INDEPENDENT WHEELCHAIR TRANSFERS IN THE BUILT ENVIRONMENT: HOW TRANSFER SETUP IMPACTS PERFORMANCE

by

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Performing the task of transferring oneself from one surface to another is highly essential for wheeled mobility device users in order to accomplish everyday activities such as going to work/school, interacting with friends, and participating in the community. Limited data is available concerning how the built environment impacts independent wheelchair transfer performance. Because of this the United States Access Board and the National Institute on Disability and Rehabilitation Research sponsored a multi-year research study on independent transfers. The objectives of the second phase of this study were to investigate the relationships between the features of transfer setup with respect to the target surface, vertical transfer height differences, location and characteristics of supports to aid with transferring, and space required for transfers. An international workgroup of experts came together to exchange ideas and information related to independent transfers to help create the study research agenda. Workgroup participant remarks and current ADA standards were used to design a new transfer data collection tool. Two-step transfers were evaluated to answer the question of what should the vertical height difference, seat widths and floor space dimensions be when transferring between two surfaces. Transfer quality was evaluated to determine if there was any effect of handheld presence and the height of the transfers performed. The study found that the 50th percentile of subjects could attain a 20.3cm vertical height difference when making a 90^o two-step transfer and a 17.8cm vertical height difference when making an angled transitioned transfer. The 5th and 50th percentile subjects used a width of 45.7cm. Handheld presence did not have a significant impact on performance but it did on quality. Higher quality transfers were found when transferring higher (with grab bars present, $p = 0.001$) and lower (with the grab bars and the backrest present, $p=0.041$). Subjects who transferred higher with grab bars and the backrest present on the station had poorer quality transfers ($r = -.409$; $p = .047$). The data collected will be used to inform engineers, architects, and designers who design public and private spaces about how to modify the environment to enable the highest degree of independence.

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PREFACE

Thank you to the faculty, staff, and students of the Human Engineering Research Laboratories where the work for this study was performed. I would especially like to thank Dr. Alicia Koontz for all the support, advice, and time she took to help me with this project. Thank you to the HERL machine shop staff for guiding me through the design process in creating the transfer station data collection tool and all my study helpers who play a huge role in collecting data. Also, thank you to my committee: Dr. Rory Cooper, and Annmarie Kelleher

1.0 INTRODUCTION

Transferring is the task of moving oneself from one surface to another. Performing the task of transferring is highly essential for wheeled mobility device (WMD) users in order to accomplish everyday activities such as going to work, going to school, interacting with friends, and participating in the community. However, very little is known about how the built environment impacts the performance of independent wheelchair transfers (Toro, Koontz, Kankipati, Naber, & Cooper, 2010).

To gain a better understanding of this action, the United States Access Board (Access Board) and the National Institute on Disability and Rehabilitation Research (NIDRR) sponsored a multi-year research project on independent transfers. Both these federal agencies are invested in improving the quality of life for people with disabilities. The Access Board is concerned with "accessible design" and the "development of accessibility guidelines and standards". They are the governing board that "develops and maintains design criteria for the built environment, transit vehicles, telecommunication equipment, medical diagnostic equipment, and information technology" ("United States access"). NIDRR is a component of the U.S. Department of Education's Office of Special Education and Rehabilitative Services (OSERS). They help improve the lives of American's with disabilities by supporting applied research, training, and development ("U.S. department of"). Since the Access Board requires data on transfers to develop guidelines for the purpose of making public facilities more accessible to persons with mobility impairments, human-subject testing is needed to ensure any new standards are evidence based.

Independent wheelchair transfers are important to study because of how strenuous they are to perform and how often they are needed to be done each day (Bayley, Cochran, & Sledge, 1987; Drongelen et al., 2005; Finley, McQuade, & Rodgers, 2005; Gagnon, et al., 2009; Pentland & Twomey, 1994). Because of the added reliability on upper extremities due to lower limb impairments, transfers are believed to a cause upper-limb pain and injury to those who perform them (Dyson-Hudson & Kirshblum, 2004; Toro, Koontz, Cooper, 2012). In terms of accessibility standards, the original Americans with Disabilities Act Accessibility Guidelines (ADAAG) were developed in the 1970's. These standards were expert and consumer opinion based rather than formulated through evidence based research. Additions describing more elements designed for transferring to recreational facilities like play areas, swimming pools, and amusement parks have been added to the standards since their creation 40 years ago. Wheelchair technology and consumer demographics have also changed since these standards were made. Power chairs are larger in size due to add-ons like powered recline and tilt and the users themselves have also grown with more bariatric chairs being developed (Koontz, Brindle, Kankipati, Feathers, & Cooper, 2010; R. A. Cooper, R. Cooper, & Boninger, 2008; Toro, Koontz, Cooper, 2012). It is clear that updating the standards may be necessary so that they better reflect the current WMD using population.

To get a better idea of how the built environment impacts the performance of an individual's transfer an expert review on current transfer knowledge was performed during the first phase of the Access Board's study on independent wheelchair transfers. No evidence was found concerning height differences, horizontal distance, and space needed next to the target surface so that areas could be accessible to a majority of WMD users (Koontz, Toro, Kankipati, Naber, & Cooper, 2011). This lead to an experimental study where WMD users performed independent transfers to and from a custom-built transfer station to evaluate how the height differential, gap, placement of a non-removable armrest, and the effect of grab bars impacted the subject's ability to transfer (Toro, Koontz, Cooper, 2012). It was found that the ADAAG guideline for grab bar height did not match up to the preferred grab bar height of the 120-subject sample of independently transferring wheelchair users (Toro, Koontz, Cooper, 2012; 2010 ADA standards, 2010; ADA accessibility, 2002; U.S. Department of justice, 1994). This study also showed that transferring higher and lower than an individual's WMD seat height, when a gap or obstacle was introduced made the task of transferring greatly more difficult (Toro, Koontz, Cooper, 2012). The data from this study were further analyzed to find the frequency counts for each hand placement option (e.g. backrest, platform, wheelchair, grab bars) used for each test protocol. The results of this analysis showed that transfer setup does impact the way people place their hands when transferring. For instance the lateral grab bar was the second most used hand placement option behind the station platform when transferring above and below a level height. However, when a front bar was added to the environment the lateral grab bar was almost never used (Jerome, Toro, Koontz, Cooper, 2012). These studies laid the groundwork for finding the limitations of the ADAAG and shed light into what still needs investigated concerning independent wheelchair transfers.

This paper describes the methods and results of the second phase of the Access Board's study on independent wheelchair transfers. The primary purpose of the second phase was to gain a better understanding of what the transfer capabilities (e.g. how high/how low someone can transfer) are for WMD users coming from a broad spectrum of disabilities and to determine how transfer setup (e.g. environmental factors) impacts overall performance. Secondary goals were to study the quality of the transfers performed in relation to performance factors. The results can be used to create more accessible environments for independently transferring WMD users.

Completing this second phase of the study consisted of three parts that are split up into three separate chapters. The first chapter describes an international workgroup of experts that was assembled to facilitate an exchange of ideas and information related to independent transfers and to develop future research directions. Experts with various backgrounds in independent wheelchair transfers met virtually to communicate the issues they perceived as problems for wheelchair users related to transferring. Nine main themes were derived from the event proceedings. Even though participants were split up into three groups focusing in either accessibility standards, additional research needs, or other issues related to transfers, all three groups independently raised issues concerning user-related factors and concerns, the transfer process, techniques and preferences, and the built environment.

The second chapter focuses on how the results from the workgroup and current ADA standards were used to design the new data collection tool built for the second phase of the Access Board Study. Height adjustable platforms, grab bars, backrests, and a sliding board designed for facilitating transfers across two steps (e.g. platform surfaces) were fabricated to help gain a better understanding of how the built environment impacts the performance of an individual's independent wheelchair transfer. The "transfer station" was modular and capable of transport.

The third chapter is the experimental study conducted on community dwelling WMD users who independently transferred to and from the custom-built transfer station in a repeated measure fashion. The study sought to determine the highest and lowest surfaces heights that individuals could transfer to and from, seat widths needed to transfer, amount of floor space needed for positioning the mobility device, and effectiveness of grab bars and backrests on the transfer surfaces. This study also investigated the relationship between the quality of a transfer and the ability to perform transfers at varying heights and environmental configurations. The results of the study will provide data that the U.S. Access Board and designers/engineers can use to modify equipment and/or environments (e.g. buildings, recreational facilities and playgrounds) for the purposes of enhancing the transfer process. The target sample required individuals who were able to transfer independently (with or without a transfer board) and who represented a broad spectrum of disabilities. Manual and power wheelchair as well as scooter users seven years of age and older that met all the study criteria were eligible to participate.

Primary data for this study involved recording the maximum height ranges attainable for each type of transfer, amount of clear space used, and transfer quality measured with the Transfer Assessment Instrument (TAI). Additional data collected that were not analyzed as part of this thesis included surfaces used to place leading and trailing hands, perceived level of exertion, upper limb pain, grip and arm strength, and the Modified Functional Reach Task (MFRT). Descriptive and correlational statistics were used to describe the data set and to explore the relationships between transfer skill and transfer performance.

2.0 INDEPENDENT WHEELCHAIR TRANSFERS WORKGROUP

2.1 INTRODUCTION

Purpose

This paper describes the methods involved with forming the Independent Wheelchair Transfer (IWT) Workgroup and the outcomes of the first meeting. The aim of the meeting was to facilitate an exchange of ideas related to the impact of the built environment on the transfer process and to develop future research directions.

Method

A web-based live meeting was chosen as a discussion forum to bring together experts in the field. The event comprised of three small group breakout meetings each one focusing on a different sub-topic area. Three independent reviewers reviewed the meeting transcriptions and identified main themes from the remarks made in each group.

Results

Thirty-one experts in the area of transfers participated in the event along with three investigators who facilitated the group discussions. Nine main themes emerged with all three groups independently raising issues concerning user-related factors and concerns, transfer process, techniques and preferences, and the built environment.

Conclusions

Comments received indicate the area of independent transfers is multi-faceted and several factors need to be taken into consideration when considering making environments more accessible to independently transferring wheelchair users. Tremendous opportunity exists for research, which could lead to better transfer technology, environments and techniques for wheelchair users.

2.2 BACKGROUND

For wheeled mobility device (WMD) users, performing independent transfers, the task of moving oneself from one surface to another, is essential to complete activities of daily living such as toileting, driving, and sleeping. However, transfers have been ranked as one of the most strenuous activities performed by WMD users and have been associated with the development of upper limb pain and injury (Drongelen et al., 2005; Bayley, Cochran, & Sledge, 1987; Dyson-Hudson, & Kirshblum, 2004). As a result, several studies have been conducted to investigate the risk factors associated with performing independent transfers with most of them focused on the techniques involved or the associated biomechanics (Koontz, Kankipati, Yen-Sheng, & Cooper, 2011; McClure, Boninger, Ozawa, & Koontz, 2011; Gagnon et al., 2009). The built environment such as the type and characteristics of transfer surfaces and the space available around the surface to position the WMD also impact the transfer process yet very little has been published about the relationship between environmental factors and transfer performance (Koontz, Toro, Kankipati, Naber, & Cooper, 2011).

To gain a better understanding of the issues related to the built environment and wheelchair transfers, the U.S. Access Board and the National Institute on Disability and Rehabilitation

Research (NIDRR) has sponsored a multi-year research project on independent transfers. In the first phase of this project, a literature review was conducted to assess current transfer knowledge related specifically to the built environment (Koontz, Toro, Kankipati, Naber, & Cooper, 2011). Thirteen experts in the field were invited to review the relative literature and agreed that none of the studies that were included addressed how high or how close a surface intended for transfer needed to be and how much space was needed next to the surface so it could be accessible to a majority of WMD users. This literature review study was followed by an experimental study where 120 community dwelling WMD users performed independent transfers to and from a custom-built, transfer station with adjustable features to evaluate how high and how close a surface needs to be, the impact of a non-removable armrest (e.g. obstacle) on the transfer process and the effect of grab bars on the ability to transfer (Toro, Koontz, Cooper, 2012). The study found that while the use of grab bars helped some people transfer higher and lower than they would without the bars, the Americans with Disabilities Act Accessibility Guidelines (ADAAG) guideline for grab bar height did not match up to the preferred grab bar height of the sample of WMD users (U.S. Department of justice, 1994; ADA accessibility, 2002; 2010 ADA standards, 2010). This study also showed that transferring higher and lower than an individual's WMD seat height and the addition of a gap or obstacle made the task of transferring more difficult or impossible for some subjects (Toro, Koontz, Cooper, 2012). Moreover, the study also demonstrated that the desired amount of clear floor space for positioning the WMD next to the transfer surface is greater than that specified in the current standards.

Before moving forward to Phase 2, it was aimed to form an international workgroup of experts with various backgrounds in independent wheelchair transfers to facilitate an exchange of ideas and information related to independent transfers and the built environment and to identify areas to direct future research on independent wheelchair transfers (IWT). The purpose of this paper is to describe the methods involved with forming the IWT workgroup and the outcomes of the focus group meetings that were held during a live web-based meeting on September 26th, 2012.

2.3 METHODS

2.3.1 Participant Selection

This study received exempt approval by the University of Pittsburgh's Institutional Review Board. Potential participants were identified by the University of Pittsburgh study investigators' and the Access Board and NIDRR project managers personal networks of collaborators and acquaintances in the field, authors of scientific papers related to transfers among wheelchair users, and by internet searches for individuals whose work closely related to this study's purpose. Invitations to participate in the workgroup were sent to 67 experts in the field. Potential participants were first approached in July 2012 by receiving an email that described the purpose of the workgroup and what would be expected of them if they chose to participate. Individuals that agreed to participate were sent another email containing a link to a website created specifically for the IWT Workgroup participants where the background reading material, a survey, and an agenda for the first live web-based meeting on September 26th, 2012 could be found.

2.3.2 Pre-workshop Participant Tasks

Participants were asked to complete a survey prior to the workshop and were asked to read the research project report from Phase 1 of this research study and the existing standards pertaining to transfers (General ADAAG Standards, 2012). All of these items could be reached from a university website (http://www.rst2.pitt.edu/ab/). The purpose of the survey was to gather information about each participant's professional background and preference for which sub-topic group they would like to be in during the breakout meetings which were used to gather input from the participants (see sub-section on Sub-topic Meetings below for details).

2.3.3 Meeting Structure

A web-based live meeting was chosen as a discussion forum for the IWT Workgroup to minimize costs, eliminate travel time and expenses, and be able to bring experts from across the globe together in one 'virtual' location. The online web-based videoconferencing program Adobe Connect 9.0 (http://www.adobe.com/products/adobeconnect.html) was used along with audio through traditional phone lines to conduct the IWT workgroup meeting. Although Adobe Connect allows for both video and audio, using the phone lines for the audio increased the reliability of the setup as Internet connections can be disrupted due to interference or noise. Three Adobe Connect 'rooms' and three separate conference phone lines were used (one for each breakout meeting with one also used as a main room). Each room was setup with 'pods' that contained a list of participants, a chat box, PowerPoint meeting slides, real-time closed captioning, notes, and a webcam view that could be seen by everyone. Figure 1 shows and example screen shot of the Adobe Connect virtual room with the "pods" used. Adobe Connect also allowed facilitators to share their screens with everyone when they took notes in Word documents. To interact with the meeting, participants were instructed to either virtually raise their hand, write in the chat box, or speak through their phone to communicate. A technical manager watched over the meetings and provided support to those who needed it. Participants were given the opportunity to test the system on their computers a week before the event.

Figure 1. Example Adobe Connect Screen Shot

The event was planned for one full working day and was comprised of a combination of two all-participant meetings (early morning and late afternoon) and three small group breakout meetings (late morning to early afternoon). The morning all-participant meeting was used as an introduction for the participants and dissemination and discussion of the first phase research results. The small groups were designed as focus groups, which elicited detailed discussions on specific topics concerning transfers. During the afternoon session's all-participant meeting, the small group facilitators provided a summary of their group's discussion points. Video and audio of the day's event were recorded using the recording feature in Adobe Connect and a telephone handset audio tap called a THAT-2 (http://www.jkaudio.com/that-2.htm) that recorded audio in and out of the telephones and saved it in real time over the video recording. The closed captioning service, Caption Colorado (http://www.captioncolorado.com/) was hired to provide real-time captioning through one of the ‘pods’ within the Adobe Connect environment. This service was also used to transcribe all the contents of the workshop.

2.3.4 Sub-topic Meeting

As the area of independent transfers is somewhat broad three sub-topic areas were presented to focus discussion during the small group meetings.

1. Identifying areas where current accessibility standards for elements designed for independent transfers need updating. (Current Standards)
2. Identifying what additional research is needed concerning independent transfers, particularly as it relates to the impact of setup on the transfer process. (Research)
3. Identifying other issues (e.g., multi-step transfers, transfer-aids, surface stability, surface slope/cross-slope, seat-to-surface gap, etc.) related to independent transfer in the built environment that requires further examination. (Other Issues)

Participants were assigned to sub-topic groups prior to the live meeting based on preference and so that each group had a relatively even distribution of the occupations and wheelchair users represented. Three study investigators with experience in facilitating focus groups each facilitated one of the sub-topic group meetings and a note-taker was present to assist them. Pre-determined questions for each sub-topic group were sent to participants in advance so that everyone would be prepared for the discussions.

2.3.5 Data Analysis

Qualitative analysis was performed on the full verbatim transcriptions of the sub-topic discussions. Three study investigators independently reviewed the meeting transcriptions to identify an initial set of codes (e.g. themes) for each of the sub-topic group discussions. The reviewers met to discuss and reach consensus on the main themes for each group. Next, the transcriptions were independently reviewed again to assign each participant’s remarks to one of the main themes. Afterwards, reviewers met to compare and contrast their findings and reach consensus on the themes and assignments for each remark. The final set of codes for each sub-topic group were compared across to further identify any overlapping themes, patterns, or relationships. Participant remarks that were made under each group for each main theme were combined across the groups.

2.4 RESULTS

2.4.1 Participants

Of the 67 invitees, 38 accepted to participate, 25 declined, and 4 did not respond. Of the 38 who accepted 7 did not attend the web event, resulting in 31 participants along with 3 investigator facilitators. The following are the occupational backgrounds of the participants: five researchers (two also a physical therapist), four engineers/designers, four academic professors, three physical therapists (PT), two architects, two graduate students (one studying rehabilitation science and one studying human factors & ergonomics inclusive design), two occupational therapists (OT), two nurses (one RN and one NP), one industrial designer, a building code consultant, an accessibility manager for a for-profit company, an accessibility specialist/designer for the federal government, a product manager for a for-profit wheelchair manufacturer, a county government employee who works on playground accessibility, and a U.S. Access Board member. Four participants were also full-time wheelchair users. One participant was a small group facilitator and the others were distributed uniformly across the three small group meetings in order to gather consumer input into each sub-topic area. The majority of the participants had at least 15 years or more experience in their current profession (67.7%), 9.7% had 10 to 15 years, 9.7% had 5 to 10 years, and 12.9% had 2 to 5 years of experience. Three participants had affiliations outside of the United States (Two from Canada, One from Finland).

2.4.2 Themes

Figure 2 list all the nine main themes identified by sub-topic group and shows where there was overlap in the themes among groups. All three groups despite the difference in the sub-topic area of discussion rose points concerning user issues, the transfer process, the built environment, and considerations regarding future research studies. The Research and Other Issues groups both made remarks related to transfer training and evaluation, education and outreach, and the complex interaction that exists between the environment, user, and/or transfer process. The Current Standards and Other Issues groups both expressed that the wheelchair design has an impact on transfers. The Research Group uniquely remarked about the lack of standardized transfer terminology and definitions in the field.

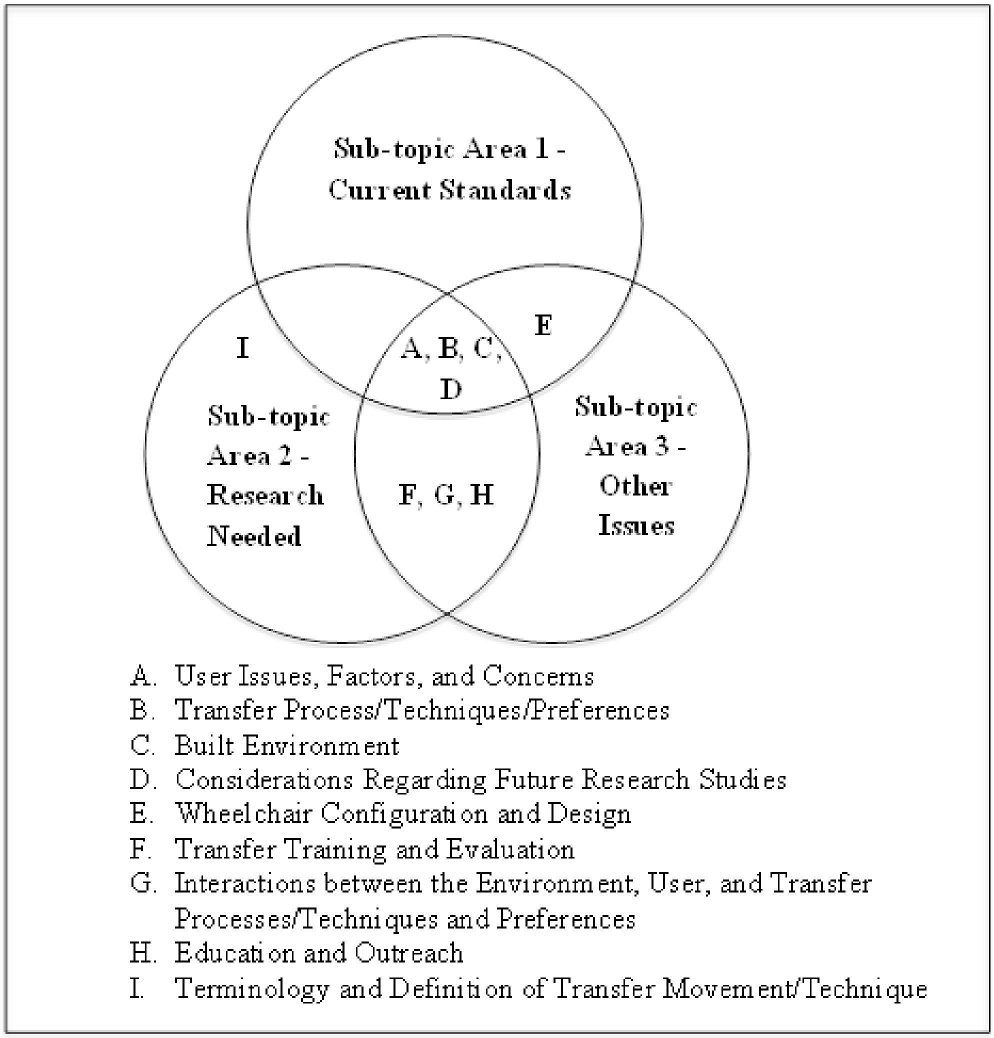

Figure 2. Overlapping Themes of the Three Sub-Topic Areas

The following paragraphs include general summaries of the information gathered under each theme. Examples of some summarized participant remarks that were made under each theme are listed in Table 1. A more detailed report containing all the participant remarks can be found at www.herl.pitt.edu/ab. A draft document with the participant remarks, summary statement for each theme and an overall summary of the event was composed and emailed to each IWT participant for review on March 22, 2013. The purpose of this was to ensure the summaries adequately reflected the remarks made and the discussions that took place during the meeting. The draft was refined based on the feedback received and a final proceedings for the meeting was generated and posted on the above mentioned website.

Table 1. Derived Themes with Example Participant Remarks

Main Themes	Participant Remarks
A. User Issues, Factors and Concerns	• Identify the cohort of people who perform independent transfers (e.g. demographics, physical characteristics, WMD types and sizes, etc.) • Need more information about the demands of users and their capabilities for different types of equipment • Identify the limiting factors for transfers according to those who perform them (e.g. pain, strength, fears, etc.) • Identify what environmental barriers are typical to WC users for their given lifestyle • Identify what environmental factors really make a difference • Consider the impact of "skill deficit" in some places • Consider the impact of stature and anthropometrics
B. Transfer Process, Techniques, and Preferences	• Consider user positioning in the wheelchair • Hand placement during transfer • Choice of preferred orientation of the device (e.g. angle) • Left and right side transferring preferences • Foot contact during transfer • Impact of footrest placement and caster designs • After the transfer to the new surface, users should be positioned optimally for the function they are engaged in • Choice of transfer type (e.g. forward, lateral, etc.) in relation to the characteristics of the transfer surface • Consider the impact that "technique" has on whether or not someone was successful at transferring • Time is a barrier
C. Built Environment Transfer Surfaces	• Consider Transfer seat height • Consider obstacles that impede the transfer surface • Transfer surface physical characteristics (e.g. size, firmness and stability, wet/dry) • Locations on the transfer surface for facilitating hand placement or grip
Space	• Consider size, shape and placement of wheelchair • Maneuvering space needed • Physical obstructions • Wheelchair stowage after transferring to new surface • Space considerations under the transfer surface • Floor surface characteristics (e.g. firmness, stability, wet/dry, cross-slopes)

Table. 1 (Continued)	
Accommodations and Equipment	• Multiple fixed [environmental] setups • User adjustable accessibility features • Transfer equipment availability in public places and weight capacity/durability • Use of an intermediate device to help with large vertical heights, unstable transfers, or bridging a gap • Grab bar physical characteristics (height, surface texture, shape, size, angle, length, contour, etc.)
Other	• Non-compliant installations and errors in construction of transfer surfaces or areas • Broken transfer surfaces and maintenance of surfaces • Changing the environment to accommodate one group of WMD users (e.g. scooters) may limit another • Need a transfer analogy to the ski slope level of difficulty indication (e.g. green slope – easy, black diamond – challenging)
D. Considerations Regarding Future Research Studies	• Consider that different users groups have different transfer abilities and needs • Consider that there is a lot of variability between users in terms of performance • There are many variables which makes it difficult to study the influence of the environment on transfers • Talking to users can provide a lot of information about transfers • Research is needed on ways to transfer that are least destructive to any tissue in the body
E. Wheelchair Configuration and Design	• Wheelchairs have changed in recent years and have a different interface with the environment • Manual wheelchair wheels that are positioned forward on the chair for enhanced propulsion efficiency make transfers parallel to the transfer surface much more difficult because the wheel is in the way • Flared castors that project forward and laterally and are designed for stability limit how close a user can position his or her chair next to the transfer surface
F. Transfer Training Evaluation	• Transfers are difficult to learn for newly injured users because they require strength to support body weight • Shorter rehab stays have led to less time spent on transfer training • Essential wheelchair skills are not being taught in rehab • Need a way to capture elements of ‘correct’ technique and describe it clinically • Identify issues related to the 90-degree pivot swing (e.g. current standard of training)

Table. 1 (Continued)	
G. Interactions Between the Environment; User; And/or Transfer Techniques/Process/Preferences	• Should we adapt techniques to the environment or environment to techniques? • Do we design an environment that everybody can independently transfer OR design an environment that people within a certain capacity can transfer within • What type of transfer is best for person with X condition in Y environment, etc. • Which wheelchair users (e.g. subgroups, types, etc.) really have problems with performing transfers and is it because of their ability, device or environment or combinations thereof? • What is the correlation between kind of transfer, the prevalence of each transfer, and the space that you are trying to make accessible?
H. Education and Outreach	Problems • Users use common household items to assist them with the transfer because they do not know what's available to them • A few things are known about technique that are not being disseminated well to clinicians • If you want to change environment you need to educate those who are creating it to make it easier to use • Wheelchair design changes to enhance transfers is not a priority right now Solutions • Showing healthcare that you can create an environment that prevents injuries gets their attention and brings changes • Users need to advocate for making the environment more accessible • Educate those prescribing chairs (Assistive Technology Practitioner (ATP) or clinicians) on how to select and configure wheelchairs to make transferring easier • Partnering between researchers, academic setting and manufacturers is needed to learn how wheelchairs can be designed to make transferring easier
I. Terminology and Definition of Transfer Movement/Technique	• Need a standardized approach to describe the movement • Consider breaking down transfer movement into distinct movements similar to gait • Develop names for events so technique during an event can be characterized

A. User Issues, Factors, and Concerns

Little is known about the cohort of people who perform independent wheelchair transfers and their requirements for transfer with regards to the type of device they use, their disability, physical characteristics, preferences, level of wheelchair transfer skills, and length of time using a wheelchair. The environmental and personal barriers to transfers in relation to lifestyle and the desire to perform a transfer are not well understood. More information is also required to determine environmental factor(s) that most often impacts transfers.

B. Transfer Process/Techniques/Preferences

The type of transfer (e.g. forward, lateral, etc.) chosen by a user is often based on the characteristics of the transfer surface. Factors to consider in the initial stages of transfer include the position of the user in the WMD, WMD orientation with respect to the transfer surface which is dependent on footrest placement and wheelchair design, and preferred direction of transfer. During the transfer, hand placement and foot contact are important. The transfer surface must not only be designed to enable for a successful transfer but also supports the user in a position that meets their functional needs. The transfer back from the surface may involve repositioning of the device and require different space needs. Transfer technique has an impact on how efficiently and safely someone transfers. Users are pressured when they have limited time to perform transfers.

C. Built Environment

Environmental factors impacting transfers include the transfer surface (size, height, firmness, stability, texture, and presence of obstacles), the space next to the transfer surface that is available for maneuvering and positioning the device, space under the transfer surface, and space for stowing the device where applicable. Characteristics of the floor surface where the transfer takes place should be considered. A number of environmental accommodations to consider include multiple fixed setups (e.g. more than one accessible bathroom stall), adjustable accessibility features, and availability and public access to transfer assist devices. Transfer assist devices are needed to help stabilize someone who needs to transfer to an unstable surface, minimize or bridge the gap and/or height differential between the mobility device and transfer surface, provide foot support, and act as an anchor to help pull or assist with transfer. More information is needed on grab bar/handhold physical characteristics, positioning and placement which needs to consider functional reach, strength of the user and indications for their use. Certain environments such as motor vehicle transfers, boat transfers, amusement park ride transfers and transfers into movie theater seats have unique challenges. Non-compliant installations of equipment, errors in construction, and broken down surfaces cause problems with transfers. Consider that changing an environment for a specific group of wheeled mobility device users may limit another. Consider a ‘level of difficulty’ rating system that would indicate the type of transfer and degree of transfer difficulty for a given environment.

D. Considerations Regarding Future Research Studies

Research on transfers should consider the variability that exists among user groups regarding the range in transfer abilities and needs, that there are many variables that impact transfers, studies involving certain user groups means the environment will be designed around that group's needs, and that laboratory based research is not directly applicable to real-world. Much can be learned by surveying and watching users perform transfers in natural environments. Biomechanics research outside of the lab would be more ecological and may be possible with portable instrumentation. Research is needed to support the importance of transfer training and to determine what types of movements should be avoided and those that are least injurious on tissues. Data are needed on clear space for those who transfer within the ADA transfer height allowances. Guidelines should be expanded to address assisted transfers.

E. Wheelchair Configuration and Design

Current wheelchair designs that are optimally designed for efficient propulsion or stability can make it harder to do transfers. Current wheelchair designs do not match up properly with areas designed for parallel wheelchair transfers. Future wheelchair designs should consider incorporating adjustments that make transfers easier.

F. Transfer Training Evaluation

Transfers are difficult to learn for newly injured users with limited strength. Equipment should be developed to support transfer training for these users. Short-term wheelchair users may not have been provided with adequate information or practice on how to properly transfer. It's difficult for long-term users who use "poor" techniques to learn and adopt "correct" techniques. The field needs a way to describe clinically what "correct" technique is. Essential wheelchair skills may not be taught in rehabilitation due to limited time. Rehab stays are too short and have resulted in less time spent on transfer training. More data are needed on transfer training outcomes to help justify longer rehab stays. Clinicians have limited time to learn, teach and evaluate transfer skills. Educational materials are needed that teach clinicians how to teach transfers that go beyond the "basics". Tele-rehabilitation and video training would enable remote training opportunities for clinicians.

G. Interactions Between the Environment; User; And/or Transfer Techniques/Process/Preferences

Interactions exist between the transfer environment, user characteristics, and transfer skill sets. These interactions make it difficult to understand the problems that wheelchair users have with transferring in different kinds of environments. Should the environment be tailored around the skill set or vice versa and what is the economic cost to configuring an environment when someone is missing a skill set? In what ways does designing an easier environment impact users? What is the relationship between the kind of transfer and the environment that is to be made accessible? The goals for making the environment more accessible need to be better defined –do we design for everybody that can independently transfer or for those with certain capabilities. A greater understanding is needed of the types of transfers that work best for users with certain conditions and in each environment.

H. Education and Outreach

There is a knowledge translation gap with transfers that exists among stakeholders. For example, users are not aware of the durable medical equipment and assistive devices that are available to help them transfer, clinicians are not aware of the evidence that exists on transfer technique and mainstream designers are not aware of the needs of those who transfer. Healthcare and wheelchair manufacturers do not regard transfer issues as a high priority. A number of potential solutions to these issues were identified including showing outcomes on what a 'good' or 'bad' environment causes, users advocating for more accessible environments, educating mainstream students and professionals who would be involved with environmental design on the needs of those who transfer early on in their careers, educating wheelchair manufacturers on why they need to keep stability during transfer in mind when designing wheelchairs, and educating clinicians on how to select and configure chairs to make transferring easier. Collaboration among stakeholders is needed to share data and bring about design changes that make transfers easier.

I. Terminology and Definition of Transfer Movement/Technique

The field needs clear and consistent terminology for describing the movements involved for various types of transfers so technique during an event can be characterized. This would enable for uniformity in communicating, sharing and distributing evidence.

2.5 DISCUSSION

2.5.1 Discussion

The purpose of the IWT workshop was to bring together experts in the field to discuss the issues that wheelchair users currently face within the built environment with regard to independent transfers and identify where to direct future research efforts. The IWT web-based meeting presented a unique opportunity to gather and share information among experts in the field. Rich information and new ideas in each sub-topic area were attained through the use of focus groups that were designed to encourage an open flow of ideas amongst participants. The diversity of professional experience and interests in each group added breadth of knowledge to the content of the information obtained from each group. Many participants commented about how well organized it was and how much they enjoyed being a part of the effort. When asked to review the draft document containing the themes and remarks participants described it as a "good job covering the many different items/topics that were discussed during the workshop", and that "it, on the whole, accurately summarizes the discussions that took place". No negative feedback was received about a participant's experience in participating in the workgroup.

Overall the goal for the workshop was to solicit feedback on how the built environment impacted transfers. However we learned that the environment is not the only critical issue that impact transfers. In addition to environment, three other areas impacting transfer performance included the WMD design, user preferences and perspectives, and the techniques used. Due to the unique nature of transfers, a separate theme emerged to address the fact that transfer outcomes are not based on any one of these factors but rather are the result of complex interactions that exist amongst them. Moreover, there were some conflicting areas between and within sub-topic groups. For example, advancements in technology have led to new wheelchair designs and an opportunity for a more diverse group of individuals with disabilities to participate in their communities (R.A. Cooper, R. Cooper, & Boninger, 2008). As a result the interface of newer wheelchairs with the built environment is different now than it was when the standards were originally developed. There were points raised about the need to address wheelchair design to adapt to the environment or whether to adapt the environment to accommodate for current wheelchair designs. Similarly, conflicting questions were raised as to whether the environment needs to accommodate what may be deficits in transfer skill or is it a matter of improving transfer training skills to overcome environmental challenges to performing transfers. Other questionable areas pertained to the *d*egree that the environment needs to be adapted in order to accommodate specific types of transfers or degrees of physical capacity. The comments received indicate that the area of independent transfers is multi-faceted and several factors need to be taken into consideration to make environments more accessible to wheelchair users who independently transfer.

Three other areas focused on what we can do better as professionals working in this field such as transfer training for clinicians and wheelchair users, educating and disseminating new knowledge about transfers, and standardizing terms used to describe transfers to facilitate communication amongst rehabilitation professionals. Changes in healthcare policy and insurance coverage have decreased the time that individuals spend in inpatient rehabilitation (Spinal Cord Injury Facts and Figures at a Glance, 2011). Subsequently, therapists have less time to spend with the patient addressing the wheelchair and transfer skills necessary to perform transfers in different environments. Individuals may be released before they have had an opportunity to develop adequate strength and physical conditioning needed to do biomechanically correct transfers. The remarks made in these other areas were felt to be beyond the scope of future research related specifically to the built environment, however they are very valuable for learning more about independent transfers and should be considered by other groups for future research studies. Researchers may find the comments made under the main theme of 'Considerations Regarding Future Research Studies' especially helpful for planning any future transfer-related studies.

The information gathered from this work will be used to develop the next phase of research for the US Access Board which will entail in part addressing issues raised related to transfers to platform surfaces with and without backrests and handheld use and locations. Points brought up during this workgroup meeting concerning perceived barriers to transfers, types of transfers people routinely do or would never do and for what reasons, and identifying the demographics of those who independently transfer will be incorporated into a questionnaire to administer to subjects who participate in future studies.

2.5.2 Limitations

While overall the web-based nature of the meeting was successful, a couple minor issues did arise. There was an added expense of calling in for international participants. As an alternative, participants could follow along with closed captioning and use the chat box to communicate. An individual calling in from outside the U.S. experienced some telephone issues where it was hard for him to hear, but was able to communicate through the chat box. He was eventually able to connect with the rest of the group by telephone. Also, the internet in one of the sub-topic meeting rooms was slower than in the other rooms which resulted in the shared screen word document where notes were being taken for all to see to freeze. However, this issue did not affect the quality of the conversation. The group participants continued their conversations over the phone and the room facilitator was still able to type up and save all the main points. Although a systematic process was followed to translate the transcripts into a summary and decide upon themes, the original remarks are the opinions of experts based on their experience and may or may not represent the opinions of other experts in the field who were not part of the focus groups.

2.6 CONCLUSION

Although a significant amount of research has already been done on independent transfers, the workshop focus groups identified additional areas where future research is warranted. Tremendous opportunity exists for collaborative research amongst the stakeholders (e.g. United States Access Board, engineers, physical and occupational therapists, university researchers, architects, and manufacturers of assistive technology), which could lead to better transfer technology, environments and techniques for wheelchair users. For the second phase of the U.S Access Board’s study on independent transfers points brought up during the workgroup such as platform surface transfers with and without grab bars and backrests, the preferred seat width needed for positioning oneself, and the act of transferring to two separate surfaces (e.g. two-step transfer) were incorporated into the study.

3.0 DESIGN AND DEVELOPMENT OF THE INDEPENDENT WHEELCHAIR TRANSFER STUDY PHASE TWO DATA COLLECTION TOOL

3.1 INTRODUCTION

In the first phase of the U.S. Access Board's study on independent wheelchair transfers it was mentioned that handhelds and alternative ways of adapting transfer elements to help eliminate obstacles and promote more level transfers needed further investigation (Toro, Koontz, Cooper, 2012). The results from this study also brought forth the idea that having elements that enable someone to pull him or herself over to a transfer destination may be helpful in the transfer process and that handhelds that are attached to a target surface should be looked into (Jerome, Toro, Koontz, Cooper, 2012). These research investigation suggestions along with other suggestions brought up during the Independent Wheelchair Transfer (IWT) Workgroup such as platform surface transfers with and without backrests and grab bars, were used to help create the data collection tool for phase two of the Access Board's study. One of the goals of the study was to determine how transfer setup (e.g. changes in vertical height) impact hand placement and performance. Preferred seat width and the space needed by an individual to position themselves for transfers was also investigated.

In order to explore the phase two research agenda a new custom-built modular transfer station was designed and fabricated. It was to be used as the data collection tool to help study independent wheelchair transfer performance in the built environment. The station was designed to investigate the impact handhelds, back rests, heights, and seat widths have on transfer performance. It consisted of a height adjustable scissor lift with two height adjustable platforms that could be secured on top. An adjustable height slide could be attached in between the two platforms. Grab bars of two varying heights and barricades could be attached to the platforms which could be used to assist with the transfers and also helped to define the transfer seat width. The platforms were cushioned to protect an individual's skin during transfers. Subjects were asked to transfer from their own wheeled mobility device (WMD) to one or both platforms (depending on the protocol) and leading/trailing hand placements and transfer height were recorded. Wheeled device positions (e.g. angular orientation and linear distances from the first platform) were recorded using a grid on the floor located in front of the station. The station was built for subjects to perform five test protocols in random order. Each protocol tested a specific environmental factor.

The design process in creating the transfer station involved a solid understanding of current Americans with Disabilities Act Accessibility Guidelines (ADAAG) as well as an understanding of the barriers wheelchair users face when transferring in different environments. The entire design and fabrication process took approximately six months to complete and took place at the University of Pittsburgh's Human Engineering Research Laboratories.

3.2 METHODOLOGY

3.2.1 Background

As the lead governing agency of accessible design criteria throughout the country, the U.S. Access Board requires data on transfers to develop guidelines for the purposes of making public facilities accessible to persons with mobility impairments. The 2002 Americans with Disabilities Act Accessibility Guidelines (ADAAG) were not based on evidence. Recommendations for facilities such as transfer height and clear floor space for positioning WMDs are limited (Toro, Koontz, Cooper, 2012; United States Access Board, 2003). The first phase of the Access Board study sought to investigate the impact height differentials play in wheelchair transfer performance. While this study also explored the role of grab bars when performing transfers, our workgroup of experts felt that this area needed further attention (Jerome, Koontz, Crytzer, Cooper, 2013). A literature review on grab bars supports the need to investigate handhelds because of the overwhelming lack of research evidence solely related to individuals with disabilities who use wheelchairs and are not in the elderly population (Arecelus et al., 2009; Biering-Sorensen, Hansen, & Biering-Sorensen, 2009; Edwards et al, 2006; Jones & Tamari, 2007; Nikolaus & Bach, 2003; Sveistrup, Lockett, Edwards, & Aminzadeh, 2006; Tzeng & Yin, 2010). Grab bars also add to the safety and accessibility of high transfer areas (e.g. in the home, bathroom, hospital, or around the community) (Edwards et al, 2006; Jones & Tamari, 2007; Nikolaus & Bach, 2003; Tzeng & Yin, 2010).

The first phase of the transfer study only investigated one-step transfers. Subjects transferred from their WMD to a transfer station and then back to their WMD. The study did not investigate the process of transferring to another surface once they made the first transfer to the station (Toro, Koontz, Cooper, 2012). Two-step transfers like this are found when transferring to an amusement park ride vehicle, into or out of a swimming pool, or to gain access to a piece of playground equipment (Accessible amusement rides, 2003; 2010 ADA standards, 2010). It is not clear how many people are comfortable with performing two-step transfers and if the guidelines for widths and heights are appropriate. The standards for transfer devices used for two-step transfers into amusement park rides currently need to have a height range between 14 and 24 inches above the load/unload area, but designers are encouraged to make these devices so that they are between 17 and 19 inches above the surface. There is no mention of what the transfer device seat width should be, but the vertical transfer should not be greater than 8 inches. Seat widths for swimming pool seat lifts should between 16 and 19 inches. The standards also mention gripping surfaces and seat paddings should be considered (but not required) when greater distances are required. There is no further explanation about what is considered to be a "greater distance" (Accessible amusement rides, 2003).

In order to investigate transfer height differentials, floor space, two-step transfers and other elements such as handhelds that could help an individual's transfer performance a new transfer station was designed and fabricated for the second phase of the Access Board study. Having the ability to test different handheld options and being able to adjust the transfer surface heights were requirements for the new station. It also needed to be able to hold at least two transfer surfaces with one of the surfaces capable of varying in height from the other surface.

3.2.2 Design

Recreational environments that wheelchair users may find themselves wanting to transfer to such as pools, playground equipment, medical diagnostic equipment, and exam tables were used as inspiration for the transfer station design. The station was to be adjustable so different elements of transfers could be evaluated. Before developing the transfer station, a consensus of what elements of transfer needed to be investigated had to be made. This involved group discussions between study investigators, the Access Board, NIDRR, and the Human Engineering Laboratory (HERL) machine shop staff. Based on expert opinion and lack of evidence, it was concluded that grab bars, backrests, seat widths, and two-step transfers were the items to be tested. The addition of a two-step transfer by way of a slide was added to the items to be investigated because of its presence in some real world transfer situations (e.g. amusement park rides) and its not currently incorporated into any standards.

The 2010 ADA Standards for Accessible Design relating to independent wheelchair transfers were used as a guide for the dimensions used to design the new transfer station (General ADAAG Standards, 2012). These standards mainly address space requirements adjacent to an element, the seat height of the element, and specifications for grab bars. The standards were developed to set the minimum accessibility requirements for State and local government facilities, public accommodations, and commercial facilities ("2010 ADA standards," 2010). Since the number of elements designed for transfers has increased in recent years accessibility standards have also expanded. Apart from traditional transfer environments like water closets, bathtubs, showers, dressing rooms, and toilet stalls, there are now standards for recreation facilities including amusement rides, boating facilities, exercise equipment, play areas, and swimming pools. Standards for medical diagnostic equipment are also currently being implemented ("2010 ADA standards," 2010). The dimensions mentioned in the standards for all of these environments were looked at while designing the transfer station so that the study could assess what people would be expected to do while transferring in different environments. The station was designed solely to be used as a data collection tool and not as a device to be manufactured to assist in transfers.

The design criteria of the transfer station consisted of it having to be height adjustable, have multiple detachable handheld options (grab bars and backrests), the capability of having two height adjustable transfer surfaces for two separate two-step transfer protocols (e.g. two platform surfaces positioned at 90^o with respect to each other and two platform surfaces with a ramp in between), and the ability to adjust transfer surface seat width. The transfer station design process began by creating a rough 3D computer-aided design (CAD) model of the station and all of its components using SolidWorks 2011. The rough model allowed everyone to see what the station would look like and gave the opportunity to discuss what materials should be ordered to fabricate the data collection tool. It also opened the discussion up for what dimensions should be used.

The dimensions of each part were chosen based on current standards. The standards give dimension ranges for elements like grab bars, backrests, and seat widths. Multiple size options of these components were designed. Since the station needed to be raised and lowered from a subject's level height, a scissor lift table was designed as the base of the station. Table 2 gives the design criteria used for the transfer surfaces. These dimensions also set the criteria needed for the scissor lift.

Table 2. Transfer Surface Design Criteria

Design Criteria needed for Scissor Lift	Dimensions
Seat Width Ranges for Platform 1 and 2	18”-30”
Seat Depth for Platform 1 and 2	16”
Vertical Height Distance Between Platform 1 and Platform 2	0”-8”
Platform 1 Vertical Height Range	8”-32”
Horizontal Distance (Gap) between Platform 1 and Platform 2	0”-8”

The minimum seat width of 18 inches was chosen based on the swimming pool seat lift standard seat width range of 16 to 19 inches. The maximum seat width of 30 inches was chosen so width greater than the maximum standard width could be tested. The maximum seat width of 30 inches plus enough room to secure grab bars on either side of the seat made 42 inches the minimum width the tabletop could be. The minimum length the tabletop could be was 40 inches based on having enough room for two 16-inch platforms lying beside each other and another 8 inches for when the sliding board was connected to both platforms. The scissor lift needed to be capable of being lowered to around 8 inches and to be raised to at least 8 inches higher than one’s level seat height (between 26 inches and 32 inches). The 8-inch threshold was based on it being the maximum allowable height of a transfer step. This dimension is mentioned under Section 1008.3.2 (play areas) and Section 1009.5.4 (swimming pools, wading pools, and spas) of the ADA standards. Since a commercially available foot pump hydraulic scissor lift table was found to meet the dimensions required for this study, it was purchased instead of fabricated. The purchased scissor lift used for the study was a Vestil SCTAB-2000 and had a 42 X 42 inch tabletop. Its maximum raised height was 34 inches, and its minimum lowered height was 8 inches. It operated by pumping a lever by foot located underneath the lift. Its maximum weight capacity was 2000lbs and its net weight was 386lbs.

The station design involved multiple platforms to be used as the transfer surfaces. These platforms were to be secured to the scissor lift tabletop. The seat depth dimension of 16 inches was chosen based on the ADA bathtub seat and pool deck wall depth requirements. Section 610.2 of the ADA gives the range of 15-16 inches for bathtub seat depth and section 1009.4.3 gives the range of 12-16 inches for swimming pool transfer walls. The maximum dimension from these ranges was chosen. The platforms were also designed to be 1 inch thick so as to make adjustments in 1-inch height increments during the two-step transfers.

Two different two-step transfers were to be evaluated during the study. The first one involved transferring to a step directly behind the first transfer surface. No gap was to be between these two surfaces. The second two-step transfer involved a sloped transfer across a ramp that spanned an 8-inch gap (chosen to be half the depth of the seat depth). The angle of the slope was allowed to vary as the second platform height changed, or in other words the ramp grew or shank in size so as to maintain a constant 8-inch gap between the two transfer steps. A maximum height differential of 8 inches was chosen based on it also being the maximum height standard for transfer steps (section 1009.5.4 of ADA). For this sloped transfer an adjustable ramp was designed to be attached to both transfer surfaces. It was designed to grow as the height differentials changed. It had a constant width of 30 inches and was 1 inch thick. The minimum length was 8 inches and the maximum length was 11 inches.

Section 609 of the ADA standards gives the acceptable dimensions for grab bars. Grab bars can have either circular or non-circular cross-sections. Study investigators chose to use circular grab bars based on them being more prevalent in the real world and with the thought that subjects would feel more comfortable using the round bars. The standard gives the outside diameter dimension range for circular cross section grab bars to be between 1.25 inches minimum and 2 inches maximum. A diameter of 1.5 inches was chosen for the grab bars used in the study. Section 1009.4.5 describes grab bars to be used on swimming pool, wading pool, and spa transfer walls. This standard gives the grab bar height range of 4 inches minimum and 6 inches maximum from the wall to the top of the gripping surface. Two grab bar heights options were designed for the study; a 6-inch and a 2.75-inch. The 6-inch height was based on the standard and the 2.75-inch was based on a recommendation of the Access Board to better simulate having a handle-like structure directly on the transfer surface. The 2.75-inch height was estimated to be the lowest height the bar could be for an average man to still be able to wrap his hand around it. A 4 inch grab bar was not used because it was believed that if someone could use the 6 inch and the 2.75 inch they would be capable of using a 4 inch and that the differences between the 6 inch and 4 inch would be negligible in the study results. Both platform 1 and platform 2 were 16 inches deep. The grab bars were designed to be 16 inches long so that they could span the depth of the platforms. Figure 3 shows both types of grab bars used during the study.

Section 1009.4.5 of the ADA standards also gives the dimensions for grab bars spacing. When two grab bars are provided there should be at least a 24-inch clearance between them. Since transfer seat width was to be investigated during the study, the grab bars were designed to have a clearance range between 18 and 30 inches. This allowed another 6 inches below and above the standard to be evaluated. Having the grab bars welded to a steel plate that could be screwed into the top transferring surfaces in different increments allowed this range to be met.

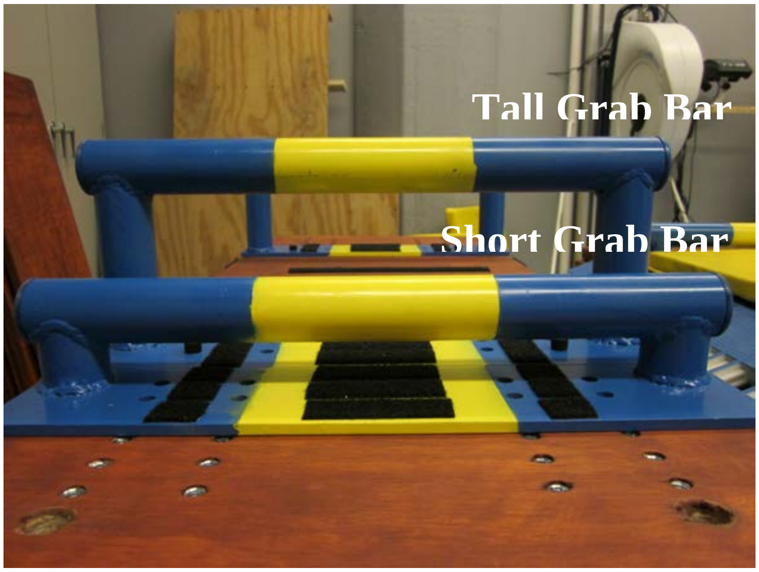

Figure 3. 6 inch and 2.75 inch Grab Bars

Besides having two grab bar options to evaluate as handhelds, multiple size backrests were also designed to be investigated as handheld options. The standard describing bench seat back supports (section 903.5 of ADA) gives a minimum of 18 inches from the seat surface to the top of the support. Three different height back supports were designed for this study; a 14-inch, a 17-inch, and a 20-inch. These heights were chosen because they range from below and above the current minimum requirement. They were designed so that they could easily be secured and taken off the station by sliding them in and out of two circular slots located in the scissor lift top. Each backrest was also designed to have a 5^{o} angle for comfort. Figure 4 shows all three of these backrests in front of or secured to the transfer station.

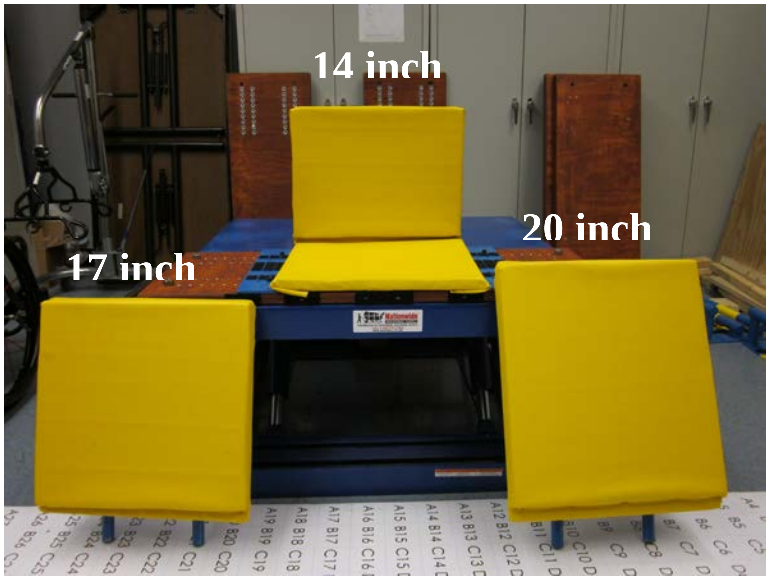

Figure 4. 14 inch, 17 inch, and 20 inch Transfer Station Seat Back Rests

3.2.3 Development

The new transfer station data collection tool and all of its components were fabricated under the supervision of the Human Engineering Research Laboratories machine shop staff. The development of the station began once the final dimensioned SolidWorks 3D CAD Model was approved by the study investigation team and the machine shop staff. The first materials ordered were the scissor lift table, wood for the platforms, and steel for the grab bars. Other materials needed to create the station consisted of tee nut inserts for wood (5/16" – 18 interior thread, 7/8" length barrel, 4 prong (drill size 3/8"), a miniature steel drive shaft (.25 inch outer diameter and a length of 36 inches), all-thread rod, rust proof spray paint, neoprene foam (1 inch thick), vinyl fabric, nuts, and Allen screws.

Wood was chosen to be the best material to use for the transfer surface top platforms. They were made from A/C Pine Plywood sheets. Two .5 inch thick 16 X 42-inch plywood pieces were cut from the sheet and were glued together with wood glue to make 1-inch boards. The boards were sanded down and stained to prevent splinters and warping. Figures 5 and 6 show examples of the sanding and staining setups. A total of 12 boards were made. Four holes were drilled through the four corners of all 12 boards so that they could be screwed into the scissor lift tabletop with a custom made bolt. Holes were manually milled into the tabletop for this purpose. Figure 7 shows the scissor lift tabletop being milled. The custom bolt was made by welding a nut to the top of a cut piece of all-thread rod. Eight bolts were created; four 12 inch and four 4 inch. The taller ones were used for securing multiple stacks of boards and the short ones were for securing 1 to 3 boards to the tabletop. The bolts screwed into nuts that were welded underneath the tabletop. Four of the 12 boards were chosen to be the top surfaces subjects would transfer to. The other boards were used for adding height differentials between two transfer surfaces. The four top surface boards had 32 more holes drilled into them where t-nuts were inserted. Figure 8 shows an example of the top surface and the height differential boards and where the holes were located. Figure 9 shows the custom made bolts used to secure the boards to the table top. The tee nuts were used to help secure grab bars to the surfaces with Allen screws. Two of the four top surfaces had 3-inch deep and 40-inch long notches made into them. The purpose of these notches was so that the height adjustable ramp could be fastened to them.

Figure 5. Transfer Platform Board Being Sanded

Figure 6. Transfer Platform Board Being Stained

Figure 7. Scissor Lift Table Top being Manually Milled

Figure 8. Top Surface and Height Differential Platforms Boards

Figure 9. Custom Made Bolts

The height adjustable ramp was fabricated using a selective laser-sintering (SLS) machine. This machine uses additive manufacturing technology to produce products that are otherwise difficult to produce using tradition machining procedures. A total of 16 hard plastic parts were made from a powder base using this machine to create all the components for the adjustable ramp. Eight of the parts were the transfer surface attachments and the other four were the ramp itself. The attachment parts were epoxy glued to the wood platforms. Since the SLS machine has a limited amount of build space the original CAD drawing of the ramp was broken down to four separate parts. These parts were also epoxy glued together so the ramp consisted of two parts. One part was attached to one platform and the other to the other platform. The two parts were designed to slide in and out of each other in different increments as the transfer surface height differentials varied. Figure 10 shows the SolidWorks 2011 CAD drawing of the assembled ramp attached to the station.

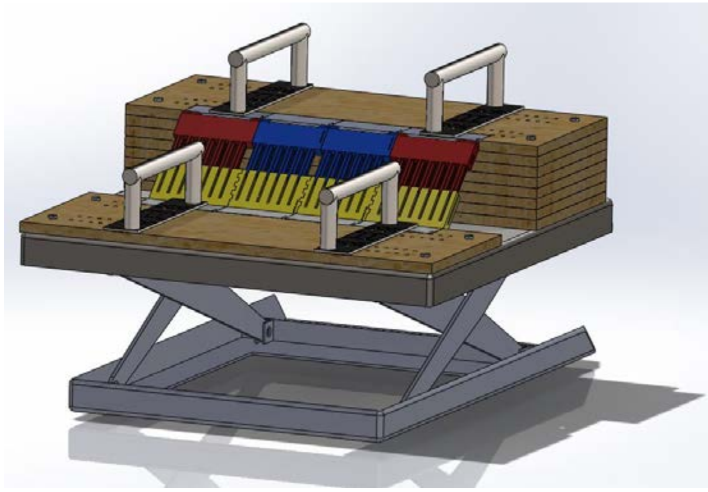

Figure 10. Solidworks 2011 CAD Drawing of the Height Adjustable Ramp Assembled to the Transfer Station

Steel tubing with an outside diameter of 1.5 inches and a wall thickness of .065 inches was used to form the grab bars. The tubing was cut down to size. Three pieces were used to form each grab bar (one long piece and two leg pieces). “Birds mouth” cuts were milled out on one end of each leg piece. This allowed the long piece to sit on top of the leg pieces securely and made it easier to weld together. Once all three pieces were welded, the grab bar was welded to a steel plate. The steel plate was .25 inches thick, 3.5 inches wide and 16 inches long. Eight .38-inch holes were cut through the plate and two circles were engraved using a computer numerical control (CNC) machine. The holes were designed to fit over the tee nuts on the transfer surfaces so it could be easily attached and unattached. The circular engravings were used as guides to place the grab bars on the plates for welding. This helped make sure each grab bar position was consistent. Figures 11 and 12 show the engravings being cut into the plate and how they look after being cut. Figure 13 shows a grab bar being welded to a plate. A total of six grab bars were made; three 6 inch and three 2.75 inch. The grab bars were polished using a wet stone tumbler and were spray painted with rust proof spray paint. Since the ends of the grab bars were hollow and sharp, caps were designed in SolidWorks 2011 to fix this issue. The caps were plastic and were produced using another additive manufacturing machine.

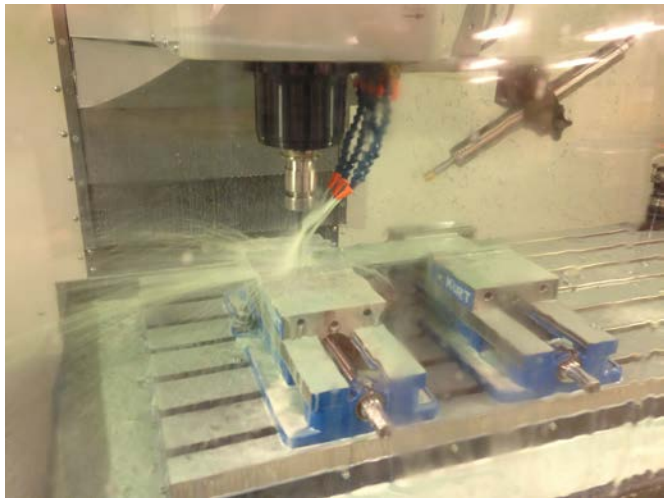

Figure 11. Circular Engravings being cut into Grab Bar Securement Plate

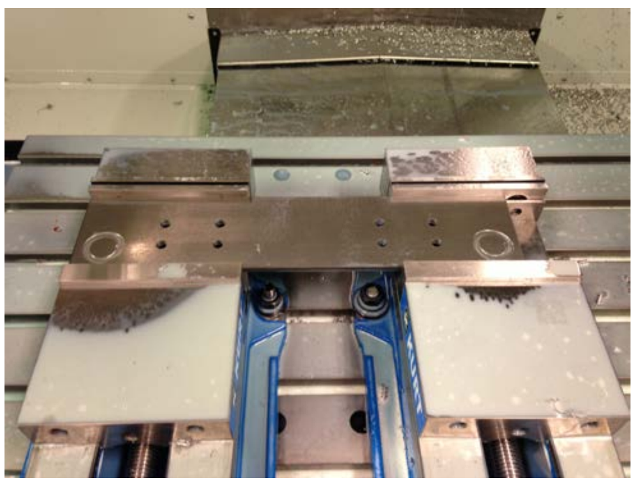

Figure 12. Grab Bar Securement Plate after Circular Engravings were cut

Figure 13. Grab Bar being welded to Securement Plate

For the protection of the subjects cushions were made for the surface platforms. These cushions were made of 1-inch thick neoprene foam and vinyl fabric. The foam was cut into two 16 X 18 inch rectangles and was wrapped with the vinyl fabric. Smaller pieces of foam were cut as well. These pieces were used as space inserts if a subject wanted to transfer to a surface larger than 16 X 18 inches. Vinyl fabric was chosen because its ability to easily wipe off to keep clean.

The angular orientation and linear distances of a subject's WMD with respect to the station needed to be recorded for both coming and leaving the station. To get these measurements a grid was made in SolidWorks 2011 using 3 X 3 inch cells with alphabetic and numeric markings labeling each cell. The grid was printed to scale with a plotter and was laminated. The grid was taped to the floor in front of the station. The idea was to record the cell coordinates of a subject's WMD when transferring to and from the station.

3.2.4 Description of Transfer Station Protocols

The transfer station was designed and fabricated so that five test protocols could be performed during the independent transfer study (see protocol descriptions in Chapter 4). These protocols were designed to understand the impact of different transfer environments on user performance.

3.3 CONSIDERATIONS AND ALTERNATIVES TO EXISTING DESIGN

The current ADA standards concerning independent transfers in the built environment were referenced during the design phase of creating the station (General ADAAG Standards, 2012). These standards provide the minimum scoping and technical requirements for "State and local government facilities, public accommodations, and commercial facilities to be readily accessible to and usable by individuals with disabilities" (2010 ADA standards, 2010, p. 5). The station was designed to help gather data on independent wheelchair transfers for the Access Board Study on independent wheelchair transfers. The data from this study will be used to inform engineers, architects, and designers who design public and private spaces about how to modify environments to be more accessible for performing transfers.

The transfer station has been a successful data collection tool for this study. No major malfunctions or breaks have occurred during subject testing. However, there were some design flaws that could be altered if a station like this is needed for future studies. One variation from the original design criteria for the station is concerning the adjustable ramp. The ramp was supposed to adjust in length over an 8-inch gap as the height differential between the two surface platforms grew from 1 to 8 inches. A miscalculation while creating the ramp design in

SolidWorks 2011 resulted in the maximum height differential to be 7 inches during the Two Step Transfer (Angled Transition) Protocol. This could easily be fixed by making the sliding pieces of the ramp longer. This was not done however because of the expensive cost to reproduce the ramp using SLS material. This was not felt to be a significant limitation of the research as this was the first pilot study to investigate using an integrated ramp structure to assist with transfers. Another issue with the station was its weight. The scissor lift alone weighed nearly 400lbs plus with all the platforms, grab bar, and backrests it was not easily transportable. A large truck was needed to travel with it and it required at least two people to load and unload everything. At least two people were needed during subject testing as well in order to position the platforms and secure everything in timely manner. An alternative to help make the station lighter would be to use a lighter wood or plastic to fabricate the platforms.

Even though the scissor lift was purchased because it met the design criteria of the study, after adding the transfer surface platform and the seat cushion the lowest height the station could be lowered to was 10 inches. This was two inches higher than what was originally discussed to be the station minimum. The seat cushion also occasionally folded back under a subject while they transferred. Tape was added to the cushion to help avoid this.

Overall the transfer station worked smoothly and valuable data was able to be collected with it.

4.0 HOW TRANSFER SETUP IMPACTS INDEPENDENT WHEELCHAIR TRANSFER PERFORMANCE

4.1 BACKGROUND

4.1.1 Purpose of Study

Limited data are available concerning transfers. Current studies have not investigated in detail the relationships between the features of transfer setup such as wheelchair positioning with respect to the target surface, vertical transfer height differences, location and characteristics of effective supports to aid with transferring, and space required for transfers. Moreover, current standards have criteria only related to surface heights and clear floor space. Studies of ambulatory individuals with mobility impairments have suggested that the addition of grab bars in public places as well as in the home have reduced the risk of falls and injury and promote a safer environment (Jones & Tamari, 1997; Sveistrup, Lockett, Edwards & Aminzadeh, 2006). Very little research has been done on grab bar usage and other environmental features that may serve to assist wheelchair users in performing transfers. In order to improve the transfer process for individuals with disabilities, the standards concerning transfers to elements in the built environment need to be updated. Data on transfers from a broad spectrum of community dwelling mobility device users is necessary to inform engineers, architects, and designers who design public and private spaces about how to modify the environment to enable the highest degree of independence. Because of these reasons the U.S. Access Board has sponsored a multi-year study on independent wheelchair transfers.

The IWT Workgroup was partially conducted in order to help gather information from experts on what environmental factors should be looked at during the second phase of the Access Board's study on independent wheelchair transfers that may not have been addressed during the first phase. Many of the topics brought up during the workgroup were incorporated into the design of the protocols and the questionnaires asked during this study. In addition there were certain questions that the Access Board specifically wanted to see addressed: 1) what should the vertical height difference be when transferring between two transfer steps, 2) how wide do transfer steps need to be, 3) do the presence of handhelds on or around the transfer step make transfers easier, and 4) how much help does adding a backrest to a transfer surface help with transfers. Moreover, there were several issues raised in the first study on transfer setup that needed to be addressed in a follow-up study. In the first study, subjects could only transfer to the station laterally. For example it was not possible for them to approach the transfer platform head-on in their WMD, which eliminated some subjects who could independently transfer. Another issue was not knowing if or how transfer skill may have impacted the results. For instance, while subjects could reach certain high/low heights they may have done so at the cost of using awkward joint motions and forces. To find a relationship between transfer performance and transfer skill quality the Transfer Assessment Instrument (TAI) was added to the data collection during the study. The TAI is an objective and quantifiable measure of transfer technique (McClure, Boninger, Ozawa, & Koontz, 2011; (Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013). It was designed so clinicians could evaluate transfer quality by assessing upper limb function, safety, and how well individuals can direct caregivers to assist them (McClure, Boninger, Ozawa, & Koontz, 2011).

The specific aims of this follow-up study were to:

1) Determine the 5^{th}, 50^{th}, and 95^{th} population-based percentile level, highest and lowest heights for transfers to a) a platform with no handhelds present, b) a platform with surface mounted grab-bars and c) a platform with surface mounted grab-bars and a backrest.

2) Determine the 5^{th}, 50^{th}, and 95^{th} population-based percentile widths for each level, highest and lowest transfers to a) a platform with no handhelds present, b) a platform with surface mounted grab-bars and c) a platform with surface mounted grab-bars and a backrest

3) Determine the 5^{th}, 50^{th}, and 95^{th} population-based percentile space needed for level, highest and lowest height transfers without handhelds, with grab-bars, and with grab bars and a backrest

4) Determine the 5^{th}, 50^{th}, and 95^{th} population-based percentile heights for a two-step transfer with and without an integrated ramp

5) Determine how the presence of surface mounted grab-bars affect ability to transfer to a higher and lower surface

Hypothesis 5) WMD users will be able to transfer higher and lower when grab bars are available

6) Determine how the addition of a backrest affects the ability to transfer to a higher or lower surface

Hypothesis 6) WMD users will be able to transfer to a higher or lower surface when a backrest is available

7) Determine the relationship between transfer quality and transfer performance

Hypothesis 7a) The quality of transfer will be higher with the surface mounted grab bars present compared to without them present

Hypothesis 7b) There will be no association between transfer quality and the highest attainable heights and transfer quality and the lowest attainable heights

This study will provide data that the U.S. Access Board and designers/engineers can use to modify equipment and/or environment (e.g. buildings, recreational facilities and playgrounds) for the purposes of enhancing the transfer process.

4.2 METHODOLOGY

4.2.1 Subjects

This study received approval by the University of Pittsburgh's Institutional Review Board. Eligibility to participate in the study was open to adult and children wheelchair users who were able to perform independent transfers to/from a WMD with or without a transfer board. They owned their own WMD and had been using a device for at least a year. The age requirement for children was seven years old and older. Subjects were excluded from the study if they had any active pressure sores or a history of pressure sores that could be aggravated while performing multiple transfers. They were also excluded if they had any pain or injury to either arm that would inhibit their ability to perform transfers or bear weight on their arms. Subject testing was conducted at the Human Engineering Research Laboratory (HERL) in Pittsburgh, Pennsylvania and at the Hiram G. Andrews Center (HGAC) in Johnstown, Pennsylvania between July 2013 and November 2013. HERL is affiliated with the University of Pittsburgh's Rehabilitation

Science and Technology (RST) Department and the Veteran's Administration (VA) Pittsburgh Healthcare System. HGAC is a post-secondary school that provides services like vocational evaluation, career exploration, and individual living skills to individuals with various types of disabilities.

Subjects were recruited using a few different methods. First, an IRB approved HERL Assistive Technology Registry was used. Individuals that were on the registry and were thought to meet the study criteria based on the information they gave on the registry were sent copies of the IRB approved study flyer. Anyone who was interested in participating contacted a study clinical coordinator who then relayed their information to the graduate student investigator for screening and scheduling. Study flyers were distributed to rehabilitation facilities, outpatient facilities, disability organizations, and local schools and universities. The flyer was also posted on different disability oriented group websites as well as the HERL website. The flyer instructed all potential subjects to call HERL for scheduling. Some subjects were recruited in person while they were participating in other research studies at the laboratory. These individuals were either given a flyer and were encouraged to call for scheduling or were screened and scheduled on the spot.

4.2.2 Questionnaire 1

On the day of testing, subjects were asked to fill out a general questionnaire after the informed consent process was finished. This questionnaire was used to collect data on subject demographics (e.g. age, race, sex, height, weight, and disability), transfer history, transfer preference, and WMD characteristics. Questions about how different aspects of transfer impact a subject's ability to transfer were incorporated into the questionnaire based on some of the feedback from the IWT Workgroup.

4.2.3 Experimental Protocols

The custom-built transfer station described in Chapter 3 was used to investigate the impact handhelds, backrests, and seat widths have on transfer quality and performance. Before performing any transfers to the station, each subject's level seat height (the height from the ground to the top of the seat posts plus the thickness of the seat cushion) was measured. The subjects were asked to transfer from their own WMD to the platforms on the station and back to their WMD. The angular orientation and linear distances of their WMD with respect to the station was recorded for both coming and leaving the station using a grid located in front of the station. At least one study personnel stood next to the subject to prevent a fall from occurring. Hand placement, method of transfer, and use of a transfer board were noted.

Each subject was asked by an investigator to perform five test protocols in random order. Protocols were performed in random order to control for fatigue-related effects and so that the protocols were not done in order of difficulty. Each protocol aimed to test a specific environmental factor. Subjects were encouraged to notify study investigators if they felt uncomfortable performing any of the transfer scenarios. No subject performed a transfer that the study investigators considered to be unsafe. After each transfer in each protocol, changes made to device positioning (if any), use of a board, and surface(s) used for leading and trailing hand placement during the transfer process were recorded. A clinician investigator using the Transfer Assessment Instrument (TAI) assessed their transfer skill ability (McClure, Boninger, Ozawa, & Koontz, 2011; Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013). The TAI was recorded for all protocols except the two-step transfer protocols since the TAI is designed to assess in part wheelchair setup relative to the surface which did not apply for these protocols (McClure, Boninger, Ozawa, & Koontz, 2011; Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013).

Every time a subject transferred from their WMD to a platform, from a platform to their WMD, or from between any two platforms it was considered one transfer. Two-step transfers were defined as transferring to one platform and then to another platform. Leading and trailing hand position (e.g. either on the backrest, platforms, slide, chair, or grab bars), wheelchair position (e.g. how far away and at what angle with respect to the platform), method of transfer (stand and pivot, combination of arms/legs or arms alone), and whether a transfer board was used were recorded. Breaks were scheduled in between transfer activities to allow the individual time to rest. This part of the protocol took about 70 minutes to complete. Primary data involved recording the maximum height ranges attainable for each type of transfer.

4.2.3.1 Initial Setup

The scissor lift was adjusted so that the first platform was level with the subject's seat height. The barricades shown in Figure 14 were adjusted to the subject's preferred seat width. The subjects were asked to position themselves next to the platform as they normally would to prepare for a transfer. The subject then transferred from their own wheelchair to the first platform and back to their chair. A clinician scored the subject's transfers using the TAI.

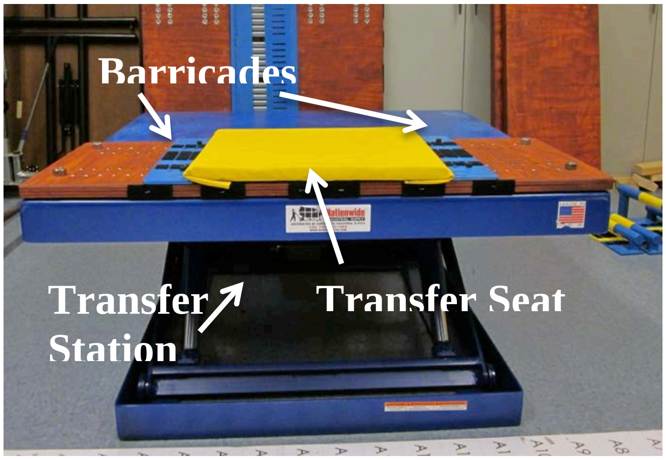

Figure 14. Front View of the Initial Setup and Adjustable Height: No Grab Bars/No Backrest Protocol

4.2.3.2 Protocol A: Adjustable Height: No Grab Bars/No Backrest Protocol

This protocol consisted of two parts: maximum height transfer and a lowest height transfer. From the Initial Setup, the scissor lift was adjusted incrementally in height so that platform 1 could be made higher or 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 subject was asked to perform a transfer at each height increment until the platform was raised/lowered to a level that they no longer felt they could perform a transfer based on their own judgment or that of the study personnel. The maximum transfer heights high/low that were attainable and TAI scores were recorded. Figure 14 above shows the same setup used for this protocol.

4.2.3.3 Protocol B: Adjustable Height Protocol: Grab Bar Option/No Backrest Protocol

This protocol consisted of three parts: level height transfer, maximum height transfer, and a lowest height transfer. From Protocol A, the barricades were replaced with grab bars of two varying heights (2.75 inches and 6 inches) depending on the subject's preference. They were also adjusted to the subject's preferred seat width if different from the initial setup. The rest of the protocol followed the same way as Protocol A where the subject transferred to the first platform and back. Figure 15 shows the setup for this protocol.

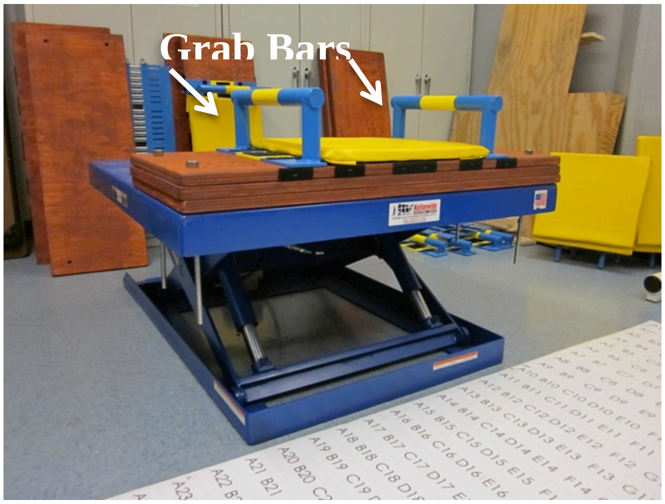

Figure 15. Front View of the Adjustable Height: Grab Bar Option/No Backrest Protocol

4.2.3.4 Protocol C: Adjustable Height: Grab Bar and Backrest Option Protocol

This protocol consisted of three parts: level height transfer, maximum height transfer, and a lowest height transfer. From Protocol B, a backrest was attached behind platform 1. The subject chose one of three different height backrests (16" X 14", 16" X 17", and 16" X 20"). The rest of the protocol followed the same as Protocol B. Figure 16 shows the setup for this protocol.

Figure 16. Front View of the Adjustable Height: Grab Bar and Backrest option Protocol

4.2.3.5 Protocol D: Two Step Transfer (90^o Transition) Protocol

This protocol consisted of two parts: level to a higher seat and level to lower seat. From Protocol B the scissor lift was adjusted so that the first platform was set level with the subjects WMD. A second platform was added to the scissor lift behind platform 1 so that they were at a 90^o angle to each other. The vertical distance between platform 1 and 2 was adjusted incrementally in height: higher and lower by adding one-inch boards to either platform. The subject was asked to perform transfers to the first platform, to the second platform, back to the first platform, and then finally back to his/her WMD. The amount of vertical distance that the second platform was raised/lowered each time depended on the subject's perceived and observed transfer abilities. The subject was asked to repeat the transfers until the second platform was raised/lowered to a level that they no longer felt they could perform a transfer based on their own judgment or that of the study personnel. The maximum and minimum vertical distances that were attainable were recorded. Figure 17 shows the setup for this protocol.

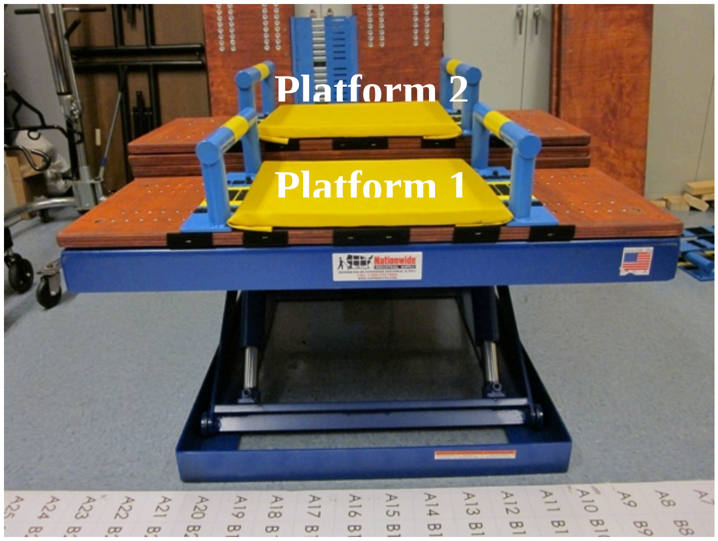

Figure 17. Front View of the Level to Increment above Two Step Transfer (90o Transition) Protocol

4.2.3.6 Protocol E: Two Step Transfer (Angled Transition) Protocol

This protocol consisted of two parts: level to a higher seat and level to lower seat. From Protocol D, the first platform was set level with the subjects WMD. An adjustable height slide was attached between platform 1 and platform 2. The slide was used as a ramp to get up to and down from platform 2. The vertical distance between platform 1 and 2 was adjusted incrementally in height: higher and lower by adding one-inch boards to either platform. The slide was capable of growing in length as the vertical distance between platforms grew. The subject was asked to perform transfers to platform 1, to platform 2 (via the adjustable height slide), back to platform 1, and then finally back to his/her WMD. The amount of vertical distance that the second seat was raised/lowered each time depended on the subject's perceived and observed transfer abilities. The subject was asked to repeat the transfers until platform 2 was raised/lowered to a level that they no longer felt they could perform a transfer based on their own judgment or that of the study personnel. The maximum and minimum vertical distances that were attainable were recorded. Figure 18 shows the setup for this protocol.

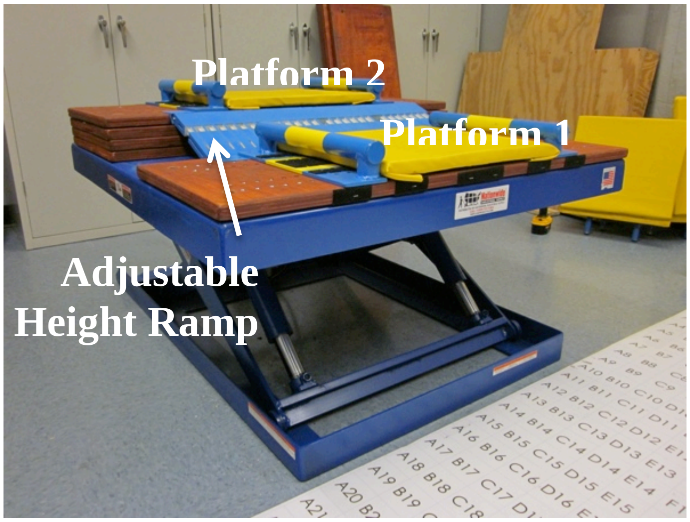

Figure 18. Front View of the Level to Increment above Two Step Transfer (Angled Transition) Protocol

4.2.4 Questionnaire 2

After completing the transfer portion of the study, subjects were asked to fill out a second questionnaire. This questionnaire consisted of two questions asking subjects to comment on the two-step transfers they performed. It asked if they would perform either of the two-step transfers in the 'real world' and to explain why or why they would not make these transfers.

4.2.5 Data analysis

Descriptive statistics were used to find the population-based percentile level, highest, and lowest heights for transfers for the one-step transfer protocols A, B, and C and the two-step transfer protocols D and E. This was done for the first attainable attempt transfers and the final attainable attempt transfers. The 5^{th}, 50^{th}, and 95^{th} percentiles were recorded along with the minimum and maximum heights attained for each part of each protocol. The same analysis was done for the maximum attainable height seat widths and for the space parameters when transferring to and from the station.

The TAI consists of two parts. The first part consists of 15 items where a clinician marks “yes”, “no”, or “not applicable” for each item while observing a subjects’ transfer. The second part is scored after all the transfers have been performed. It consists of 12 items that are scored on a Likert scale with 0 meaning, “strongly disagree” and 4 meaning, “strongly agree”. The scores for both parts are averaged to get the final TAI score which is in a range from 0 (poor transfer skill) to10 (excellent transfer skill). For this study for each protocol (A, B, and C) three total TAI scores were obtained; one for each level height, highest height, and lowest height. For the full explanation of the TAI and how it is calculated please refer to McClure, Boninger, Ozawa, & Koontz, 2011 and Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013.

Most of the variables tested were normally distributed according to the Shapiro-Wilk normality test results. Therefore, to examine the effects that surface mounted grab bars and backrests had on transfer performance (e.g. ability to transfer higher and lower) and transfer quality, multiple repeated measures ANOVA tests with Bonferroni post-hoc tests were used. Pearson bivariate correlations were performed to find if there was a correlation between transfer quality and the highest and lowest attainable heights achieved. The level of significance for all tests was 0.05.

4.3 RESULTS

4.3.1 Subjects

Out of the 29 participants enrolled in the study one subject was unable to independently transfer to and from the transfer station. This subject reported that he used a transfer board at home to independently transfer. A transfer board was available to him to use, but he was not able to independently transfer to the station without assistance. The remaining subjects consisted of 24 men and 4 women with an average age of 36.4 ± 13.4 years, body mass of 78.4 ± 28.6 kg, and height of 1.7 ± .2 m. Table 3 gives these general subject demographics including the average number of hours a day they use their WMD (11.6 ± 4.1), the average number of years they have been using a WMD (13.7 ± 8.9), and the average perceived number of level and non-level transfers they perform each day (15.6 ± 19.9 and 10.3 ± 18.9 respectively).

Table 3. General Demographics of Subjects

	Average	Max	Min	Std. Deviation
Age	36.4	57	18	13.4
Height (m)	1.7	2.0	1.2	0.2
Weight (kg)	78.4	129.3	22.2	28.6
Seat Height (cm)	58.2	86.4	52.1	6.0
Hours Using Wheelchair (Per Day)	11.6	18	2.5	4.1
Years Using Wheelchair	13.7	37	1	8.9
Number of Level Transfers	15.6	100	2	19.9
Number of Non-Level Transfers	10.3	100	0	18.9

Participants came from a broad spectrum of disabilities including spinal cord injury (SCI), cerebral palsy (CP), spina bifida, amputation, osteogenesis imperfecta, among others. Table 4 shows the number of participants by their self-reported type of disability. There were 16 manual wheelchairs, 9 power wheelchairs, 2 scooters, and 1 manual power-assist user. The average seat height (wheelchair seat plus cushion height) was 58.2 ± 6 cm. The median seat height was 57.2 cm and the range was from 52.1 to 36.5 cm. The overall width and lengths of the WMDs were 61.6 ± 4.7 cm and 94.3 ± 11.6 cm, respectively. Of the total population, 60.7% reported not having any formal transfer training, 14.3% had between 1 to 3 hours of training, and 28.6% had six or more hours of training. No one reported having between three and six hours of transfer training.

Subjects were able to judge where they thought their highest and lowest transfer heights would be before they transferred. This saved time and the number of total transfers performed during the study since subjects did not have to transfer to all height increments. The station was either raised or lowered until the subject felt that they no longer could transfer safely. The total number or transfers performed by each subject varied based on the number of transfer trials they took to reach their highest and lowest heights. The average number of transfers performed during the study per participant was 39 ± 9. Out of the 28 subjects enrolled in the study, 100% were able to attain the level, maximum height, and lowest height one-step transfers whether or not there were handheld options available (Figure 19). For the 90^{o} two-step transfer protocol 93% (26/28) were able to attain a level to an increment higher transfer, and 96% (27/28) were able to attain a level to an increment lower transfer. Slightly fewer subjects (n=26) attempted the angled transition two-step transfer protocol. For the level to an increment higher part of this protocol 85% (22/26) were able to attain this transfer, and 96% (25/26) were able to attain the level to an increment lower part. Figure 19 shows the number of subjects who attempted each protocol and the number of subjects who were able to attain the transfers within protocols. Table 5 gives the demographics of the subjects who were not able to attain a transfer within a protocol and the subjects that did not attempt a transfer within a protocol. The table also gives the demographic information of the subject withdrawn from the study.

Table 4. Number of Participants by Self-Reported Type of Disability, WMD, and Gender (n = 28)

	Men (n=24)				Women (n=4)			
Disability	Manual WC	Power WC	Scooter	MPA	Manual WC	Power WC	Scooter	MPA
Spinal cord Injury (SCI) ranging from C4-T9	8	2	0	0	1	0	0	0
Cerebral palsy	0	0	1	0	0	2	0	0
Spina Bifida	2	1	0	0	0	0	0	0
Amputee								
Double Amputee	1	0	0	0	0	0	0	0
Below Knee	1	0	0	0	0	0	0	0
Osteogenesis Imperfecta	1	0	0	1	0	0	0	0
Other[a]	2	4	0	0	0	0	1	0
Total	15	7	1	1	1	2	1	0

Note. WMD= Wheeled Mobility Device; WC= Wheelchair, MPA= Manual Power Assisted. [a]Other disability types include: Arthritis(1), Multiple Sclerosis(1), Muscular Dystrophy(1), Side effect of liver disease(1), Thrombocytopenia with absent radius (TAR) Syndrome(1), Side effect of heart attacks(1), Stroke, Edema, and Chronic obstructive pulmonary disease (COPD) (1).

Table 5. Characteristic of Subject Who were Withdrawn, Unable to Attain a Transfer, or did not Attempt a Transfer

Participant ID	Diagnosis[a]	Sex	Age (yrs)	Weight (kg)	Height (m)	Protocol(s) Unattain-able	Protocol(s) Not Attempted	WC[b] Type
S1 Withdrawn	Double Amputee/Stroke	M	57	129.3	1.9	All	All	P
S2	SCI (C4-C5)	M	49	124.7	1.8	E1	NA	P
S3	Stroke, Edema, COPD	M	57	127	1.8	D1, E1	NA	P
S4	CP	F	45	49.9	1.5	E1	E2	P
S5	MS	M	56	95.3	1.8	D1, D2	E1, E2	P
S6	SCI	M	31	95.3	2.0	E2	E1	M
S7	MD	M	50	40.8	1.7	E1	NA	M

Note. D1 = Protocol D transfer level to increment higher, D2 = Protocol D transfer level to increment lower, E1 = Protocol E transfer level to increment higher, E2 = Protocol E transfer level to increment lower, NA = not applicable (e.g. subject attempted every protocol). [a]Diagnosis acronyms = SCI (Spinal cord injury), COPD (and Chronic obstructive pulmonary disease), CP (Cerebral palsy), MS (Multiple Sclerosis), MD (Muscular Dystrophy). [b]WC Type = Wheelchair Type used, P (power wheelchair), M (manual wheelchair).

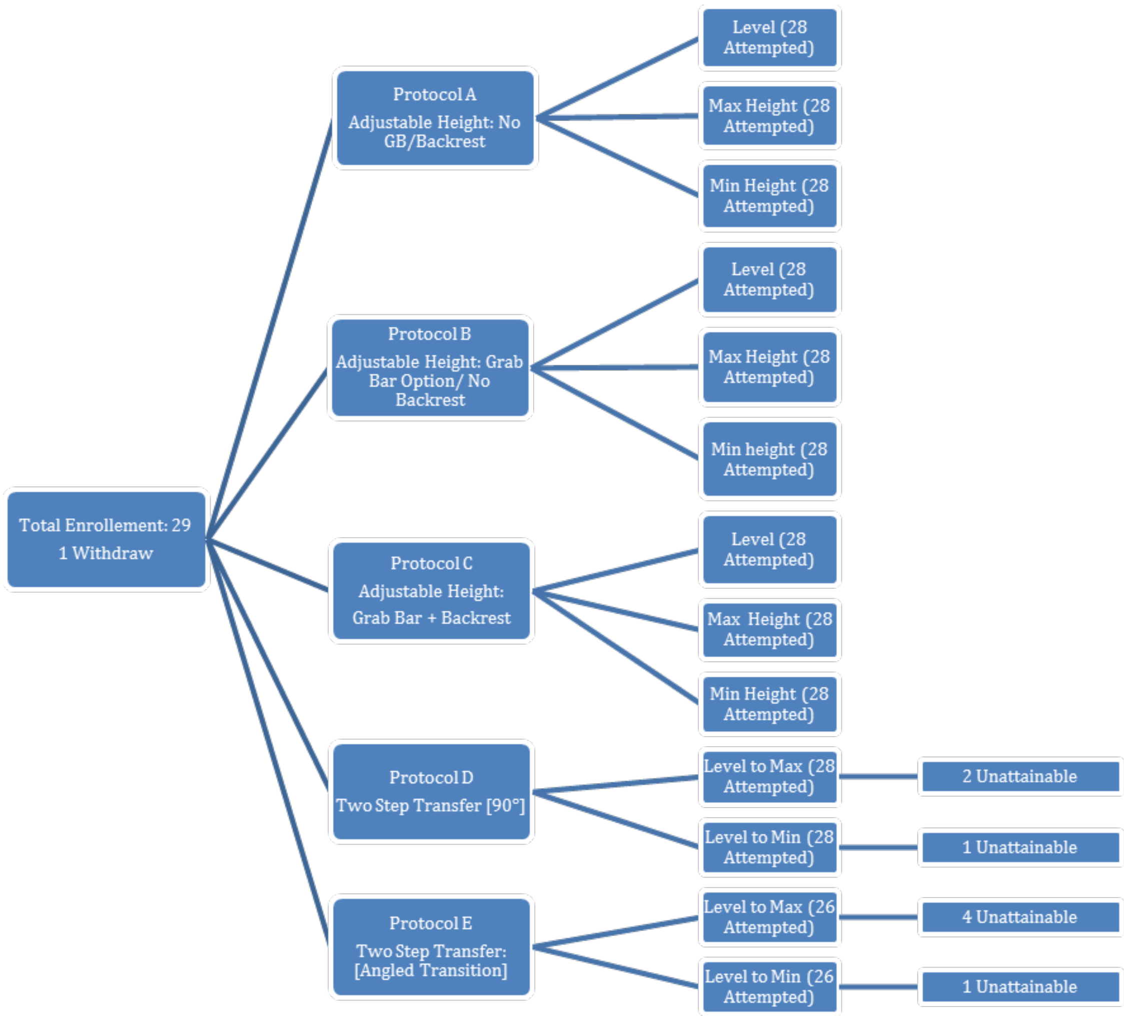

Figure 19. Total Number of Participants Who Attempted Each Protocol and Number of Participants Who Were Unable to Attain Transfers within Each Protocol

4.3.1.1 Highest and Lowest Heights Attained

The highest and lowest heights attained were found for both the first and last transfers within each protocol (Table 6 and 7 respectively). The 95th percentile highest and lowest transfers were similar to the maximum highest and lowest heights reported in both tables. This can be associated to a ceiling effect since some subjects were able to reach the highest and lowest heights the station could cover. The same was true for the two-step transfers whereby a ceiling effect can be found. Note that the values for the two-step transfers are smaller because the height differentials were restrained to 20.3 cm (8 inches) maximum for the 90^{o} step and 17.8 cm (7 inches) maximum for the angled transition to and from the step. In comparing the data between the first and last transfers within a protocol, the subjects did a better job estimating where their 'highest' height was than they did for judging where their 'lowest' height was with the first attempt. Differences in the 50th percentiles for the first and last transfers across protocols were between .6 and 2.6 cm for highest height and between 0 and 10.5 cm for lowest height.

Table 8 gives the number of subjects who selected either the tall or short grab bars or either the tall, medium, or short size backrests. The tall grab bar was selected more than the short one for all protocols. The short backrest was selected more than the medium and tall backrests. Only one subject selected the tall backrest.

Table 6. First Attainable Attempt Height Variable Percentiles (in centimeters)

Protocol	Percentile 5th	50th	95th	Minimum	Maximum	Interquartile Range
Level Height (n=28, a = 28)	52.6	57.2	62.4	52.1	63.5	4.5
Adjustable Height: No Grab Bars/No Backrest						
Highest Height (n = 28, a =28)	55.5	69.5	87.8	55.3	88.9	7.62
Lowest Height (n = 28, a =28)	25.4	38.1	58.4	25.4	58.4	20.0
Adjustable Height: Grab Bar Option/No Backrest						
Highest Height (n = 28, a =28)	52.6	68.6	86.7	52.1	87.0	16.7
Lowest Height (n = 28, a =28)	25.4	31.1	58.4	25.4	58.4	19.5
Adjustable Height: Grab Bar and Backrest Option (n = 28)						
Highest Height (n = 28, a =28)	59.6	71.8	86.7	58.4	87.0	12.1
Lowest Height (n = 28, a =28)	25.4	35.9	58.4	25.4	58.4	20.5
Two Step Transfer Height Differentials from Subject Level Seat Height						
Two Step Transfer: [90° Transition]						
Highest Height (n = 28, a = 26)	4.3	17.8	20.3	2.5	20.3	10.8
Lowest Height (n = 28, a = 27)	2.5	17.8	20.3	2.5	20.3	10.2
Two Step Transfer: [Angled Transition]						
Highest Height (n = 26, a = 22)	5.5	15.2	17.8	5.1	17.8	5.7
Lowest Height (n = 26, a = 25)	2.5	17.8	17.8	2.5	17.8	7.6

Note. The value of "n" represents the number of subjects who attempted the protocol and the value of "a" represents the number of subjects who were able to attain the transfer

Table 7. Maximum Attainable Attempt Height Variable Percentiles (in centimeters)

Protocol	Percentile 5th	50th	95th	Minimum	Maximum	Interquartile Range
Adjustable Height: No Grab Bars/No Backrest						
Highest Height (n = 28, a =28)	55.5	71.8	90.6	55.3	92.1	13.0
Lowest Height (n = 28, a =28)	25.4	33.0	57.3	25.4	58.4	17.0
Adjustable Height: Grab Bar Option/No Backrest						
Highest Height (n = 28, a =28)	52.6	70.5	100.1	52.1	101.0	19.4
Lowest Height (n = 28, a =28)	25.4	25.4	58.4	25.4	58.4	14.6
Adjustable Height: Grab Bar and Backrest Option (n = 28)						
Highest Height (n = 28, a =28)	60.7	72.4	87.0	58.4	87.0	17.3
Lowest Height (n = 28, a =28)	25.4	25.4	58.4	25.4	58.4	14.6
Two Step Transfer Height Differentials from Subject Level Seat Height						
Two Step Transfer: [90° Transition]						
Highest Height (n = 28, a = 26)	4.3	20.3	20.3	2.5	20.3	10.2
Lowest Height (n = 28, a = 27)	5.1	20.3	20.3	5.1	20.3	10.2
Two Step Transfer: [Angled Transition]						
Highest Height (n = 26, a = 22)	5.8	17.8	17.8	5.1	17.8	3.2
Lowest Height (n = 26, a = 25)	2.5	17.8	17.8	2.5	17.8	7.6

Note. The value of "n" represents the number of subjects who attempted the protocol and the value of "a" represents the number of subjects who were able to attain the transfer

Table 8. Number of Subjects Selecting Certain Grab Bars and Backrest Options for the Protocols they were Available

Protocol	Handheld Options				
	Tall Grab Bar (15.24 cm)	Short Grab Bar (6.99cm)	Tall Backrest (50.8cm)	Medium Backrest (43.18cm)	Short Backrest (35.56cm)
Protocol B Highest Height:	n = 21	n = 7	NA	NA	NA
Protocol B Lowest Height:	n = 22	n = 6	NA	NA	NA
Protocol C Highest Height:	n = 20	n = 8	n = 1	n = 9	n = 18
Protocol C Lowest Height:	n = 23	n = 5	n = 1	n = 9	n = 18
Protocol D Level to Highest Height	n = 21	n = 5	NA	NA	NA
Protocol D Level to Lowest Height	n = 23	n = 4	NA	NA	NA
Protocol E Level to Highest Height	n = 17	n = 5	NA	NA	NA
Protocol E Level to Lowest Height	n = 21	n = 4	NA	NA	NA

Note. NA = represents that the handheld option was not available for a particular protocol.

4.3.1.2 Preferred Widths

The seat width percentiles for the first transfers were the same as the last transfers within each protocol (Table 9). For all protocols the majority of subjects used the 45.7 cm seat width to make their attainable transfers and the widths did not vary much between protocols.

Table 9. Maximum Attainable Attempt Seat Width Percentiles (in centimeters)

Protocol	Percentile 5th	50th	95th	Minimum	Maximum	Interquartile Range
Level Height (n =28, a =28)	45.7	45.7	68.8	45.7	71.1	0.0
Adjustable Height: No Grab Bars/No Backrest						
Highest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0
Lowest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0
Adjustable Height: Grab Bar Option/No Backrest						
Highest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0
Lowest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0
Adjustable Height: Grab Bar and Backrest Option (n = 28)						
Highest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0
Lowest Height (n =28, a =28)	45.7	45.7	71.1	45.7	71.1	0.0

Note. The value of "n" represents the number of subjects who attempted the protocol and the value of "a" represents the number of subjects who were able to attain the transfer

4.3.1.3 Space Needs

The space dimensions while transferring to and from the transfer station were determined using the cell coordinates off the grid located on the floor in front of the transfer station. A scaled version of this grid showing its dimensions and location to the station can be seen in Figure 20 The overall size of the grid was 182.9cm (72in) long by 228.6cm (90in) wide. It was positioned so that it was centered with the middle of the transfer station. A coordinate system was assigned to the grid so that each cell was given an alphabetic (y-direction) and numeric (x-direction) name. The center point (0,0) was located in-between the grid values A15 and A16. There were a total of 720 cells in the grid all with dimensions 7.62 X 7.62 cm (3 X 3in) in size. The four outer most points concerning the location of the WMD were marked for the transfer moving to the station and again for the transfer coming back to the WMD. The angle the WMD was positioned with respect to the transfer station was measured from the A column edge of the grid. An angle of 0 degrees was given if the WMD was positioned parallel to the x-direction of the coordinate system. An angle of 90 degree was given if the WMD was positioned parallel to the y-direction of the coordinate system.

Tables 10 and 11 show the 5^{th}, 50^{th}, and 95^{th} percentiles for the space used when transferring to and from the transfer station. The amount of space changed slightly between protocols and between the directions of transfer. The amount of space that changed between protocols is shown graphically in Figures 22, 23, 25, and 26. These figures show the 50^{th} percentile space parameters for protocols A and B. Larger differences were observed within protocols when comparing the maximum and 5^{th} and 95^{th} percentiles to the 50^{th} percentile space used, (Figure 21 and 24). A reason for this is that some subjects were able to stand and walk to the station to transfer. These subjects tended to leave their WMDs further out on the grid than the subjects who performed arms and arms and leg transfers. The amount of space also changed slightly between transferring to and from the station within protocols. Figure 27 shows the 50th percentile spaces needed for transferring to and from the station for protocol B highest height attained.

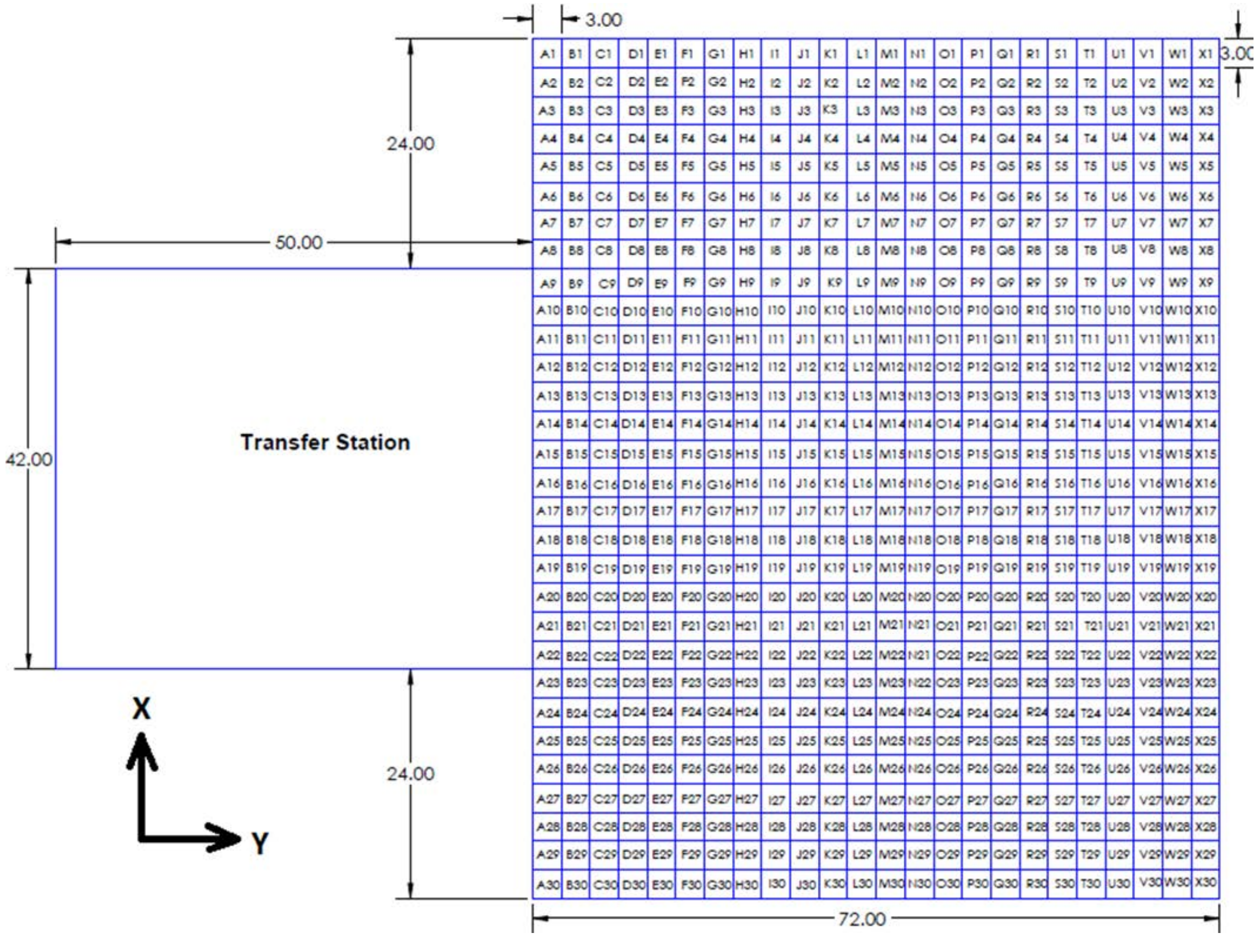

Figure 20. Scaled Version of the Grid used to find the Space Parameters of Subjects Transferring To and From the Station (measurements in inches)

Table 10. Percentiles for Space Parameters while Transferring TO Station

Protocol	Percentile 5th	50th	95th	Minimum	Maximum	Interquartile Range
Level:						
No Grab Bars/No Backrest						
Right of Center (cm)	-30.9	21.0	82.4	-34.3	87.6	27.6
Left of Center (cm)	-105.3	-45.7	11.4	-110.5	11.4	46.7
Depth (cm)	55.0	73.4	130.7	53.3	141.0	20.0
Angle (degrees)	0	25	90	0	90	35.3
Highest Height:						
No Grab Bars/No Backrest						
Right of Center (cm)	-13.5	26.7	90.9	-15.2	102.9	20.0
Left of Center (cm)	-93.9	-34.3	17.3	-99.1	19.5	40.0
Depth (cm)	46.7	76.2	127.3	38.1	141.0	34.3
Angle (degrees)	0	30.5	90	0	90	35.5
Lowest Height:						
No Grab Bars/No Backrest						
Right of Center (cm)	-19.1	19.1	89.2	-19.1	102.9	34.9
Left of Center (cm)	-101.2	-49.5	17.3	-102.9	19.1	52.39
Depth (cm)	58.9	80.0	125.5	57.2	141.0	23.8
Angle (degrees)	0	29.5	90	0	90	25.5
Highest Height:						
Grab Bars/ No Backrest						
Right of Center (cm)	-25.7	19.1	92.6	-34.3	102.9	27.6
Left of Center (cm)	-105.3	-45.7	17.3	-110.5	19.1	44.8
Depth (cm)	57.2	73.4	127.3	57.2	141.0	23.8
Angle (degrees)	0	28.0	90	0	90	35
Lowest Height:						
Grab Bars/ No Backrest						
Right of Center (cm)	-15.2	26.7	92.6	-15.2	102.9	30.1
Left of Center (cm)	-99.1	-43.8	19.1	-99.1	19.1	50.5
Depth (cm)	21.5	78.1	125.5	-7.6	141.0	35.2
Angle (degrees)	0	29.5	90	0	90	30.3
Highest Height:						
Grab Bar and Backrest						
Right of Center (cm)	-13.5	26.7	82.5	-15.2	87.6	26.7
Left of Center (cm)	-93.9	-38.1	11.4	-99.1	11.4	39.1
Depth (cm)	57.2	78.1	127.3	57.2	141.0	26.7
Angle (degrees)	0	24	90	0	90	38
Lowest Height:						
Grab Bar and Backrest						
Right of Center (cm)	-17.3	26.7	82.5	-19.1	87.6	42.9
Left of Center (cm)	-101.2	-38.1	13.5	-102.9	15.2	53.4
Depth (cm)	58.9	78.1	127.3	57.2	141.0	28.6
Angle (degrees)	0	29.5	90	0	90	30.5

Table 11. Percentiles for Space Parameters while Transferring FROM Station

Protocol	Percentile 5th	50th	95th	Minimum	Maximum	Interquartile Range
Level:						
No Grab Bars/No Backrest						
Right of Center (cm)	-35.1	17.1	82.5	-41.9	87.6	37.6
Left of Center (cm)	-105.3	-52.4	11.4	-110.5	11.4	46.7
Depth (cm)	55.1	72.4	130.7	53.3	141.0	22.9
Angle (degrees)	0	25	90	0	90	37.8
Highest Height:						
No Grab Bars/No Backrest						
Right of Center (cm)	-13.5	24.8	90.9	-15.2	102.9	23.8
Left of Center (cm)	-94.0	-34.3	17.3	-99.1	19.5	40.0
Depth (cm)	57.2	80.0	127.3	57.2	141.0	35.2
Angle (degrees)	0	30.5	90	0	90	43.8
Lowest Height:						
No Grab Bars/No Backrest						
Right of Center (cm)	-19.1	24.8	89.2	-19.1	102.9	34.9
Left of Center (cm)	-101.2	-41.9	4.6	-102.9	19.1	52.39
Depth (cm)	58.9	78.1	99.8	57.2	141.0	26.7
Angle (degrees)	0	28	90	0	90	29.3
Highest Height:						
Grab Bars/ No Backrest						
Right of Center (cm)	-13.5	21.0	69.7	-15.2	102.9	40.0
Left of Center (cm)	-93.9	-38.1	15.2	-110.5	19.1	44.8
Depth (cm)	57.2	72.4	110.5	57.2	141.0	34.3
Angle (degrees)	0	30.5	90	0	90	29.3
Lowest Height:						
Grab Bars/ No Backrest						
Right of Center (cm)	-15.2	26.8	80.0	-15.2	102.9	40.0
Left of Center (cm)	-93.9	-40.0	11.8	-99.1	19.1	50.5
Depth (cm)	21.5	80.0	113.5	-7.6	141.0	35.2
Angle (degrees)	0	30.5	90	0	90	29.3
Highest Height:						
Grab Bar and Backrest						
Right of Center (cm)	-13.5	22.9	69.0	-15.2	87.6	26.7
Left of Center (cm)	-93.9	-41.9	11.4	-99.1	11.4	39.1
Depth (cm)	57.2	76.2	103.6	57.2	141.0	28.6
Angle (degrees)	0	29.5	90	0	90	47.8
Lowest Height:						
Grab Bar and Backrest						
Right of Center (cm)	-15.2	26.7	73.2	-15.2	87.6	43.8
Left of Center (cm)	-93.9	-38.1	11.4	-102.9	15.2	53.4
Depth (cm)	55.1	78.1	87.6	53.3	141.0	25.7
Angle (degrees)	0	20	90	0	90	37.3

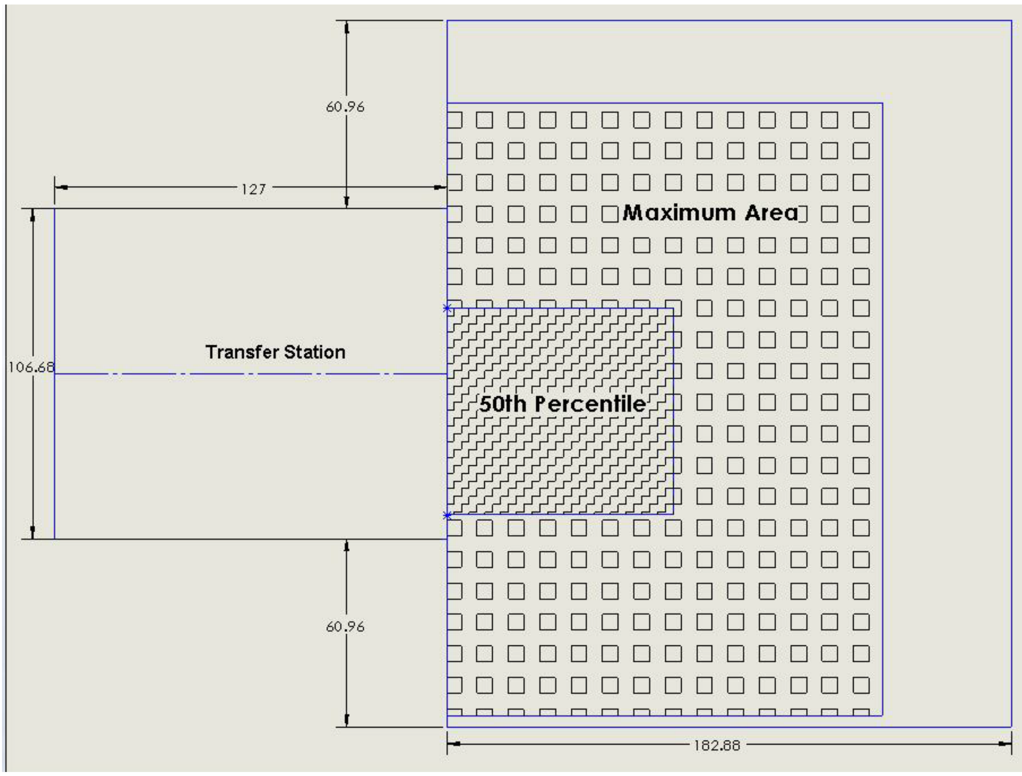

Figure 21. The 50th Percentile and Maximum Space Needed for Level Height Transfers while Transferring TO the Station

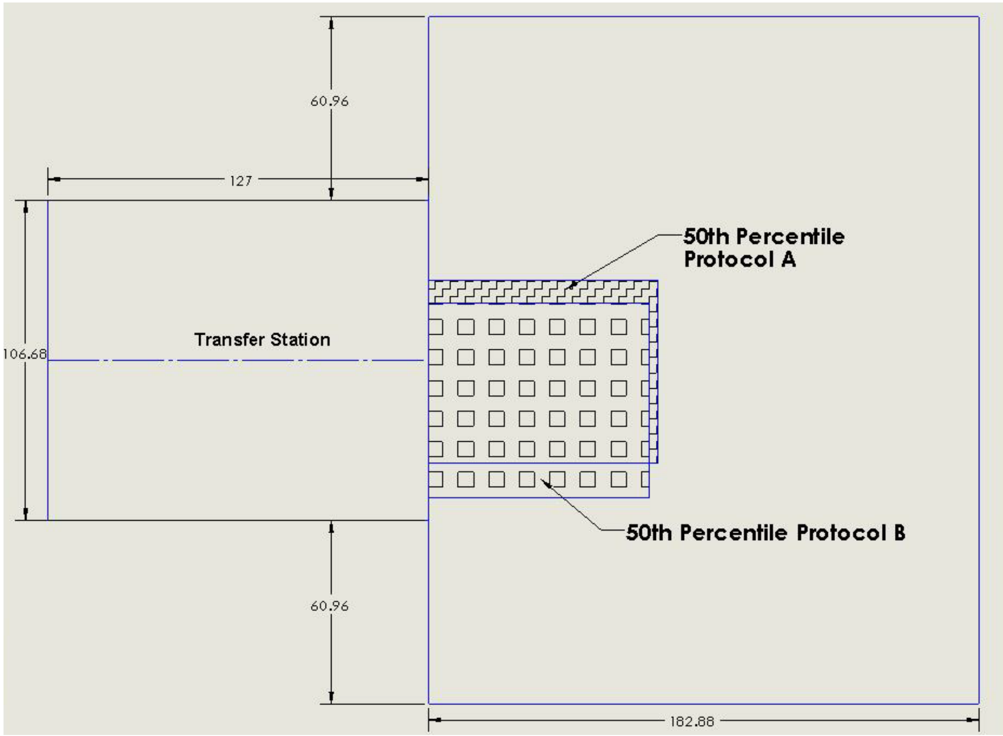

Figure 22. The 50th Percentile Spaces Needed for Protocols A and B (Highest Height Attained) while Transferring TO the Station

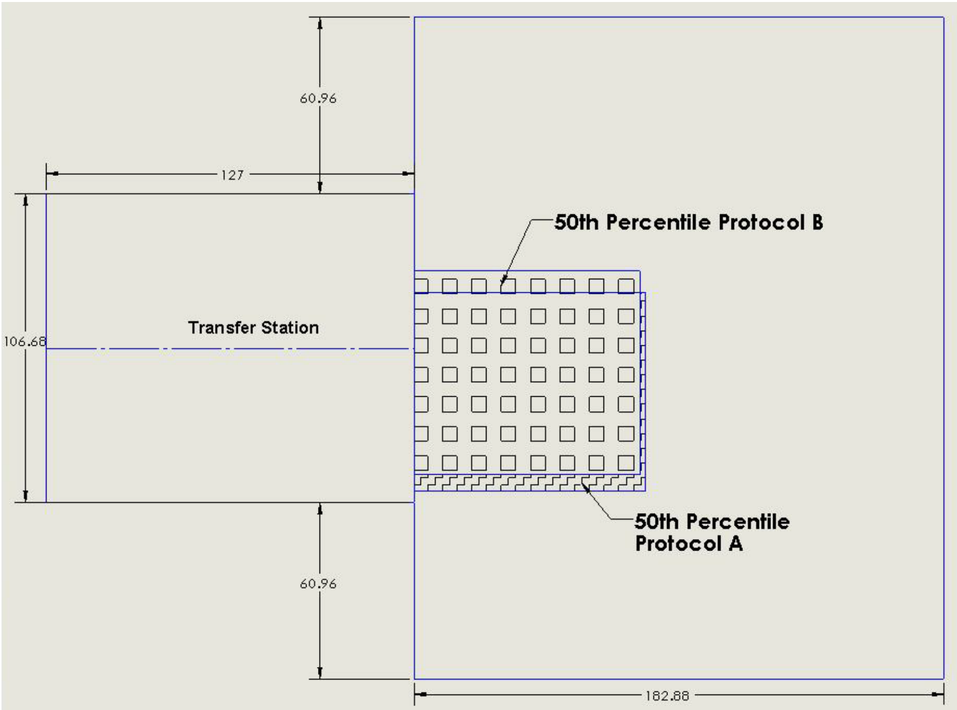

Figure 23. The 50th Percentile Spaces Needed for Protocols A and B (Lowest Height Attained) while Transferring TO the Station

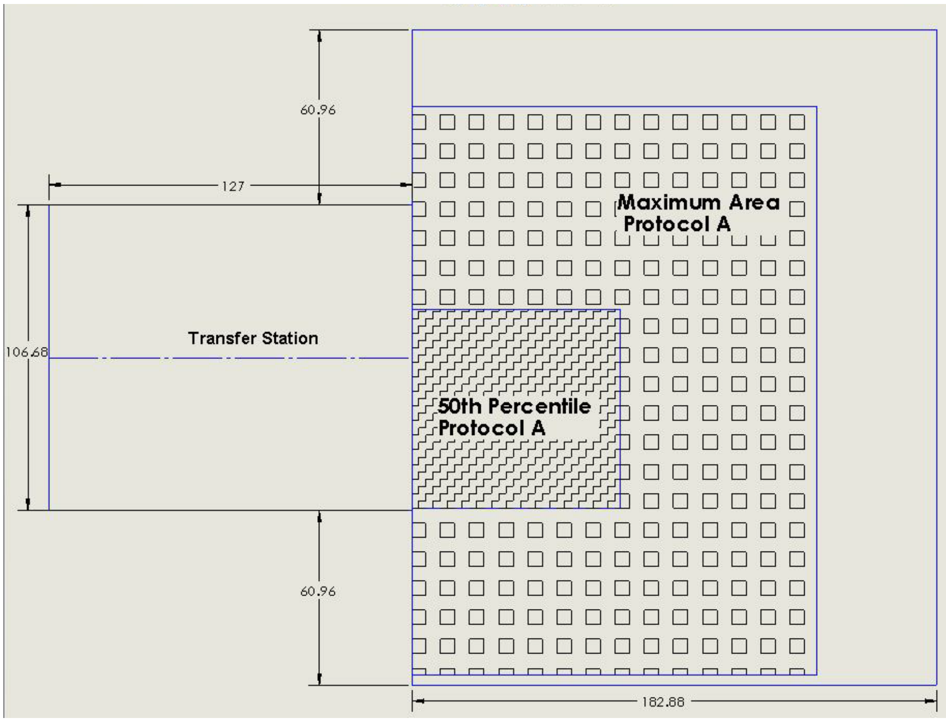

Figure 24. The 50th Percentile and Maximum Space Needed for Level Height Transfers while Transferring FROM the Station

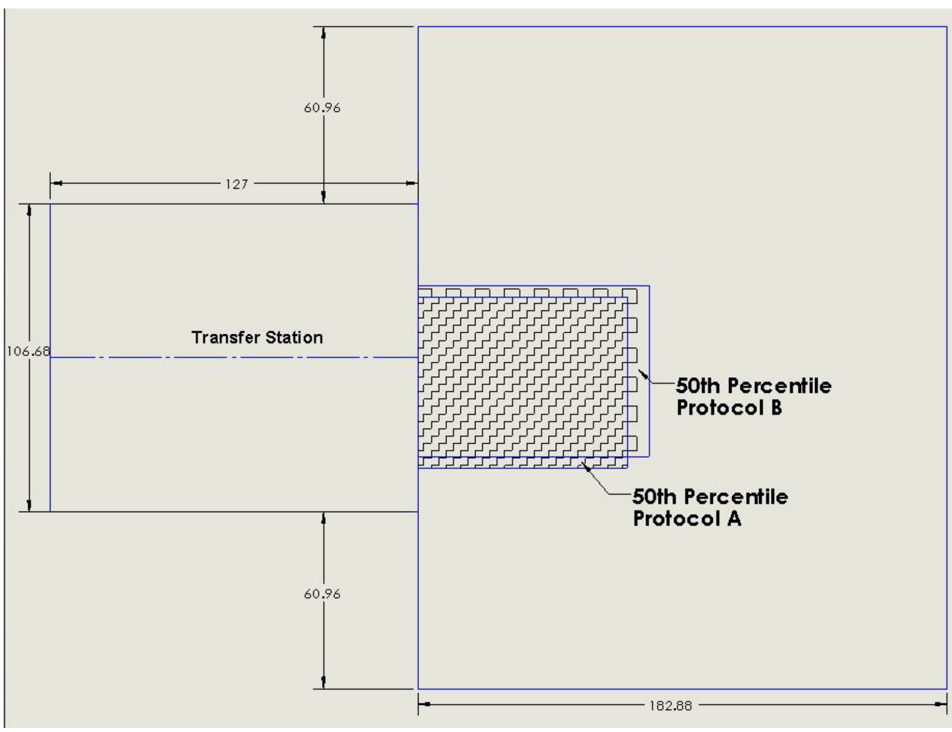

Figure 25. The 50th Percentile Spaces Needed for Protocols A and B (Highest Height Attained) while Transferring FROM the Station

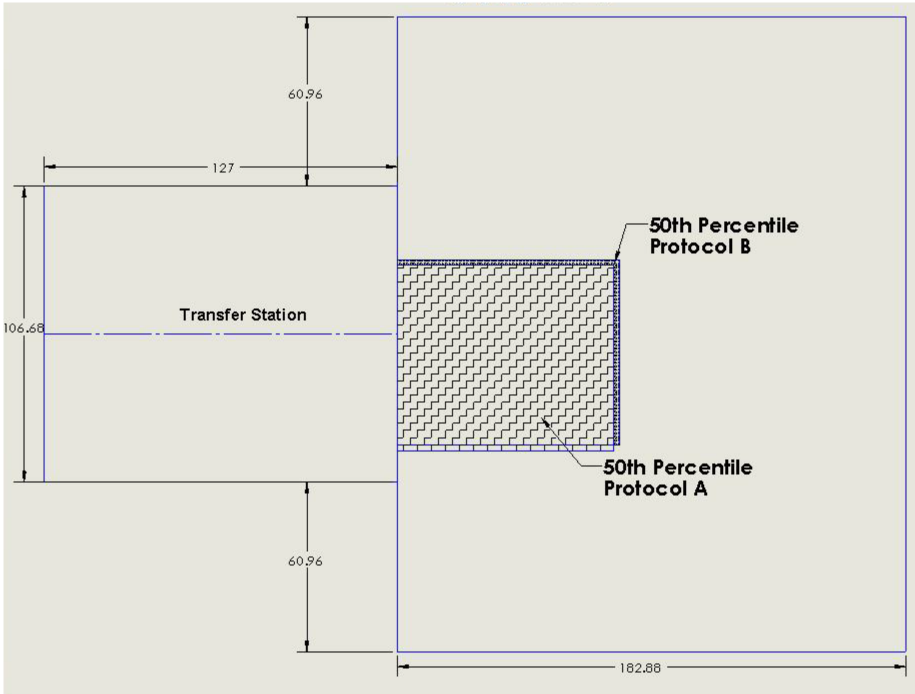

Figure 26. The 50th Percentile Spaces Needed for Protocols A and B (Lowest Height Attained) while Transferring FROM the Station

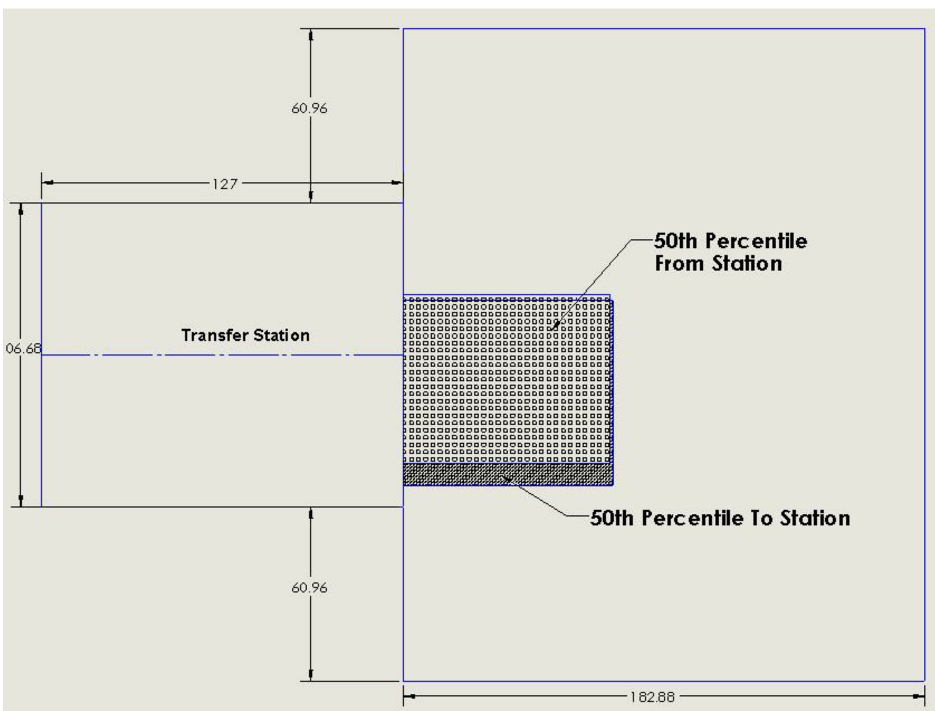

Figure 27. The 50th Percentile Spaces Needed for Transferring TO and FROM the station for Protocols B (Highest Height Attained)

4.3.1.4 Effect of Handhelds on Transfer Heights

The highest and lowest heights attained across protocols A, B, and C were evaluated to see if the presence of handhelds would impact the height differentials subjects attained. Although the highest heights were higher and lowest heights were lower when grab bars and grab bars and a backrest were available, the difference did not reach significance at a 0.05 level (Table 12).

Table 12. Effects of Handhelds on Highest and Lowest Height Attained Transfers

		Protocol A No Grab Bars/No Backrest	Protocol B Grab Bars/ No Backrest	Protocol C Grab Bar and Backrest	p-value
Highest Height Attained	Mean	72.7	70.8	75.3	.129
	Std. Deviation	9.6	13.0	8.6	
	Median	71.8	70.5	72.4	
Lowest Height Attained	Mean	35.5	33.3	33.5	.097
	Std. Deviation	10.9	11.0	11.2	
	Median	33.0	25.4	25.4	

4.3.1.5 Effects of Handhelds on Transfer Quality

Our hypothesis for this analysis was that the quality of transfer would be higher with the surface mounted grab bars present compared to without them present. The results showed that there was not a significant difference between handheld presence and the quality of level transfers. However, there was significant difference between handheld presence and quality of highest height transfers between protocol A and protocol B (Table 13). When only grab bars were added to the station there was a significant increase in transfer quality compared to when there were no handheld options. There was also a significant difference between handheld presence and the quality of lowest height transfers between protocol A and protocol C. When grab bars and a backrest were added to the station there was a significant increase in transfer quality from when there were no grab bars or a backrest on the station.

Table 13. Effects of Handhelds on Level, Highest, and Lowest Height and Transfer Quality

		Protocol A No Grab Bars/No Backrest TAI Score	Protocol B Grab Bars/ No Backrest TAI Score	Protocol C Grab Bar and Backrest TAI Score
Level Height Transfers .168*	Mean	7.5	6.7	7.7
	Std. Deviation	1.2	2.8	1.2
	Median	7.5	7.6	7.9
Highest Height Attained .001*	Mean	7.3	7.9	7.6
	Std. Deviation	1.2	0.9	1.2
	Median	7.5	7.9	7.7
Lowest Height Attained .024*	Mean	7.5	7.7	7.8
	Std. Deviation	1.2	1.0	1.0
	Median	7.8	8.1	8.0
Pairwise comparison p-values		Protocol A to Protocol B	Protocol A to Protocol C	Protocol B to Protocol C
Level Height Transfers		.639	.693	.410
Highest Height Attained		**.001**	.194	.150
Lowest Height Attained		.126	**.041**	1.00

*Significant main effect

4.3.1.6 Relationship between Transfer Quality and Transfer Heights

The hypothesis for this analysis was that there would be no association between transfer quality and the highest and lowest attainable heights. Figures 25 to 30 show the scatter plots and statistical results for this analysis. The relationship between transfer quality and the highest height attained by subjects in Protocol C was statistically significant. The Pearson product-moment correlation coefficient (r-value) for these data was -.409. This indicates a negative correlation meaning that subjects who had higher TAI scores did not transfer as when the station was equipped with both grab bars and backrests.

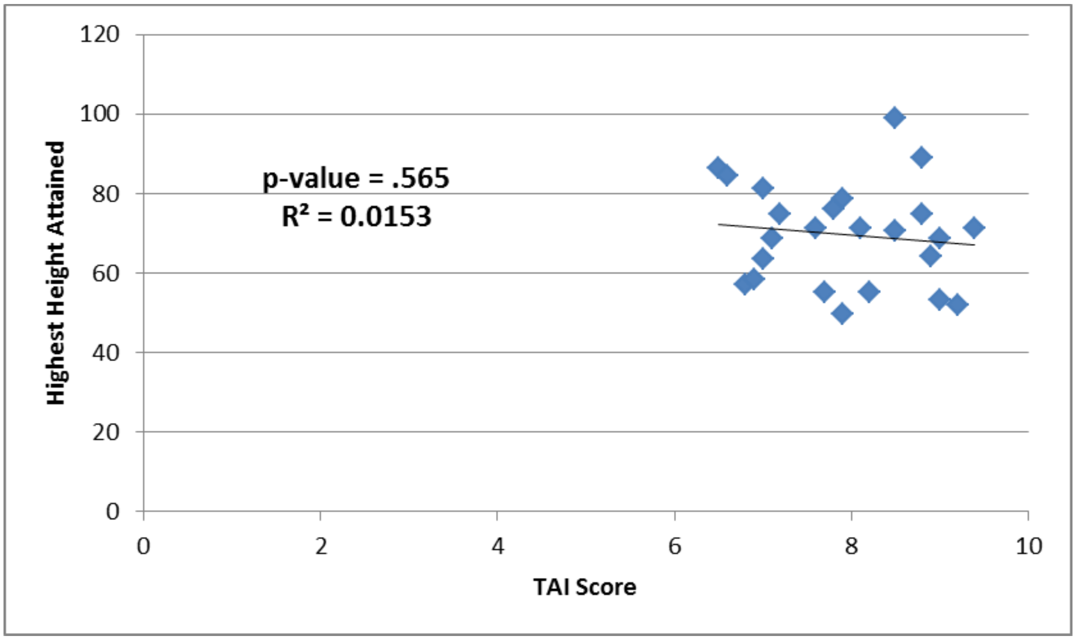

Figure 28. Transfer Quality vs. Highest Heights Attained by Subjects for Protocol A

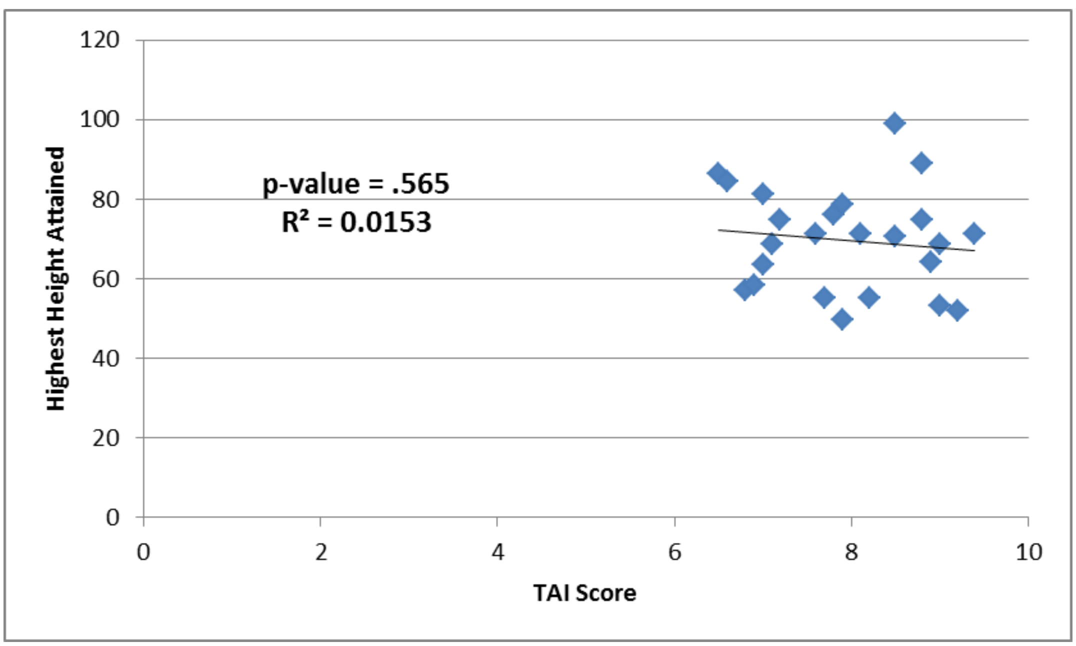

Figure 29. Transfer Quality vs. Highest Heights Attained by Subjects for Protocol B

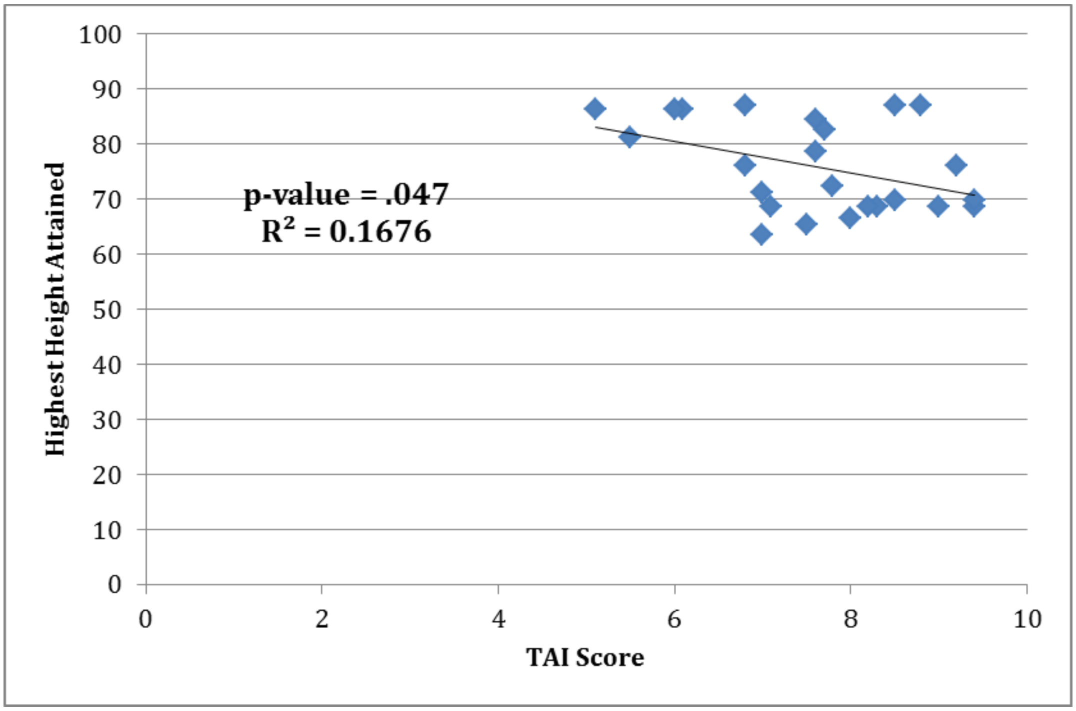

Figure 30. Transfer Quality vs. Highest Heights Attained by Subjects for Protocol C

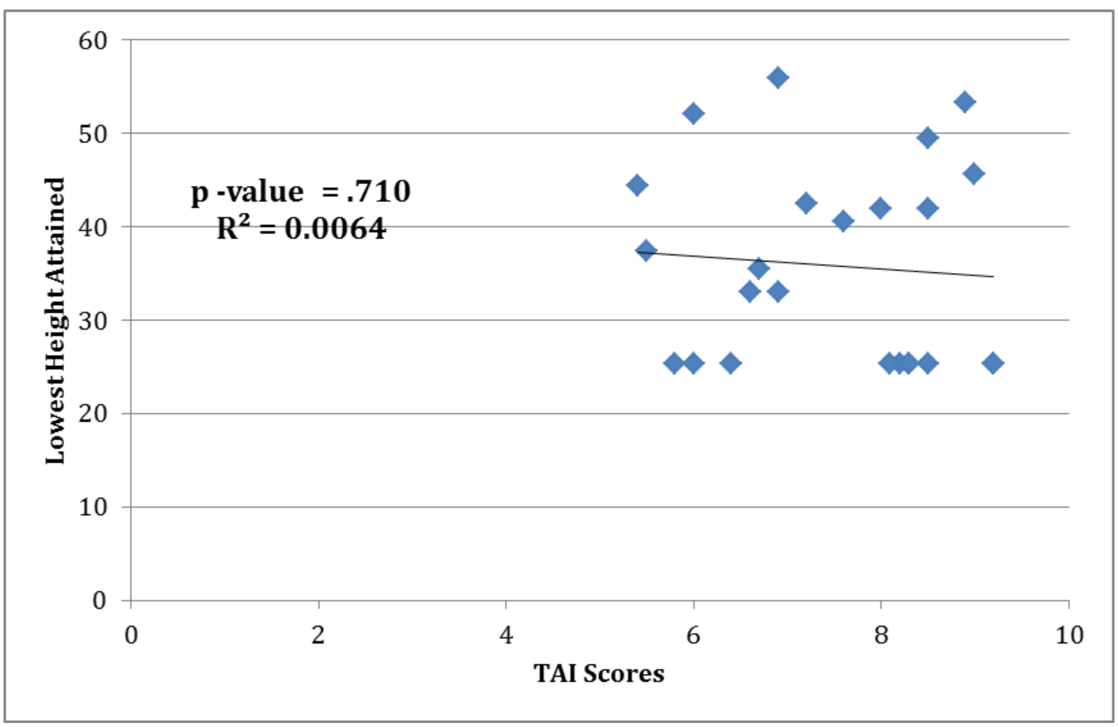

Figure 31. Transfer Quality vs. Lowest Heights Attained by Subjects for Protocol A

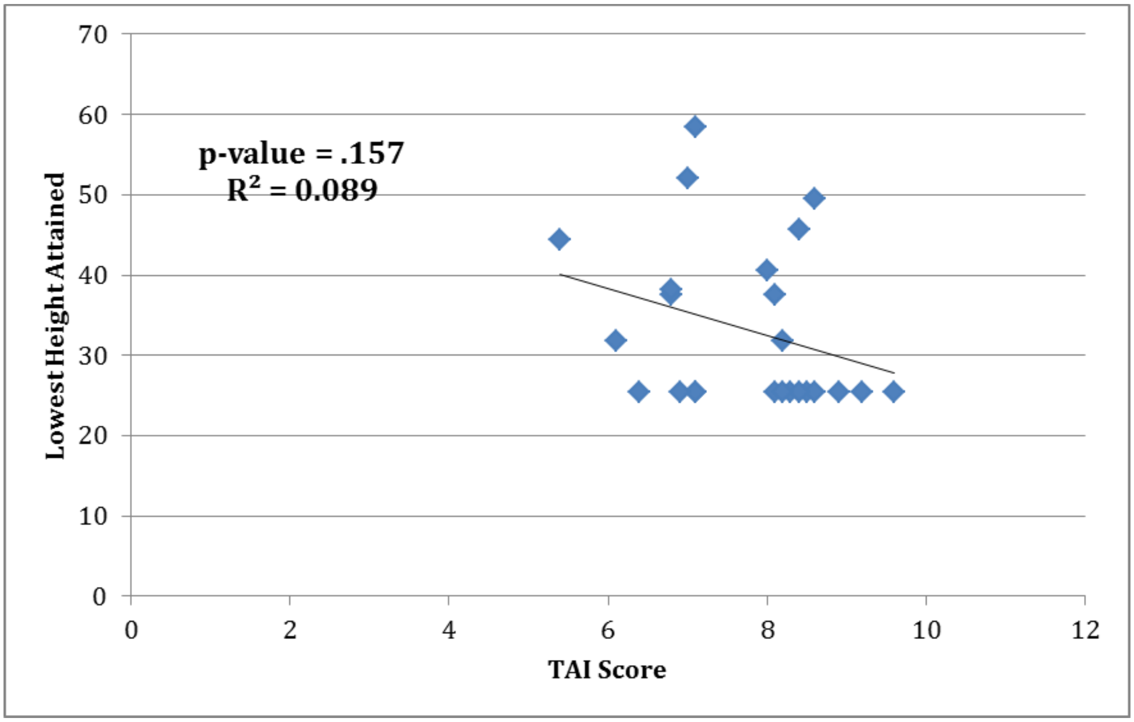

Figure 32. Transfer Quality vs. Lowest Heights Attained by Subjects for Protocol B

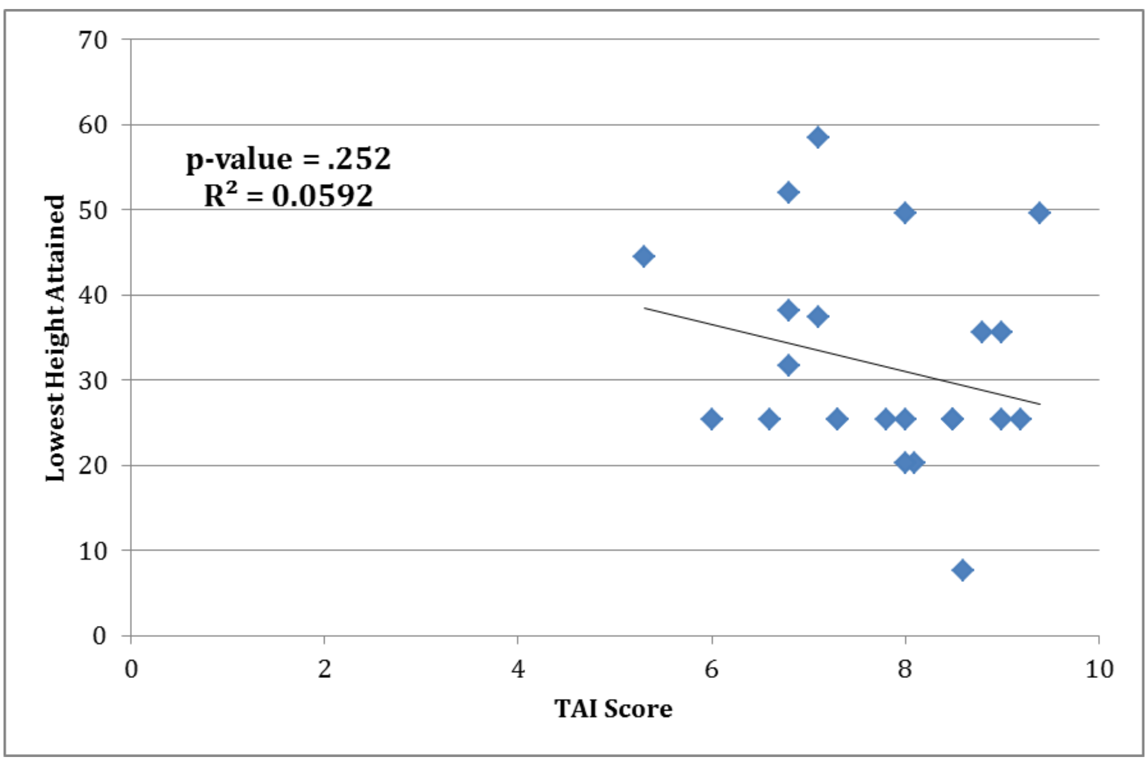

Figure 33. Transfer Quality vs. Lowest Heights Attained by Subjects for Protocol C

4.3.1.7 Questionnaire on Two-Step Transfers

Out of the 28 subjects who attempted the two-step 90^o transfers (Protocol D), 68% (19/28) said they would make this type of transfer again in a ‘real world’ situation and 32% (9/28) said they would avoid it. Even though only 26 subjects attempted the angled transition two-step transfers (Protocol E) the subjects that did not perform this transfer still filled out the questionnaire so their reasons why they did not attempt the transfer could be recorded. Out the 28 subjects who filled out the questionnaire 57% (16/28) said they would make angled transition transfers in ‘real world’ situations and 43% (12/28) said they would avoid making these transfers again. Table 14 gives some of the subject’s responses for either willing to transfer or wanting to avoid the two-step transfers they performed.

Table 14. Subject Responses to Questionnaire 2 about Two-step Transfers

90^o Two-step/ Angled Transition Two-step	Participant Remarks
Transfer/Transfer	"I will definitely keep using these transfers because they're safe and easy to do."
Avoid/Avoid	Felt unsafe and feared falling
Avoid/Avoid	“It was manageable but too much of a pain to perform in a public setting”
Avoid/Avoid	Felt they were difficult and not practical
Avoid/Avoid	The 90^o was not comfortable to perform and did not have enough strength or felt safe performing the angled transfer
Transfer/Transfer	The 90^o was a lot like climbing stairs. The ramp on the angled transfer gave more ground to transfer on instead of a straight drop. This made it more comfortable.
Avoid/Avoid	Subject would find a different way to get to the transfer destination instead of both these two-step transfer types. The setup interfered with their leg braces

Table. 14 (Continued)	
Transfer/Transfer	Felt the transfers were easy since they had smaller legs. The ramp makes the angled transfer more comfortable.
Transfer/Transfer	Felt the two-step process made transferring easier
Transfer/Transfer	"Yes I would certainly do them over again. I found it very fun!"
Transfer/Transfer	"If it was something that needed done I would do it. I try not to set limitations."
Transfer/Transfer	Felt the transfer were easier because of the grab bars
Transfer/Transfer	As an active wheelchair user they would make these transfers in the real world
Transfer/Avoid	Felt more comfortable transferring to a direct vertical height instead of the angled transfer. Felt less stable during the angled transfer.
Avoid/Avoid	Had difficulty positioning legs to perform both two-step transfers. Thinks they could make the transfers if they had to, but did not find them to be ideal.
Transfer/Avoid	The 90^{o} felt a lot like transferring up stairs. The angled transfer was like scooting up a hill. He would avoid doing this unless he needed to go up a hill.
Transfer/Avoid	Both transfers were new for them. The angled transfer was very demanding to perform. Overall both the two-step transfers were rough and shoulder pain made it worse.
Transfer/Transfer	Would make these transfers if they needed to.

4.4 DISCUSSION

4.4.1 Discussion

The results of this study showed many similarities to the first phase of the independent transfer study (Toro, Koontz, Cooper, 2012). For instance the level seat height of the first phase was 55 ± 3 cm while the level seat height of this study was 58.2 ± 6 cm. Both of these heights differ from the recommended standard for amusement park seats which states that ride seats should be between 43.1 and 48.3 cm (Toro, Koontz, Cooper, 2012). Transfer surface heights should be raised in the standards to accommodate a larger population based on average level seat heights reported in this and the previous study since transfers to level heights require less upper limb exertion ((Toro, Koontz, Cooper, 2012; Gagnon et al., 2005; Gagnon, Nadeau, Noreau, Eng, & Gravel, 2008; Nyland et al., 2000). The amounts of space required by the 50th percentiles of this study sample were smaller than the first phase space requirements. The space required by the 50^{th} percentile of our population for transferring was between 59.1 and 70.5 cm wide by between 72.4 and 80 cm deep. These values are also smaller than the ADAAG standard of the minimum of 76.2 cm wide by 121.9 cm deep (Toro, Koontz, Cooper, 2012). A reason why the space dimensions for this study are smaller may be because the subjects were able to approach the transfer platform head-on in their WMD which they could not do during the first phase. The angles WMD users positioned their devices in order to transfer were similar for both studies. For both studies they were between 0 and 90 degrees and the 50^{th} percentile around 30 degrees (Toro, Koontz, Cooper, 2012). Seat width was not evaluated during the first phase of the independent transfer study, but the majority of subjects (both the 5^{th} and the 50^{th} percentiles) used a 45.7cm seat width to attain their level, highest, and lowest height transfers which was the smallest width tested. This value is in-between the swimming pool transfer seat standard seat width range (40.6 to 48.3 cm). Seat widths also did not change much over the protocols. It was felt that some subjects would have had greater performance with the station if they had opted for a larger seat width and more room to position the hands for transfer, but since they did not ask to increase the width when the option was offered to them it was left the same. It may be valuable to investigate transfer performance when the seat width is forced to vary between protocols and transfer trials. This was not done in this study to minimize the number of transfers performed.

Grab bar and backrest subject selection was reported for this study with the tall grab bar and the short backrest being selected the most. However, the actual use of the backrest and grab bars as handhelds during the transfer process was not analyzed. Further analysis is needed on the leading and trailing hand placements used by subjects while transferring to and from the station and between transfer surfaces to see how often subjects used these surfaces to assist with their transfers. The results of this type of analysis may better explain why there was not a significant difference between handheld presence and the highest and lowest height transfers subjects attained.

Another transfer element that was incorporated into this study that was not present during the first phase of the Access Board study was the evaluation of two-step transfers. The two-step transfers performed were a vertical height difference (level to high and level to low) 90^{o} transfer and an angled transition transfer over a constant gap to heights higher and lower than subject seat level. These were the only protocols not attainable by all subjects. Results from the second questionnaire asking subject opinion on these transfers reflect a mixed review of the ease and practicality of these two-step transfers. Comments on the two-step transfers varied from thinking they were fun, easy, and safe to impractical, difficult, and uncomfortable. More people felt that they would perform the 90^o transfer again in a 'real world' situation over the angled transition transfer. Having angled two-step transfers built into more recreational environments may hinder a larger group of users than having vertical height difference transfers. The 50^{th} percentiles for both these two-step transfers were able to attain the maximum height ranges available (20.3cm for the 90^o transfer, and 17.8cm for the angled transition transfer). It is recommended that vertical height differences between two transfer's surfaces should not exceed 20.3cm and a lower height (about 5.1 cm) would be needed to accommodate the 95th percentile of users who would attempt this type of transfer. In comparing the 90^o setup to the angled transition, the 5^{th} percentile of subjects were able to transfer 1.5cm higher using the angled transition than they did using the 90^o setup. However, these subjects were able to transfer 2.6cm lower with the 90^o setup than they could with the angled transition two-step transfer.

Transfer quality was also evaluated to find if there was any effect of handheld presence on the quality of the transfers performed. The hypothesis for this analysis was that the quality of transfer would be higher with the surface mounted grab bars present compared to without them present. The results showed that when transferring to a higher height having only grab bars attached to the station significantly increased transfer quality over not having any handhelds present. When transferring to a lower height transfer quality significantly increased when both grab bars and a backrest was present compared to having no handheld options. The hypothesis for determining the relationship between transfer quality and transfer performance was that there would be no association between transfer quality and the highest attainable heights and transfer quality and the lowest attainable heights. This was true for all protocols except when transferring to a higher height with the presence of grab bars and a backrest. However, the correlation coefficient for this comparison was not very strong ($r = .4$, $p = .047$).

4.4.2 Limitations

Some limitations that occurred with this study were that occasionally the grab bars would get in the way of a subject transferring to or from the station since they were located on either side of the transfer surface. These subjects were observed having to reposition their chair or having to transfer around the grab bar instead. A protocol or an option of using only one grab bar or having a removable grab bar may be worth investigating in the future. Some subjects also asked if they could use both size of grab bars on either platform during the two-step transfers. They mentioned that the taller ones were more helpful for going to lower elevations and the lower ones for transferring higher. This was not an option for this study and it may that developing a grab bar that is angled or easily adjustable in height be considered for future work. There was not a backrest available behind the second platform for the two-step transfers. When performing these transfers to a higher elevation subjects could be transferring to a seat around 80cm off the ground. Even though there were spotters standing behind this platform having a wall, backrest, or another step available there would have added to the safety of the transfer. The grab bars attached to this surface did help with keeping the subjects stable by allowing another surface to grip onto.

The study was open for children seven years old and older to participate. While extensive efforts were made to advertise the study to different schools, hospitals, and organizations known to work with children only one family contacted us to participate and have yet to be tested. The Access Board was particularly interested in collecting data from school aged WMD users especially for playground equipment standards. We were able to collect data from young and small adults. The youngest subject was 18 years old and four subjects were under 1.5m tall.

4.5 CONCLUSION

This study sought to answer the questions posed by the Access Board during this second phase of their independent wheelchair transfer study. Two-step transfers were evaluated to answer the question of what should the vertical height difference be when transferring between two transfer steps. The study found that the 50^{th} percentile of subjects could attain a 20.3cm vertical height difference when making a 90^{o} two-step transfer with no gap and a 17.8cm vertical height difference when transferring over an 8-inch gap up a ramp. The width used by the 5^{th} and 50^{th} percentiles for all protocols was 45.7 cm. This value fits within the current standard for swimming pool transfer seats. Different sized grab bars and backrests were evaluated to see if their presence had any impact of transfer performance. Even though it was hypothesized to allow subjects to transfer higher and lower than they could without them, there was no significant impact on transfer performance however they improved the quality of the transfer. Studying a larger population of WMD users may increase the strength of these relationships. Lower TAI scores were moderately associated with higher transfer heights. This is an indication that subjects performing higher height transfers may also be using higher forces and awkward joint motions. A more detailed analysis into the TAI items is needed to provide greater insight into the specific aspects of the transfer process that are adversely affected during the higher height transfers. Moreover a subsequent analysis may be needed to make an adjustment to the percentiles so that the recommended heights also account for the quality of movement.

The results from this study along with the results from the first phase should be taken into consideration when designing and building environments for independent wheelchair transfers and in particular recreational areas like amusement parks, playgrounds, and pools as well as other areas that require the need for transfers like medical diagnostic equipment and exam tables.

5.0 CONCLUSIONS

This paper describes the methods and results used to complete the second phase of the Access Board's study on independent wheelchair transfers. To gain a better understanding of what community dwelling WMD users transfer capabilities are a broad spectrum of subjects with varying disabilities were studied to determine how transfer setup (e.g. environmental factors) impacts overall performance and quality of transfers. Before data collection occurred an international workgroup of experts was assembled to facilitate an exchange of ideas and information related to independent transfers. The nine main themes derived from the IWT Workgroup included such issues as user-related factors and concerns, the transfer process, techniques and preferences, and the built environment. The information gathered during this event along with the results from the first phase of the study helped create the research agenda of this second phase study. The workgroup participant remarks and current ADA standards were also used to help design a new transfer station to serve as a data collection tool. This new station consisted of height adjustable platforms, grab bars, backrests, and a sliding board to make transfers across two non-level steps easier.

The phase two study on independent wheelchair transfers sought to find the relationship between the quality of a transfer and the ability to perform transfers at varying height ranges and environmental configurations. Level height measurements from this study were similar to the first phase results, yet these heights are still higher than current standards require. The space dimensions in this study were smaller than the first phase and within the current standard widths and depths measurements. There was no significant relationship between the presence of surface mounted grab bars and backrests with transfer performance. However, there were significant relationships between transfer quality and the presence of grab bars while transferring to a higher height and the presence of both grab bars and a backrest while transferring to a lower height. A negative correlation was found between transfer quality scores and the highest height attained by subjects. This significant relationship occurred when both grab bars and a backrest were attached to the station and suggests the possibility that subjects achieving higher heights were not using the grab bars and backrest as they should or were using them improperly. The results from this study will provide data that the U.S. Access Board and designers/engineers can use to modify equipment and/or environments (e.g. buildings, recreational facilities and playgrounds) for the purposes of enhancing the transfer process. The results can be used to create more accessible environments for independently transferring WMD users.

APPENDIX A

SOLIDWORKS FIGURES OF TRANSFER STATION

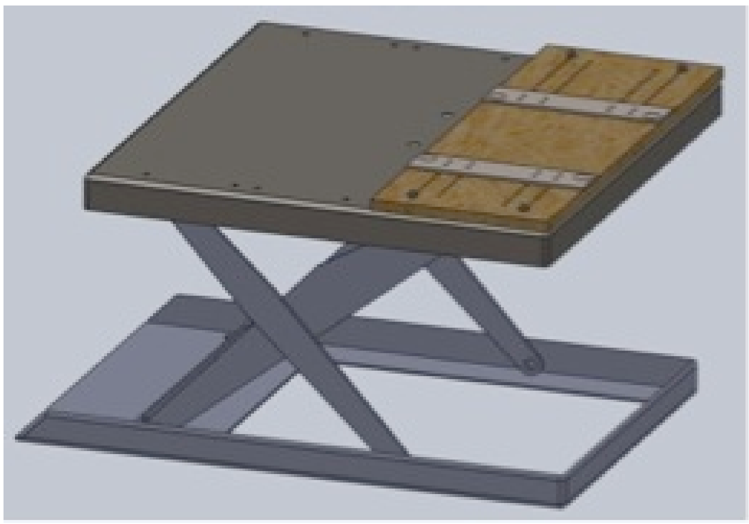

Figure 34. Protocol A: Adjustable Height: No Grab Bars/No Backrest (SolidWorks)

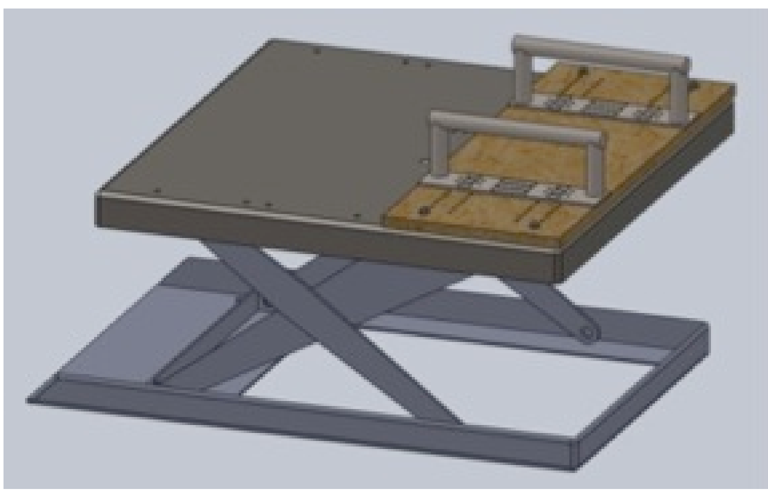

Figure 35. Protocol B: Adjustable Height Protocol: Grab Bar Option/No Backrest (SolidWorks)

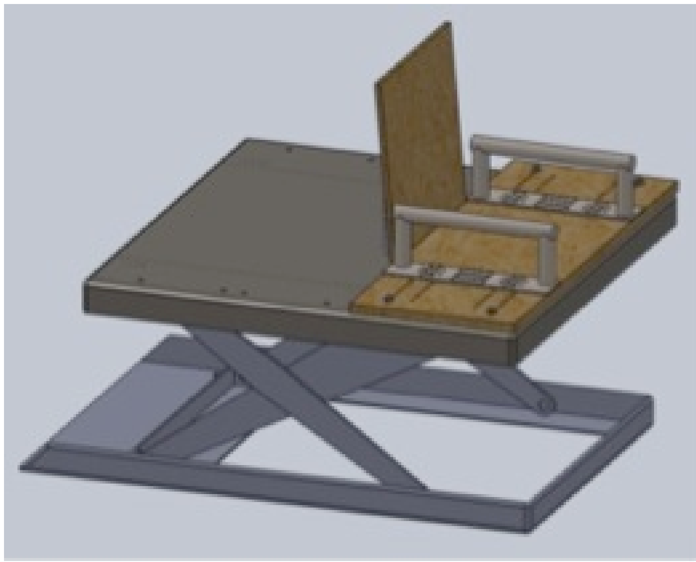

Figure 36. Protocol C: Adjustable Height: Grab Bar and Backrest Option (SolidWorks)

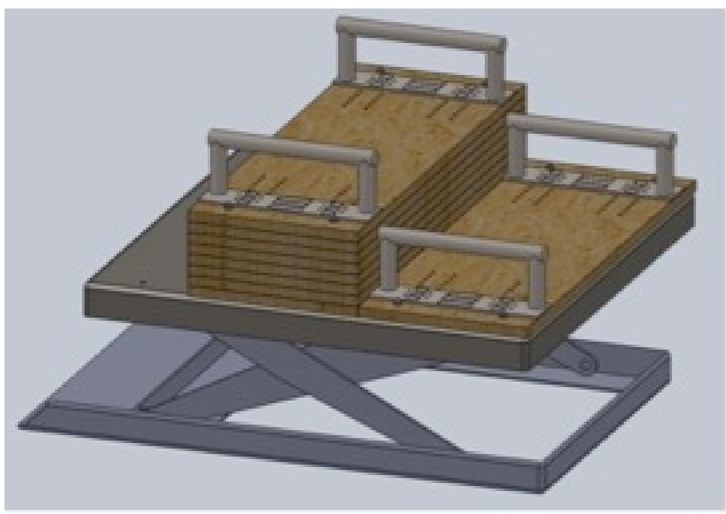

Figure 37. Protocol D: Two Step Transfer (90^{o} Transition) (SolidWorks)

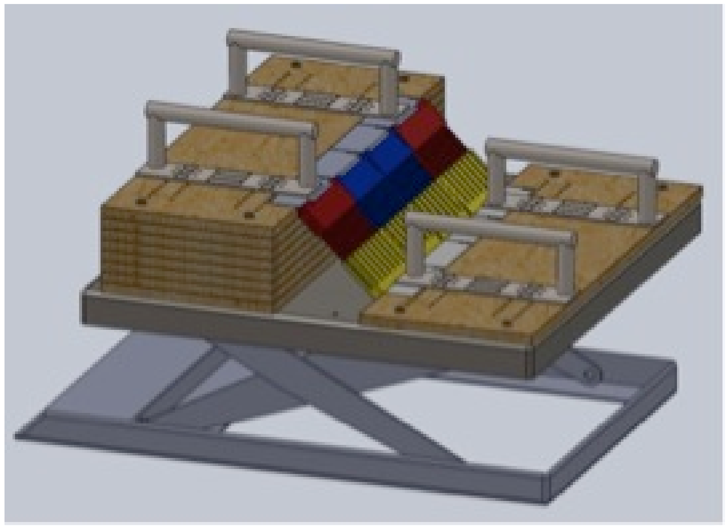

Figure 38. Protocol E: Two Step Transfer (Angled Transition) (SolidWorks)

APPENDIX B

TRANSFER STATION BILL OF MATERIALS

- Scissor lift table
- A/C Pine Plywood - Platforms
- Steel tubing – Grab bars
- Steel plates – Grab bars
- Tee nut wood inserts – Grab bar securement for platforms
- Miniature steel drive shaft – Adjustable ramp
- All-thread rod – Custom bolt
- Nuts – Custom bolt
- Rust proof spray paint – Grab bars
- Neoprene foam – Protective cushions
- Vinyl fabric – Protective cushions
- Allen screws – Grab bar securement

BIBLIOGRAPHY

Accessible amusement rides - a summary of accessibility guidelines for recreation facilities. US Access Board; 2003.

ADA accessibility guidelines for buildings and facilities (ADAAG). (2002). Washington, DC: U.S. Access board. Retrieved from http://www.access-board.gov/adaag/

Arcelus, A., Holtzman, M., Goubran, R., Sveistrup, H., Guitard, P., &Knoefel, F. (2009, September).*Analysis of commode grab bar usage for the monitoring of older adults in the smart home environment*., Minneapolis, MN.

Bayley, J. C., Cochran, T. P., Sledge, C. B. (1987). The weight-bearing shoulder. The impingement syndrome in paraplegics. *Journal of bone and Joint surgery-Series A*, 69, 676-678.

Biering-Sorensen, T., Hansen, R. B., &Biering-Sorensen, F. (2009). Home aids and personal assistance 10-45 years after spinal cord injury. *Spinal Cord International Spinal Cord Society*, *47*, (405-412).

Cooper, R. A. Cooper, R., & Boninger, M. L. (2008). Trends and issues in wheelchair technologies. *Assistive Technology*, 20, 61-72.

Drongelen S. V., Woude, L. V. D., Jassen, T., Angenot, E., Chadwick, E., & Veeger D. (2005). Glenohumeral contact forces and muscle forces evaluated in wheelchair-related activities of daily living in able-bodied subjects versus subjects with paraplegia and tetraplegia. *Archinves of Physical Medicine and Rehabilitation,* 86, 1434-1440.

Dyson-Hudson, T. A., Kirshblum, S. C. (2004). Shoulder pain in chronic spinal cord injury. Part I. *Journal of Spinal Cord Medicine,* 27, 4-17.

Edwards, N., Birkett, N., Nair, R., Murphy, M., Roberge, G., & Lockette, D. (2006). Access to bathtub grab bars: Evidence of a policy gap. Canadian Journal on Aging, 25(3), (295-304).

Finley, M., McQuade, K., & Rodgers, M., (2005). Scapular kinematics during transfers in manual wheelchair users with and without shoulder impingement. *Clinical Biomechanics*, 20, 32-40.

Gagnon, D., Nadeau, S., Noreau, L., Eng J., & Gravel, D. (2008). Trunk and upper extremity kinematics during sitting pivot transfers performed by individuals with SCI. *Clin Biomechanics*, 23, 279-290.

Gagnon, D., Nadeau, S., Gravel, D., Noreau, L., Lariviere, C., McFadyeb, B. (2005). Movement patterns and muscular demands during posterior transfers toward an elevated surface in individuals with SCI. *Spinal Cord*, 43:74-84.

Gagnon, D., Koontz, A., Mulroy, S., Nawoczenski, D., Butler-Forslund, E., Granstrom, A., &…Boniger, M. (2009). Biomechanics of sitting pivot transfers among individuals with SCI: A review of the current knowledge. *Topics in SCI Rehabilitation,* 15, 33-58.

Gagnon, D., Nadeau, S., Noreau, L., Eng, J., & Gravel, D. (2009). Electromyographic patterns of upper extremity muscles during sitting pivot transfers performed by individuals with SCI. J Electromyogr Kinesiol, 3, 509-520.

General ADAAG Standards (2012). Retrieved from http://www.rst2.pitt.edu/ab/Holder/TransferStandardsDoc.pdf

Jerome, G. M., Toro, M. L., Koontz, A.M., Cooper, R.A. (2012).The impact of transfer setup on hand positioning during independent transfers, Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Baltimore, MD, CD-ROM

Jerome G. M., Koontz A.M., Crytzer T.M., Cooper R.A. (2013). Identifying Research Needs for Wheelchair Transfers in the Built Environment, Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Seattle, WA.

Jones, K. E., & Tamari, I. E. (1997). Making our offices universally accessible: guidelines for physicians. Canadian Medical Association, 156(5), (647-656).

Koontz, A. M., Brindle, E., Kankipati, P., Feathers, D., & Cooper, R. A. (2010). Design features that affect the maneuverability of wheelchairs and scooter. *Archives of Physical Medicine and Rehabilitation*, 759-439.

Koontz, A. M., Kankipati, P., Yen-Sheng, L., & Cooper, R. A. (2011). Upper limb kinetic analysis of the three sitting pivot wheelchair transfer techniques. Clinical Biomechanics, 26, 923-929.

Koontz, A.M., Toro, M. L., Kankipati, P., Naber, M., & Cooper, R. A. (2011). An expert review of the scientific literature on independent wheelchair transfers. *Disability and Rehabilitation: Assistive Technology, 7,* 20-29.

McClure, L. A., Boninger, M. L., Ozawa, H., & Koontz, A. M. (2011). Reliability and validity analysis of the transfer assessment instrument. *Archives of Physical Medicine and Rehabilitation, 92, 499-508.*

Nikolaus, T., & Bach, M. (2003). Preventing falls in community-dwelling frail older poeple using a home intervention team (hit): Results from the randomized falls-hit trail. *American Geriatrics Society*, *51*(3), (300-3005).

Nyland J., Quigley P., Huang C., Llyod J., Harrow J., Nelson A., Preserving transfer independence among individuals with SCI. (Review) (70 refs). Spinal cord 2000; 38:649-657.

Pentland, W., & Twomey, L. (1994). Upper limb function in persons with long-term paraplegia and implications for independence: Part II. *Paraplegia,* 32, 219-224.

Sanford, J. & Bosch, S. (2013). An investigation of noncompliant toilet room designs for assisted toileting. Health Environments Research & Design, 6(2), (43-57).

Spinal Cord Injury Facts and Figures at a Glance. (2011). National Spinal Cord Injury Statistical Center.

Sveistrup, H., Lockett, D., Edwards, N., & Aminzadeh, F. (2006). Evaluation of bath grab bar placement for older adults. Technology and Disability, 18, (45-55).

Toro, M. L., Koontz, A. M., Kankipati, P., Naber, M., & Cooper, r. A. (2010, June). *Independent wheelchair transfer: A systematic literature review.* Paper presented at the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Las Vegas, NV.

Toro M. L., Koontz A. M., Cooper R. A. (2012). The impact of transfer setup on the performance of independent transfers, Human Factors: The Journal of the Human Factors and Ergonomics Society, 55, (567-580).

Tsai, C. Y., Rice, L. A., Hoelmer, C., Boninger, M. L., Koontz, A. M. (2013). Basic psychometric properties of the transfer assessment instrument (Version 3.0). Arch Phys Med Rehabil, Epub ahead of print.

Tzeng, H., & Yin, C. (2010). Adding additional grab bars as a possible strategy for safer hospital stays. Applied Nursing Research, 23, (45-51).

United Stated Access Board. Accessible amusement rides – a summary of accessibility guidelines for recreational facilities; 2003.

United States Access Board. (n.d.). Retrieved from http://www.access-board.gov/the-board

U.S. Department of Education: OSERS. (n.d.). Retrieved from http://www2.ed.gov/about/offices/list/osers/nidrr/index.html?src=mr

U.S. Department of Justice. (1994). ADA standards for accessible design. Retrieved from http://www.ada.gov/adastd94.pdf

U.S. Department of Justice, (2010). 2010 ADA standards for accessible design. Retrieved from http://www.ada.gov/regs2010/2010ADAStandards/2010ADAStandards_prt.pdf