# THE IMPACT OF TRANSFER SETUP ON THE PERFORMANCE OF INDEPENDENT TRANSFERS

by

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University of Pittsburgh, 2011

For individuals who rely on wheeled mobility devices (WMD), performing transfers is essential to independence with activities of daily living at home and participation in the community. Transfers are required for getting to and from the device to bed, bath tub, car seat, among others. The United States Access Board develops guidelines and maintains design criteria for the built environment to maximize accessibility to public places. The objective of this study was to analyze the impact of transfer setup on performance of independent transfers. The first aim of the study was to perform an expert review of the current knowledge regarding transfers and the impact of setup. Results showed a consensus among studies that transferring to a higher surface implies greater exertion of the upper limb. Yet, there is no evidence concerning height differences, horizontal distance, and space needed next to the target surface so it can be accessible by a majority of WMD users. The second aim was to compare the current guidelines for amusement park rides with the results obtained by evaluating the impact of setup on transfer performance using a custom-built transfer station. We evaluated community-dwelling WMD users who were able to transfer independently and who represented a broad spectrum of disabilities. We evaluated the impact of height differential, gap, placement of a non removable armrest, and the effect of a grab bar. Results showed that height differentials above and below WMD height, gaps and obstacles pose serious transfer-related accessibility problems for WMD users. Current guidelines for amusement park rides fall short in terms of height recommendations and space available for the WMD and could exclude up to 72% of our sample. The third aim was to evaluate the relationship between functional performance (i.e. upper limb strength and trunk control) and transfer ability in people with spinal cord injury. Results found that trunk stability and gender are significant predictors of transfer ability. Rehabilitation plans should include balance training and core strengthening in addition to upper limb conditioning when teaching transfer skills. Improving transfer ability has the potential to increase community participation and independence among WMD users.

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# 1.0 INTRODUCTION

The United States Architectural and Transportation Barriers Compliance Board[1] (Access Board) is an independent Federal agency dedicated to accessibility for people with disabilities. The Board is in charge of developing and maintaining design criteria for the built environment, transit vehicles, telecommunications equipment, and for electronic and information technology. It sponsors and coordinates research to develop information for its use in developing or updating these accessibility guidelines. This research program is focused on the study of accessibility relating to architecture and design, communication, and transportation.

In 2002 the board published the Accessibility Guidelines for Recreation Facilities for newly construct or altered recreation facilities ("Accessibility Guidelines for Recreation Facilities," 2002). These facilities include amusement rides, boating facilities, golf courses, and shooting facilities among others. These guidelines establish minimum accessibility requirements to provide a general level of usability for people with disabilities. The recreation facility guidelines were developed with significant public participation by establishing an advisory committee composed from representatives from different group an organizations such as American Ski Federation, Disabled American Veterans, Self Help for Hard of Hearing People, and Walt Disney Imagineering among others. The public was given an opportunity to comment

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[1] US Access Board. http://www.access-board.gov/about.htm

on the guidelines and the Board made changes based on this input. However, these recommendations were not based on evidence and provide limited specifications concerning design criteria for facilitating the transfer process. For instance, current standards have criteria only related to seat height and clear floor space for wheelchair users (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003).

The Access Board requires data on transfers to develop guidelines (e.g. design criteria) for the purposes of making recreational devices accessible to persons with mobility impairments. The primary goal of this project is to determine acceptable ranges for non-level transfers (e.g. vertical height differences), gaps between the target and wheelchair, and the clear space (length/width) needed to position the wheelchair in proximity to the target. A secondary goal is to study the relationship between physical capacity (e.g. strength and balance control) and transfer performance. The target sample required community-dwelling wheeled mobility device users who were able to transfer independently (with or without a transfer board) and who represent a broad spectrum of disabilities. Participants in the study were assessed in a repeated measures fashion. They performed up to 50 transfers under a variety of combinations of height and gap in addition to when a side guard and/or a handle to grab onto was present to facilitate transfers into a custom-build modular transfer station. Primary data consisted of recording the maximum ranges attainable for each setup parameter (e.g. maximum height achieved).

The first chapter of this study is a literature review that sought expert opinion on the relevance and strength of the evidence concerning set up and transfer performance. Our goal was to evaluate the specific relevance related to transfer setup (i.e. vertical transfer distance; transferring across gap; number of transfers to go from the initial location to final surface; use of transfer assistive device). Our study revealed a small number of studies that directly relate to the influence of transfer setup on performing independent transfers and thus points to a critical need for more studies in this area. The strength of the evidence was generally considered to be low, calling for stronger research designs to be employed in future studies on transfers.

The second chapter is a study that was performed on 120 community dwelling wheeled mobility device users to collect data on wheelchair transfers in order to make recreational facilities more accessible for people with mobility impairments. The aims included to study environmental variables such as height differential (up/down), gaps between the target and wheelchair, clear space needed to position the wheelchair, and describe how transfer ability was affected by placing an obstacle (i.e. non-removable armrest) between the mobility device and the destination surface, and by providing a grab bar in front of the destination surface. Findings fell short to current ADA standards.

The third chapter studied the relationship between physical function and ability to perform varying transfer ranges for a sub-set of the sample studied in Chapter 2 (54 subjects with spinal cord injury). The specific aims and hypothesis of this study included:

**Specific Aim 1:** Determine which subject specific factors are best predictors of transfer ability.

**Hypothesis 1a:** Subjects with greater upper limb strength and trunk balance measured by manual muscle test and the Modified Functional Reach Test (MFRT) respectively have greater ability to transfer to higher, lower and/or farther surfaces.

**Hypothesis 1b:** Subjects with greater grip strength measured by hand-held dynamometer have greater ability to transfer to higher, lower and/or farther surfaces.

**Hypothesis 1c:** Subjects with lower body mass index (BMI) measured by weight and height have greater ability to transfer to higher, lower and/or farther surfaces.

Our findings pointed out trunk balance as the stronger predictor of transfer ability.

# 2.0 EXPERT REVIEW OF THE SCIENTIFIC LITERATURE ON INDEPENDENT WHEELCHAIR TRANSFERS

## 2.1 ABSTRACT

Purpose

The purpose of this study was to perform a literature review and seek expert opinion on the relevance and strength of the evidence concerning set up and transfer performance.

Methods

Scientific literature databases were searched until June 2009 using 43 keywords resulting in 339 articles. These were internally reviewed and narrowed to 41 articles which were formally assessed by thirteen external experts. Articles that 80% or more of the reviewers scored as moderately or highly relevant were included in the final results.

Results

Nineteen articles met the relevancy criteria. The aspects of setup that experts felt were addressed to some degree included vertical transfer distance, transferring across a gap and position of the mobility device relative to target destination. None of the 19 articles were scored as having strong to very strong resulting evidence.

Conclusions

There is a consensus among studies that transferring to a higher surface implies greater exertion of the upper limb. However, there is no evidence concerning how high or low, how close, and how much space is needed next to the target surface so it can be accessible by a majority of wheelchair users.

Keywords: wheeled mobility, activities of daily living, accessibility standards

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## 2.2 INTRODUCTION

For individuals who rely on wheeled mobility devices, performing transfers is essential to achieving independence with activities of daily living (ADL) in the home and full participation in occupational and social activities in the community. For example, transfers are required for getting to and from the device to bed, bath tub/shower seat, commode seat, motor vehicle seat and so on. The United States (US) Access Board develops and maintains design criteria for the built environment to maximize accessibility to public places. These criteria are described in the Americans with Disabilities Act Accessibility Guidelines (ADAAG) ("ADA accessibility guidelines for buildings and facilities (ADAAG)," 2002) which were developed by a team of experts and public input. Little information is provided in the guidelines concerning design and space requirements to enable accessible wheelchair transfers to elements in the built environment (e.g. commode). In 2002, the Board published a revision to these guidelines which included recommendations for transfers in recreation facilities (e.g. amusement park rides). However, again these recommendations were not based on evidence and provide limited specifications concerning design criteria for facilitating the transfer process (ADAAG, Section 15) (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003) which consists of transfer height requirements and clear space allowances for positioning of the mobility device. There is no guidance on gap size (e.g. horizontal distance separating the wheelchair and target surface); space allowances for feet and legs around the target surface, physical obstacles present near or on the target surface (e.g. side rail) and target surface firmness.

Transfers have been ranked among the most strenuous wheelchair-related activities (Bayley, Cochran, & Sledge, 1987; Drongelen et al., 2005) and are believed to be a major contributor to the development of upper limb pain and injuries (Dyson-Hudson & Kirshblum, 2004). Within the scientific community there has been a recent surge of interest in investigating transfers for the purposes of understanding the etiology of upper limb pain and injury and to identify movement strategies that are more efficient and safer for individuals (Gagnon et al., 2009; Kankipati, Koontz, Boninger, & Lin, 2009; Kankipati, Koontz, & Turkovich, 2008). In this study, we sought to identify evidence in the literature that would provide insight into the burden that setup has to the performance of independent transfers. The purpose of this study was to conduct a literature review and seek expert opinion on the relevance and strength of the evidence concerning setup and transfer performance. Independent transfer was operationally defined as a transfer by which the individual requires no human assistance to perform. Setup was broadly defined as environmental type factors that impact transfer performance such as height and gap differences, space available next to the target element, and obstacles near or around transfer surfaces.

Results from the study will be used to identify where additional research is necessary to help define optimal design characteristics for transfer surfaces that have the least negative impact for community-dwelling wheeled mobility devices users.

## 2.3 METHODS

### 2.3.1 Literature Review Process

Scientific and medical databases were searched until June 2009 using Scopus (1966 to 2009), OVID Medline® (1950 to 2009), Compendex (1969 to 2009), and EMBASE (1974 to 2009). Keywords used in this literature review in alphabetical order were: wheelchair + activities of daily living; biomechanics; efficiency; electromyographic; force; force plate; function; functional electrical stimulation; gait; isokinetic; kinematics; kinetics; measurement system; moment; motion analysis; movement; muscle balance; muscular demand; orthosis; paralysis; paraplegia; rehabilitation; scapula; shoulder; spinal cord injury (SCI); stroke; SCI patient; shoulder impingement; standing up; task performance and analysis; technology; tetraplegia; torque; torque ratio; transfer; transfer motion; transfer strategy; transfer movement strategies; upper extremity; upper limb; weight-bearing; and three dimensional kinematics. These keywords were chosen based on the authors' expertise and background knowledge of the field, clinical and research experiences involving training and assessment of transfer performance. Three-hundred and thirty-nine articles (excluding duplicates) were initially identified by keyword search, followed by backward searching and finishing with forward searching (Levy & Ellis, 2006).

### 2.3.2 Expert Review and Scoring Procedures

Titles and abstracts of the articles were reviewed internally by two experts with at least four years of direct clinical and research experience working with full-time wheelchair users. Articles that both experts agreed were relevant to the performance of independent wheelchair transfers were selected for the next step of review. Thirteen external reviewers who are collaborators and work in the assistive technology and/or the rehabilitation field were invited to participate in a study to formally evaluate the remaining studies. Two reviewers held at minimum a bachelors degree, seven reviewers masters degree, one was a physician and three held PhD degrees. All the reviewers had greater than five years of clinical research and/or practical clinical experience. The study was approved by the University of Pittsburgh Institutional Review Board.

External reviewers were sent a cover letter that described the purpose of the study and asked them to score each of the articles identified by the internal reviewers using a scoring sheet specifically devised for this study (Figure 1). For question one, if a reviewer responded that they have no expertise to evaluate the article, the reviewer did not complete the subsequent questions and was instructed to proceed to the next article. As a result, when an article was not reviewed, his/her data were not considered when calculating the highly/moderate relevance frequency count. Question two asked how relevant the article was to the performance of independent transfers in general and was scored zero- not relevant to three- highly relevant. Question three provided a list of items pertaining to transfer setup that were generated in consultation with the US Access Board. These items were also scored like question three on a zero to three relevancy scale. Question four was scored zero- Case study, nonsystematic review, or similar very weak design, to five- Systematic review or meta-analysis of randomized trials based on the hierarchy of research design as described in the Spinal Cord Medicine Clinical Practice Guideline (Medicine, 2005). To verify study type design, all studies were evaluated by a research methodologist external to the study.-Finally, the strength of the resulting evidence was scored zero- weak resulting conclusions to 3- very strong resulting conclusions.

Please rate the following:

1. **Your expertise to evaluate this article**
   ☐ No expertise in this area (***please skip to the next article)***
   ☐ Minimal level of expertise in this area
   ☐ Moderate level of expertise in this area
   ☐ High level of expertise in this area

2. **Relevance of the research topic**
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant

3. **Relevance of the research topic to performing independent transfers**
   **a)** vertical transfer distance (up and down)
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **b)** transferring across a gap (e.g. space between the initial location and final destination)
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **c)** number of transfers to go from the initial location to the final destination
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **d)** use of transfer assist devices
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **e)** position (in three dimensions) of mobility device relative to final transfer destination
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **f)** location and characteristics of effective supports to aid with transferring
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **g)** constrained space available for transfers
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **h)** physical obstacles or barriers present while transferring
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **i)** transferring into a device that is capable of moving
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant
   **j)** transferring to/from an unstable of soft surface
   ☐ Not relevant ☐ Minimally relevant ☐ Moderately relevant ☐ Highly relevant

4. **Strength of the research study**
   ☐ Systematic review (or meta-analysis) of randomized trials
   ☐ Randomized clinical trial
   ☐ Systematic review (or meta-analysis) of observational studies (case-control, prospective cohort, and similar strong designs)
   ☐ Single observational study (case-control, prospective cohort or similar strong designs)
   ☐ Case series, pre-post study, cross sectional study, or similar design
   ☐ Case study, nonsystematic review, or similar very weak design

5. **Strength of the resulting evidence**
   ☐ Weak resulting conclusions ☐ Intermediate resulting conclusions
   ☐ Strong resulting conclusions ☐ Very strong resulting conclusions

**Figure 1.** Scoring sheet used to score the articles

### 2.3.3 Data Analysis

The frequency of reviewers' responses on question 2 for answers of moderate and high relevancy of the topic was calculated. Articles that 80% or more of the reviewers scored as moderately or highly relevant to the research topic were included in the results. For these articles, a mean score of the reviewers' responses were tabulated for each of the remaining items on the scoring sheet. Item means rather than frequencies were computed so that articles could be ranked by their relevance score.

## 2.4 RESULTS

The two internal experts identified forty-two articles related to the performance of independent wheelchair transfers. One of these articles was a peer-reviewed conference proceeding and was excluded from further analysis. One of the articles was a literature review (Nyland et al., 2000) and the remaining articles were all original research. Nineteen of the 41 articles met the inclusion criteria of relevance based on the external reviewers percentages. Table 1 includes all 19 articles and the average scores of the reviewers. The articles that did not meet the relevancy criteria are listed in Table 3.

In general the 18 original research studies contained small sample sizes (ranging from one to 36) and a mixture of case, descriptive, pre-experimental and case-control studies (Table 1). A majority of studies focused on a spinal cord injury population. Most of the studies measured biomechanical or electromyographic variables while subjects performed sitting-pivot transfers (also referred to in the literature as depression, side-approach, or lateral transfers). The term sitting-pivot transfers will be used from this point forward for clarity. This is the most common transfer incurred in daily living because it works for a variety of level and non-level surfaces (e.g. from a wheelchair to/from vehicle, bed, commode, etc.) (Somers, 2001). The sitting-pivot transfer entails bringing the buttocks forward towards the edge of initial surface, placing feet in a stable position on the floor, leaving one hand on the initial surface (trailing) while placing the other hand on the target surface (leading). Then muscles in the arms are used to push up off of the surfaces and pivot the body about the feet, swinging the trunk over to land the buttocks onto the adjacent surface.

Other types of independent transfers studied in the literature included long-sitting lateral and posterior transfers. In the long-sitting position the legs are generally extended out in front of the body. In long-sitting lateral transfers individuals move by placing their hands in a comfortable position and transferring as far as they can laterally (Allison, Singer, & Marshall, 1996). In long-sitting posterior transfers subjects move backward while weight-bearing on both upper extremities using their normal transfer strategies from a long sitting position (Gagnon et al., 2003). While these types of transfers are less common they may be useful for dealing with certain setup or environmental situations such as bed mobility and body positioning activities (Gagnon, et al., 2003).

The last column in Table 1 lists the details (if any) provided concerning the setup of the transfer if a transfer was performed as part of the protocol. As indicated the most common and only setup issue specifically manipulated in the pre-experimental studies was vertical transfer distances (up or down). Many articles noted the angle in between either the wheelchair if used or initial surface relative to the target surfaces as either a fixed angle (ranging from 0° to 90°) or set based on user preference however the angle in between was not manipulated as part of the study design.  Only five of the 18 original research studies included the wheelchair as part of the transfer process.

Consistent with the nature of the study designs, reviewers felt the overall strength of the evidence across the 18 original research articles was weak to intermediate.  None of the articles were scored as having strong to very strong resulting evidence. Specific setup issues with an average score of one or greater (e.g. minimally relevant) included vertical transfer distance, transferring across a gap and position of the mobility device relative to target destination.  The other seven setup issues scored less than one on average.

**Table 1.** Summary descriptives on the articles that met reviewer relevancy criteria

| Article | Sample Size | Population | Study Design | Key measures | Setup Details |
|---|---|---|---|---|---|
| **Bayley et al, 1987** (Bayley, et al., 1987) | 94* | SCI paraplegia+ | Descriptive | Self-reported shoulder pain, those that reported pain (n=23) had shoulder arthrography, and 5 had intra-articular shoulder pressure measured during sitting-pivot transfers. | Wheelchair to bed transfer; No description of the setup. |
| **Allison et al, 1996** (Allison, et al., 1996) | 10 M | SCI C5-T10<br>8 tetraplegia<br>2 paraplegia | Descriptive | Upper extremities kinematics during long-sitting transfers | Lateral displacement of upper body on a single platform with feet on floor |
| **Gagnon et al, 2003** (Gagnon, et al., 2003) | 11M | SCI C7-L2 | Descriptive | Kinematics and electromyography of upper extremities and trunk during posterior transfers | Posterior displacement of body on a level surface with legs and feet also on surface |
| **Nawoczenski et al, 2003** (Nawoczenski et al., 2003) | 20 M<br>5 F | Without disability | Descriptive | Shoulder kinematics during weight-relief raise and during sitting-pivot transfers | Level transfer (51 cm) between the wheelchair and mat table with fixed angle between of 0° |
| **Gagnon, Nadeau, Noreau et al, 2008** (Gagnon, Nadeau, Noreau, Eng, & Gravel, 2008) | 10 M | SCI T4-T11 complete | Pre- experimental | Trunk and upper extremity kinematics during sitting-pivot transfers | Level (50 cm), downhill (40 cm), and uphill (60 cm) transfer; Fixed angle between the two platform surfaces of 90° |
| **Finley et al, 2005**(Finley, McQuade, & Rodgers, 2005) | 23M | 18 SCI T4-T12 complete and incomplete<br>5 others (Osteomyelitis, multi-trauma, spina bifida, cerebral | Case-control | Shoulder kinematics and electromyography during sitting-pivot transfers | Level transfer between two benches (set at same height as subject's wheelchair) and at a fixed angle between of 45° |

| | | | | | |
|---|---|---|---|---|---|
| | | palsy, tropical paresis) | | | |
| **Perry et al, 1996**(Perry, Gronley, Newsman, Reyes, & Mulroy, 1996) | 12 M | SCI T8-L1 | Descriptive | Shoulder electromyography during sitting-pivot transfers | Level transfer (set at same height as subject's wheelchair) between the wheelchair and mat table; The wheelchair was placed according to the subject's preference |
| **Gagnon, Nadeau, Noreau, Dehail et al, 2008**(Gagnon, Nadeau, Noreau, Dehail, & Gravel, 2008) | 12 M | SCI T4-T11 complete | Pre-experimental | Reaction forces under hands, feet and buttocks during sitting-pivot transfers | Level (50 cm), downhill (40 cm), and uphill (60 cm) transfer with a fixed angle between the two platform surfaces of 65° |
| **Gagnon et al 2009** (Gagnon, Nadeau, Noreau, Eng, & Gravel, 2009) | 10 M | SCI T4-T11 complete | Pre-experimental | Upper extremity electromyography during sitting-pivot transfers | Level (50 cm), downhill (40 cm), and uphill (60 cm) transfers; Fixed angle between the two platform surfaces (angle not noted) |
| **Gagnon et al, 2005**(Gagnon et al., 2005) | 10 M | SCI C7-L2 complete | Pre-experimental | Kinematics of head trunk, and upper extremities and electromyography of upper extremity and trunk during posterior transfers. | Posterior displacement of body on a level surface and on a surface 10 cm higher |
| **Gagnon, Nadeau, Noreau, Dehail, Piotte, 2008**(Gagnon, Nadeau, Noreau, Dehail, & Piotte, 2008) | 13 M | SCI T4-T11 complete | Pre-experimental | Upper extremity kinematics and reaction forces under hands, feet and buttocks during sitting-pivot transfers and weight-relief lifts. | Level (50 cm) transfer between two platforms with a fixed angle between of 65°and weight-relief lift with hands placed onto a higher platform (60 cm) |
| **Gagnon, Nadeau, Desjardins et al, 2008**(Gagnon, Nadeau, Desjardins, & Noreau, 2008) | 1 M | SCI T6 complete | Case study | Upper extremity kinematics during sitting-pivot transfers | Level transfer (50 cm height) and uphill transfer (60 cm); Fixed angle between the two platform surfaces of 65°. |

| | | | | | |
|---|---|---|---|---|---|
| **Allison & Singer, 1997**(Allison & Singer, 1997) | 1 M | SCI C5 complete | Case study | Upper extremity, trunk, and head kinematics during a long-sitting transfer with and without an orthosis | Lateral displacement of upper body on a single platform with feet on floor |
| **Tanimoto et al, 2008**(Tanimoto, Nanba, Tokuhiro, Yamamoto, & Ukida, 2008) | 10 M<br>1 F | SCI C7-L1<br>2 tetraplegia 9 paraplegia | Descriptive | Inclination degree of the trunk and reaction forces of legs, hands, and buttocks during sitting-pivot transfers. | Level transfer between the wheelchair and table; The angle between was set according to the subject's preference. |
| **Forslund et al, 2007**(Forslund, Granstrom, Levi, Westgren, & Hirschfeld, 2007) | 7 M<br>6 F | SCI T2-T10 complete and incomplete | Descriptive | Kinematics of upper extremity, trunk, and head and hands and buttocks reaction forces during sitting- pivot transfers | Wheelchair was the target surface and was 7cm lower than the initial platform surface; The wheelchair was placed according to the subject's preference. |
| **Bergstrom et al 1985**(Bergstrom, Frankel, & Galer, 1985) | 33 M<br>3 F | SCI C6-T5 complete | Descriptive | Anthropometric measures and ability to perform a long-sitting transfer | Lateral displacement of upper body on a single platform |
| **Pentland & Twomey, 1991**(Pentland & Twomey, 1991) | 22 F | 11 SCI paraplegia+ complete and 11 without disability | Case-control | Upper limb pain, isokinetic strength, grip strength, ROM, and ADL performance assessed by interview/questionnaire | N/A |
| **Harvey & Crosbie, 1999**(Harvey & Crosbie, 1999) | 6 M | SCI C5-C6 complete | Pre-experimental | Upper extremity kinematics and kinetics during a pressure relief maneuver | Push-up with hands level with buttocks and again with hands on blocks 4.5, 9 and 13.5 cm higher than the sitting surface |

* Gender not reported
+ Spinal cord injury level not reported
M: Male F: Female
SCI: Spinal Cord Injury
ROM: range of motion
ADL: activities of daily living

**Table 2.** Average scores obtained for the articles

| Article<br><br>N=19 | Relevance of research topic | Relevance of the research topic concerning specific setup issues | | | | | | | | | | Strength of the resulting evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vertical transfer distance | Transfer across gap | Number of transfers | Use of transfer assistive device | Position 3D | Effective supports | Constrained space | Physical obstacles or barriers | Transfer into a moving device | Transfer to from soft surface | |
| **Nyland et al, 2000*** | 2.91 | 2.09 | 1.82 | 1.45 | 1.45 | 1.18 | 1.27 | 1.18 | 1.27 | 1.18 | 1.09 | 1.82 |
| **Gagnon, Nadeau, Desjardins et al, 2008** | 2.85 | 2.38 | 1.62 | 1.15 | 0.69 | 0.92 | 0.92 | 0.92 | 0.92 | 0.69 | 0.85 | 0.92 |
| **Gagnon et al 2009** | 2.85 | 2.92 | 1.92 | 1.15 | 0.69 | 0.92 | 0.77 | 0.69 | 0.54 | 0.46 | 0.62 | 1.75 |
| **Gagnon, Nadeau, Noreau et al, 2008** | 2.77 | 2.83 | 1.92 | 0.92 | 0.54 | 1.54 | 0.77 | 0.62 | 0.85 | 0.54 | 0.38 | 1.69 |
| **Forslund et al, 2007** | 2.77 | 2 | 1.85 | 0.85 | 0.54 | 1.69 | 1 | 0.69 | 0.54 | 0.85 | 0.77 | 1.31 |
| **Tanimoto et al, 2008** | 2.75 | 1.92 | 1.92 | 1.17 | 0.55 | 1.67 | 1.17 | 0.58 | 0.5 | 0.5 | 0.5 | 1.42 |
| **Gagnon, Nadeau, Noreau, Dehail et al, 2008** | 2.75 | 2.58 | 1.83 | 1.08 | 0.75 | 1.25 | 0.83 | 0.67 | 0.58 | 0.67 | 0.58 | 1.64 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gagnon, Nadeau, Noreau, Dehail, Piotte, 2008** | 2.69 | 2.08 | 1.77 | 1.23 | 0.77 | 1.23 | 0.77 | 0.69 | 0.69 | 0.69 | 0.62 | 1.77 |
| **Bayley et al, 1987** | 2.67 | 1.58 | 1.5 | 0.83 | 0.67 | 0.58 | 0.5 | 0.5 | 0.42 | 0.67 | 0.83 | 1.36 |
| **Nawoczenski et al, 2003** | 2.62 | 1.69 | 1.85 | 1 | 0.62 | 1.54 | 0.92 | 0.62 | 0.46 | 1 | 0.62 | 1.54 |
| **Allison et al, 1996** | 2.58 | 1.5 | 1.25 | 0.67 | 0.92 | 0.92 | 0.45 | 0.42 | 0.33 | 0.25 | 0.33 | 0.92 |
| **Gagnon et al, 2003** | 2.54 | 1.23 | 1.38 | 0.77 | 0.31 | 0.69 | 0.54 | 0.38 | 0.31 | 0.38 | 0.54 | 1.5 |
| **Finley et al, 2005** | 2.54 | 1.31 | 1.69 | 1 | 0.46 | 1.08 | 0.54 | 0.46 | 0.62 | 0.54 | 0.46 | 1.46 |
| **Perry et al, 1996** | 2.5 | 1.67 | 1.67 | 0.75 | 0.42 | 1.17 | 0.42 | 0.42 | 0.33 | 0.75 | 0.5 | 1.5 |
| **Gagnon et al, 2005** | 2.5 | 2.83 | 1.67 | 1.08 | 0.58 | 1.25 | 0.83 | 0.42 | 0.42 | 0.17 | 0.58 | 1.58 |
| **Harvey & Crosbie, 1999** | 2.45 | 1.91 | 1.18 | 0.82 | 0.55 | 0.64 | 0.64 | 0.27 | 0.36 | 0.27 | 0.27 | 1.36 |
| **Allison & Singer, 1997** | 2.38 | 1.46 | 1.62 | 1.31 | 2.42 | 0.85 | 1.92 | 0.77 | 0.69 | 0.77 | 0.85 | 1 |
| **Pentland & Twomey, 1991** | 2.31 | 1 | 1.08 | 0.92 | 0.54 | 0.69 | 0.46 | 0.77 | 0.69 | 0.62 | 0.62 | 0.69 |
| **Bergstrom et al 1985** | 2.25 | 1.17 | 1.33 | 0.67 | 0.5 | 0.67 | 0.42 | 0.25 | 0.42 | 0.25 | 0.5 | 0.58 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Maximum score** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Mean** | **2.61** | **1.9** | **1.62** | **0.99** | **0.74** | **1.08** | **0.8** | **0.6** | **0.58** | **0.59** | **0.61** | **1.36** |
| **Standard deviation** | **0.19** | **0.59** | **0.27** | **0.22** | **0.47** | **0.36** | **0.37** | **0.23** | **0.24** | **0.26** | **0.2** | **0.37** |

* Literature review

**Table 3.** Articles that were not included in the results and discussion sections (N=22)

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|---|
| Boninger ML, Koontz AM, Sisto SA, Dyson-Hudson TA, Chang M, Price R, Cooper RA. Pushrim biomechanics and injury prevention in spinal cord injury: recommendations. Journal of Rehabilitation Research and Development. 2005 May-June 42(3 Suppl 1) 9-19. |
| Dallmeijer AJ, Van Der Woude LHV, Hollander PAP, Angenot ELD. Physical performance in persons with Spinal Cord injury after Discharge from Rehabilitation. Medicine and Science in Sport and Exercise. 1999 August 31(8) 1111-1117. |
| Van Drongelen S, Van Der Woude LH, Janssen TW, Angenot EL, Chadwick EK, Veeger DH. Mechanical load on the upper extremity during wheelchair activities. Archives of Physical Medicine and Rehabilitation. 2005 June 86(6) 1214-1220. |
| Bahrami F, Riener R, Jabedar-Maralani P, Schmidt G. Biomechanical analysis of sit-to-stand transfer in healthy and paraplegic subjects. Clinical Biomechanics (Bristol, Avon). 2000 February 15(2) 123-133. |
| Grevelding P, Bohannon RW. Reduced push forces accompany device use during sliding transfers of seated subjects. Journal of Rehabilitation Research and Design. 2001 Jan-Feb 38(1) 135-139. |
| Van Drongelen S, Van Der Woude LH, Janssen TW, Angenot EL, Chadwick EK, Veeger DH. Glenohumeral contact forces and muscle forces evaluated in wheelchair-related activities of daily living in able-bodied subjects versus subjects with paraplegia and tetraplegia. Archives of Physical Medicine and Rehabilitation. 2005 July 86(7) 1434-1440. |
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| Dalyan M, Cardenas DD, Gerard B. Upper extremity pain after spinal cord injury. Spinal Cord. 1991 March 37(3) 191-195. |
| Aissaoui R, Boucher C, BourbonnaisD, Lacoste M. Effect of seat cushion on dynamic stability in sitting during a reaching task in wheelchair users with paraplegia. Archives of Physical Medicine and Rehabilitation. 2001 February 82(2) 274-281. |
| Alm M, Saraste H, Norrbrink C. Shoulder pain in persons with thoracic spinal cord injury: Prevalence and characteristics. Journal of Rehabilitation Medicine. 2008 April 40(4) 277-283. |
| Gefen JY, Gelmann AS, Herbison GJ, Cohen ME, Schmidt RR. Use of shoulder flexors to achieve isometric elbow extension in C6 tetraplegic patients during weight shift. Spinal Cord. 1997 May 35(5) 308-313. |
| Curtis KA, Kindlen CM, Reich KM, White DE. Functional Reach in Wheelchair Users: The effects of Trunk and Lower Extremity Stabilization. Archives of Physical Medicine and Rehabilitation. 1995 April 76(4) 360-367. |
| Marciello MA, Herbison GJ, Cohen ME, Schmidt R. Elbow extension using anterior deltoids and upper pectorals in spinal cord-injured subjects. Archives of Physical Medicine and Rehabilitation. 1995 May 76(5) 426-432. |
| Reyes ML, Gronley JK, Newsam CJ, Mulroy SJ, Perry J. Electromyographic analysis of shoulder muscles of men with low-level paraplegia during a weight relief raise. Archives of Physical Medicine and Rehabilitation. 1995 May 76(5) 433-439. |
| Kotajarvi BR, Basford JR, An KN,. Upper-extremity torque production in men with paraplegia |

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|---|
| who use wheelchairs. Archives of Physical Medicine and Rehabilitation. 2002 April 83(4) 441-446. |
| Curtis KA, Drysdale GA, Lanza RD, Kolber M, Vitolo RS, West R. Shoulder pain in wheelchair users with tetraplegia and paraplegia. Archives of Physical Medicine and Rehabilitation. 1999 April 80(4) 453-457. |
| Harvey LA, Crosbie J. Biomechanical analysis of a weight-relief maneuver in C5 and C6 quadriplegia. Archives of Physical Medicine and Rehabilitation. 2000 April 81(4) 500-505. |
| Dehail P, Gagnon D, Noreau L, Nadeau S. Assessment of agonist-antagonist shoulder torque ratios in individuals with paraplegia: a new interpretive approach. Spinal Cord. 2008 August 46(8) 552-558. |
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| Harvey LA, Crosbie J. Effect of elbow flexion contractures on the ability of people with C5 and C6 tetraplegia to lift. Physiotherapy Research International: the journal for researchers and clinicians in physical therapy. 2001 6(2) 76-82. |
| Seelen HAM, Vuurman EFPM. Compensatory Muscle Activity for Sitting Posture During Upper Extremity Task Performance in Paraplegic Persons. Scandinavian Journal of Rehabilitation Medicine. 1991 23(2) 89-96. |


## 2.5 DISCUSSION

Our review of the literature revealed a small number of studies that directly relate to the influence of transfer setup on performing independent transfers and thus points to a critical need for more studies in this area. This study is different from other literature reviews that have been published previously on the topic of transfers in that it reflects expert reviewers' perception of the relevancy and strength of the evidence on independent transfers in relation to transfer setup. Despite finding articles that were moderately relevant, the strength of the evidence was generally considered to be low, none of the articles were scored as having strong to very strong resulting evidence, calling for stronger research designs to be employed in future studies on transfers. All the studies identified also involved small groups of subjects and all of them included either subjects with SCI or unimpaired subjects except for one study (Finley, et al., 2005) and thus a vast majority of them would not be generalizable to other populations who do independent transfers.

There is a consensus among studies that transferring to a higher surface implies greater exertion of the upper limb (Gagnon, et al., 2005; Gagnon, Nadeau, Noreau, Eng, et al., 2008; Gagnon, Nadeau, et al., 2009; Nyland, et al., 2000). However, there were no studies that specifically investigated the range of heights feasibly attainable by subjects which is important for determining the suitability of existing accessibility guidelines concerning transfers (ADAAG, Section 15) ("ADA accessibility guidelines for buildings and facilities (ADAAG)," 2002).

Although transferring across a gap and position (in three dimensions) of mobility device relative to final destination had a relevancy score higher than one on average, none of the studies systematically looked at how these attributes affect transfer performance. Wheelchair or surface positioning and gap distances differed across studies (Table 1) and in several cases were not documented or standardized for most studies thus it remains unknown how these attributes affect the transfer. Few studies involved the wheelchair as part of the transfer process (Table 1). Transferring into/out of a wheelchair occurs most often outside of the home and poses different challenges compared to transferring between two surfaces that are firm, flat and free of any physical barriers to the transfer. There is not enough evidence available at the present time to determine the limits of setup that would make transfers in the built environment accessible to a majority of wheelchair users.

Reviewers scored a majority of the items on transfer setup low in terms of relevancy (e.g. average scores were less than one) including: use of assistive devices such as transfer board, constrained space available, physical obstacles or barriers like side guards, transferring into a device capable of moving, number of transfers needed to get from point A to point B, and transferring to or from a soft surface. Transfer boards are a common aid used to facilitate transfers for those who have limited arm strength and/or situations where the height differential between the initial and target seats or gap difference is too large for them to negotiate without assistance. As the latter is a function of environment, we hoped to find studies that addressed the use of transfer boards or other similar technologies for circumventing environmental barriers. There were no studies identified that specifically addressed the use of assistive aids in facilitating transfer performance except for Allison et al. who reported transfer outcomes for a single subject with SCI using a custom trunk orthotic system described in detail above (Allison & Singer, 1997). One of the original group of 41 studies investigated the advantages of four devices in reducing pushing forces when passively transferring subjects but 80% of the expert reviewers did not score the article's relevancy high enough regarding it's applicability to the performance of independent transfers (Grevelding & Bohannon, 2001).

In addition to transfer aids, experts also felt none of the original research studies were relevant to the issue of constrained space available for transfers. This item was geared to identifying issues concerning transfers into/out of an airplane seat, amusement park ride, or motor vehicle, by which the individual has a limited space to position the feet or legs when moving over to or from the target surface. All the studies listed in Table 1 were conducted in laboratory settings versus 'real-world' environments with experimental setups that appeared free from any barriers that would limit leg/foot placement. Proper positioning of the feet is believed clinically to be a very important consideration for setting up for a safe and efficient transfer (Gagnon, Koontz, et al., 2009; Sisto, Druin, & Sliwinski, 2009) and thus may be critical for space planning in public areas where transfers are expected.

Physical obstacles and barriers are commonly observed for transfers to and from airline seats (e.g. arm rest is fixed) and amusement park rides (e.g. ride side rail/guard is fixed). Boats, kayaks, and other sorts of recreational equipment pose a similar barrier to transfers. None of the research identified described how well individuals are able to overcome physical barriers in between the wheelchair and target surfaces. In our own observations we see individuals going around or over the top of obstacles (e.g. transferring onto the obstacle first and then down into the seat/surface). The later is an example of a scenario that was scored separately for the item ‘number of transfers to go from the initial location to the final destination’ which was another aspect of setup reviewers identified as lacking evidence. There is no evidence suggesting how large (e.g. how high, tall and wide) an obstacle can be and still be accessible to a majority of wheelchair users.

Another area lacking sufficient evidence concerns the location and characteristics of effective supports to aid with transferring. This item encompassed for example the use of handholds, grab bars, or other environmental fixtures designed to facilitate a transfer to a target surface. None of the 41 studies or in our initial search of the literature specifically investigated wheelchair transfers in conjunction with environmental fixtures. However, many studies have looked at grab bar use during bathing tasks in older community-dwelling adults with and without disabilities, but who do not rely on wheelchairs as a primary mode of mobility.

Reviewers felt there was little relevant evidence on transfers into moving devices such a motor vehicle, boat, train, airplane, park ride, etc. This was somewhat surprising as car transfers have been reported to be the most essential wheeled mobility task to daily living among community-dwelling wheelchair users (Fliess-Douer, Woude, & Vanlandewijick, 2009). Current research also offered no guidance concerning soft surfaces and transfers. This was also surprising as clinicians are trained to teach their patients how to alter transfer techniques when moving to smooth surfaces as balance is further challenged and motions may require more force and effort to overcome the soft surface (Sisto, et al., 2009). Thus, from an environmental perspective, an individual for example may be able to handle a 3" (1.18 cm) uphill transfer if the target surface is hard but only half this height difference if the surface is padded.

## 2.6 LIMITATIONS AND CONCLUSION

The items on the scoring sheet were derived internally with insight from our collaborators at the US Access Board. The scoring sheet was not reviewed externally to evaluate whether the wording of the items was clear and unambiguous in meaning. This could have led to scoring biases from varied interpretations of what the issue encompassed. Overall the expert reviewers' views on the strength of evidence however were highly consistent with the range of study designs indicating that they possessed a good understanding of scientific rigor.

While there appears to be a growing body of literature on transfers there is scarce evidence related to the impact of setup on the performance of independent transfers. The results of this expert review of the literature highlight the need for future studies particularly as it relates to how environmental factors such as height and gap distances, use of handholds, surface softness, number of transfers needed to go from the initial location to the final destination, use of assist devices, space available for transfer, and obstacles or barriers impact the ability to perform independent transfers. Gathering more evidence on these issues will help to determine what the limits of setup should be in order to refine current accessibility standards related to transfers in the built environment.

# 3.0 THE IMPACT OF TRANSFER SETUP ON THE PERFORMANCE OF INDEPENDENT TRANSFERS

## 3.1 INTRODUCTION

For individuals who rely on wheeled mobility devices (WMD), performing transfers is essential to achieving independence with activities of daily living inside and outside the home (Toro, Koontz, Kankipati, Naber, & Cooper, 2010). Transfers have been ranked among the most strenuous wheelchair-related activities (Bayley, et al., 1987; Drongelen, et al., 2005) and are believed to be a major contributor to the development of upper limb pain and injuries (Dyson-Hudson & Kirshblum, 2004). There are several types of transfers, sitting-pivot transfers (also referred to in the literature as depression, side-approach, or lateral transfers) is the most common transfer incurred in daily living because it works for a variety of level and non-level surfaces (e.g. from a wheelchair to/from vehicle, bed, commode, etc.) (Somers, 2001). Other types of independent transfers studied in the literature included long-sitting lateral and posterior transfers. While these types of transfers are less common they may be useful for dealing with certain setup or environmental situations such as bed mobility and body positioning activities (Gagnon, et al., 2003). Within the scientific community there has been a recent surge of interest in investigating transfers for the purposes of understanding the etiology of upper limb pain and injury and to identify movement strategies that are more efficient and safer for individuals (Gagnon, Koontz, et al., 2009; Kankipati, et al., 2009; Kankipati, et al., 2008).

Transfer setup was defined as environmental type factors that impact transfer performance such as height and gap differences, space available next to the target element, and obstacles near or around transfer surfaces (Koontz, Toro, Kankipati, Naber, & Cooper, 2011). An expert review of the scientific literature on independent wheelchair transfers revealed a small number of studies that directly relate to the influence of transfer setup on performing independent transfers and thus points to a critical need for more studies in this area (Koontz, et al., 2011). In addition, all the studies identified in this review involved small groups of subjects and all of them included either subjects with SCI or unimpaired subjects except for one study (Finley, et al., 2005) and thus a vast majority of them would not be generalizable to other populations who do independent transfers (a transfer by which the individual requires no human assistance to perform) (Koontz, et al., 2011). There is not enough evidence available at the present time to determine the limits of setup that would make transfers in the built environment accessible to a majority of wheelchair users (Koontz, et al., 2011). For example, physical obstacles are commonly observed for transfers to and from airline seats and amusement park rides. None of the research identified described how well individuals are able to overcome physical obstacles in between the wheelchair and target surfaces (Koontz, et al., 2011). Handholds, grab bars, or other environmental fixtures designed to facilitate a transfer to a target surface also lack evidence concerning their location and characteristics (Gagnon, Koontz, et al., 2009; Koontz, et al., 2011).

The US Access Board produced the Americans with Disabilities Act Accessibility Guidelines (ADAAG) which includes general recommendations on transfer heights and clear space for a limited number of elements where transfer is expected ("ADA accessibility guidelines for buildings and facilities (ADAAG)," 2002; "ADA standards for accessible design," 1994). Current standards have criteria only related to seat height and clear floor space (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003). Data on transfers from a broad spectrum of community-dwelling WMD users is needed on the use and placement of handhelds or grab bars for facilitating transfers, the ranges of heights that individuals can realistically transfer up and down to, how close the transfer surfaces need to be, and how obstacles in between the device and target surface effect transfer performance. This kind of information is essential to refining the guidelines related to transfers and enabling designers and engineers to create an environment that is more accessible to individuals who independently transfer. Therefore, the aim for this study is to define acceptable ranges for critical transfer parameters and compare our results to the portions of ADAAG that address transfers in the built environment.

## 3.2 METHODOLOGY

### 3.2.1 Subjects

Subjects were eligible to participate if they (1) were at least 18 years old, (2) able to independently perform a transfer to/from a WMD with or without transfer board, (3) owned a WMD, and (4) had been using the WMD for at least one year. Subjects were excluded from the study if they had (1) significant upper extremity pain or injury that would inhibit the ability to perform transfers (2) active or recent history of pressure sores pressure sores. Subjects were tested at the 24th National Disabled Veterans Winter Sport Clinic in Snowmass Village, Colorado during March 2010; at the 30th National Veterans Wheelchair Games in Denver, Colorado during July 2010; at the Hiram G Andrews Center in Johnstown, Pennsylvania during November 2010 and March 2011; during the US Access Board In-Person Meeting in Chicago, Illinois during September 2010; at the Human Engineering Research Laboratories in Pittsburgh, Pennsylvania between June 2010 and April 2011; and at H. John Heinz III VA Progressive care center in June 2011.

### 3.2.2 Description of the Transfer Station

A custom-built modular, transfer station was designed using Solid Edge 2009 and consisted of a height adjustable platform with a range between 10” to 29” with increments every inch (25.4-73.7 cm in 2.5 cm) with a fixed backrest 17” wide by 25” high (63.5x43.2 cm) and a 95° recline; a lateral grab bar (fixed height of 32” or 81.3 cm) (Figure 2) and allows for attaching/detaching side guards (e.g. obstacle to transfer) and an optional front grab bar of varying height (Figure 3) of 19”-38” (48.3-96.5 cm) with increments every 2” (5.1 cm). The grab bars’ diameter is 1.5” (3.8cm). The space for the legs and feet has a fixed dimension of 14.5” deep by 22.5” wide (36.8x57.2cm).

**Figure 2.** Transfer station initial setup

**Figure 3.** Transfer station with front grab bar and side guard.

### 3.2.3 Experimental Protocol

For the initial setup, the platform was adjusted to be level with the subject's WMD seat, with no side guard or front grab bar in place. The subjects were asked to position themselves next to the platform as they normally would to prepare for a transfer. Angular orientation and linear distances of the WMD with respect to the front most corner of the platform were recorded (Figure 4). Each subject was asked to perform a transfer from their WMD to the station and back to their WMD. Grab bar(s) use was noted. Next, they were asked to perform five protocols in random order. Subjects were asked to exercise sound judgment in performing the transfers and to only do transfers they felt comfortable and safe doing. Subjects were spotted in the event they would begin to slip/fall during a transfer in which the case the transfer was declared 'unattainable'. After each transfer in each protocol, changes made to device positioning (x, y, α, Figure 4) and leading/trailing hand placement were recorded. The angle between the WMD and the transfer station is defined from 0°-180°. When the WMD is parallel to the transfer station and the subject is facing towards the front of the station the angle is defined as 0° and when the WMD is parallel to the transfer station but the subject is facing towards the back of the station the angle is defined as 180°.

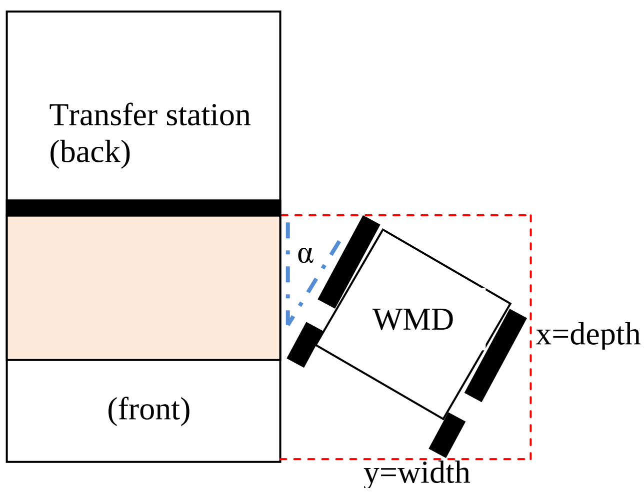


**Figure 4.** WMD position measures taken to calculate the overall space needed to transfer

Adjustable height protocol: From initial setup, only the height of the platform was adjusted incrementally: higher and lower than the subject's seat. The amount of vertical distance that the seat was raised/lowered each time depended on the subject's perceived and observed transfer abilities. The maximum and minimum heights the subject could transfer to/from the platform were recorded.

Adjustable gap protocol: From initial setup, just the horizontal distance between the WMD and platform was incrementally increased by placing plywood blocks of 3.5” (8.9cm) width between the transfer station and the WMD. The platform height remained level with their WMD seat height. The amount of horizontal distance increased each time again depended on the subjects perceived and observed transfer abilities. The maximum horizontal distance the subject could transfer to/from the platform was recorded.

Adjustable height/gap protocol: From the initial setup, a gap separating the device and platform was introduced with the plywood blocks of 3.5” (8.9cm) and then the height of platform was adjusted incrementally higher/lower. This procedure was repeated until the largest horizontal distance was reached. The maximum and minimum heights attainable with the largest horizontal distance were recorded.

Side guard protocol: From initial setup, two side guards adjusted 6” (15.2 cm) higher than the subject’s WMD seat were attached, and subjects were asked to perform a level height transfer. Then the height of the platform was adjusted incrementally in height: higher and lower than the subject’s seat and the maximum transfer heights high/low that were attainable were recorded. Then from initial setup, the horizontal distance between the wheelchair and platform was incrementally increased and the maximum attainable gap distance was recorded. The side guard height was adjusted to always remain at 6” from the WMD seat when lowering the station and was not adjusted when the station’s height was above the height of the WMD seat.

Front grab bar protocol: From initial setup, a grab in front of the platform was added and four conditions in random order were tested: low grab bar no side guard; high grab bar no side guard, low grab bar and side guard, high grab bar and side guard. Subjects had the option to use the front grab bar or not and selected the grab bar height in each condition tested. They performed a level height transfer in each condition and afterwards performed the variable height portion of the protocol as described previously (e.g. Adjustable height protocol). Maximum and minimum heights attainable, front grab use, and grab bar heights were recorded.

### 3.2.4 Data Analysis

The number of subjects that attempted to perform each protocol and the number of subjects that were not able to attain the transfer(s) with that configuration are reported for each protocol. Descriptive statistics (e.g. means, medians, frequencies, standard deviations) of the data were calculated for the subjects that were able to attain the transfers in each protocol. Population proportion confidence intervals (CI) were determined at 95%.

## 3.3 RESULTS

### 3.3.1 Subjects

The sample consisted of 88 men and 24 women with an average age of 47.7 ± 15.3 years, body weight of 77.8 ± 21.8 kg, and height of 1.70 ± 0.14 m. We enrolled subjects with a broad variety of disabilities ranging from spinal cord injury (SCI), multiple sclerosis (MS), cerebral palsy (CP), and post-polio among others. Table 4 contains the self-reported type of disabilities and the number of subjects that reported them. We asked those with spinal cord injury to report their level of injury as well as type of injury (complete or incomplete). Table 5 contains the self-reported levels of spinal cord injuries for the subjects that reported only spinal cord injury as their type of disability. 59% of this group reported having incomplete spinal cord injuries.

**Table 4.** Subjects' self-reported type of disability (n=120).

| Disability | Number of subjects |
|---|---|
| **SCI** | 54 |
| **MS** | 10 |
| **CP** | 11 |
| **Lower extremity amputation** | 9 |
| **Spina bifida** | 6 |
| **MS and SCI** | 3 |
| **Osteogenesis imperfect** | 2 |
| **Post-polio** | 2 |
| **Traumatic brain injury (TBI) and SCI** | 2 |
| **TBI and lower extremity amputation** | 1 |
| **Muscular dystrophy** | 2 |
| **Rheumatoid arthritis** | 2 |
| **TBI** | 2 |
| **SCI and lower extremity amputation** | 1 |
| **Osteoporosis** | 1 |
| **Stroke** | 1 |
| **Adams-Oliver syndrome** | 1 |
| **Ambulatory Dysfunction** | 1 |
| **Reflex sympathetic dystrophy** | 1 |
| **Spinal stenosis** | 1 |
| **Epidemiral cyst** | 1 |
| **Double lower extremity amputation and stroke** | 1 |
| **Amyotrophic lateral sclerosis** | 1 |
| **Respiratory problems** | 1 |
| **Sarcoidosis** | 1 |
| **Knee replacement complications** | 1 |
| **Hip injury** | 1 |

**Table 5.** Level of spinal cord injury for the subjects that only self-reported SCI as their disability (n=54).

| Level of injury | Number of subjects |
|---|---|
| **C3** | 1 |
| **C4** | 2 |
| **C5** | 2 |

| | |
|---|---|
| **C6** | 4 |
| **C7** | 2 |
| **T2** | 1 |
| **T3** | 2 |
| **T4** | 2 |
| **T5** | 4 |
| **T6** | 3 |
| **T7** | 6 |
| **T8** | 2 |
| **T9** | 2 |
| **T10** | 1 |
| **T11** | 6 |
| **T12** | 5 |
| **L1** | 2 |
| **L2** | 1 |
| **L4** | 3 |
| **Not reported** | 3 |

The sample as a whole had been using a WMD for 14.9 ±12.1 years with a range from 1 to 59 years. Wheelchair seat plus the cushion height measured at the edge was 21.6 ± 1.4" (54.8 ± 3.4 cm) median was 22" (55.8 cm) and range: 17 – 25" (43.2 – 63.5 cm). There were 84 manual wheelchair, 29 power wheelchair, 5 scooter, and 2 power assist users. 18% (22/120) reported using assistive technology for transfers: 14 used transfer board, 3 lifts, 3 canes, and 2 walkers.

Four of the 120 subjects enrolled in the study met inclusion criteria for independent transfer but were unable to transfer to/from the station based on space constraints and their method of approach. All these subjects were power wheelchair users except for subject S4 who used a manual wheelchair. Subject S3 used a transfer board in his transfers. This group's demographics are expanded in Table 6. The remaining 116 subjects completed all or portions of the study. The reason for not completing all portions of the study was mainly due to time constraints. A few subjects ended the study early due to experiencing fatigue or pain. The average number of transfers performed during the study was 22.9 ± 9.6 (range: 0-48). Moving from the WMD to the transfer station and from the transfer station to the WMD counted as two transfers.

**Table 6.** Demographics characteristics of the subjects who were not able to attain any transfers.

| Subject ID | Diagnosis | Gender | Age | Weight | Height | Years using WMD |
|---|---|---|---|---|---|---|
| **S1** | Cerebral palsy | Male | 57 | 140lbs (63.5kg) | 68in (1.73m) | 52 |
| **S2** | Cerebral palsy | Male | Unknown | Unknown | Unknown | Unknown |
| **S3** | Stroke and double above knee amputee | Male | 55 | 250lbs(113.4kg) | 72in (1.83m) | 4 |
| **S4** | Cerebral palsy | Female | 41 | 160lbs(72.6kg) | 57in (1.45m) | 40 |

### 3.3.2 Adjustable Height Protocol

One hundred and sixteen (116) subjects were tested under this protocol and five were unable to transfer to the platform at any height in the configuration shown in Figure 2 (e.g. no side or front grab bar in place). 96%, CI[91%,99%] of the sample (107/111) could transfer at a height of 22" (50.8cm). Fewer numbers of subjects could transfer above and below this height (Figure 5).

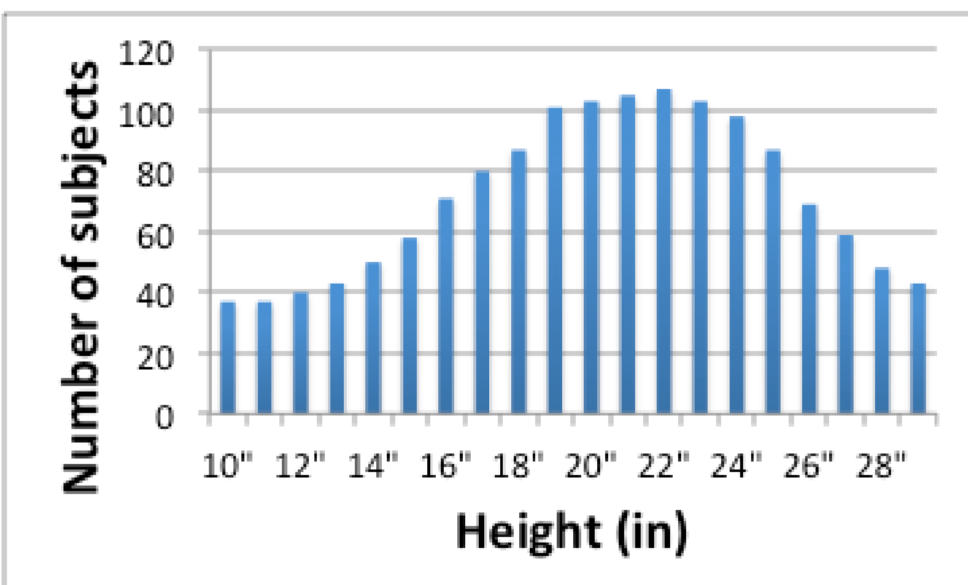


**Figure 5. Number of subjects (y-axis) able to transfer at each height increment (x-axis).**

Table 7 contains the height differentials that subjects were able to attain. The results suggest that 2” transfer heights are acceptable for the majority of the subjects that could attain Adjustable Height protocol.

**Table 7.** Percentage of subjects that were able to attain step heights.

| Steps Heights | Attainable (%) |
|---|---|
| **-6”** | 59% |
| **-5”** | 67% |
| **-4”** | 72% |
| **-3”** | 81% |
| **-2”** | 90% |
| **-1”** | 96% |
| **0”** | 100% |
| **+1”** | 100% |
| **+2”** | 95% |
| **+3”** | 81% |
| **+4”** | 67% |
| **+5”** | 54% |
| **+6”** | 45% |

**Subjects that could not attain the protocol**

In addition to the 4 subjects that could not attain any of the protocols, two additional subjects (1 woman, 1 man) could not attain the adjustable height protocol. The woman was 51 years old and had a an incomplete spinal cord injury at level L4, weighted 170 lbs, was 64” tall, and had been using a manual wheelchair for one year. The man was 68 years old and had a complete spinal cord injury at level T2, weighted 185 lbs, was 71” tall, had been using a manual wheelchair for 7 years, and used a walker to aid with his transfers.

### 3.3.3 Adjustable Gap Protocol

One hundred and fourteen (114) subjects were tested under this protocol and six could not transfer with a gap of any size added between their WMD and the platform in the configuration shown in Figure 2. 100% (108/108) of the sample were able to safely attain a level transfer with a gap of 3” (7.6cm). Around 85% (92/108), CI[77%,91%] of the sample were able to transfer with a gap of 9” (22.9 cm) or less (Figure 6).

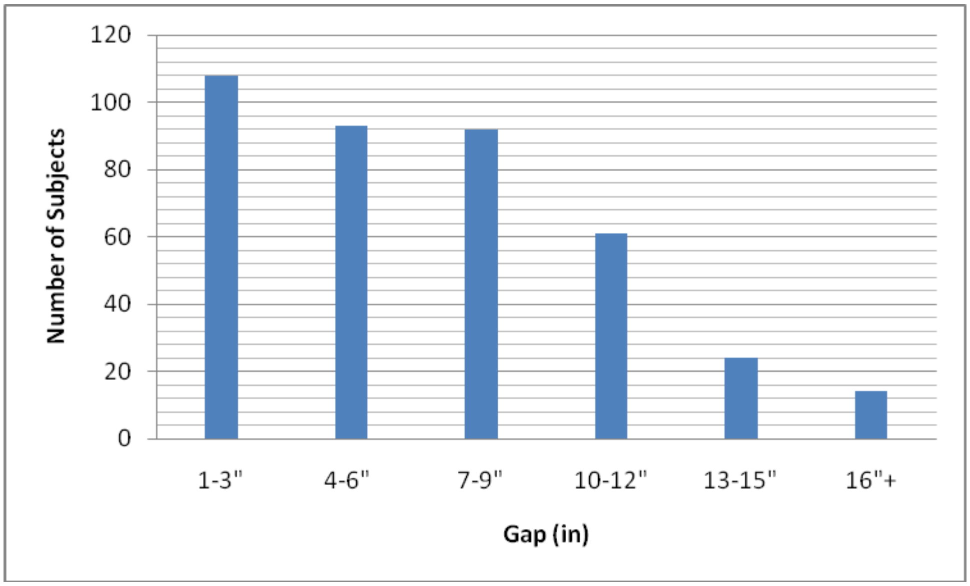


**Figure 6.** Number of subjects (y-axis) able to transfer with a certain gap (x-axis).

## Subjects that could not attain the protocol

In addition to the 4 subjects that could not attain any of the protocols, two additional men could not attain the adjustable gap protocol. One was a 41 year old men that had a traumatic brain injury and double lower knee amputation, weighted 192 lbs, did not report his height, and had been using a manual wheelchair for twenty years. The second subject was 68 years old and had a complete spinal cord injury at level T2, weighted 185 lbs, was 71” tall, had been using a manual wheelchair for 7 years, and used a walker to aid with his transfers. This last subject could not attain the adjustable height protocol as mentioned above.

### 3.3.4 Adjustable Height/Gap Protocol

One-hundred and sixteen (116) subjects were tested under this protocol, of which seven were unable to transfer with a height/gap combination in the configuration shown in Figure 2. 92% (100/109), CI [85%, 96%] of the sample were able to attain a height of 22” (55.9 cm) with a gap between 1” and 3” (2.5 – 7.6 cm). 90% (98/109), CI[83%,92%] of the sample attained a height of 20” (50.8 cm) with a gap between 1” and 3” (2.5 – 7.6 cm). 79% (84/109), CI[68%,84%] of the sample attained a height of 22” (55.9 cm) with a gap between 4” and 6” (10.2– 19.3 cm). The number of subjects who are able to achieve transfers for any height beyond a 7-9” (17.8 – 22.9 cm) gap distance dropped off dramatically (Figure 7).

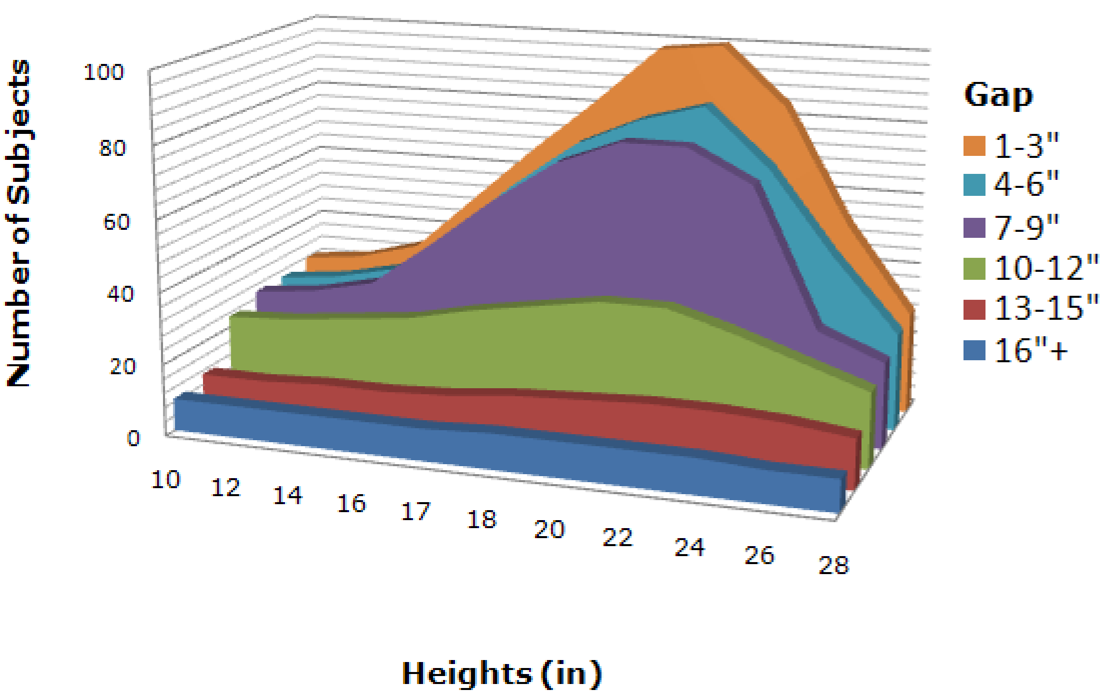


**Figure 7.** Number of subjects (z-axis) able to attained a certain gap (y-axis) at a certain height (x-axis).

**Subjects that could not attain the protocol**

In addition to the 4 subjects that could not attain any of the protocols, three additional men could not attain the adjustable height/gap protocol. One had a complete spinal cord injury at level L4, weighted 145 lbs, 67” tall, and had been using a manual wheelchair for twenty years and used a transfer board during transfers. The second subject had a complete spinal cord injury at level T2, weighted 185 lbs, was 71” tall, had been using a manual wheelchair for 7 years, and used a walker to aid with his transfers. This subject could not attain the adjustable height protocol and adjustable gap as mentioned above. The last subject of this group was a 69 year old men who had amyotrophic lateral sclerosis, weighted 130 lbs, 67” tall, and had been using a power wheelchair for one year.

### 3.3.5 Side Guard Protocol

One-hundred and thirteen (113) subjects were tested under this protocol. 42% (47/113), CI[30%,47%] of the subjects could not achieve a transfer with the side guard in place and with the platform at level with the WMD. When the conditions were changed (height raised/lowered or gap introduced) the transfers were unattainable to up to 47% (53/113), CI[37%,55%] of the participants. Of the 60 subjects that were able to transfer to a higher level than their own WMD, 98% (59/60), CI[91%,99%] were able to transfer to height of 22” (55.9cm) (Figure 8). At the extreme ranges of platform heights 42% (25/60), CI[30%,54%] were able to transfer to the highest height of 29” (73.7 cm). Of the 61 subjects that were able to transfer to a lower level than their own WMD, 44% (27/61), CI[32%,58%] were able to transfer to the lowest height of 10” (25.4cm).

When a gap was introduced with the side guard 60 subjects were able to attain this transfer. 80% (48/60), CI[68%,88%] were able to transfer at a height level with their WMD and a gap between 4 to 6” (10.2 to 19.3 cm). Only 13% (8/60), CI[7%,24%] could transfer with a 16” (40.6cm) or greater gap (Figure 9).

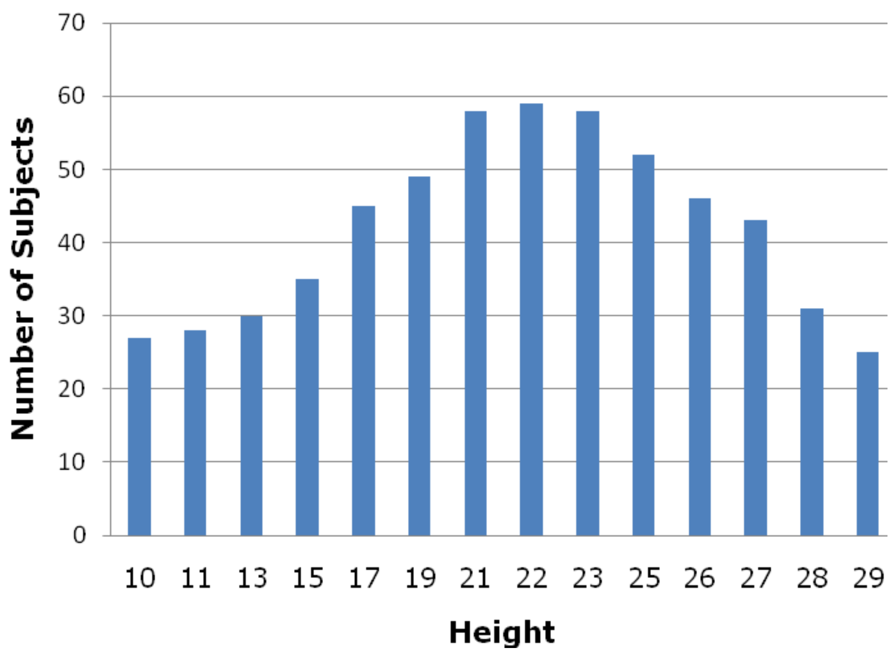


**Figure 8.** Number of subjects (y-axis) able to transfer at different heights (x-axis) with the side guard in place.

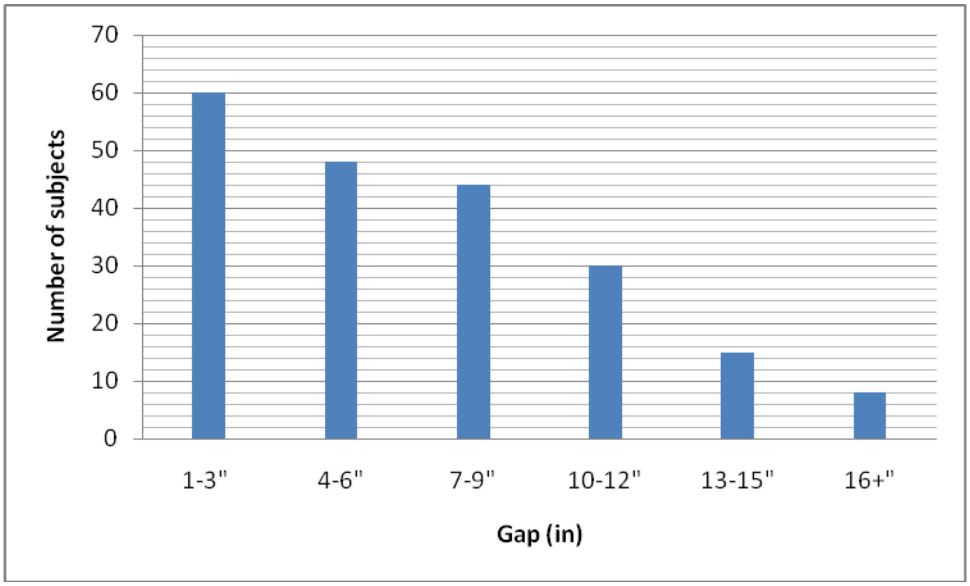


**Figure 9.** Number of subjects (y-axis) able to transfer with different gaps (x-axis) at a level transfer with the side guard in place

## Subjects that could not attain the protocol

In addition to the 4 subjects that could not attain any of the protocols, forty-three additional subjects could not attain the side guard protocol. Table 8 contains basic demographic characteristics of these 43 subjects.

**Table 8.** Demographics of the subjects that could not attain protocol side guard.

| Diagnosis | Gender | Age | Weight (lbs) | Height (lbs) | Years using WMD | Type of WMD | AT for transfers |
|---|---|---|---|---|---|---|---|
| **SCI T7-C** | M | 40 | 142 | 67 | 15 | M | |
| **SCI T6-C** | M | 47 | 216 | 74 | 1 | M | |
| SCI T11 **–C** | M | 34 | 130 | 70 | 2 | M | |
| **MS** | M | 52 | 203 | 71 | 10 | P | Transfer board |
| **RSD** | F | 37 | 118 | 62 | 5 | M | Transfer board |
| MS | M | 62 | 180 | 60 | 37 | S | |
| SCI | M | 56 | 165 | 62 | 22 | M | |
| SCI T5-**I** | M | 57 | 160 | 72 | 16 | M | |
| AK amputee | M | 62 | 245 | 69 | 11 | P | |
| SCI L1 **–C** | M | 65 | 150 | 68 | 25 | M | |
| **SCI L3-I/**LAKA | M | 65 | 211 | 72 | 13 | P | |
| SCI C5 **–**I | M | 53 | 160 | 71 | 26 | M | Transfer board |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SCI L4 –I | M | 71 | 228 | 70 | 10 | P | |
| SCI T11-C | M | 65 | 195 | 70 | 4 | P | Transfer board |
| SCI T11- I | M | 46 | 194 | 68 | 16 | M | |
| MS | M | 58 | 205 | 69 | 20 | M | Transfer board |
| SCI T3 –I | M | 55 | 225 | 56 | 10 | M | |
| SCI T12 –C | M | 61 | 150 | 70 | 4 | M | |
| MS | F | 61 | 125 | 69 | N/A | M | |
| CP | M | 57 | 140 | 68 | 52 | P | |
| SCI T12-I | M | 54 | 190 | 72 | 30 | M | |
| MS | M | 36 | 160 | 63 | 9 | M | |
| Post polio | F | 66 | 250 | 62 | 56 | M | |
| SCI C6 –I | M | 29 | 120 | 70 | 5 | M | |
| SCI T5 –I | M | 31 | 170 | 73 | 10 | S | |
| SCI L3 -I | M | 39 | 287 | 69 | 15 | M | |
| SCI T4- C | M | 35 | 165 | 72 | 17 | M | |
| CP | F | 22 | 140 | 63 | 12 | M | |
| Spina Bifida | F | 20 | 110 | 60 | 20 | M | |
| CP | 53 | M | 190 | 72 | 24 | P | |
| SCI T7 -C | M | 63 | 115 | 63 | 24 | M | |
| CP | M | 46 | 158 | 69 | 16 | S | |
| SCI T6-C | M | 46 | 158 | 69 | 16 | M | |
| Doble AKA-Stroke | M | 55 | 250 | 72 | 4 | P | |
| SCI T3-C | M | 27 | 110 | 67 | 12 | M | |
| SCI C7-I | F | 48 | 170 | 65 | 3 | M | |
| SCI L1- C | F | 55 | 115 | 66 | 30 | M | |
| SCI C6- I | F | 33 | 180 | 77 | 5 | M | |
| CP | F | 41 | 160 | 57 | 40 | M | |
| SCI T12-I | M | 58 | N/A | 74 | 28 | M | |
| SCI C5 – I | M | 49 | 161 | 70 | 25 | M | |
| RA | F | 44 | 230 | 64 | 18 | M | Transfer board |
| SCI T7-C/TBI | M | 29 | 200 | 70 | 6 | M | Transfer board |
| TBI | M | 43 | 180 | 70 | 28 | P | |
| SCI T4-C | M | 41 | 170 | 67 | 21 | P | Transfer board |
| Spina Bifida | F | 40 | 145 | 59 | 29 | M | |
| SCI T11 -I | F | 24 | 235 | 72 | 3 | M | Transfer board |
| **Total** | **12 F**<br>**35 M** | **47±13** | **175±42** | **68±5** | **18±12** | **34M**<br>**10 P**<br>**3 S** | **10 used TB** |

Abbreviation: SCI-spinal cord injury, C-complete, I-incompelte, MS- multiple sclerosis, RSD-reflex sympathetic dystrophy, CP-cerebral palsy, AK-above knee, RA- rheumatoid arthritis, N/A data not reported.

### 3.3.6 Grab Bar Protocol

One hundred and fifteen (115) subjects were tested under this protocol and four were unable to perform any transfers because this particular configuration posed significant barriers to their transfer. These four subjects were the ones that could not attain any of the other protocols.

When transferring to a lower height, with the front grab bar available, and without side guard, 53% (59/111), CI[69%,84%] used the front bar, and 21% (23/111), CI[14%,29%] could transfer to a lower height when using the bar, and the bar height preference was 30 ± 3.9" (76.2±9.9cm) median 30" (76.2cm). When transferring to a higher height, with the front grab bar, and without side guard, 61% (68/111), CI[52%,70%] used the front bar, 18% (20/111), CI[12%,26%] could transfer to a higher height when using the bar, and the bar height preference was 33.4 ± 3.1" median 32" (84.8±7.8cm, median 81.3 cm).

One-hundred and fifteen subjects performed the part of the protocol that included the side guard. 65% (75/115), CI[56%,73%] attained the transfer at level with their WMD and 23% (11/47) , CI[14%,37%] of the subjects who could not transfer with the side guard in place in the previous protocol could transfer with the grab bar in front. When transferring to a lower height, with the front grab bar available and side guard in place 85% (64/75), CI[76%,92%] used the front bar and 29% (22/75), CI[20%,40%] could transfer to a lower height when using the front grab bar. When transferring to a higher height, with the front grab bar available, and the side guard, only 72 could transfer to a higher height and 82% (59/72), CI[71%,89%] used the front bar and 18% (20/72) , CI[19%,39%] could transfer to a higher height when using the bar. Although presented with the option to change the front grab bar height, subjects chose the same height for all the low height and high height transfers as they used when the side guard was not present.

### 3.3.7 Lateral Bar Use

Table 9 shows the number of subjects for each protocol who used the lateral grab bar for initial placement of their leading or trailing hands and in what percentage of their transfers. It can be noted that the lateral grab bar is used by more subjects when the transfer setup increases in level of difficulty (i.e. gap/height in combination or side guard).

**Table 9.** Lateral grab bar use

| Protocol | % Subjects (subjects/total protocol specific) | % of Transfers used Mean ± standard deviation (range) |
|---|---|---|
| Height | 22% (25/111) | 32 ± 25% (5-100%) |
| Gap | 11% (12/108) | 61 ± 32% (16-100%) |
| Height/Gap | 44% (48/109) | 58 ± 32% (13-100%) |
| Side guard | 64% (42/66) | 56 ± 34% (8-100%) |
| Grab bar | 25% (28/111) | 37 ± 20% (8-100%) |

### 3.3.8 Space requirements for WMD

Table 10 summarizes the average clear space required for our subjects to position their WMD to perform a transfer in each protocol in terms of width, depth, and angle of approach (Figure 4). In the side guard protocol subjects tended to locate their wheelchair close to a perpendicular position with respect to the transfer station. The transfer setups that posed more barriers for our subjects such as height/gap, side guard, and side guard with front grab bar required more space for positioning the WMD.

**Table 10.** Average clear space needed and WMD orientation for transfer for each protocol (mean ± standard deviation).

| Protocol | Width | Depth | Angle (degrees) |
|---|---|---|---|
| Height | 38.3 ± 11.6” | 40.7 ± 10.7” | 34±38 |
| Gap | 39.9 ± 15.7” | 39.6 ± 12.2” | 34±38 |

| | | | |
|---|---|---|---|
| Height/Gap | 39.8 ± 13.8 | 40.5 ± 11.3” | 29±31 |
| Side guard | 38.7 ± 15.2” | 44.9 ± 18.1” | 37±35 |
| Grab bar | 36.1 ± 13.0” | 47.9 ± 14.1” | 40±32 |

### 3.3.9 Results comparison with current accessibility guidelines

ADAAG current standards for amusement park rides address recommendations for amusement ride seats designed for transfer in two places. First, it recommends a transfer height between 14 to 24” (35.6 to 61.0cm) and does not specify an allowable gap distance (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003). Within this range, transfer surfaces are encouraged to be between 17 and 19” (43.2-48.3cm) high (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003). Table 11 summarized the percentage of the subjects that could attain these heights for each protocol. Second, it suggests a minimum of 30” (width) by 48” (76.2x121.9cm) for a transfer with the WMD positioned parallel to the ride and assume a parallel approach for the transfer (0°) (*Accessible amusement rides - a summary of accessibility guidelines for recreation facilities*, 2003). Table 11 shows that the majority of WMDs (94%) could manage a 19” high surface with no gap and with or without the use of a front grab bar. For the protocols that included the side guard, it may look that there was a decrease in performance when the front grab bar was provided since the overall percentage is smaller. However, the number of subjects that could attain the height was larger as well as the overall number that could attain the protocol. Thus, the front grab bar use presented a useful aid for transfer.

**Table 11.** Percentage of subjects in the sample that could attain the heights recommended in the ADA.

| Protocol | 14” high | 17” high | 19” high | 24” high |
|---|---|---|---|---|
| Height | 45%(50/111) | 72%(80/111) | 94%(104/111) | 89%(99/111) |
| Height/Gap (3” gap) | 32%(35/109) | 62%(67/109) | 82%(90/109) | 77%(84/109) |
| Side guard | 51%(31/61) | 74%(45/61) | 80%(49/61) | 88%(53/60) |
| Grab bar without side guard | 49%(54/111) | 74%(82/111) | 94%(105/111) | 91%(101/111) |
| Grab bar with side guard | 44%(33/75) | 73%(55/75) | 88%(66/75) | 86%(62/72) |

## 3.4 DISCUSSION

Our results clearly indicate that height above and below WMD height, gaps and obstacles pose serious transfer-related accessibility problems for WMD users. Based on the information on Table 11, we can conclude that current standards would exclude up to 73% of our sample of WMD users. A majority of our subjects (96% of the sample, CI[91%,99%]) managed a height at 22” (51cm) with no gap in place which is more similar to their own seat height. Note that none of the subjects had WMD with seats lower than 17” (43cm). Thus it follows that transfers are the easiest to achieve when the height of surface to transfer onto is at the same height as the WMD (seat height + cushion). This is consistent with other research results that have found that level transfers require less exertion of the upper limb (Gagnon, et al., 2005; Gagnon, Nadeau, Noreau, Eng, et al., 2008; Nyland, et al., 2000). Study results suggest that an element’s height should fall within a range of 19”-23” to include 90% and within 21”-23” to include 94% of our sample. In addition, 2” transfer step heights were acceptable for 90% of our sample; while current guidelines for pools and spas say step height up to 8” are acceptable (*Accessible pools and spas - a summary of accessibility guidelines for recreational facilities*, 2003)

Although gap has not been researched specifically (Koontz, et al., 2011), it is intuitive that the closer one is to the surface the easier it will be to move your body across. Our results also showed that fewer subjects were able to attain larger height differentials with a gap in place as compared to the setup without the gap. Therefore, attaining transfers at different heights than the WMD seat height across a gap is even more complicated.

Our results showed that in terms of minimum area available for the transfer the guidelines are insufficient (Table 10). Mainly because our subjects positioned their device at an angle instead of the parallel approach the guidelines suggest as well as the likelihood that today's WMD's vary more in size (Steinfeld, Maisel, Feathers, & D'Souza, 2010). ADAAG guidelines for pools and spas have recognized that people do not necessarily transfer parallel to the transfer target and suggest a clear deck area of 60" by 60" for transfer walls (*Accessible pools and spas - a summary of accessibility guidelines for recreational facilities*, 2003). This area could better accommodate our results' mean plus one standard deviation of the area needed for our sample.

Introducing the side guard obstacle posed a significant barrier to transfer greatly reducing the number of subjects who were able to attain transfers at any height and/or gap. Despite the absence of recommendations regarding obstacles for transferring in the recreational facilities, guidelines for aircraft transportation for wheelchair users recognize that when the seat has a fixed armrest transferring is further complicated but it does not specifically recommend that armrest should be able to pivot ("Guidelines for aircraft boarding chairs,"). ADAAG guidelines for pools and spas suggest that if the lift seat has armrests, these need to be able to pivot so people can transfer from/to their WMD and the lift more easily (*Accessible pools and spas - a summary of accessibility guidelines for recreational facilities*, 2003). Our data suggest that adding a grab bar in front of the transfer seat helps to overcome a 6" obstacle and thus might be a worthwhile design criteria to include in future revisions of the guidelines. When the front grab bar was added in conjunction with the side guard, it was used more often but it did not help as many subjects to attain a higher or lower transfer compared to using the front bar without the obstacle in place. There was a high frequency of lateral grab bar use and front grab bar/lateral grab bar together upon initial hand placement. However, a decreased frequency of the use of the lateral bar was found in the grab bar protocol due to increased frequency of front bar use. Bars and the side guard were used often for repositioning the trunk and buttocks onto the platform after landing however the frequency of which these bars were used for this purpose was not documented.

ADAAG guidelines concerning handholds and grab bars where transfers are expected are not very detailed in general and are absent in the guidelines for amusement park rides. There are only recommendations regarding the height of a horizontal grab bar (parallel to the floor) to be between 33”-36” (83.8-91.4cm) for water stalls, water closets, bathtubs, and bathrooms. Our study’s results suggest that for our transfer station configuration the recommended front grab bar height should be between 30”-33” (76.2-83.8cm). ADAAG guidelines for play areas require that handrails, handgrips, or custom design handholds be provided where there are elements that the person is expected to transfer(*Accessible play areas - a summary of accessibility guidelines for play areas*, 2005). These guidelines do not provide information on the location of the transfer supports but suggest that the elements that are intended for transfer should have open sides (or an open side), back supports, and hand supports to help facilitate easy transfer and access (*Accessible play areas - a summary of accessibility guidelines for play areas*, 2005). A recent literature review of current knowledge on the biomechanics of sitting pivot transfers among individuals with spinal cord injury mentions further research is needed on alternative hand placement strategies during transfers and the benefits of various hand positions and grips (Gagnon, Koontz, et al., 2009).

Many studies have evaluated current accessibility guidelines in terms of space for maneuverability and finding them insufficient for current devices sizes (Dutta, King, Holliday, Gorski, & Fernie, 2011; King, Dutta, Gorski, Holliday, & Fernie, 2011; Koontz, Brindle, Kankipati, Feathers, & Cooper, 2010). These design parameters of the standard should be revised to reflect the setup of current WMD users as devices have changed since the standards were created in the 1970s. In 25 years, many changes have occurred in WMD users demographics and body sizes, as well as equipment characteristics (Steinfeld, et al., 2010). Equipment characteristics include increased use of positioning systems (e.g. tilt, recline, or combination which increases the effective length of the WMD), use of pressure-relieving cushions, and the availability of a wider range of wheel sizes (Steinfeld, et al., 2010).

### 3.4.1 Limitations

There are several limitations to this study worth noting. A large number of our subjects were veterans who participated in organized sports-related activities who may be representative of a highly functioning sample and therefore these results may not be generalizable to the population of WMD users. However, by recruiting at different locations we attempted to obtain a representative sample of the population of community-dwelling wheelchair users that perform independent transfers in a variety of environments. If comparing the demographics of our sample to LaPlante et al (2010) who reported subject demographics among adult wheelchair users using data obtained by the US Census Bureau we find some similarities and some differences (Table 12). It is important to note that the LaPlante (2010) statistics are inclusive of full-time, part-time WMD users and those who rely on human assistance for wheeled mobility. The demographics of our sample resemble more closely other studies that have specifically targeted community dwelling independent mobility users thus further supporting the external validity of our study. For instance, a study that researched minimum space requirements for wheeled mobility device maneuverability enrolled the majority of their subjects with spinal cord injury followed by central nervous system disorders (i.e. multiple sclerosis, cerebral palsy, and spina bifida) (Koontz, et al., 2010). In the same way, a pilot study that investigated environmental barriers and facilitators for wheelchair users had the majority of its subjects with spinal cord injury followed by multiple sclerosis (Meyers, Anderson, Miller, Shipp, & Hoenig, 2002). Another study researched the effect of cross-slopes on the mobility of manual wheelchair users and also reported the majority of their subjects having spinal cord injury followed by multiple sclerosis, cerebral palsy, spina bifida, and amputations (Souza, Teodorski, Sporner, & Cooper, 2010).

**Table 12.** Comparison between WMD users demographics reported by LaPlante (2010) and our study's subjects demographics.

| Demographics characteristic | Our sample | LaPlante (2010) (LaPlante & Kaye, 2010) |
|---|---|---|
| ***Mobility device*** | | |
| **Manual wheelchair** | 72% | 82.7% |
| **Power wheelchair** | 24% | 9% |
| **Scooter** | 4% | 8.3% |
| ***Gender*** | | |
| **Male** | 80% | 39% |
| **Female** | 20% | 61% |
| ***Age*** | | |
| **18-24** | 12% | 6.4% |
| **25-64** | 75% | 37.7% |
| **>65** | 13% | 55.9% |
| ***Race*** | | |
| **Caucasian** | 68% | 73.7% |
| **African American** | 26% | 12.5% |
| **Hispanic** | 3% | 7.9% |
| **Asian Pacific Islander** | 2.5% | 1.9% |
| **Other** | - | 3.9% |
| ***Disability causing use of WMD*** | | |

| | | |
|---|---|---|
| **Paraplegia** | 45% | 3.6% |
| **Cerebral palsy** | 9.2% | 3.1% |
| **Absence or loss of lower extremity** | 9.9% | 3.7% |
| **Multiple sclerosis** | 8.3% | 5% |
| **Stroke** | 1.7% | 11.1% |
| **Arthritis or rheumatism** | 1.7% | 13.4% |
| **Orthopedic impairment of lower extremity** | 1.7% | 3.6% |
| **Other** | 22.5% | 56.5% |

Finally, we selected certain parameters to hold constant (e.g. side guard height) and others to vary to keep the number of transfers to a minimum. Only a front grab bar of variable height was introduced as an optional handhold. Other handhelds including overhead grips may be useful but were not tested in this study. Future studies should investigate optimal locations for grab bars and handhelds for wheeled mobility users.

## 3.5 CONCLUSION

Height differentials of 2” (2.54cm) above and below WMD height, gaps and obstacles pose serious transfer-related accessibility problems for WMD users. Results showed that transferring to a height similar to the average wheelchair seat to floor height of the sample (21”, 53.3 cm) is achievable by 95% of adult wheelchair users who independently transfer. Current ADAAG recommendations for amusement park rides fall short in terms of height recommendations and space available for WMD users. More investigation is needed on handhelds and different ways to adapt rides to enable for more level transfers. The results of this study could help airline, motor vehicle, amusement park ride and adaptive equipment manufacturers to improve and create designs that facilitate the transfer process.

# 4.0 THE RELATIONSHIP BETWEEN PHYSICAL FUNCTION AND PERFORMANCE OF INDEPENDENT TRANSFERS IN PEOPLE WITH SPINAL CORD INJURY

## 4.1 INTRODUCTION

Safe transfers are essential for the independence of individuals who are dependent on wheeled mobility devices. Transfer performance is a function of physical capabilities, subject's characteristics, and transfer technique (Hirschfeld, 2007). Different studies have researched the relationship between function and factors such as strength, level of injury, and trunk stability. Fujiwara et al studied the relationship between shoulder muscle strength by manual muscle testing (MMT) and the Functional Independence Measure (FIM) (Fuijiwara, Hara, Akaboshi, & Chino, 1999) exclusively in 14 complete tetraplegia at level C6. Manual muscle testing (MMT) was used to determine a total shoulder strength score. The shoulder strength score correlated highly with the FIM transfer score (Spearman's correlation coefficient 0.93, $p<0.001$). Subjects were classified in Independent and Dependent based on the ability to independently perform a bed-wheelchair transfer. The Independent group had greater shoulder strength than the Dependent group ($p<0.05$). In transfers and push-up motions, people with spinal cord injury (SCI) need to lift and move their bodies by the upper extremities. Muscles in the shoulder girdle, especially the serratus anterior, upper part of pectoralis major, and latissimus dorsi muscle, play a key role in those motions (Allison, Singer, & Marshall, 1995; Formal, Cawley, & Steins, 1997;

Perry, 1978; Reyes, Gronley, Newsman, Mulroy, & Perry, 1995). Therefore, these muscles play an important role in functional independence, especially in relation to transfer tasks. However, the predictive aspect of total shoulder strength on different types of sitting-pivot transfers has yet to be realized (Fuijiwara, et al., 1999).

Bergstrom et al (Bergstrom, et al., 1985) studied anthropometric characteristics as predictors of the ability to transfer in subjects with tetraplegia below C6 level. Thirty-six subjects were evaluated in terms of static measurements such as stature, sitting height, functional arm length, shoulder flexibility, head circumference, body weight, and skinfold thicknesses over biceps, triceps, subscapular, and suprailiac marked sites. Ability was measured in terms of being able to adopt a lifting position but no lift possible; lifting on a firm surface but no clear space between surface and buttocks; lifting and able to transfer with a transfer board; and ability to perform a level transfer without a transfer board. Based on the inability/ability to perform a level sitting-pivot transfer they subdivided the subjects in non-transfer or transfer groups. Sitting height and body weight were positively correlated to inability to transfer. More body fat was found to be detrimental in attempting a lift and a transfer.

Chen et al studied the relationship between sitting stability and functional performance in twenty-seven (27) men and three women with paraplegia (Chen et al., 2003). Sitting stability was measured by the Balance Performance Monitor[2] (Haas & Whitmarsh, 1998) and a stopwatch was used to record how long they took to perform upper body dressing and undressing, lower-body dressing and undressing, and transferring. Subjects with low thoracic injury showed better dynamic sitting stability than those with high thoracic injuries; the injury level and trunk length were predictors for the outcome of dynamic sitting stability. However, injury level and sitting

[2] SMS Healthcare, Elizabeth Way, Harlow, Essex, CM 19 5TL, UK.

stability were not significantly correlated with completion time for lower-body dressing/undressing and transfer. They concluded, in order to develop functional activities of daily living (ADL) skills it is necessary to combine strengthening, range of motion exercises, and postural control training programs with specific training on each activity .

Gagnon et al (Gagnon, Koontz, et al., 2009) compiled publications about biomechanics of sitting pivot transfers and listed research that complement the recommendations stated in the Clinical Practice Guidelines on Preservation of Upper Limb Function in SCI (*Consortium for Spinal Cord Medicine Clinical Practice Guidelines, ed. Preservation of Upper Limb Function Following Spinal Cord Injury:A Clinical Practice Guideline for health-Care Professionals*, 2005). Based on the kinetics, kinematics and electromyography findings of the review, they further recommend developing optimal upper limb muscle strength when initiating sit-and-pivot transfer training. For instance including strength training the muscles of the scapulohumeral joints(Caldwell, 1962) (shoulder flexors and adductors) and muscles that have a role in the stability of these joints(Paine & Voight, 1993; Wilk, Arrigo, & Andrews, 1997) (serratus anterior, rhomboids, upper trapezius, levator scapu,a and pectorlis major).

Pentland and Twomey assessed 52 subjects with paraplegia and 52 able-bodied comparing concentric isokinetic average torque for the shoulder, elbow, grip, active range of shoulder and elbow motion, and upper limb pain (Pentland & Twomey, 1994a). They also assessed the impact of upper limb problems on performance of ADL; including transfers to a bed, toilet, bath, and car. Transfers were commonly reported as one of the activities that elicit upper limb pain, as well as an activity that allow interaction in the community and is associated with roles that are important for independence and self esteem. They did not find significant difference in upper limb strength between wheelchair users and able bodied individuals.

Endurance and balanced strengthening of the muscles acting around the shoulder may be more critical to independence and the avoidance of injuries and strains (Pentland & Twomey, 1994a). Additionally, it is important to ensure the availability of appropriate assistive devices, and barrier free environments (Pentland & Twomey, 1994b).

Upper limb pain is highly prevalent among the SCI population (Nichols, Norman, & Ennis, 1979; Pentland & Twomey, 1991). Transfer activities have been found to have a substantial impact on upper extremity pain and dysfunction. An individual with SCI typically performs 14-18 transfer per day (Finley, et al., 2005; Pentland & Twomey, 1994b). Sixty-five percent of participants with upper extremity dysfunction evaluated by Dalyan, et al reported that pain interfered with their ability to perform transfers (Dalyan, Cardenas, & Gerard, 1991). Therefore, the independence of transfers relies on the integrity of the upper limbs (Gellman, Sie, & Waters, 1988; Pentland & Twomey, 1991).

The objective of this study was to investigate the relationship between subject characteristics (gender, age, number of years using a mobility device, level of SCI and completeness), anthropometry (weight, height, body mass index BMI), functional measures (MMT, grip strength, and MFRT), pain (as measured on WUSPI and NRS) and transfer performance. Understanding these relationships is important for guiding clinical practices regarding transfer skill training and for recognizing when therapeutic and technological interventions are necessary to facilitate the transfer process.

## 4.2 METHODOLOGY

### 4.2.1 Subjects

Approval from the Institutional Review Board (IRB) was obtained prior to the initiation of the study. Participants provided informed consent prior to participation. Subjects were eligible to participate if they (1) had a spinal cord injury, (2) were at least 18 years old, (3) were able to independently perform a transfer to/from a wheeled mobility device with or without transfer board, (4) owned a wheeled mobility device, and (5) had been using a wheeled mobility device for at least one year. Subjects were excluded from the study if they had (1) significant upper extremity pain or injury that would inhibit the ability to perform transfers or bear weight on the upper extremities, (2) active pressure sores, or a history of recurrent pressure sores, (3) psychological disorders. Subjects were tested at the 24th National Disabled Veterans Winter Sport Clinic in Snowmass Village, Colorado, March 2010; at the 30th National Veterans Wheelchair Games in Denver, Colorado, July 2010; at the Hiram G Andrews Center in Johnstown, Pennsylvania; during the US Access Board In-Person Meeting in Chicago, Illinois, September 2010; and at the Human Engineering Research Laboratories in Pittsburgh, Pennsylvania.

### 4.2.2 Physical Function Measurements and Experimental Protocol

Manual muscle testing (MMT) of the non-dominant upper extremity was used to measure strength of shoulder extension, shoulder flexion, biceps, triceps, shoulder internal rotation, shoulder external rotation, shoulder abduction, and shoulder adduction. It was performed using the digital medical handheld dynamometer microFET 2™[3] with the participant seating in his/her own mobility device. Grip strength of the same extremity was measured using Jamar®[4] hydraulic hand dynamometer. Three trials were performed and recorded for each strength measurement and the maximum reading obtained was used in the analysis of the data. The modified functional reach test (MFRT) was used as a measure of sitting balance, defined as the ability of a person to maintain control over upright posture during forward reach without stabilization (Lynch, Leahy, & Barker, 1998). As proposed by Lynch et al. (1998), each subject had two practice trials of maximal forward reach, followed by three trials during which data were collected (Lynch, et al., 1998). The mean of these three trials was recorded and used in the data analysis. Additionally, subjects were asked to fill out a questionnaire about general demographics such as gender, height, weight, level and type of injury (complete/incomplete), and number of years utilizing a wheelchair. The wheelchair user's shoulder pain index (WUSPI) (Curtis et al., 1995) was administered to measure pain during typical daily activities (Curtis et al., 1999) and an 11-point numerical rating scale (NRS) was administered to measure pain in the right and left shoulders, elbows, and wrists in the past the last 24 hours.

Each subject was asked to perform several transfers from their wheelchair to a custom-built transfer station and back to their wheelchair. The custom-built transfer station consisted of a platform that was adjustable in height from 0.25-0.74 m (10- 29 in). Five different scenarios in random order were tried to evaluate transfer ability:

Adjustable height protocol: From initial setup, only the height of the platform was adjusted incrementally: higher and lower than the subject's seat. The amount of vertical distance

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[3] Hoggan Heatlh Industries, PO Box 488 West Jordan, UT 84084

[4] Patterson Medical, 1000 Remington Blvd, Bolingbrook, IL 60440

that the seat was raised/lowered each time depended on the subject's perceived and observed transfer abilities. The maximum and minimum heights the subject could transfer to/from the platform were recorded.

Adjustable gap protocol: From initial setup, just the horizontal distance between the wheeled mobility device (WMD) and platform was incrementally increased by placing plywood blocks of 3.5" (8.9cm) width between the transfer station and the WMD. The platform height remained level with their WMD seat height. The amount of horizontal distance increased each time again depended on the subjects perceived and observed transfer abilities. The maximum horizontal distance the subject could transfer to/from the platform was recorded.

Adjustable height/gap protocol: From the initial setup, a gap separating the device and platform was introduced with the plywood blocks of 3.5" (8.9cm) and then the height of platform was adjusted incrementally higher/lower. This procedure was repeated until the largest horizontal distance was reached. The maximum and minimum heights attainable with the largest horizontal distance were recorded.

Side guard protocol: From initial setup, two side guards adjusted 6" (15.2 cm) higher than the subject's WMD seat were attached, and subjects were asked to perform a level height transfer. Then the height of the platform was adjusted incrementally in height: higher and lower than the subject's seat and the maximum transfer heights high/low that were attainable were recorded. Then from initial setup, the horizontal distance between the wheelchair and platform was incrementally increased and the maximum attainable gap distance was recorded. The side guard height was adjusted to always remain at 6" from the WMD seat when lowering the station and was not adjusted when the station's height was above the height of the WMD seat.

Front grab bar protocol: From initial setup, a grab in front of the platform was added and four conditions in random order were tested: low grab bar no side guard; high grab bar no side guard, low grab bar and side guard, high grab bar and side guard. Subjects had the option to use the front grab bar or not and selected the grab bar height in each condition tested. They performed a level height transfer in each condition and afterwards performed the variable height portion of the protocol as described previously (e.g. Height protocol). Maximum and minimum heights attainable, front grab use, and grab bar heights were recorded.

For every protocol except Gap, the height differential between the subject's wheelchair floor to seat height and transfer station height was calculated and used for the statistical analysis.

### 4.2.3 Data Analysis

For all data analysis, SPSS (SPSS Inc, Chicago, IL) was used. Alpha was established a priori at 0.05. Trends are mentioned in the results section when $p<.10$. Depending on the nature of the variable, two-tailed spearman rho, point-biserial correlation, or phi coefficient was used to determine if there was a statistically significant relationship between subject characteristics (gender, age, number of years using a mobility device, level of injury, and type of injury), anthropometry (weight, height, body mass index BMI), functional measures (MMT, grip strength, and MFRT), pain (as measured on WUSPI and NRS) and transfer performance (wheelchair to transfer station height differential, gap length, and ability/inability to transfer with a side guard in place). The individual item scores in the WUSPI were summed to give a total score. Because many of the subjects did not perform one or more activities measured in WUSPI items, we calculated a performance corrected shoulder pain score PC-WUSPI by dividing the raw total WUSPI score by the number of activities performed and then multiplying by 15 (Curtis, et al., 1999). Thus, this reflects the actual intensity of shoulder pain experienced during activities performed rather than assuming equivalent activity levels between subjects (Curtis, et al., 1999). For each upper extremity joint, correlation was evaluated between the pain score given and transfer ability. For analysis purposes level of injury was ranked from 1 to 22 corresponding to cervical vertebrae three (C3) to lumbar vertebrae four (L4). Significant variables were entered into regression models to predict transfer performance. Depending on the nature of the dependent variable (transfer ability), linear single or multiple (stepwise) regression or logical regression models were run. Because we found more than one MMT score was significantly correlated, we selected shoulder adduction to include in the regression model. This muscle was chosen since the sternal pectoralis major, which functions to flex and adduct the shoulder, was the only muscle that has shown moderate to high level of intensity during the preparation, lift, and descent phases of sitting-pivot transfers in both trailing and leading arms (Perry, et al., 1996). Approximately 60-100% of long term wheelchair users experience shoulder pain (Nichols, et al., 1979; Pentland & Twomey, 1991). One study reported that there was more prevalence of shoulder pain (73%), followed by wrist pain (55%), and finally elbow pain (9%) (Pentland & Twomey, 1991). Thus, when more than one NRS pain measure was correlated to the dependent variable the shoulder joint was chosen over the wrist and elbow, and the wrist before elbow in the regression models.

For the NRS, if all six pain items (3 joints x 2 sides) were scored 0-zero the subject was categorized in an *absence of pain* group, otherwise he/she was categorized in a *presence of pain* group.

Pairwise comparisons were performed using the Mann-Whitney U tests to evaluate the difference between transfer performance (e.g. height differentials and gap length) and:

- Level of injury: two groups (*cervical* and *thoracic and lumbar*)
- Type of injury: two groups (*complete* and *incomplete*)
- Transfer method: (*only arms use* and *arms and legs use*)
- Overall pain measured by the NRS (*absence of pain* and *presence of pain*)
- Gender

## 4.3 RESULTS

### 4.3.1 Subjects

The sample consisted of 48 men and 6 women with SCI and an average (± standard deviation) age of 41 ± 13 years, mass of 77.2 ± 20.1 kg, BMI of 26.4 ± 6.1 kg/m$^2$, and height of 1.75 ± 0.10 m. Their levels of SCI ranged from L4 to C3 with 63% of the sample with incomplete injuries, 55% transferred using only their arms, and they were 13.2 ± 8.8 years post SCI. Seven were power wheelchair users and 47 were manual wheelchair users.

In terms of transfer ability, 50% were able to cover the full height range of the platform (e.g. Height protocol, no gap). Only one subject could not transfer with their mobility device set at a gap greater than 0.08 m (3in), 74% were able to transfer across a gap of at least 0.18m (7in) when their wheelchair seat was level with the platform, 44% were able to transfer with a side guard in place. One subject was able to transfer to the station only when the front grab bar was provided, without this element he was unable to perform any of the other protocols. We found that men were able to transfer to a higher target (*Mdn*=6) than women (*Mdn*=3), U= 38.50, z= -2.477, p=0.013, r= -0.058. Same result was found when transferring to a higher target with a gap in place for men (*Mdn*=4) compared to women (*Mdn*=2), U= 59.50, z= -2.269, p=0.023, r= -0.044.

### 4.3.2 Anthropometry

Table 13 contains the significant correlations results between anthropometric measures and transfer ability. Correlation analysis showed that taller subjects were able to attain transfers to higher surfaces ($r_s$=.300, p=.031) and lighter subjects were able to transfer to lower surfaces with and without a gap (r<-.436, p<0.010). Subjects with lower BMI could transfer to lower surfaces ($r_s$= -.369, p=.009) and lower surfaces with a larger gap in place ($r_s$= -.257, p=.069).

**Table 13.** Significant correlations between anthropometric measures and transfer ability

| Anthropometry | Transfer ability | Correlation coefficient |
|---|---|---|
| **Stature** | Maximum height differential transferring to a **higher** target | $r_s$=.300, p=.031 |
| **Weight** | Maximum height differential transferring to a **lower** target | $r_s$= -.436, p=.002 |
| | Maximum height differential transferring to a **lower** target with **gap** in place | $r_s$= -.357, p=.010 |
| **BMI** | Maximum height differential transferring to a **lower** target | $r_s$= -.369, p=.009 |

### 4.3.3 Functional Measures

<u>Modified functional reach test</u>

Table 14 contains the significant correlation results between transfer ability and MFRT. Subjects with greater truck balance as measure by MFRT were able to transfer to higher surfaces with/without gap and with side guard in place. Additionally, subjects with greater trunk balance were able to transfer across larger gaps with their wheelchair at level with the transfer station, with greater height differentials, and with the side guard in place. Finally, subjects with greater trunk balance were more likely to attain a transfer with the side guard in place. Subjects with better trunk balance tended to transfer to a lower surface with a gap in place ($r_s$= .243, p=.082).

**Table 14.** Significant correlation results between MFRT and transfer ability

| | Transfer Ability | Correlation Coefficient |
|---|---|---|
| **MFRT** | Maximum height differential transferring to a **higher** target | $r_s$= .326, p=.018 |
| | Maximum **gap** length at level transfer | $r_s$= .558, p=.000 |
| | Maximum height differential transferring to a **higher** target with largest **gap** in place | $r_s$= .399, p=.003 |
| | Attain a transfer with the **side guard** in place | $r_{pb}$= .394, p=.004. |
| | Attain a transfer with the **side guard** and front grab bar in place | $r_{pb}$= .475, p=.000 |
| | Maximum height differential transferring to a **higher** target with **side guard** in place | $r_s$= .471, p=0.020 |
| | Maximum **gap** with the **side guard** in place | $r_s$= .582, p=.004 |
| | Maximum height differential transferring to a **higher** target with **side guard** and front **grab bar** in place | $r_s$= .417, p=0.016 |

Upper extremity strength

Subjects with greater grip strength had the ability to transfer across a larger gap between the wheelchair and the transfer station. Subjects who were weaker in shoulder and elbow strength in general were likely to transfer with the side guard in place; with larger gaps with the wheelchair at level with the transfer station; across larger gaps when the height of the transfer station was changed; with larger height differentials transferring to lower surfaces when the side guard and the front grab bar were in place; and with larger height differentials transferring to higher surfaces. Table 15 shows the significant correlations found between upper limb strength and transfer ability. No significant correlation was found between transfer performance and shoulder extension strength.

**Table 15.** Significant correlation results between upper limb strength and transfer ability.

| Upper limb strength | Transfer ability | Correlation coefficient |
|---|---|---|
| **Grip** | Maximum **gap** length at level transfer | $r_s$= .315, p=.026 |
| **Shoulder flexion** | Attain a transfer with the **side guard** in place | $r_{pb}$=-.306,p=.031 |
| **Biceps** | Maximum **gap** length at level transfer | $r_s$= -.359, p=.011 |
| | Attain a transfer with the **side guard** in place | $r_{pb}$=-.400, p=.004 |
| | Attain a transfer with the **side guard** and front **grab bar** in place | $r_{pb}$=-.295 , p=.034 |
| **Triceps** | Maximum **gap** length at level transfer | $r_s$= -.283, .046 |
| | Attain a transfer with the **side guard** in place | $r_{pb}$=-.283, p=.047 |
| **Internal rotation** | Maximum **gap** length at level transfer | $r_s$= -.312, p=.027 |
| | Attain a transfer with the **side guard** in place | $r_{pb}$= -.392, p=.005 |
| **External rotation** | Maximum height differential transferring to a **lower** target with **side guard** and front **grab bar** in place | $r_s$=-.385, p=.027 |
| **Shoulder abduction** | Attain a transfer with the **side guard** in place | $r_{pb}$=-.361, p=.010 |
| **Shoulder adduction** | Maximum height differential transferring to a **higher** target | $r_s$=-.301, p=.032 |
| | Maximum **gap** length at level transfer | $r_s$=-.446, p=.001 |
| | Attain a transfer with the **side guard** in place | $r_{pb}$= -.394, p=.005 |
| | Attain a transfer with the **side guard** and front **grab bar** in place | $r_{pb}$=-.298 , p=.032 |

Pain

One subject did not complete the pain questionnaires, so the total number of subjects was 53. PC-WUSPI scores were 12.7 ± 18.4, 4.6 median and range [0, 77.9]. We found that those subjects that reported having more shoulder pain through the PC-WUSPI score were able to transfer to higher surfaces with a gap in place ($r_s$ =.279, p=.047). Similarly, subjects who reported higher pain scores using the NRS in their right and left wrist and right elbow were able to transfer to higher surfaces (p<.047). Those who reported higher pain scores in their right wrist and right elbow were able to transfer to higher surfaces with the gap in place (p<.043). Approximately 26% (14/53) reported pain in the left wrist, 34% (18/54) pain in the right wrist, and 28% (15/53) in the right elbow. The greatest pain score was reported by one subject in his right elbow. Besides this score all other scores were less or equal to 6. Twenty-eight subjects

(52%) did not report any pain in the NRS. No significant difference was found between absence and presence of pain groups using NRS regarding transfer ability. Table 16 includes the significant correlations found between upper limb pain and transfer ability.

**Table 16.** Significant correlation between self-reported pain measurements and transfer ability.

| **Pain** | **Transfer ability** | **Correlation coefficient** |
|---|---|---|
| **PC-WUSPI** | Maximum height differential transferring to a **higher** target with largest **gap** in place | $r_s$ =.279,p=.047 |
| **NRS left wrist** | Maximum height differential transferring to a **higher** target | $r_s$= .318,p=.023 |
| **NRS right wrist** | Maximum height differential transferring to a **higher** target | $r_s$= .325, p=.020 |
| | Maximum height differential transferring to a **higher** target with largest **gap** in place | $r_s$=.284,p=.043 |
| **NRS right elbow** | Maximum height differential transferring to a **higher** target | $r_s$ =.279,p=.047 |

Spinal cord injury level

Forty nine of 54 subjects reported their level of injury. 24% (12/49) had injuries at the cervical level and 76% (37/49) had thoracic or lumbar injury. Twenty-three out of 49 (47%) were able to transfer with the side guard in place and 18 of the 23 subjects (78%) had an injury at thoracic or lumbar level. When we classified our subjects into two groups (cervical and thoracic/lumbar), no significant difference was found between ability to attain a transfer with the side guard in place and the level of injury. However, when the level of injury was ranked, we found that the lower the level of injury the higher the surface the subject could transfer to ($r_s$=0.394, p=0.005) and the greater the ability to transfer across a larger gap with the platform at level with the wheelchair ($r_s$=.295, p=.042).

Spinal cord injury type

Forty seven of 54 subjects reported their type of injury. 32% (15/47) had complete injury and 68% (32/47) incomplete injury. More individuals with incomplete SCI were able to transfer with the side guard in place (phi=.340, p=.020). Subjects with incomplete injuries were able to transfer with large gaps with the side guard in place ($r_{pb}$= .493, p=.027). There was a trend of subjects with incomplete injuries to attain higher surfaces with the side guard and front grab bar in place ($r_{pb}$= .311, p=.088), higher surfaces with the side guard in place ($r_{pb}$= .381, p=.089), and higher height surfaces with a maximum gap in place ($r_{pb}$= .270, p=.063). Those with incomplete injuries (*Mdn*=9), were able to transfer across a larger gap with the side guard than those with complete injuries (*Mdn=0*), U= 3.00, z= -2.404, p=0.016, r= -0.120. No difference was found in transfer performance based on transfer method (*only arms* or *arm and legs*).

Regression Models

Regression analysis found that MFRT was a significant predictor for: Maximum height (p=.025), Maximum gap at level (p<.001), Maximum height with a gap in place (p=.002), Maximum gap with height change (p=.004), Maximum gap with side guard in place (p=.005), and Maximum height with side guard and front grab bar (p=.033). This predictor accounted for 29.6% of the variance (p=.004) in transferring with a gap with the side guard in place. Shoulder adduction MMT was a significant predictor for Maximum gap at level (.024) and Maximum gap with height change (p=.034). Weight was a significant predictor for Minimum height (p=.001) and Minimum height with gap in place (p=.016). Table 17 presents results for significant regression models.

**Table 17.** Multiple regression analysis results using forced entry method. Only significant models* and significant predictors are included.

| Criterion Variable | Adjusted $R^2$ | Predictor Variable | B | SE | Beta | p |
|---|---|---|---|---|---|---|
| **Maximum height (N=48+)** | .352 | Constant& | | | | .408 |
| | | MFRT | .038 | .016 | .290 | .020 |
| | | Gender | -1.903 | .856 | -.265 | .032 |
| | | SCI level | .133 | .047 | .342 | .007 |
| | | Shoulder adduction MMT& | | | | .149 |
| | | Stature& | | | | .080 |
| **Minimum height (N=48+)** | .192 | Constant | 15.342 | 2.241 | | .000 |
| | | Weight | -.044 | .013 | -.458 | .001 |
| **Maximum gap at level (N=45+)** | .362 | Constant | 8.851 | 2.271 | | .000 |
| | | MFRT | .127 | .032 | .546 | .000 |
| | | Shoulder adduction MMT | -.091 | .039 | -.305 | .024 |
| | | SCI Level& | | | | .134 |
| | | SCI type& | | | | .362 |
| **Maximum height with gap in place (N=51+)** | .269 | Constant | 2.939 | .432 | | .000 |
| | | MFRT | .055 | .017 | .399 | .002 |
| | | Gender& | | | | .059 |
| | | NRS Right wrist& | | | | .071 |
| **Minimum height with gap in place (N=51+)** | .094 | Constant | 12.239 | 2.528 | | .000 |
| | | Weight | -.035 | .014 | -.335 | .016 |
| **Maximum gap at level with side guard (N=23+)** | .296 | Constant& | | | | .211 |
| | | MFRT | .199 | .062 | .573 | .004 |
| **Maximum height with side guard and front grab bar (N=33+)** | .111 | Constant | 2.971 | .827 | | .001 |
| | | MFRT | .067 | .030 | .372 | .033 |
| | | SCI type& | | | | .486 |

*Models for minimum height with and without side guard were not significant.
+Number of subjects that could attain the protocol
&Non-significant predictors

Logistic regression results with ability to transfer with the side guard in place as the dependent variable revealed MFRT and biceps strength as significant predictors, which explained 33.8% of the variation in the ability to transfer with the side guard, based on the

Nagelkerke pseudo R-square statistic. Ability to transfer with the side guard and front grab bar in place revealed MFRT as the predictor that explained 35.2% of the variation in the ability to transfer with the side guard when the front grab bar was provided. Table 18 presents the results for significant logistic regression models.

**Table 18.** Logistical regression results for significant predictors and models

| Criterion Variable | Predictor Variable | OR | CI | p |
|---|---|---|---|---|
| **Transfer with side guard in place (N=50)** | MFRT | 1.049 | 1.006-1.095 | .027 |
| | Biceps MMT | .893 | .893-.991 | .020 |
| **Transfer with side guard and front grab bar in place (N=52)** | MFRT | 1.007 | 1.021-1.136 | .006 |
| | Biceps MMT | | | .150 |

Abbreviations: OR - Odds Ratio; CI - Confidence Interval; MMT – Manual Muscle Testing

## 4.4 DISCUSSION

This is the first study to compare transfer ability across subjects with varying levels and completeness of spinal cord injury. Not surprising trunk balance was the single most important predictor for transfer ability. Our results also showed that anthropometric measures like weight and height were correlated with transfer ability in a similar manner to that reported previously (Bergstrom, et al., 1985). We also found that men have significantly better transfer ability which aligns well with another study that found that men were able to manage more complicated transfers such as getting off of the floor (Forslund, et al., 2007). However, physical function measures such as strength and pain revealed results that were surprising and may shed new insight into the relationship of these issues in relation to transfer performance.

Anthropometrics

We can deduce from our results and related findings of others that maintaining a healthy BMI is important for achieving a high level of function with transfers. In addition, being taller may have an advantage in transfers (e.g. longer arm span, greater leverage) thus, petite persons should be considered more carefully as candidates for transfer assist devices (elevating seats, boards, etc.) to facilitate higher/lower and gap transfers. Taller subjects were able to transfer to higher surfaces and lighter subjects were able to transfer to lower surfaces with larger gaps. This follows the line of results presented by Bergstrom et al (Bergstrom, et al., 1985) in which greater sitting height (distance highest point on the head to the base sitting surface) and lower body weight were also correlated to better transfer ability.

Modified functional reach test

Based on our study, trunk control plays a key role in determining transfer ability. The regression models pointed to MFRT as the best predictor of transfer performance. Performing this simple test with a patient can provide a clinician with insight into how well that person will be able to transfer in the community. It emphasizes the importance of trunk/posture stability and core exercises to increase core function so transfers of various kinds can be performed independently. Chen et al (Chen, et al., 2003) recognized that sitting balance is necessary to perform functional activities such as transfers, but they did not find significant correlation between completion time needed to transfer and sitting stability. However, time may not be as sensitive of a measure because speed does not necessarily equate with function (Chen, et al., 2003).

Upper extremity strength

All of the significant correlations that we found between strength and transfer performance were negative. This implies that the weaker the participant, the better the transfer ability which contradicts other studies that have shown that transferring higher and lower demands more shoulder muscle activation compared to level transfers (Gagnon, Nadeau, et al., 2009). Moreover, shoulder strength has been found correlated to ability/inability to transfer is people with SCI at C6 level post-rehabilitation (Fujiwara, Hara, Akaboshi, & Chino, 1999). Therefore it might be expected that individuals with stronger limbs should be able to manage more challenging transfers. While upper limb strength is likely important, transfers also require simultaneous coordination between posture and movement (Forslund, et al., 2007) and the types of transfers tested in this study were much more complex than those evaluated in other studies. Further, as one study showed increased shoulder strength measured isokinetically does not necessarily imply that a more optimal manual propulsion strategy will be used (Ambrosio et al., 2005). Similarly, transfers are one of the most difficult activities of daily living to perform and require some level of structured training and a honing of skills depending on the different kinds of transfers necessary to maintain a high level of independence in the home and out in the community. Our sample were experienced with performing transfers based on the average length of time they had been injured and were likely able to compensate for deficiencies in upper limb strength with different techniques and strategies that they have acquired overtime.

Another possible explanation for this finding could be related to the absence or level of impairment of trunk and abdominal muscles during strength testing as these muscles are not fully available to help stabilize the core thus leading to underestimations in upper extremity strength. Consequently, those with greater trunk impairment could be stronger but they appear weaker if the trunk is not adequately supported. As transfers occur in a seated position with the arms used to support and stabilize the trunk throughout the task we performed MMT in the subject's own WMD. Most were equipped with customized seating configurations (e.g. ultralight systems) with seat angle adjustments and seating systems (e.g. cushions and back supports) to help stabilize the pelvis and spine during sitting, propulsion, reaching and other activities. They were also free to use compensatory strategies to stabilize their trunk (e.g. hold onto the wheelchair with their other arm or hook it over the backrest). Performing MMT in a supine position may have enabled for isolating shoulder muscles from the trunk better. Stronger grip strength was associated with larger gap distances but was not found as a significant predictor of transfer ability.

Pain

More shoulder pain was found related to the ability to transfer to higher surfaces with a gap in place. Tasks that are commonly associated with upper limb pain including transfers, outdoor wheeling, and driving also happen to be the activities that allow interaction in the community and greater independence (Pentland & Twomey, 1994a). It is important to note that an inclusion criteria was that the subject did not have upper extremity pain that would inhibit the ability to transfer and the data confirm this (e.g. the level of pain that subjects reported in this study was low (average WUSPI score = 13.0 out of 150 total possible points on the scale). A case-control study between SCI subjects with and without shoulder impingement syndrome concluded that those with impingement performed compensatory movement patterns that allowed them to maintain transfers (Finley, et al., 2005). Similarly, subjects with pain in this study could be employing compensatory strategies to overcome various barriers to transfers. None of the pain measurements that were found significantly correlated to transfer ability were a significant predictor in the regression models.

Spinal cord injury type and level

Many authors agree that the neurological level of spinal cord injury is the most important factor for predicting functional outcomes. Correlation between level of injury when classified in group (cervical, thoracic/lumbar) was found non-significant. A reason for this outcome could be that the sample size of those with cervical injury was small (n=12). In addition, since this variable was self-reported, we could have found greater differences if ASIA motor exam had confirmed function. However, when the level of injury was ranked our results showed that better performance was related to lower level injuries. Those with lower injuries were more likely to transfer with the side guard in place and to transfer to a higher surface. And those with incomplete injuries were able to transfer across a larger gap and a higher height with the side guard in place. Level of injury (ranked) was found to be a significant predictor of the ability to transfer to a higher surface. This may be in part due to subjects with low-level paraplegia being able to partially support their body-weight during transfer using functional abdominal or low back muscles (Bayley, et al., 1987). Another study suggested that those with lesion at C7 were able to displace their center of pressure (defined by the centroid of the vertical force distribution) during long-sitting transfers better than those with lesion at C5 and C6 (Allison, et al., 1996). Similarly those with incomplete injuries are likely able to bear more weight through the legs and have greater volitional control over trunk muscles.

Transfer method (arms only versus arms and legs combined) was not significantly correlated to transfer performance. The rationale behind this finding could be that during seat and pivot transfers, a proportion of the body weight (30%) is still passively supported by the lower limbs despite the severe sensory-motor impairment (Gagnon, Nadeau, Noreau, Dehail, & Gravel, 2008). Also as described earlier those using their arms only may use different strategies to overcome barriers to transfers in the environment.

## 4.5 CONCLUSIONS

Weight, height, strength, pain, and sitting stability were found significantly correlated to transfer ability. Our study overall highlights how much more important core function is relative to upper limb strength when considering transfers of varying levels of difficulty. Rehabilitation plans should include balance training and core strengthening in addition to upper limb conditioning when teaching transfer skills. Improving transfer ability has the potential to increase community participation and independence among wheeled mobility device users.

# 5.0 STUDY CONSIDERATIONS AND FUTURE WORK

The first chapter which describes an expert literature review study on the impact of transfer setup on the performance of independent transfers called for more and stronger studies in this area. The second chapter describes the study we designed to address limitations uncovered in the literature review and look at the impact of height differentials, gaps, obstacles, and placement of handholds and supports on transfer performance. The third chapter describes a study that went further into examining what subjects characteristics best predict transfer performance.

In the beginning, the US Access Board wanted us to focus the second study on independent transfers in recreational facilities and in particular amusement park rides. Thus the transfer station was designed to mock an amusement park ride with fixed constraint space for foot placement, be adjustable in height, be adjustable in gap, include a fixed height lateral grab bar, adjustable height front grab bar, and a removable obstacle (side guard). The results of this study were compared with the current accessibility recommendations for amusement park rides that are designed for transfers. Results showed that the current guidelines fall short in terms of height and space available for the wheeled mobility device. It was realized however as the study proceeded that the data could be useful for considering transfers to other types of elements as well. Thus Chapter 2 included how the results relate to other aspects of ADAAG concerning transfer elements (e.g. absolute heights, step heights, etc.). However, the transfer station built was limited to lateral transfers due to the front of the station being blocked by boards; it had fixed features, and did not provide overhead grips. Thus the next study should consider addressing these limitations to allow for evaluating transfers to the broad spectrum of elements covered by ADAAG.

Other considerations that limit generalizability of the study include that the study only involved adults and those who are independent with transfers. The sample had few scooter and power wheelchair users. It did not assess multiple transfers which could have been performed to overcome large height differentials. The number of handhelds, their positioning, and how they were used throughout the transfer process were not comprehensively studied. Therefore, there is a need for more research that studies handheld location and positioning and the effect of multi-step transfers (e.g. potential ways to adapt elements to enable for more level transfers). Further research should include a broader spectrum of diagnosis, more women, and more power wheelchair and scooter users.

Our study did not address all the issues pertaining to transfers to other elements described in ADAAG. Efforts should be made to mine the data gathered to determine how much of it can be applied to other kinds of elements. A workshop and/or discussion panels with stakeholders (i.e. consumers, manufacturers, researchers, designers and Access Board members) could help to determine what other critical issues need to be researched which would help to guide the future direction of research in this field.

For the investigation of personal characteristics and transfer ability in spinal cord injury, the results showed that trunk control was a significant predictor of transfer ability. However, more research needs to be done to understand what other factors are predictors of this activity. One of the limitations for both the second and third study is that we did not assess the quality of the transfers and we did not measure any biomechanics. The transfers that we tested were not conventional transfers that are tested in laboratory settings. Additional quantitative information about the transfers could have provided better insight into whether the transfers achieved were performed in the least injurious way possible. Since one of the design criteria for the transfer station was that it had to be portable, we had to sacrifice recording these quantitative data. Results suggest that future work should study MFRT as a predictor of transfer performance. This tool could help in wheelchair clinics as a validated outcome measure to help support the need of power wheelchair seat functions such as an elevating seat when someone has difficulty performing transfers to elements that meet ADAAG criteria.

Further investigations are needed to understand the transfer process in community settings. This could help refine or develop accessibility standards of elements that are intended for transfers. This may improve participation of wheeled mobility device users in public spaces. Additionally, by understanding the effect of personal characteristics (i.e. weight, trunk control) on transfer ability, rehabilitation programs could be implemented that target improving those characteristics that are predictors of better transfer performance to increase independence and participation.

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