injured because of your participation as a research subject in this research study, the VA medical facility will provide you with necessary medical treatment.

If you need emergency care:

4. Go to your nearest hospital or emergency room right away. Call 911 for help. It is important that you tell the doctors at the hospital or emergency room that you are participating in a research study. If possible, take a copy of the consent form with you when you go.

Call the study doctors as soon as you can. They will need to know that you are hurt or ill. Call Dr. John Lloyd at 813-558-3925 or Dr. Ron Olney at (813) 558-3968. In case of emergency, please report to the nearest hospital, emergency room, and contact your family doctor.

If you need emergency care in a private hospital, have a friend or family member contact the VA immediately at (813) 972-7037; and your study doctor so that they can coordinate care with a private hospital. If an eligible veteran requires admission to a non-VA hospital as a result of an emergency, the Department of Veterans Affairs will not be responsible for the cost incurred unless the Department of Veterans Affairs is involved immediately.

If you do NOT need emergency care:

5. Go to your regular doctor. It is important that you tell your regular doctor that you are participating in a research study. If possible, take a copy of this consent form with you when you go.

If you are harmed while taking part in the study:
If you believe you have been hurt or become sick because of something that is done during the study, you should call Dr. John Lloyd at 813-558-3925 immediately.

What happens if you decide not to take part in this study?
You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study to please the study doctor or the research staff.

If you decide not to take part:
1. You will not be in trouble or lose any rights you normally have.
2. You will still have the same health care benefits.
3. You can still get your regular treatments from your regular doctor.

What if you join the study and decide you want to stop later on?
Appendix A (continued)

You can decide after signing this informed consent document that you no longer want to take part in this study. If you decide you want to stop taking part in the study, tell the study staff as soon as you can.

- We will tell you how to stop safely. We will tell you if there are any dangers if you stop suddenly.
- If you decide to stop, you can continue getting care from your regular doctor.

Are there reasons we might take you out of the study later on?
Even if you want to stay in the study, there may be reasons we will need to take you out of it. You may be taken out of this study if:

1. We find out it is not safe for you to stay in the study. For example, your health may worsen or we may find that transferring in and out of the vehicle might harm you.
2. You are not coming for your study visits as scheduled.

Authorization for Release of Your Health Information for Research Purposes

Who will see the information that you give?
In our research, we use and share information about people and their health. We know that this information is private. Federal law protects health information.

The law lets us use and share health information for research if you agree to let us do this. If you let us use and share information about you, we will protect it as required by law.

If you sign this form, it means you are letting us use and share this information for research.

Who will disclose (share), receive, and/or use your information?
To do this research, James A. Haley VA Hospital and the people and organizations listed below may use or share your information. They may only use and share your information:

1. With the people and organizations on this list.
2. With you or your personal representative.
3. As allowed by law.

James A. Haley VA Hospital and the people and organizations listed below may use or share information about you to do this research:

1. The medical staff who are taking care of you.
2. The research team, including the Principal Investigator, study coordinator, research nurses, and all other research staff. Research staff may include the KT, the wheelchair consultant, the biomechanist, the engineer and the study physician.
3. All health care and other James A. Haley VA Hospital staff who treat and serve you as a part of this research.
4. Every research site for this study. This includes the research and medical staff at each site and James A. Haley VA Hospital.
Appendix A (continued)

1. Any agency of the federal, state, or local government that regulates this research. This includes the Food and Drug Administration (FDA), Florida Department of Health, and the Department of Health and Human Services (DHHS)

2. The USF Institutional Review Board and its related staff who have oversight responsibilities for this study.

3. The designated peer review committees such as: Protocol Review and Monitoring Committee; Data and Safety Monitoring Board; VA Research Services

4. Data Managers

The organizations and people listed above may employ or pay various consultants and companies to help them understand, analyze, and conduct this study. All of these people may not be known now, but if you would like to have that information at any time during the study, you may ask the study doctor and you will be provided that information.

Who else can use and share this information?
Certain people may need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Once any information leaves James A. Haley VA Hospital, we cannot promise that others will keep it private. James A. Haley VA Hospital cannot stop others from using or sharing information they have about you. The sponsor may share your information. If the sponsor or others share your information, your information may no longer be protected by federal privacy laws.

What information will be used or shared?
Others not listed here may be able to get information about you from those listed above. That is only allowed when the law does not require them to keep your information private.

By signing this form, you are letting James A. Haley VA Hospital collect, use, and share the following information:

1. Your whole research record
2. All of your medical and other records held by James A. Haley VA Hospital. This includes, but is not limited to, biomechanical data, information on muscle activity, and data from questionnaires.

By signing this form, you are giving your permission to use and/or disclose your protected health information as described above. Your authorization to use your health information will not expire until the end of this research study unless you revoke that authorization in writing.

Your Rights:
You can refuse to sign this form. If you do not sign this form:
Appendix A (continued)

1. You will not be able to take part in this research and therefore not be able to receive the research study drug or procedure. However, you can receive other procedures that are currently available for your spinal cord injury as part of your regular medical treatment.

2. This will not change your health care outside of this study.

3. This will not change your health care benefits.

4. This will not change the costs of your health care.

You can revoke this form at any time. This means you can tell James A. Haley VA Hospital to stop using and sharing your information. If you revoke this form:

1. **We will stop collecting information about you.**

2. **The information that we have collected before you tell us to stop may already have been used or shared, or we may need it to complete the research so you cannot withdraw that information.**

3. **Staff may follow-up with you if there is a medical reason to do so.**

To revoke this form, you must tell us in writing. To revoke your authorization, you must write to the Release of Information Office at this facility or you can ask a member of the research team to give you a form to revoke the authorization. Your request will be valid when the Release of Information Office receives it. If you revoke this authorization, you will not be able to continue to participate in the study.

If you revoke this authorization, your research doctor or staff can continue to use information about you that was collected before receipt of the revocation. The research team will not collect information about you after you revoke the authorization.

While we are doing this research, we cannot let you see or copy the research information we have about you. After the research is done you have a right to see and copy the information about you, as allowed by James A. Haley VA Hospital policies.

The VHA complies with the requirements of the Health Insurance Portability and Accountability Act of 1996 and its privacy regulations and all other applicable laws that protect your privacy. We will protect your information according to these laws. Despite these protections, there is a possibility that your information could be used or disclosed in a way that it will no longer be protected. Our Notice of Privacy Practices (a separate document) provides more information on how we protect your information. If you do not have a copy of the Notice, the research team will provide one to you.

**What will we do to keep your study records private and confidential?**

There are federal laws that say we must keep your study records private. We will keep the records of this study private and confidential by retaining them in a secure building in locked files. All computer data will be encrypted to protect patient confidentiality and saved on VA ISO approved secured computer systems. Any electronic transmission will use PKI. Data will be maintained and destroyed in accordance with the VA record control schedule.
Appendix A (continued)

We may publish what we learn from this study. If we do, we will not let anyone know your name. We will not publish anything else that would let people know who you are.

You can get the answers to your questions, concerns, complaints or issues. If you have any questions, concerns, complaints or issues about this study, call Dr. John Lloyd at (813) 558-3925.

If you have questions about your rights as a person taking part in this study, call the Division of Research Integrity and Compliance of the University of South Florida at (813) 974-9343.

If you would like to contact someone independent of the research study, or cannot reach the research staff, you may contact the James A. Haley VA Hospital Research Compliance Officer at (813) 972-2000 ext. 7872.

Statement of Participation in Research and Authorization for the Collection, use and Disclosure of Health Information

It is up to you to decide whether you want to take part in this study. If you want to take part, please read the statements below and sign the form if the statements are true.

I freely give my consent to take part in this study and authorize that my health information as agreed above, be used/disclosed in this study. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

Signature of Person Taking Part in Study                     Date/Time

Printed Name of Person Taking Part in Study

________________________________________________________________________

Signature of Witness (must not be affiliated with the study team) Date/Time

Printed Name of Witness

Statement of Person Obtaining Informed Consent / Research Authorization

I have carefully explained to the person taking part in the study what he or she can expect.

I hereby certify that when this person signs this form, to the best of my knowledge, he or she understands:

1. What the study is about.
2. What procedures/interventions/investigational drugs or devices will be used.
3. What the potential benefits might be.
4. What the known risks might be.
Appendix A (continued)

I also certify that he or she does not have any problems that could make it hard to understand what it means to take part in this research. This person speaks the language that was used to explain this research.

This person reads well enough to understand this form or, if not, this person is able to hear and understand when the form is read to him or her.

This person does not have a medical/psychological problem that would compromise comprehension and therefore makes it hard to understand what is being explained and can, therefore, give informed consent.

This person is not taking drugs that may cloud their judgment or make it hard to understand what is being explained and can, therefore, give informed consent.

______________________________  ________________________
Signature of Person Obtaining Informed Consent                   Date/Time

______________________________  ________________________
Printed Name of Person Obtaining Informed Consent                 Date/Time
## Appendix B – Clinical Evaluation Form

SUBJECT#       DATE: __________

<table>
<thead>
<tr>
<th>Physician Evaluation</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed Consent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### MEDICAL CHART REVIEW:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of injury (ASIA A T2 through L5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration since injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac / Respiratory impairment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence of current or recent UE injury / disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other disease or unstable medical condition, including pregnancy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Has not been on extended bed-rest in last month</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### OBSERVATIONAL EVALUATION

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper extremity range of motion – similarity between left &amp; right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper extremity strength – similarity between left &amp; right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uses manual vs. power chair for mobility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is not ventilator dependent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make / Model of patient's wheelchair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer method / technology typically used by the patient</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After evaluating the subject’s history and pertinent physical findings, this subject may safely participate in the wheelchair transfer study.

Subject not recommended for participation. Reason:

Signature of physician:
### Appendix C – Pain Questionnaire FABQ-P (Fear Avoidance Beliefs Questionnaire – Physical Subscale)

**SUBJECT# _____**

Here are some of the things which other patients have told us about their pain. For each statement, please circle any number from 0 to 4 (or not applicable) to indicate how much physical activities affect or would affect your upper extremity pain.

<table>
<thead>
<tr>
<th></th>
<th>Completely Disagree</th>
<th>Unsure</th>
<th>Completely Agree</th>
<th>I Don’t Have Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Physical activity makes my pain worse</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2. Physical activity might harm me</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3. I should not do physical activities which (might) make my pain worse</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4. I cannot do physical activities which (might) make my pain worse</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
**Appendix D – Pain Intensity Numeric Ratings Scale**

SUBJECT# _____

Please consider any pain you have experienced in your shoulders, arms, elbows, wrists, or hands when answering the following questions.

**A.** On the following scale where 0 = “No Pain” to 10 = “Worst Pain Ever”, please circle the appropriate number to indicate how you would rate yourself in the following areas:

<table>
<thead>
<tr>
<th>No Pain</th>
<th>Worst Pain Ever</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td></td>
</tr>
</tbody>
</table>

Rate the **CURRENT LEVEL OF PAIN** you are now experiencing

Rate your **USUAL LEVEL OF PAIN** during the **PAST WEEK**

Rate your pain at its **BEST** during the **PAST WEEK**

Rate your pain at its **WORST** during the **PAST WEEK**

**B.** On the following scale from “pain rarely interferes” to “pain always interferes”, please make a mark along the horizontal line to indicate how you would rate yourself in the following areas:

<table>
<thead>
<tr>
<th>Pain Rarely Interferes</th>
<th>Pain Always Interferes</th>
</tr>
</thead>
<tbody>
<tr>
<td>______________________</td>
<td>______________________</td>
</tr>
</tbody>
</table>

Rate how your current level of pain limits your **ABILITY TO PROPEL** your wheelchair

Rate how the current pain limits your **ABILITY TO TRANSFER** in and out of your wheelchair
Appendix E – Product Evaluation Questionnaire

SUBJECT# _____

Product I.D: __________________

Examine the product very carefully and answer the following questions as they relate ONLY to this product.

Please answer each of the following questions on a scale from 0 to 5, by circling the number that matches your impression, where 0 indicates very poor and 5 indicates very good.

1. How would you rate your OVERALL COMFORT during use of this product?

<table>
<thead>
<tr>
<th>Very Poor</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Good</th>
</tr>
</thead>
</table>

1. What is your impression of this product’s OVERALL EASE-OF-USE?

<table>
<thead>
<tr>
<th>Very Poor</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Good</th>
</tr>
</thead>
</table>

1. How EFFICIENT do you feel this product will be in use of your TIME

<table>
<thead>
<tr>
<th>Very Poor</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Good</th>
</tr>
</thead>
</table>

1. How SAFE do you feel during USE of this product?

<table>
<thead>
<tr>
<th>Very Poor</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Good</th>
</tr>
</thead>
</table>

Investigator notation as to method of transfer:

_____________________________________________
Appendix F – Supplemental Results

F.1 Kinetics

The following graphs and tables are supplemental information of the kinetics data. This data shows the magnitudes of the forces and moments with a table of the value of each data point.

![Figure F.1: Max Forces per Transfer Task](image)

Table F.1: Max Forces (N) per Transfer Task

<table>
<thead>
<tr>
<th></th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transfer Board</strong></td>
<td>292 (94)</td>
<td>295 (104)</td>
<td>299 (108)</td>
<td>300 (129)</td>
<td>303 (130)</td>
<td>308 (133)</td>
</tr>
<tr>
<td><strong>Unassisted</strong></td>
<td>471 (69)</td>
<td>491 (72)</td>
<td>501 (74)</td>
<td>462 (109)</td>
<td>468 (118)</td>
<td>475 (117)</td>
</tr>
<tr>
<td><strong>Glide 'n' Go</strong></td>
<td>179 (66)</td>
<td>175 (68)</td>
<td>181 (68)</td>
<td>343 (103)</td>
<td>345 (112)</td>
<td>348 (118)</td>
</tr>
<tr>
<td><strong>Ryno Lift</strong></td>
<td>437 (69)</td>
<td>432 (68)</td>
<td>432 (68)</td>
<td>210 (159)</td>
<td>197 (134)</td>
<td>196 (114)</td>
</tr>
</tbody>
</table>
Appendix F (continued)

Statistically significant differences were found at the left UE. For the left shoulder, elbow and wrist the Ryno Lift and unassisted transfers were found to be different from the transfer board and Glide ‘n’ Go transfers.

![Figure F.2: Mean Forces per Transfer Task](image)

<table>
<thead>
<tr>
<th></th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Board</td>
<td>106 (21)</td>
<td>105 (19)</td>
<td>108 (19)</td>
<td>126 (93)</td>
<td>129 (98)</td>
<td>134 (98)</td>
</tr>
<tr>
<td>Unassisted</td>
<td>190 (5)</td>
<td>196 (2)</td>
<td>203 (2)</td>
<td>204 (25)</td>
<td>209 (20)</td>
<td>211 (11)</td>
</tr>
<tr>
<td>Glide ‘n’ Go</td>
<td>64</td>
<td>55</td>
<td>53</td>
<td>143 (53)</td>
<td>143 (52)</td>
<td>140 (42)</td>
</tr>
<tr>
<td>Ryno Lift</td>
<td>165 (30)</td>
<td>162 (30)</td>
<td>163 (31)</td>
<td>115 (77)</td>
<td>105 (70)</td>
<td>102 (66)</td>
</tr>
</tbody>
</table>

Table F.2: Mean Forces (N) per Transfer Task
Appendix F (continued)

![Figure F.3: Max Moments per Transfer Task](image-url)

**Table F.3: Max Moments (Nmm) per Transfer Task**

<table>
<thead>
<tr>
<th>Task</th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Board</td>
<td>86653</td>
<td>88702</td>
<td>22515</td>
<td>86934</td>
<td>86425</td>
<td>14970</td>
</tr>
<tr>
<td>Unassisted</td>
<td>49705</td>
<td>122875</td>
<td>22686</td>
<td>81155</td>
<td>126215</td>
<td>57008</td>
</tr>
<tr>
<td>Glide ’n’ Go</td>
<td>45666</td>
<td>42075</td>
<td>7416</td>
<td>75967</td>
<td>92781</td>
<td>17408</td>
</tr>
<tr>
<td>Ryno Lift</td>
<td>192068</td>
<td>127787</td>
<td>20713</td>
<td>60307</td>
<td>48923</td>
<td>10476</td>
</tr>
</tbody>
</table>

Note: Values in parentheses are in thousands.
Appendix F (continued)

Statistically significant differences were found at the left UE. For the left elbow the Glide ‘n’ Go transfer was found to be different than the unassisted transfer. At the left wrist the unassisted transfer was found to be different from the Glide ‘n’ Go and transfer board transfers. The Glide ‘n’ Go was also found to be different from the Ryno Lift transfer.

![Figure F.4: Mean Moments per Transfer Task](image)

Table F.4: Mean Moments (Nmm) per Transfer Task

<table>
<thead>
<tr>
<th>Transfer Task</th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Board</td>
<td>32261 (14908)</td>
<td>28174 (6667)</td>
<td>5005 (1132)</td>
<td>25264 (3672)</td>
<td>34325 (27561)</td>
<td>6198 (4440)</td>
</tr>
<tr>
<td>Unassisted</td>
<td>19771 (588)</td>
<td>48961 (3973)</td>
<td>8871 (436)</td>
<td>27327 (6022)</td>
<td>52014 (6875)</td>
<td>9915 (811)</td>
</tr>
<tr>
<td>Glide ‘n’ Go</td>
<td>14955</td>
<td>11303</td>
<td>1905</td>
<td>28682 (12151)</td>
<td>36629 (16419)</td>
<td>6939 (2345.9)</td>
</tr>
<tr>
<td>Ryno Lift</td>
<td>67936 (33288)</td>
<td>44545 (14027)</td>
<td>6946 (1013)</td>
<td>37061 (21372)</td>
<td>26916 (23633)</td>
<td>5179 (4206)</td>
</tr>
</tbody>
</table>
Appendix F (continued)

Statistically significant differences were found at the left UE. For the left shoulder the steering wheel was found to different from the grab handle and vehicle door. At the left elbow the grab handle was found to be different from the the vehicle door.

![Figure F.5: Max Moments per Transducer Location](image)

Table F.5: Max Moments (Nmm) per Transducer Location

<table>
<thead>
<tr>
<th></th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door</td>
<td>12154</td>
<td>41089</td>
<td>7671</td>
<td>124617</td>
<td>124617</td>
<td>45306</td>
</tr>
<tr>
<td></td>
<td>(572)</td>
<td>(12329)</td>
<td>(1091)</td>
<td>(37773)</td>
<td>(37773)</td>
<td>(76983)</td>
</tr>
<tr>
<td>Handle</td>
<td>50361</td>
<td>128045</td>
<td>22254</td>
<td>63317</td>
<td>124617</td>
<td>45306</td>
</tr>
<tr>
<td></td>
<td>(13063)</td>
<td>(18383)</td>
<td>(2514)</td>
<td>(24081)</td>
<td>(37773)</td>
<td>(76983)</td>
</tr>
<tr>
<td>Wheel</td>
<td>167643</td>
<td>92158</td>
<td>18825</td>
<td>104348</td>
<td>62964</td>
<td>11067</td>
</tr>
<tr>
<td></td>
<td>(72099)</td>
<td>(45387)</td>
<td>(12117)</td>
<td>(39994)</td>
<td>(20637)</td>
<td>(3453)</td>
</tr>
</tbody>
</table>
Appendix F (continued)

Statistically significant differences were found at the left UE. For the left shoulder the steering wheel was found to be different from the grab handle and vehicle door. At the left elbow and left wrist the grab handle was found to be different from the vehicle door.

![Figure F.6: Mean Moments per Transducer Location](image)

**Table F.6: Mean Moments (Nmm) per Transducer Location**

<table>
<thead>
<tr>
<th></th>
<th>Left Shoulder</th>
<th>Left Elbow</th>
<th>Left Wrist</th>
<th>Right Shoulder</th>
<th>Right Elbow</th>
<th>Right Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door</td>
<td>6170 (487)</td>
<td>9176 (2557)</td>
<td>1604 (401)</td>
<td>26077 (7628)</td>
<td>53982 (19933)</td>
<td>10026 (3159)</td>
</tr>
<tr>
<td>Handle</td>
<td>19350 (2009)</td>
<td>40719 (7673)</td>
<td>7535 (1559)</td>
<td>53982 (19933)</td>
<td>10026 (3159)</td>
<td></td>
</tr>
<tr>
<td>Wheel</td>
<td>58079 (29563)</td>
<td>33322 (17659)</td>
<td>5161 (2108)</td>
<td>32169 (11612)</td>
<td>20859 (10987)</td>
<td>3825 (2083)</td>
</tr>
</tbody>
</table>