Biomechanics of Independent Wheelchair Transfer in Individuals with Spinal Cord Injury

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by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering
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Abstract

Individuals with a low level spinal cord injury (SCI) at T1 or below must use a wheelchair for mobility and in order to accomplish daily activities, such as using a recreational wheelchair for sports. These individuals must transfer into and out of their wheelchair several times a day. It is most beneficial for the individual to complete these transfers independently, without the help of a caretaker or assistive device. It is important that these transfers be successful and safe, because improper technique can result in a serious injury from a fall or by repeated small damage to the arms and shoulders. The purpose of this study was to examine the biomechanics of independent wheelchair transfer and its associated energy expenditure for individuals with a low level SCI into recreational wheelchairs at a height equal to the seat of the subject’s personal chair and 10 centimeters below, as well as better understand the population’s participation in wheelchair sports and their use and satisfaction with their current recreational wheelchairs. Subjects with low level SCI transferred independently into the two recreational wheelchairs at each height while their movements were collected via motion capture simultaneously with several exertion metrics. Significant differences between the equal height and lower height were only found in the leading arm for shoulder flexion for the Racer, in the leading arm for elbow flexion in both recreational wheelchairs, and in the wrist rotation of the trailing arm for the Sport. Respondents to an online survey reported that they participated in eight different wheelchair sports, including cycling, sled hockey, wheelchair basketball, and wheelchair rugby, and that they were all highly satisfied with their current recreational wheelchairs.
Chapter 1: Introduction

1.1 Wheelchair Transfer

For individuals who use manual wheelchairs, such as those with spinal cord injuries (SCI), an independent transfer is a necessary part of everyday life. A single independent transfer consists of an individual moving unaided from his or her wheelchair to another seat. Many wheelchair users can be assisted by a caretaker or nurse to perform a dependent transfer. A dependent transfer is easier for the individual as he or she is not relying solely on himself or herself, but independent transfers are more beneficial; they have been found to improve the individual’s quality of life and mental health, as well as to provide the individual with a sense of independence which helps to promote rehabilitation[1, 2]. Despite the many benefits of independent transfer, safety remains paramount. An incorrect transfer can easily result in injury from as little as a minor skin abrasion to as serious as a fall[2]. Additionally even if a noticeable injury does not occur at the time of the transfer, many repeated improper transfers can still result in upper limb damage over time[2]. Therefore, proper technique is essential. Currently the Transfer Assignment Instrument (TAI) is used by clinicians to instruct and assess proper technique. The TAI outlines steps to safely maneuver oneself out of and back into a wheelchair[3]. While this is considered the optimal movement strategy for independent transfer, it may not represent the actual movement strategies wheelchair users employ.

Like the proper biomechanical technique, the energy expenditure of an independent transfer is also vital to its safe completion. Not only are these transfers frequent throughout the day, but they also occur with a variety of different target seats depending on the needs and
lifestyle of the individual. These transfers are needed to complete many daily activities including but not limited to: using the toilet, entering a vehicle, accessing a bed, and using a recreational wheelchair for a sport. As the number of transfers per day increases, the energetic demand on the individual also increases. If an individual is fatigued particularly at the end of the day or physical activity, he or she may be unable to complete the transfer or may injure themselves in the process[2]. More so, previous upper limb damage can further increase the energy demand[4]. Ideally each transfer would require the least amount of energy to safely complete.

1.2 Literature Review

There is limited research on the biomechanics of independent wheelchair transfer. Between the studies that have investigated transfer biomechanics, there is little methodological consistency. Of the five studies examined prior to this study, no two studies used the same exact experimental set-up or tested for the same outcome measures. In general, each set up was comprised of at a minimum an initial seat where the subject was seated prior to the start of the transfer and a target seat at some angle relative to the initial seat. The initial seat was either the subject’s personal wheelchair, a seat of the same dimensions[5], or a table[1, 6]. All of the reviewed studies examined a target seat at the same height as the initial seat[1, 3-6], and one also examined a target seat 10 cm higher than the initial seat[6]. No studies placed the target seat lower than the initial seat which contradicts the instructions of the TAI[3]. The placement of the two seats relative to each other also varied; the two seats were placed at an angle of 30°[7], 45°[4], 65°[6], or 180°[1] if the angle was specified[5]. The TAI requires the two seats to be at a 20-45° from each other[3]. The outcomes of each of the studies included kinematics[1, 4-7], back and upper limb muscle activity[1, 4], and reaction forces[5-7]. Most restricted kinematics to the upper body[1, 6, 7], while one tracked the full body[5], and the other the upper torso only[4]. All
studies which recorded reaction forces examined those of the upper limbs[5-7], and one study included reaction forces at the seat and legs as well[5].

The area of wheelchair transfer is not widely explored and the energy costs associated with transfer are even less understood. The few studies that do collect metabolic data during transfer do so under conditions which are very different from an actual wheelchair transfer that an individual with SCI would complete in his or her normal day[1, 4, 8]. One study found that a typical estimation of exercise intensity for able-bodied people, an MET formula, is not accurate when applied to individuals with SCI[9]. This further complicates an already unknown area. Some comparisons have been made within the groups of individuals with SCI, however; one study shows that upper limb muscular demands during transfer are higher in subjects with high SCI (C7 to T6) than subjects with low SCI (T11 to L2)[4]. Additionally, transfers have been found to be one of the more costly physical activities in oxygen consumption (VO\textsubscript{2})[8] and SCI MET[9].

1.3 Research Question and Specific Aims

The goal of this study was to answer the following research question: What are the biomechanics and the energy expenditure associated with wheelchair transfer to seats of different heights in lower SCI individuals?

In order to answer this question, the following four aims were established for this study:

1. Characterize periods of transfer by kinematics of upper limbs and muscle activation.
2. Determine target seat heights which require higher energy expenditure and/or more time for transfer.
3. Rate adherence to guidelines of the Transfer Assessment Instrument (TAI).
4. Determine the prevalence of sports and recreation participation in the population and the users’ satisfaction with their current recreational wheelchairs.
Chapter 2: Background

2.1 Spinal Cord Injury

2.1.1 Physiology

The human spinal cord is encompassed and protected by the vertebral column. The vertebral column is divided into five regions: the cervical, thoracic, lumbar, sacral and coccygeal regions. Sensory and motor nerves from the spinal cord exit through openings between the vertebrae to innervate portions of the body[10].

A physical trauma or disease can damage the spinal cord resulting in a complete, fully severed, or incomplete, damaged but not severed, SCI. The body parts affected is determined by the level of SCI. The portions of the body that are innervated by nerves at and below the level of injury are affected. The severity of the SCI determines the level of motor and sensory control lost[11].

Independent transfers are only possible for individuals with SCI at the level of T1 or lower, namely SCI in the thoracic or lumbar region. Higher SCI, those in the cervical region, flexion of the glenohumeral joint and elbow joint as well as wrist function[10]. These movements are integral to independent transfers.

2.2.2 Sports and Recreation

Physical activity is especially important for individuals with SCI. This population has shown not only decreased physical fitness[12], but also decreased mental health, as exhibited by increases in anxiety and depression after injury[13]. Physical activity, such as participation in
sports and recreation, results in better physical health. Individuals with a SCI who participate in more physical activity, particularly in sports recreation which promote socializing with others, have improved mental with lower anxiety and depression[14].

2.2 Transfer Assessment Instrument

Developed at the University of Pittsburgh’s Model Center on Spinal Cord Injury, the Transfer Assessment Instrument (Appendix A) is the first evaluation tool to be established for wheelchair transfer. The 3.0 version of the TAI which was used in this study is comprised of 2 parts. The first part contains 15 statements on the current clinically recommended steps of transfer and is scored by either YES, NO, or N/A. These steps include the position and angle of the subject’s wheelchair relative to the target seat, the position of the subject’s limbs before and during the transfer, and the subject’s interactions with any helper if the transfer is not intendent. The second part contains 12 statements regarding the subject’s set-up prior to the transfer as well as the conservation and quality of the transfer. These statements are scored on a five-choice Likert scale with a range of Strongly Disagree to Strongly Agree.
Chapter 3: Methodology

3.1 Two Studies

This document combines the findings of two separate studies: an online survey and an in-person 3D motion capture data collection.

3.2 Inclusion/Exclusion Criteria

3.2.1 Survey Subject Inclusion/Exclusion Criteria

All survey participants were at least 18 years of age and utilized a manual wheelchair as their primary means of mobility. Only participants who reported that they were able to independently transfer into and out of their wheelchair without assistance from a caretaker or assistive device, that they had a low level SCI of T1 or below and that participated in some sport of recreation were included in the survey data.

3.2.2 Motion Capture Subject Inclusion/Exclusion Criteria

To be included in the in-person study, subjects had to be 18 years of age or older and able to independently transfer into and out of their wheelchair without assistance from another person or any device. Additionally, subjects had to be long term manual wheelchair users which was defined as using a manual wheelchair as their primary mode of mobility for two or more years at the time of the study. Subjects also were required to have a low level SCI which was defined as a SCI at T1 or below. To reduce the risk of a fall during transfer, potential subjects could be excluded if they had a shoulder injury or surgery, a neuromuscular or musculoskeletal disorder affecting their upper limbs, or and pulmonary or cardiac disease. Potential subjects could also be
excluded if they met or exceeded 250 lbs, the maximum weight capacity of the recreational wheelchairs.

3.3 Kinematics

3.3.1 Marker Set

To collect kinematics, a 23 marker set was used (Figure 3.1). The markers were placed on bony landmarks as shown in Table 3.1.

![Figure 3.1 Marker Set](image)

<table>
<thead>
<tr>
<th>Marker Label</th>
<th>Full Marker Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1\textsuperscript{st} Thoracic Vertebrae</td>
</tr>
<tr>
<td>T10</td>
<td>10\textsuperscript{th} Thoracic Vertebrae</td>
</tr>
<tr>
<td>CLAV</td>
<td>Clavicle</td>
</tr>
<tr>
<td>STRN</td>
<td>Sternum</td>
</tr>
<tr>
<td>LBAK</td>
<td>Left Back</td>
</tr>
<tr>
<td>LPSI, RPSI</td>
<td>Left and Right Posterior Superior Iliac Spine</td>
</tr>
<tr>
<td>LASI, RASI</td>
<td>Left and Right Anterior Superior Iliac Spine</td>
</tr>
<tr>
<td>LSHOP, RSHOP</td>
<td>Left and Right Shoulder Posterior</td>
</tr>
<tr>
<td>LSHOA, RSHOA</td>
<td>Left and Right Shoulder Anterior</td>
</tr>
<tr>
<td>LELB, RELB</td>
<td>Left and Right Elbow Lateral</td>
</tr>
<tr>
<td>LELBM, RELBM</td>
<td>Left and Right Elbow Medial</td>
</tr>
<tr>
<td>LWRA, RWRA</td>
<td>Left and Right Wrist A</td>
</tr>
<tr>
<td>LWRB, LWRB</td>
<td>Left and Right Wrist B</td>
</tr>
<tr>
<td>LFIN, RFIN</td>
<td>Left and Right Finger</td>
</tr>
</tbody>
</table>

Table 3.1 Marker set anatomical landmarks
3.3.2 Vicon Nexus Motion Capture System

Kinematics was collected using an eight-camera passive motion capture system, Vicon Nexus with Nexus 1.8.2 software at 120 Hz.

![Motion Capture Laboratory](image)

Figure 3.2 Motion Capture Laboratory

3.4 Energy Expenditure Metrics

3.4.1 Electromyography

Muscle activation of the left and right biceps brachii was measured by electromyography (EMG) using the BioNomadix wireless dual-channel EMG transmitter and receiver module with the MP150 System by Biopac Systems Inc. All EMG data was collected at 960 Hz and synchronized with Vicon Nexus.

3.4.2 Electrocardiogram and Respiration

Heart rate was measured by electrocardiogram (ECG) using the BioNomadix wireless dual-channel ECG transmitter and receiver module with the MP150 System by Biopac Systems Inc. All EMG data was collected at 960 Hz and synchronized with Vicon Nexus.
3.4.3 Rate of Perceived Exertion

The Borg scale for rate of perceived exertion (RPE) was used to estimate effort and fatigue during physical activity. This self-reported metric shows an individual’s perception of his or her own exertion. Individuals select their Borg rating on a scale from 6 to 20 based on exertion descriptions ranging from no exertion to maximal exertion. Each of the ratings are approximately one tenth of the individual’s heart rate during the corresponding intensity of activity[15].

3.4.4 Time of Transfer

The time of each transfer and each phase of transfer was measured in seconds and the mean and standard deviation of the duration of each phase for each recreational wheelchair at each height was calculated.

3.5 Recreational Wheelchairs

The two target seats for the motion capture collection were the Top End Pro-2 All Sport Wheelchair (Sport) and the Top End Eliminator Racing Wheelchair with Open V Cage (Racer).
3.6 Procedures

3.6.1 Online Survey

Potential subjects received the consent form along with a link to the electronic survey (Appendix B). More than 30 local, state, and national organizations for SCI support and rehabilitation and wheelchair sports were contacted to distribute the survey to their members.

3.6.2 Motion Capture Collection

3.6.2.1 Initial Visit

The in-person motion capture collection consisted of two visits to the Rehabilitation Robotics and Prosthetics Testbed: the initial visit and the second visit. The initial visit was a pre-screening meeting to determine if the potential subject is eligible for the study. After the subject read and signed the consent form along with the optional photograph and video release, the potential subject with his or her wheelchair and then his or her empty wheelchair were weighted using two AMTI force plates. The subject’s weight was calculated by subtracting the weight of the empty wheelchair from the combined weight of the potential subject and his or her wheelchair. If any subject had exceeded 250 lbs, they would be excluded from the study, since
the recreational wheelchairs’ maximum weight limit was 250 lbs. If this weight was below 250 lbs, the subject then answered the Subject Questionnaire (Appendix D). The questionnaire ensures that the potential subject meets the inclusion criteria and does not meet any of the remaining exclusion criteria. If the subject was eligible for the study, the second visit was scheduled.

3.6.2.2 Second Visit

The purpose of the second visit was to collect the subject’s kinematics and energy expenditure metrics. Each subject arrived with his or her manual wheelchair to be used during the collection. Each subject was prepared for the collection. A set of passive reflective markers were adhered to the subject’s upper limbs and torso. The wireless transmitters were strapped around the subject’s torso and connected to the adhesive, surface electrodes that were placed on the subject’s torso and upper arms. After ensuring that each transmitter was connected to the receiver, the subject was instructed to enter the collection space to begin the trial.

For each trial, the subject was asked to independently transfer themselves from their personal wheelchair to one of two recreational wheelchairs at an equal height to and 10 cm lower than the seat of the subject’s personal wheelchair. The only direction given to the subjects was to transfer as they would in an everyday situation. Each subject transferred 12 times in total, 3 times into each recreational wheelchair at each height. The recreational wheelchairs were secured to the capture platform to prevent them from moving during the transfer. Subjects positioned and braked their personal wheelchairs for each trial.

Subjects were be given adequate time between trials to rest and were reminded to communicate any discomfort or fatigue to the research team. The trial was be stopped if the subject communicates any concerns..
Chapter 4: Data Analysis

4.1 Analysis of Kinematics

4.1.1 Phases of Transfer

From the literature, a single independent transfer is typically divided into three phases: prelift, lift, and postlift[7].

During the pre lift phase, the subject prepares and orients his or her body and wheelchair to transfer. This phase can include activities such as, positioning and locking the wheelchair, positioning and locking the target seat, scooting the buttock to the edge of the seat, positioning the leading hand on the target seat, positioning the trailing hand on the wheelchair, and positioning the legs. Since subjects transferred consecutively three times to the same target seat, the subject positioned and locked his or her own wheelchair prior to the collection before the first
trial and this motion was not included in the analysis. Additionally, the target seat was positioned and locked before the start of the subject’s first trial for safety, so this motion was also not included in the analysis. When the subject’s buttocks leave the seat of the wheelchair the prelift phase ends and the lift phase begins. During the lift phase, the subject’s weight is supported by the upper limbs and, depending on the level of SCI, the legs. The subject’s feet are on the floor the leading hand is on the target seat, the trailing hand is on the wheelchair, and the body is smoothly moved to the target seat. When the subject’s buttocks contact the target seat, the left phase ends and the postlift phase begins. The postlift phase can include activities such as, removing the leading and trailing arm from their starting positions, positioning the legs, repositioning the buttocks on the seat, and unlocking the target seat. The target seat remained locked in position for the duration of the trials. The activities performed during the prelift and postlift phases of the transfers varied between the four subjects, nor did the subjects perform the activities in common in the same order. For this reason, the kinematics of the prelift and postlift phase is unable to be compared between subjects, therefore only the kinematics of the lift phase was analyzed.

4.1.2 Glenohumeral Joint

The glenohumeral joint, or shoulder joint, has three degrees of freedom: flexion and extension, abduction and adduction, rotation. The neutral shoulder position is defined as the arms at the subject’s sides parallel with the subject’s torso. Flexion and extension of the glenohumeral joint occur in the sagittal plane. Flexion is reported as positive degrees from neutral and extension is reported as negative degrees from neutral. Abduction and Adduction occur in the frontal plane. Adduction is reported as positive degrees from neutral, and abduction is reported in negative degrees from neutral.
Recommended by the Standardization and Terminology Committee of the International Society of Biomechanics, the motion of the glenohumeral joint was calculated by the humerus relative to the thorax with the origin of the humerus of the coordinate system placed at its center of rotation estimated as halfway between the anterior and posterior aspect of the acromion and the origin of the thorax coordinate system placed at the suprasternal notch [16]. Angles were calculated with the biomechanics analysis software, C-Motion Visual 3D.

Figure 4.2 Glenohumeral Joint Motions (a) Flexion of the glenohumeral joint is reported in positive degrees from neutral and extension is reported in negative degrees from neutral. (b) Abduction is reported as negative degrees from neutral and Adduction is reported in positive degrees from neutral.

4.1.3 Elbow Joint

The elbow joint has one degree of freedom: flexion and extension. The neutral elbow position is defined as the long axis of the forearm in line with that of the upper arm. Flexion is reported as positive degrees from neutral and extension as negative degrees from neutral.

Recommended by the Standardization and Terminology Committee of the International Society of Biomechanics, the motion of the elbow joint was calculated by the forearm relative to the humerus with the origin of the forearm coordinate system placed at its center of rotation estimated as halfway between the medial point of the ulnar styloid and the lateral point of the radial styloid and the origin of the humerus of the coordinate system placed at its center of...
rotation estimated as hallway between the medial and lateral epicondyle [16]. Angles were calculated with the biomechanics analysis software, C-Motion Visual 3D.

Figure 4.3 Elbow Joint Motion. Flexion is reported in positive degrees from neutral.

4.1.4 Wrist Joint

The wrist joint has three degrees of freedom: flexion and extension, radial and ulnar deviation, and pronation and supination. The neutral wrist position is defined the long axis of the hand in line with that of the forearm. Flexion, ulnar deviation, and supination are reported as positive degrees from neutral, and extension, radial deviation, and supination are reported as negative degrees from neutral.

Recommended by the Standardization and Terminology Committee of the International Society of Biomechanics, the motion of the wrist joint was calculated by the third metacarpal relative to the forearm with the origin of the third metacarpal coordinate system estimated as the joint center and forearm coordinate system placed at its center of rotation estimated as halfway between the medial point of the ulnar styloid and the lateral point of the radial styloid [16]. Angles were calculated with the biomechanics analysis software, C-Motion Visual 3D.
Figure 4.4 Wrist Joint Motions. (a) Flexion of the wrist is reported in positive degrees from the neutral position and extension is reported in negative degrees. (b) Radial deviation is reported in negative degrees from the neutral position and ulnar deviation is reported in positive degrees. (c) Pronation of the wrist is reported in negative degrees from the neutral position and supination is reported in positive degrees.

4.2 Analysis of Analog Signals

Because the duration of each transfer is so short, the heart rate and respiration rate was calculated by the total number of beats or breaths, respectively, over the entire trial.

Muscle activation signals were fully rectified. An estimated cutoff frequency was calculated based on the sample rate of 960 Hz. The signals were filtered with that estimated cutoff frequency and the relative mean residual between the raw and filtered signals were calculated and used to calculate the optimum cutoff frequency. The raw signals were filtered using an 8th order Butterworth low-pass filter with the optimum cutoff frequency[17]. Muscle activation during life phase was normalized to 100% of the lift phase and percent of the lift phase when the peak activation occurs was recorded. The mean of the occurrences of the peak activation for each recreational wheelchair at each height was calculated.
4.3 Analysis of Perceived Rate of Exertion

PRE was self-reported by each of the subjects. The Borg scale with the activity level description corresponding to the scale value was nearby the subject for reference. The reported scores were averaged for each recreational wheelchair at the two heights.

4.4 Transfer Assessment Instrument

Evaluation of each subject’s adherence to the TAI was conducted by reviewing the video footage of each trial and rating the subject’s performance as either: yes, no or not applicable for Part 1 and strongly disagree to strongly agree on Part 2.

Due to the constraints of the study, some questions on the TAI were not applicable. The recreational wheelchairs and the subjects’ personal wheelchairs did not have removable armrest, therefore Question 4 in Part 1 of the TAI was not applicable. For this study subjects were not allowed to alter the height of the recreational wheelchair, therefore Question 5 in Part 1 of the TAI and Question 3 in Part 2 of the TAI were not applicable. For this study subjects were required to transfer without the help of a transfer device or another person, therefore Question 17 in Part 1 of the TAI and Questions 6, 10, and 11 in Part 2 of the TAI were not applicable. For this study subjects’ dominant arm was the leading arm for every trial, therefore Question 7 in Part 2 of the TAI was not applicable.

To calculate the score of the TAI, all yes answers from Part 1 are counted as 1 point and all no answers as 0 points. Any answers of not applicable are included in the scoring. The sum of the scores from part 1 are multiplied by 10 and averaged. The result is a score on a scale of 1 to 10. To calculate the score for Part 2, the Likert scale choices are scored from 0 to 4. To have another score on a scale of 1 to 10, the sum of the Part 2 answers are multiplied by 2.5 and
averaged. An overall score for the TAI from 1 to 10 is calculated by averaging the scores from Part 1 and 2.

4.5 Statistics

4.5.1 Survey Statistics

Descriptive Statistics were used for subject demographics and the ranked importance of transfer factors.

4.5.2 Motion Capture Collection Statistics

Descriptive Statistics were used for subject demographics. Joint angles were averaged across the four subjects. The discrete range of motion of each joint was compared as well as point to point. One way ANOVA with a significance level of 0.05 was used for joint angles, percent of lift phase of peak muscle activation, heart rate, respiration rate, RPE, and the duration of the phases of transfer to compare the results from each recreational wheelchair at the lower seat height with that of the respective recreational wheelchair at the equal seat height.
Chapter 5: Results

5.1 Online Survey

5.1.1 Subject Demographics

<table>
<thead>
<tr>
<th>Table 5.1 Survey Subject Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCI Level</td>
</tr>
<tr>
<td>SCI Level</td>
</tr>
<tr>
<td>C1-C4</td>
</tr>
<tr>
<td>C5-C8</td>
</tr>
<tr>
<td>T1-S5</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Severity of SCI</td>
</tr>
<tr>
<td>Complete</td>
</tr>
<tr>
<td>Incomplete</td>
</tr>
<tr>
<td>Number of Transfers per Day</td>
</tr>
<tr>
<td>(mean ± standard deviation)</td>
</tr>
<tr>
<td>Vehicle</td>
</tr>
<tr>
<td>Recreational wheelchair</td>
</tr>
<tr>
<td>Toilet</td>
</tr>
<tr>
<td>Bed</td>
</tr>
<tr>
<td>Chair</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Years since SCI (mean ± standard deviation)</td>
</tr>
<tr>
<td>Vehicular</td>
</tr>
<tr>
<td>Medical/surgical complication</td>
</tr>
<tr>
<td>Disease</td>
</tr>
<tr>
<td>Sport/recreation</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Able to Independently Transfer</td>
</tr>
<tr>
<td>Yes, without help</td>
</tr>
<tr>
<td>Sometimes</td>
</tr>
<tr>
<td>No, not without help</td>
</tr>
<tr>
<td>Primary Mode of Mobility</td>
</tr>
<tr>
<td>Manual</td>
</tr>
<tr>
<td>Power</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Owns a recreational wheelchair</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Participates in a sport or recreation</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>
Of the 16 respondents to the survey, nine had a low level SCI, T1-S5, 5 of the remaining respondents reported their SCI between C5 and C8, and the remaining 2 reported their SCI between C1 and C4. The same 2 respondents reported that they were unable to transfer without the help of another individual or an assistive device, that their primary mode of mobility was either a power wheelchair or other, but not a manual wheelchair, and that they did not own a recreational wheelchair or participate in any wheelchair sport or recreation. This finding agrees with the reported abilities of individuals with high SCI.

5.1.2 Quantitative Results

The survey asked in which sports are respondents currently participating and approximately how many hours each week is spent to participating in those sports. Archery, boccia, wheelchair curling, and wheelchair fencing were excluded from Figure 5.1 since no respondent participated in any of those sports. Wheelchair rugby, cycling, and sled hockey had the most participants and the most time per week, with wheelchair rugby being the greatest in both categories. Respondents also participate in rowing, table tennis, wheelchair basketball, wheelchair tennis, and an unidentified other recreation. The most popular sports reported were cycling, wheelchair basketball, and sled hockey (Figure 5.2)

The survey also asked respondents to rate on a scale of the quality of several transfer factors that are mentioned in the TAI[3]. The position of the respondent’s feet during the transfer was rated extremely important by the most people. The location of the rear wheel of the target seat was rated as not at all important by the most people (Figure 5.3).
Each rank of importance was assigned a number from 1 to 5, 1 being not at all important and 5 being extremely important. The mean importance score for each transfer factor was calculated. The means of each of the transfer factors fell between 3, moderately important, and 5 extremely important. The position of the feet was rated the most important transfer factor with a mean score of 4.5, between very important and extremely important. The height of the target seat
was rated the least important of the transfer factors with a mean score of 3, moderately important.

![Figure 5.3 Importance of Transfer Factors](image)

![Figure 5.4 Mean Importance of Transfer Factors ± Standard Deviation](image)

5.1.3 Qualitative Results

The survey included open-ended questions to collect which recreational wheelchairs are currently being utilized and how the users feel about transferring into them. Predominately
respondents are using Top End recreational wheelchairs, including the Force 3 and RX hand cycles and the Schulte basketball wheelchair. All respondents who participated in wheelchair rugby are using a Melrose wheelchair. Some respondents reported using the same recreational wheelchair as others, but many respondents’ answers were unique. All respondents were extremely satisfied with their current recreational wheelchairs with the exception of a Melrose user and an unnamed Top End user who were both somewhat satisfied with their current recreational chairs.

All but one respondent rated the transfers in the current recreational wheelchairs as either very easy or moderately easy. Despite the low importance attributed to the height of the target seat, the predominant reason respondents provided for the ease of their transfers was that the transfer was either level, the seats were the same height, or downhill, the target seat was lower than the everyday wheelchair. The other reason provided was the sturdiness of the recreational wheelchair; it is well fixed in placed during transfers. One respondent rated his or her unnamed low point defensive rugby wheelchair as moderately difficult to transfer into. This respondent cited the lower seat of his recreational wheelchair as one of the reasons for the difficulty of the transfer. This does not agree with the opinion of the majority of respondents. The other reason provided for this user’s difficulty was the lack of brakes on him rugby wheelchair, which may have made the chair more likely to move around during the transfer, and the obstruction of the rear wheels. Because of the rear wheels, the respondent felt that the two wheelchairs could not get close enough to make the transfer easy. This factor was rated the second most important factor for transferring.
5.2 Motion Capture Collection

5.2.1 Subject Demographics

Four subjects participated in the motion capture collection. The average age of the subjects was 38. Two of the subjects’ SCI was at L-1, another at T-12, and the other at T-4. Three of the subjects were male and one female. All subjects were right hand dominant. Three of the subjects’ SCI were incomplete and one was complete. Subjects reported performing between 15 and 50 independent transfers per day. All subjects reported that they used some type of recreational wheelchair other than their everyday wheelchair to participate in a sport or some recreation (Table 5.2).

<table>
<thead>
<tr>
<th></th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
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<td>38</td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td>SCI Level</td>
<td>L-1</td>
<td>T-12</td>
<td>L-1</td>
<td>T-4</td>
</tr>
<tr>
<td>Sex</td>
<td>F</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Dominant Hand</td>
<td>Right</td>
<td>Right</td>
<td>Right</td>
<td>Right</td>
</tr>
<tr>
<td>Complete/Incomplete</td>
<td>C</td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>Transfers per day</td>
<td>20</td>
<td>20-50</td>
<td>15</td>
<td>20-30</td>
</tr>
<tr>
<td>Recreational Wheelchair</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

5.2.2 Joint Angles

Joint angles were analyzed during the lift phase of transfer. Each of the subjects prepared for transfer during the pre lift phase differently, so joint angles during the pre lift phase were not comparable. During the post lift phase subjects checked the adherence of different reflective markers pressing the markers down firmly to make sure they would not fall off. Because this is not a motion that would occur in the subject’s everyday lives when they transfer, the post lift phase is also not shown.
In both Racer and Sport transfers, the glenohumeral joint of the leading arm begins the lift phase at around 30°- 40° of flexion, returns to neutral around halfway through the lift phase, and end the lift phase in approximately 10° in extension. From 30% to 85% of the of the lift phase, the glenohumeral joint is in significantly greater flexion in the Racer at the lower height than that of the equal height (Figure 5.5a) No significant differences were found for the Sport between the equal height and the lower height (Figure 5.5c).

Figure 5.5 Flexion and Extension of the Glenohumeral Joint
The glenohumeral joint of the trailing arm for both the Racer and Sport at each height began the lift phase in approximately the neutral condition. The glenohumeral joint for both Racer heights flexes until it reaches peak flexion of 40°-50° at between 90% and 100% of the lift phase (Figure 5.5b). The glenohumeral joint of the trailing arm for the Sport flexes until reaching peak flexion at approximately 70% of the lift phase and extends to end the lift phase at approximately 20° of flexion (Figure 5.5d). Figure 5.6 shows the flexion and extension of the leading arm and trailing arm for one subject for each recreational wheelchair at each height. No significant differences were found between the two heights for the Racer or the Sport.

![Figure 5.6 Leading and Trailing Glenohumeral Flexion and Extension of One Subject in Each Condition](image)

The range of motion was calculated using the maximum flexion and either the maximum extension or the minimum flexion of the mean joint angles, since the joint did not extend or reach neutral in some of the conditions. For the leading arm, the Sport at the equal height showed the greatest extension of the glenohumeral joint and resulted in the smallest range of motion of approximately 47°. The Sport at the lower height showed the greatest flexion and resulted in the
largest range of motion of approximately 56° (Figure 5.7). For the trailing arm, the Racer at the equal height showed the greatest flexion and the largest range of approximately 48°. The Sport at the lower height showed the greatest extension. The Sport at the equal height showed the smallest range of motion of approximately 38° (Figure 5.8).

![Figure 5.7 Mean Leading Glenohumeral Range of Flexion and Extension](image1)

![Figure 5.8 Mean Trailing Glenohumeral Range of Flexion and Extension](image2)

The glenohumeral joint of the leading arm for the Racer and Sport begin lift phase 45° and 50° of abduction, respectively. Peak abduction occurs at around 15% of the lift phase for
both the Racer and Sport. The leading arm of the Racer and Sport adducts to end the left phase at 15° and 25° of abduction, respectively (Figure 5.9a,c). No significant differences were found between the equal height and lower height for either the Racer or the Sport for the leading arm.

![Figure 5.9 Abduction and Adduction of the Glenohumeral Joint](image)

The glenohumeral joint of the trailing arm begins the lift phase at approximately 20° of abduction. For the Racer, peak abduction of 45° is reached around 75% and 80% of the lift phase for the equal height and lower height, respectively (Figure 5.9b). For the Sport, peak abduction of 35° and 45° for the equal and lower height respectively, occurs around 70% of the lift phase.
for both heights (Figure 5.9d). Figure 5.10 shows the abduction of the leading and trailing arms for one subject for each recreational wheelchair at each height. No significant differences were found between the equal height and lower height for either the Racer or the Sport for the trailing arm.

Figure 5.10 Leading and Trailing Glenohumeral Abduction and Adduction of One Subject in Each Condition

The range of motion was calculated using the maximum and minimum adduction of the mean joint angles. For the leading arm, the Racer at the equal height showed the greatest range of motion of approximately 40° of adduction. The Racer at the lower height showed the least adduction. The Sport at the lower height showed the greatest adduction and the smallest range of motion of approximately 18° (Figure 5.11). For the trailing arm, the Racer at the lower height showed the least adduction but the greatest range of motion of approximately 32°. The Sport at the lower height showed the greatest adduction but the smallest range of motion of approximately 17° (Figure 5.12).
The elbow of the leading arm for the Racer begins the lift phase in approximately 30° of flexion and extends to end the lift phase in approximately 60° of flexion (Figure 5.13a). The elbow of the leading arm is significantly more flexed for the lower height than the equal height from 45% to 60% of lift phase. Peak flexion occurs for the lower height around 50% of lift phase and for the equal height around 30% of lift phase. The elbow of the leading arm for the Sport begins lift phase at around 50° and 35° of flexion for the equal height and lower height.
respectively. Peak flexion occurs at approximately 30% and 40% of lift phase for the equal height and lower height respectively. The elbow of the leading arm for the lower height ends lift phase significantly less flexed, around 45°, than that of the equal height, approximately 65° (Figure 5.13c).

![Flexion Extension of the Elbow Joint](image)

**Figure 5.13** Flexion Extension of the Elbow Joint

The elbow of the trailing arm for the Racer begins lift phase around 30° of flexion and ends the lift phase around 15° of flexion (Figure 5.13b). The elbow of the trailing arm for the Sport begins lift phase around 45° of flexion extends to reach a minimum of approximately 25°
of flexion at around 80% of lift phase and flexes to end lift phase at 30˚ and 40˚ for the equal height and lower height respectively (Figure 5.13d). Figure 5.13 shows the leading and trailing elbow flexion of one subject for each recreational chair at each height. No significant differences were found between the equal height and lower height of the either the Racer or Sport.

The range of motion was calculated using the maximum and minimum flexion of the mean joint angles. For the leading arm, the Racer at the equal height showed the largest range of motion of approximately 44˚. The Racer at the lower height showed the least flexion. The Sport at the equal height showed the greatest flexion. The Sport at the lower height showed the smallest range of motion of approximately 27˚ (Figure 5.15). For the trailing arm, the Racer at the lower height showed the least flexion and the smallest range of motion of approximately 22˚. The Sport at the lower height showed the greatest flexion and the largest range of motion of approximately 32˚ (Figure 5.16).
The wrist of the leading arm for the Racer begins lift phase in approximately 30° of extension and ends lift phase in approximately 60° of extension (Figure 5.17a). The wrist of the leading arm for Sport for the equal and lower height begins lift phase extended to 20° and 30° respectively, reaches peak extension of approximately 60° and 50° respectively around 60% of lift phase, and flexes to end lift phase at 45° and 35° of extension respectively (Figure 5.17c). No
significant differences were found between the equal height and the lower height for the Racer or Sport.

The wrist of the trailing arm for the Racer at equal height and lower height begin lift phase at 70° and 50° of extension respectively, reach peak extension of approximately 90° and 70° respectively around 30 % of lift phase, and flex to end left phase at approximately 40° of extension (Figure 5.17b). The wrist of the trailing arm for the Sport at equal height and lower height begins lift at 60° and 70° of exention respectively,and flexes to end lift ahse at 50° and 40°
of extension respectively (Figure 5.17d). Figure 5.18 shows the leading and trailing wrist flexion of one subject for each recreational chair at each height. No significant differences were found between the equal height and the lower height for the Racer or Sport.

Figure 5.18 Leading and Trailing Wrist Flexion and Extension of One Subject in Each Condition

Figure 5.19 Mean Leading Wrist Range of Flexion and Extension
The range of motion was calculated using the maximum and minimum extension of the mean joint angles. For the leading arm, the Racer at the lower height showed the greatest extension and the largest range of motion of approximately 46°. The Sport at the lower height showed the least extension and the smallest range of motion of approximately 36° (Figure 5.19). For the trailing arm, the Racer at the lower height showed the smallest range of motion of approximately 37°. The Sport at the equal height showed the least extension, and at the lower height showed the greatest extension and the largest range of motion of approximately 64° (Figure 5.20).

The wrist of the leading arm for the Racer and Sport began lift phase with an ulnar deviation of approximately 20° and ended lift phase with an ulnar deviation of approximately 50° (Figure 5.21a, c). No significant differences were found between the equal height and the lower height for the Racer or Sport.

The wrist of the trailing arm for the Racer at equal height and lower height began lift phase at 50° and 35° of ulnar deviation respectively and ended lift phase at 25° and 20° of ulnar
deviation respectively (Figure 5.21b). The wrist of the trailing arm for the Sport at equal and lower height begins lift phase at 50° and 35° of ulnar deviation respectively and ends lift phase at 30° and 20° of ulnar deviation respectively (Figure 5.21d). Figure 5.22 shows the leading and trailing wrist deviation of one subject for each recreational chair at each height. No significant differences were found between the equal height and the lower height for the Racer or Sport.

![Figure 5.21 Radial and Ulnar Deviation of the Wrist Joint](image)

The range of motion was calculated using the maximum and minimum ulnar deviation of the mean joint angles. For the leading arm, the Racer at the equal height showed the least ulnar
deviation. The Sport at the equal height showed the greatest ulnar deviation and the greatest range of motion of approximately 39˚. The Sport at the lower height showed the smallest range of motion of approximately 32˚ (Figure 5.23). For the trailing arm, the Racer at the lower height showed the smallest range of motion of approximately 19˚. The Sport at the equal height showed the least and greatest ulnar deviation as well as the largest range of motion of approximately 38˚ (Figure 5.24).

![Wrist Deviation Graph](image)

Figure 5.22 Leading and Trailing Wrist Deviation of One Subject in Each Condition

The wrist of the leading arm for the Racer begins lift phase pronated to approximately 40˚ and ends lift phase slightly less pronated at 30˚ (Figure 5.25a). The wrist of the leading arm for the Sport at equal height and lower height began lift phase at 50˚ and 30˚ of pronation respectively and ended lift phase at 30˚ and 35˚ of pronation respectively (Figure 5.25c). Figure 5.26 shows the wrist rotation of one subject for each condition. No significant differences were found between the equal height and the lower height for the Racer or Sport.
The wrist of the trailing arm for the Racer at equal height and lower height began lift phase at 10° and 20° of pronation respectively and ended lift phase at 30° of pronation (Figure 5.25b). No significant differences were found between the equal height and lower height of the Racer. The wrist of the trailing arm for the Sport at lower height began lift phase at 10°, significantly less pronated than that of the equal height. By the end of lift phase, both Sport
heights are pronated to approximately 30° (Figure 5.25d). Figure 5.26 shows the leading and trailing wrist deviation of one subject for each recreational chair at each height.

The range of motion was calculated using the maximum and minimum supination of the mean joint angles. For the leading arm, the Racer at the lower height showed the smallest range of motion of approximately 23°. The Sport at the equal height showed the greatest supination and the largest range of motion of approximately 34°. The Sport at the lower height showed the least supination (Figure 5.27). For the trailing arm, the Racer at the equal height showed the least supination and the largest range of motion of approximately 34°. The Racer at the lower height
showed the smallest range of motion of approximately 20°. The Sport at the equal height showed the greatest supination (Figure 5.28).

Figure 5.26 Leading and Trailing Wrist Rotation of One Subject in Each Condition

Figure 5.27 Mean Leading Wrist Range of Rotation
5.2.3 Biceps Brachii Activation

The peak muscle activation of the biceps brachii was calculated to show when during the lift phase it occurred. For the leading arm of both Racer and Sport and for the trailing arm of Racer, the peak muscle activation at the lower height occurred later in lift phase than that of the equal height. The peak muscle activation of the trailing arm of Sport at lower height occurred earlier in lift phase than that of the equal height. The standard deviations of all peak muscle activations were quite large. No significant differences between the peak occurrences of at equal and lower height for either Racer or Sport were found.

Table 5.3 Mean ± standard deviation of the percent of lift phase of the peak biceps brachii activation

<table>
<thead>
<tr>
<th></th>
<th>Racer</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leading Arm</td>
<td>Trailing Arm</td>
</tr>
<tr>
<td>Equal Height</td>
<td>39 ± 23</td>
<td>27 ± 19</td>
</tr>
<tr>
<td>Lower Height</td>
<td>45 ± 27</td>
<td>44 ± 27</td>
</tr>
</tbody>
</table>

Figure 5.28 Mean Trailing Wrist Range of Rotation
5.2.4 Heart Rate and Respiration

The mean of the subjects’ heart rate for both recreational wheelchairs at equal height were found to be less than that of both the corresponding recreational wheelchairs at the lower height, but not significantly different. Although not significantly different, the standard deviation of the subject’s heart rate for both recreational chairs at the equal height was greater than that of the corresponding recreational chairs at the lower height (Table 5.4).

Table 5.4 Mean ± standard deviation of heart rate in beats per minute

<table>
<thead>
<tr>
<th></th>
<th>Racer</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Height</td>
<td>83.4 ±15.1</td>
<td>86.3 ±11.2</td>
</tr>
<tr>
<td>Lower Height</td>
<td>93.1 ± 4.0</td>
<td>94.4 ±7.9</td>
</tr>
</tbody>
</table>

The mean of the subjects’ respiration rate for the Racer at the equal height was less that of the Racer at the lower height, whereas the mean of the subject’s respiration rate for the Sport at the equal height was greater than the Sport at the lower height, though neither were significantly different. The standard deviation of the subject’s heart rate for both recreational chairs at the equal height was greater than that of the corresponding recreational chairs at the lower height, though not significantly different (Table 5.5).

Table 5.5 Mean ± standard deviation of respiration rate in breaths per minute

<table>
<thead>
<tr>
<th></th>
<th>Racer</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Height</td>
<td>28.8 ± 8.8</td>
<td>28.5 ± 4.1</td>
</tr>
<tr>
<td>Lower Height</td>
<td>31.2 ± 4.4</td>
<td>25.3 ± 2.0</td>
</tr>
</tbody>
</table>

5.2.5 Rate of Perceived Exertion

Subjects perceived that transfers for each of the conditions ranged from no exertion, rated as a 6, to more than very, very light exertion, rated an 8. There was no significant difference between the RPE reported between the two heights of the Racers, the two heights of the Sports
the two recreational wheelchairs at equal heights, or the two recreational wheelchairs at the lower heights (Table 5.6).

<table>
<thead>
<tr>
<th></th>
<th>Racer</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Height</td>
<td>7 ± 1</td>
<td>7 ± 1</td>
</tr>
<tr>
<td>Lower Height</td>
<td>7 ± 1</td>
<td>8 ± 1</td>
</tr>
</tbody>
</table>

5.2.6 Time for Transfer

The mean and standard deviation for the time duration of each phases of transfer as calculated. No significant difference was found within the duration of any of the phases of transfer between the equal height and lower height of either the Racer or the Sport. Pre lift and post lift were longer in duration than lift phase, and produced greater standard deviations than lift phase (Figure 5.29).

![Duration of Phases of Transfer](image)

5.2.7 Transfer Assessment Instrument

For the Racer, the mean TAI score for equal height and lower height were 8.8 and 8.5 respectively, so the subjects performed better transfers at equal height though not significantly
so. For the Sport, the mean TAI score for equal height and lower height were 8.5 and 9.0 respectively, therefore the subjects performed better transfers at the lower height, but not significantly so.

<table>
<thead>
<tr>
<th></th>
<th>Racer</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Height</td>
<td>8.8 ± 0.3</td>
<td>8.5 ± 0.7</td>
</tr>
<tr>
<td>Lower Height</td>
<td>8.5 ± 1.1</td>
<td>9.0 ± 0.3</td>
</tr>
</tbody>
</table>

5.2.8 Observations and Subject Comments

During the motion capture collection subjects commented on the study as a whole, the individual trials, their own perceptions and thought processes approaching a new target seat, and their own experiences transferring and participating in sports and recreation outside of the study. Subjects wanted to use their own recreational wheelchairs rather than those provided. Their own recreational wheelchairs had already been fit to them, particularly the width of the seat, and the provided recreational wheelchairs were much larger than the subjects were accustomed to.

Subjects varied greatly in their approach to a transfer. Some subjects preferred to position their legs near the target seat before transferring while others preferred to only remove their feet from the footplate of their wheelchair, stabilize their legs and then reposition them after the transfer. For some subjects this approach differed between the Racer and the Sport. The front bar and tire of the Racer forced some subjects to position their legs around the bar first to prevent catching on it during the transfer. Subjects also were concerned and even distracted by the markers as they had a tendency to fall off and of the wires which connected the electrodes to their corresponding transmitter on the subject’s body. Often a portion of the pre lift and post lift was occupied by the subject touching the markers to make sure they were adhered completely.
One subject even altered her normal technique for moving her legs into position, because the wrist markers would be brushed off accidently.

The subjects employed different strategies during the lift phase as well. Some subjects lifted their body just enough to not catch any part of their wheelchair or the recreational wheelchair, swung their body horizontally, and then landed on the recreational chair. One subject exhibited an almost hopping motion to pick up her body and drop it into the seat of the recreational wheelchair. The subject’s chosen strategy remained consistent for each recreational wheelchair and at each height.

Although both recreational wheelchairs were secured to the floor, subjects commented that the Sport felt less stable than the Racer because of its ability to swivel unlike the Racer. Some subjects commented that the transfers were easier since the recreational chairs were secured to the floor unlike in an ordinary situation. Subjects also commented that the Racer was easier to transfer into because it did not have a cage like the Sport. Conversely, the front bar and tire of the Racer was said to be a hindrance which made the transfer more difficult.
Chapter 6: Discussion

6.1 Sports and Recreation Participation

The results of individuals with SCI and their participation in sports in recreation is inconsistent. This may be due to the small number of respondents to the survey. There is approximately the same number of respondents who spend a many hours each week devoted to a single sport. The assumption may be that those sports are team-based and require many pre-scheduled practices or competitions. This may be true for wheelchair rugby, one of the most time-consuming sports reported, as it is a team sport, but it is not true for cycling, the other most time-consuming sport reported, as it is typically a solitary sport. Perhaps wheelchair rugby and cycling require more time spent in order to remain competitive.

An unanticipated result is that many respondents participated in multiple sports.

6.2 Phases of Wheelchair Transfer

The pre lift phase of transfer is easy to identify as it begins with the subject begins to prepare for the transfer and ends when their buttocks leaves the seat, but what occurs during the phase is more difficult to quantify. For the pre lift phase of transfer, many subjects performed the same actions, such as scooting to the front of the seat and positioning their legs and arms, but in a different order or multiple times. Some subject performed other actions as well, such as touching the markers and adjusting their clothing. The order of the transfer preparations and the number of adjustments that the subject must do during pre lift may increase the duration of the
phase, but do not affect the success of the transfer provided that the subject is positioned correctly when lift phase begins.

Variations in the kinematics of lift phase are due in part to the positioning the subject has completed when the phase begins and in part to the subject’s target seat. At the beginning of lift phase the subject’s leading shoulder is flexed and abducted and the leading elbow is slightly flexed to allow the subject to reach the target seat. The leading wrist is supinated as the palm of the hand lies flat on the target seat. The wrist remains in supination even if the subject improperly places a fist on the target seat rather than a flat palm. The leading wrist is radially deviated to turn the hand in toward the subject’s body and provide more support. The wrist is extended if the hand is palm down on the target seat. If the subject places a fist on the target seat instead the wrist can be either in the neutral position or even slightly flexed. To prepare to support body weight, the trailing shoulder is in the neutral position near the subject’s side and slightly abducted to allow the arm to reach and hold the edge of the seat. The trailing elbow is flexed and ready to extend to help propel the body to the target seat. The trailing wrist is in extension, supination, and slight radial deviation to allow the hand to grip the edge of the seat. As lift phase continues, the leading shoulder extends, adducts, and, as the body comes to rest on the target seat, reaches the neutral position and extend slightly. The leading shoulder reaches neutral around 50% of lift phase when the seats are of equal height. The leading shoulder may reach neutral later in the lift phase when the target seat is lower than the starting seat since the shoulder must compensate for the greater distance. The leading elbow extends slightly and then flexes more through the second half of lift phase to allow for a smooth and controlled landing. If the target seat is lower than the starting seat, the leading elbow may extend more before flexing and may reach minimum flexion later in lift phase than if the seats were of equal height. It may
also begin to extend again in the last 20% of lift phase. The leading wrist extends more and then around 50% of lift phase flexes, but not enough to return to the original extension. The leading wrist undergoes further radial deviation for support. Overall the supination of the leading wrist remains the same throughout lift phase, with some fluctuates which may be due to the compressibility of the target seat. When the target seat is lower than the starting seat, the leading wrist may supinate much less than if they were equal, but not so much that it reaches neutral.

Post lift phase is varied much like pre lift phase. There is no consensus on kinematics, because the actions performed by the subject can differ greatly. In post lift phase the subject can move their body to a more comfortable position in the seat, adjust their clothing that may have moved during lift phase, and reposition their feet on the footplate. These actions can be completed in any order with some omitted entirely.

6.3 Seat Heights

None of the energy expenditure metrics showed a significant difference in the exertion between transferring to a target seat that is equal to or less than the starting seat. The subjects’ heart rates and respiration rates did not differ which is not entirely unexpected since the duration of the transfer is so short. The subjects themselves did not perceive any change in exertion as evidenced by their almost completely constant RPE scores. There was no significant difference in the time of the lift phases of the transfers that may have shown a change in difficulty. A difference of 10 centimeters in height is not large enough to produce a change in exertion, especially since the subjects transferred down to a lower height rather than up to a higher height.
6.5 Transfer Assessment Instrument

According to the high TAI scores, individuals are generally following the recommendations outlined in the TAI. The areas where they lost points were fairly consistent for each subject and between subjects. Many points were lost for improperly gripping either the leading or trailing arm. Subjects would plant their hand in a fist on each seat rather than gripping the handgrip, seat, or wheel. The recreational wheelchairs used each had a wide seat in order to accommodate a large number of people. Typically, an individual’s recreational wheelchair is fit to their size. It may be that the improper leading hand position was used because the individuals could not comfortably reach across to the opposite side of the recreational wheelchair to grip the seat or opposite wheel. Had the recreation wheelchair been the proper size for the subject, perhaps a proper hand grip could have been used.

Additionally, the respondents of the survey and the subjects in the motion capture collection showed that they were aware of the guidelines in the TAI. Respondents to the survey reported the importance of many of the statements made in the TAI. Some respondents repeated the statements again when they were asked the reason for the ease of their transfers. They most often reported that the downhill transfer was easier. Subjects in the motion capture collection mentioned some of the statements in the TAI to the research staff unprompted during the collection. Subjects noted that they needed to position their own wheelchair to avoid the rear wheels of the recreational wheelchair. The subject may have been citing the TAI specifically, but they were certainly in agreement with many of its statements. The TAI is a good assessment of the quality of independent transfers and largely represents the technique of successful transfers that individuals are utilizing currently.
6.5 Comparison with Literature

The upper limb joint angles and their pattern of motion during lift phase of transfer found in this study are consistent with those found by Gagnon et al.[6]. The maximum and minimum flexion of the elbow joint are consistent with those found by Koontz, et al.[7] Muscle activation findings are not in complete agreement with those found by Gagnon et al. which show a clear peak in muscle activation around 50% of lift phase[1].

6.6 Limitations

The low number of survey respondents prevents any meaningful speculation on the population of individuals with SCI as a whole.

The motion capture collection alone has many limitations. An independent transfer is a movement of short duration. Therefore, it is difficult to capture exertion metrics when there is such a small period of time between rest. Additionally, the body twists and bends during the transfer which increases the likelihood that markers will be blocked by the subject’s body and not recorded or knocked off as the subject does not usually wear them during a transfer and therefore account for their position. This can create large gaps in the kinematic data that cannot be retrieved. Lastly, a very low number of subjects were able to be recruited for the motion capture collection. Those that were recruited all were either active members in a wheelchair sport team or regularly participated in physical recreation. Because of their fitness, independent transfers were low effort for them which did not result in any meaningful differences in their exertion.
Chapter 7: Conclusion

7.1 Specific Aims

The first aim, to characterize periods of transfer by kinematics of upper limbs and muscle activation, was accomplished successfully for lift phase of transfer, but not for pre lift phase or post lift phase. Pre lift phase and post lift phase are too varied in activities to be reliably characterized by the upper limb joint angles or muscle activation.

The second aim, to determine target seat heights which require higher energy expenditure and/or more time for transfer was answered unexpectedly. Heart rate, respiration rate, RPE and the duration of transfer showed no difference between the effort exerted for the two seat heights. Neither seat height required more or less exertion than the other.

The third aim, to rate adherence to guidelines of the TAI, was accomplished. All subjects earned high scores on the TAI which shows that they adhere closely to the TAI.

Lastly, the fourth aim, to determine the prevalence of sports and recreation participation in the population and the users’ satisfaction with their current recreational wheelchairs, was accomplished through the survey results. Respondents participated in a variety of wheelchair sports for anywhere to a few hours a week to more than 6 hours a week. Overwhelmingly, respondents were satisfied with their currently used recreational wheelchair.

7.2 Contribution to the Field

Results from this study contributed to the body of knowledge of the kinematics associated with independent transfer in an environment more similar to the subject’s everyday life. Previous studies which have examined the biomechanics of independent wheelchair transfer
did so under conditions unlike those in which individuals with SCI would normally complete a transfer. This study utilized the subject’s own wheelchair as well as a recreational wheelchair which can both be positioned to the subject’s preference rather than a table[1] or two seats at a fixed angle[6].

Furthermore, this study makes a case for individuals with SCI who do not currently participate in wheelchair sports to begin participating. Results from the survey show that individuals do not need to devote a large portion of their time to a sport; many respondents spend 2 hours or less a week in their chosen sport. Clearly from the survey results, those who are currently participating in a wheelchair sport are satisfied with their recreational wheelchairs and overwhelming find transferring into them to be easy. The low RPE scores from the motion capture study agree with this. For individuals who may find joining a sport team or participating in recreation post injury intimidating or fear that it the exertion would be too much for their level of fitness or ability, this study shows those fears to be unfounded. These findings can be used to support and promote increased participation in sport and recreation for this population which has been shown to be of great benefit physically and mentally[12-14].

7.3 Future Studies

Continuing the motion capture collection to increase the number of subjects may improve results. In future iterations of the study, also analyzing trunk tilt which was not possible in this study due to marker drop out. Rather than using markers adhered to the subject’s skin which are easily knocked off during transfer, a different wearable sensor which can be strapped to the subjects and still provides kinematic data would be advisable. A different wearable sensor may also allow for the collection of pelvis kinematics to calculate trunk tilt since it would not rely on cameras, and thus not be hidden by the subject’s wheelchair. Additionally, collecting other
upper limb and torso muscle activation would provide richer data than merely bicep brachii activation.

Rather than aggregating several subjects into one, this approach of this study may be more beneficial on an individual level. Large standard deviations in the joint angles may imply large differences between the subjects' kinematics during lift phase. Collecting on individuals and comparing to themselves may yield more clear conclusions, if only for that individual. For example, this method of motion capture may be a helpful tool when a newly injured individual is completing rehabilitation and is first learning how to transfer. In the long term, it can reveal how the individual has progressed and improved over time or, in the short term, highlight areas of in need of improvement.
References


Appendix A: Transfer Assessment Instrument

Table 1: The first 7 questions of Part 1 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, Archives of Physical Medicine and Rehabilitation, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.

<table>
<thead>
<tr>
<th>Part 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The subject’s wheelchair is within 3 inches of the object to which he is transferring on to.</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• This item is N/A for a person using a transfer lift.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>2. The angle between the subject’s wheelchair and the surface to which he is transferring is approximately 20-45 degrees.</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• This item is N/A for a person using a transfer lift.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>Front of chair</td>
<td>20-45°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The subject attempts to position his chair to perform the transfer forward of the rear wheel (i.e., subject does not transfer over the rear wheel).</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• This would be N/A for a person using a transfer lift or a PWC or standing pivot transfer.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>4. If possible, the subject removes his armrest or attempts to take it out of the way.</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• If help is required, the subject asks an assistant in a clear and assertive manner.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>• This would be N/A for a person using a transfer lift, who does not have arm rests or the arm rests/sidewards are hulled into the chair.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>5. The subject performs a level or downhill transfer, whenever possible.</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• Seat cushion is at least level with the surface to which the subject is transferring.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>• N/A for a person using a transfer lift.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>6. The Subject places his feet in a stable position (on the floor if possible) before the transfer.</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• If help is required, the subject asks an assistant to position his feet in a clear and assertive manner.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>• N/A for a person using a transfer lift.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>7. The subject scoots to the front edge of the wheelchair seat before he transfers (i.e., moves his buttocks to the front 2/3rds of the seat).</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>• If help is needed, the subject asks an assistant to scoot him to the front 2/3rds of the chair in a clear and assertive manner (the subject specifically tells the evaluator what position on the chair he needs to be scooted to).</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>• N/A for a person using a transfer lift and standing pivot transfer.</td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
<td><strong>N</strong></td>
</tr>
</tbody>
</table>
Figure A.2 The last 7 questions of Part 1 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, Archives of Physical Medicine and Rehabilitation, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.
Figure A.3 The first 3 questions of Part 2 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, *Archives of Physical Medicine and Rehabilitation*, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.
Figure A.4 Questions 4 through 7 of Part 2 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, *Archives of Physical Medicine and Rehabilitation*, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.
Figure A.5 Questions 4 through 7 of Part 2 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, *Archives of Physical Medicine and Rehabilitation*, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.
<table>
<thead>
<tr>
<th>Part 2, continued</th>
<th>0 - Strongly Disagree</th>
<th>1 - Disagree</th>
<th>2 - Neutral</th>
<th>3 - Agree</th>
<th>4 - Strongly Agree</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. The transfer is smooth and well controlled.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>9. For any assistance the subject needs, he is able to clearly communicate his needs in an assertive and polite manner.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>10. The subject does not allow the assistant to pull on his arms during the transfer.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>11. The subject corrects the assistant if the assistant attempts to perform the transfer in an unsafe manner, (i.e., pulling on arms, transferring uphill when a downhill transfer is possible)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>12. The subject is able to correctly direct his care in an assertive and polite manner.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Performance Criteria:

**Strongly Agree.** The subject performs the tasks in a consistent manner throughout the entire session. Performing the task appears to be the subject's natural movement. The subject does not appear to have to think deeply about the task.

**Agree.** The subject performs the tasks on a fairly consistent basis approximately 67-80% of the time, but appears to require extra time to think about the task. The task is not a natural movement, but a forced activity.

**Neutral.** The subject performs the task correctly approximately 44-66% of the time. The subject does not perform the tasks consistently and appears uncertain as to how the task should be performed.

**Disagree.** The subject performs the task correctly 25-44% of the time. The subject appears to be putting minimal thought into the correct procedure, and performing the transfer with little regard for technique.

**Strongly Disagree.** The subject performs the task incorrectly during the entire session. The subject displays no regard for the proper technique to be used and simply performs the transfer that is being asked. If the subject performs the task correctly, it is by coincidence only.

Figure A.6 The last 5 questions of Part 2 of the TAI. Note. From "Basic psychometric properties of the transfer assessment instrument (version 3.0)" by C-Y. Tsai, C. Hoelmer, M. L. Boninger, and A. Koontz, Archives of Physical Medicine and Rehabilitation, vol. 94, pp. 2456-64. Copyright 2013. Reprinted with permission.
Appendix B: Copyright Permission

The email thread below provides permission for the use of the TAI in Appendix A.

---

From: Lam, Michael <michael.lam@pitt.edu>
Sent: Tuesday, October 13, 2020 3:00 PM
To: Koontz, Alicia M <akoonzt@pitt.edu>
Subject: Re: Transfer Assessment Instrument Use Permission Request
Importance: High

Dr. Koontz, please see below.

Michael Lam
Communications Specialist
Human Engineering Research Laboratories
6422 Penn Avenue, Suite 400, Pittsburgh, PA 15206
412-278-6989  http://www.herl.com

---

From: Fults, Ashleigh <afults@ufl.edu>
Sent: Tuesday, October 13, 2020 3:56 PM
To: Lam, Michael <michael.lam@pitt.edu>
Subject: Re: Transfer Assessment Instrument Use Permission Request

---

Good afternoon Michael,

I am a master’s student in Biomedical Engineering at the University of South Florida currently working on my thesis titled Biomechanics of Independent Wheelchair Transfer in Individuals with Spinal Cord Injury. For one metric in my thesis, I used the Transfer Assessment Instrument 3.0 developed at the University of Pittsburgh to evaluate the transfers of my subjects. I wanted to include the TAI in the appendix of my thesis. My thesis will eventually be openly accessible in our Institutional Repository.

I would like to request permission for republication of the TAI 3.0 evaluation sheet in my thesis. Please let me know if you have any questions.

Ashleigh Fults
Student Research Assistant
Center for Assistive, Rehabilitation and Robotics Technologies
University of South Florida

---
Appendix C: Sports and Recreation Survey

Please answer each question completely and truthfully. We do not anticipate any of the following questions to cause you distress. However, if at any time while you are answering this survey a question makes you feel uncomfortable or causes you distress, stop and do not continue with the survey. Remember that this survey is voluntary, and you do not have to submit any answers if you do not want to.

Select your sex.

- Male
- Female
- Prefer not to say
Select your birthday.

Month
Day
Year

Select your ethnicity.

☐ White
☐ Hispanic or Latino
☐ Black or African American
☐ American Indian or Alaska Native
☐ Asian
☐ Native Hawaiian or Pacific Islander
☐ Other

For how many years have you been injured with your SCI?

Select your level of spinal cord injury.

☐ C1-C4
☐ C5-C8
☐ T1-S5

Select the severity of your spinal cord injury.

☐ Complete
☐ Incomplete
Select the cause of your spinal cord injury.

- [ ] Vehicular
- [ ] Sport/recreation
- [ ] Fall
- [ ] Medical/surgical complications
- [ ] Disease
- [ ] Violence
- [ ] Other

Can you transfer yourself without help into and out of your wheelchair?

- [ ] Yes, I can transfer myself without any help every time.
- [ ] Yes, I can transfer myself without help, but sometimes I require help from a person and/or device.
- [ ] No, I cannot transfer myself without help.

Select your primary mode of mobility.

- [ ] Manual wheelchair
- [ ] Power wheelchair
- [ ] Other
What is the model of wheelchair you selected for the previous answer? If you selected Other in the previous question, please specify.

Approximately how many times per day do you transfer into/out of the following things?

Number of transfers into each thing per day

- Vehicle
- Recreational wheelchair
- Toilet
- Bed
- Chair
- Other

<table>
<thead>
<tr>
<th>How many hours per week do you participate in the corresponding sport/recreation?</th>
<th>Wheelchair Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Less than 1 hour</td>
</tr>
</tbody>
</table>

- Archery
- Boccia
- Cycling
- Rowing
- Sled Hockey
- Table Tennis
- Wheelchair Basketball
- Wheelchair Curling
- Wheelchair Fencing
- Wheelchair Rugby
- Wheelchair Tennis
- Other
How difficult do you find transferring from your primary wheelchair into your Placeholder?

Very easy  
Moderately easy  
Neither easy nor difficult  
Moderately difficult  
Very difficult

Why is it difficult to transfer from your primary wheelchair into your Placeholder?

How satisfied are you overall with your Placeholder?

Extremely satisfied  
Somewhat satisfied  
Neither satisfied nor dissatisfied  
Somewhat dissatisfied  
Extremely dissatisfied
How important are the following factors for making a transfer into a recreational chair successful and easy for you?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Not at all important</th>
<th>Slightly important</th>
<th>Moderately important</th>
<th>Very important</th>
<th>Extremely important</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proximity of your wheelchair to the recreational wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your wheelchair in contact with the recreational wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The location of the rear wheel of the recreational wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The angle between your wheelchair and the recreational wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The height of the recreational wheelchair compared to the height of your wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The position of your feet before you transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your location on the seat of your wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The location of the leading arm before transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The location of the trailing arm before transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: Subject Questionnaire

The form below is the Subject Questionnaire which all in-person subjects answered to determine their eligibility for the study.

[Subject Questionnaire form]

Title: Biomechanics of Independent Pivot Transfers for Recreational Wheelchairs
IRB Study Fast 06/13/726

The following questions are in regards to your general medical history. If at any time you have questions or concerns, please bring them up to a member of the study team.

Last Name: 
First Name: 

Phone Number: 
Email Address: 

Birth Date: 
SCT Level: 
Weight: 

Circle your answer:

Gender: Male Female Do Not Wish to Disclose

Dominant hand: Left Right

ALS A-Impairment levels: A B C D E

Circle Yes or No to the following questions:

Can you complete a wheelchair transfer without help? Yes No

Have you had a prior shoulder surgery? Yes No

Do you have a neuromuscular or musculoskeletal disorder which affects your arms? Yes No
Appendix E: IRB Approval for STUDY000997

The letter below from the USF Institutional Review Board approved the protocol for STUDY000997 for Review Exemption on June 10 2020.
Appendix F: IRB Approval for Initial Review of Pro00036726

Appendix G: IRB Approval for Continuing Review of Pro00036726