DEVELOPMENT OF A CUSTOMIZED ELECTRONIC REMINDER TO FACILITATE POWERED SEATING FUNCTION USAGE AND COMPLIANCE WITH CLINICAL RECOMMENDATIONS: DESIGN PROCESS AND CLINICAL EFFICACY

by

Hsin-Yi Liu

B.S. in Physical Therapy, National Taiwan University, 2001

M.S. in Rehabilitation Science and Technology, University of Pittsburgh, 2008

Submitted to the Graduate Faculty of

School of Health and Rehabilitation Science and Technology in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2013

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

This dissertation was presented

by

Hsin-Yi Liu

It was defended on

November 18, 2013

and approved by

Daniel P Siewiorek, PhD, the Buhl University Professor,
Computer Science, Carnegie Mellon University

Mark Schmeler, PhD, Assistant Professor,
Rehabilitation Science and Technology, University of Pittsburgh

Dan Ding, PhD, Associate Professor,
Rehabilitation Science and Technology, University of Pittsburgh

Rosemarie Cooper, MPT, Assistant Professor,
Rehabilitation Science and Technology, University of Pittsburgh

Dissertation Advisor: Rory A Cooper, PhD, Distinguished Professor,
Rehabilitation Science and Technology at University of Pittsburgh

DEVELOPMENT OF A CUSTOMIZED ELECTRONIC REMINDER TO FACILITATE POWERED SEATING FUNCTION USAGE AND COMPLIANCE WITH CLINICAL RECOMMENDATIONS: DESIGN PROCESS AND CLINICAL EFFICACY

Hsin-Yi Liu, PhD

University of Pittsburgh, 2013

Compliance with clinical guidance on powered seating function (PSF) usage is very low among individuals who use electric powered wheelchairs (EPWs), leading to high risks for secondary complications, with potentially devastating health consequences, and drastically reduced quality of life. The purposes of this research project were to 1) develop a pervasive and persuasive reminder system, Virtual Seating Coach (VSC), to facilitate appropriate use of PSFs for health management following clinical recommendations; and 2) evaluate the efficacy of VSC on facilitating PSF usage and improving compliance with clinical recommendations.

Survey studies, in-lab tests, and a pilot test study were conducted to ensure that users' feedback was incorporated in the development of the VSC. The research team gradually improved and refined the VSC in the development process. A randomized group study was conducted to evaluate the efficacy of the VSC. Participants used study EPWs equipped with the VSC for 8 weeks, including 2 weeks of baseline data collection and 6 weeks of intervention by receiving an educational program or the VSC in conjunction with the educational program. The educational program included providing educational materials in video, pamphlet, and flash cards formats, and recurrent meetings with a clinician once every two weeks to discuss PSF usage.

Twenty six individuals participated in the study, and sixteen of them completed the study protocol. The study results showed that the intervention of the VSC in conjunction with the educational program increased the compliance rate around 40%, while the intervention of the educational program alone increased the compliance rate around 18% compared to the baseline period. Providing timely cues, accessible instructions and feedback were critical to facilitate a desired health behavior.

Participants had large variability in the directions and strength of correlations between PSF usage and measures of quality of life (QoL). Gender, experience in EPW and PSF usage, and ambulatory ability may affect the relationships between PSF usage and QoL. More studies are needed to determine how to interpret the measures of QoL as outcome measurements for the effect of PSF usage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

This Ph.D. dissertation contains the results of research undertaken at the Department of Rehabilitation Science and Technology of the University of Pittsburgh and Human Engineering Research Laboratories of VA Pittsburgh Healthcare System. The research was conducted under the supervision of Professor Rory A. Cooper between September 2008 to November 2013. This study was made possible through funding from The Quality of Life Technology-Engineering Research Center, NSF (EEC0540865), the U.S. Department of Veterans Affairs, Rehabilitation Research and Development Service, Center of Excellence for Wheelchair and Associated Rehabilitation Engineering (B3142C) and Merit Review grant (B6591R). Without funding from these sources, this project would not have been possible.

I would like to thank my advisor, Dr. Cooper, for his mentorship and confidence in me and the opportunity to carry out this project. Also, I would like to thank Dr. Siewiorek, Dr. Schmeler, Dr. Ding, and Professor Rosemary Cooper for their support and guidance. In addition, I would like to thank Annmarie Kelleher, Tasia Bobish, Theresa Crytzer, Elizabeth Benton, John Coltellaro, and Chad Evans for their generous support and help for recruiting participants and providing clinical guidance. I would like to thank Garrett Grindle, Josh Brown, Ben Gebrosky, Mark McCartney, Corey Blauch, Zach Mason, and Dr. Pearlman for their dedication and professional work on the hardware of the study wheelchairs and the virtual seating coach. I would like to thank Chengshiu Joshua Chung, Yu-kuang Eric Wu, and Robert Filippi for generously providing their techniques and professional work on the interface and software program of the virtual seating coach. In particular, I would like to express my gratitude to the many powered wheelchair users and their families, who I have worked with over the years. They inspired me to work through the challenges, taught me valuable knowledge by sharing their life experience and reflections, and reminded me of the vision and purpose for this journey.

Thanks to all of my friends and family who have supported me through this process.

1.0 INTRODUCTION

Powered seating functions (PSFs), including seat tilt (tilt), backrest recline (recline), elevating legrests, and seat elevation functions, allow individuals who have limited or absent upper limb and trunk functions to adjust their posture independently and dynamically. Appropriate use of tilt, recline, and elevating legrests functions can enhance sitting stability and postural control, minimize fatigue while maintaining an upright position, help to manage lower limb contractures and muscle tightness, perform pressure relief to reduce the risk of developing pressure sores, manage dependent edema in lower limbs, and improve seating comfort. PSFs can also be used to help address physiological issues, such as orthostatic hypotension, respiration, oral function, digestion, bowel and bladder movements, and arousal level [1-5]. The seat elevation function can be used to assist with performing gravity-assisted transfers, decrease strength demand for standing up from sitting, and ease reaching activities [1, 6].

Proper training in use of mobility devices has been identified as an important factor which may facilitate using devices in daily activities and in communities, and improve driving safety, user acceptance, and user satisfaction [7, 8]. Currently the recommendations for PSF usage are scattered and written in academic-scientific formats for clinicians and researchers. There is a need to gather and organize the information and develop a user guide to provide referable guidance and support to the end-users beyond clinical settings. Based on health behavior models for individuals, desired health behaviors can be facilitated by appropriate interventions. A tailored electronic reminder, Virtual Seating Coach (VSC), was developed to assist with clinical education on PSF usage for health management.

1.1 POWERED SEATING FUNCTION USAGE

Adjusting posture and position is a basic need to perform daily tasks and maintain comfort and health [9]. Muscle pain and leg swelling are the most recognized adverse results from static and prolonged sitting [9]. We are constantly moving while performing relative static tasks, such as typing on a computer [10]. Even when watching a movie, we are subconsciously shifting our weight once every 1 to 20 minutes [11]. For people who are not able to adjust their posture effectively, besides pain and swelling, pressure sores and fatigue further affect their health and quality of life in addition to the limitations due to disability.

1.1.1 Using PSFs for Pressure Relief

Development of pressure ulcers is the primary complication staying in a static position for an extended duration of time. Pressure ulcers will increase complexity of health management, result in hospitalization, decrease quality of life, and even lead to sepsis and death due to infection. Prevalence of pressure ulcers in wheelchair users ranges between 10 to 40% [12-14]. It is estimated to cost 70,000 to treat a full-thickness pressure ulcer [14] with a very high recurrence rate, ranging from 30 to 90 % [14, 15].

1.1.1.1 Recommended Positions

Use of the tilt function or the combination of the tilt and recline functions shifts the weight backward and unload the soft tissues underneath sacrum and ischial tuberosities (ITs). For participants with spinal cord injuries, tilting the seat more than 30° with the backrest reclined at 100° significantly reduced the peak interface pressure underneath the ITs by 20% and sacrum by 10% compared to the seat at 0° of tilt. If the seat was tilted further backward to 40°, the pressure underneath ITs and sacrum decreased by around 40% [16]. Tilting the seat less than 20° provided very limited or no benefit of pressure reduction [16, 17]. Compared to an upright sitting position, the combination of *recline 100° and tilt 35°* and the combination of *recline 120° and tilt more than 15°* significantly increase skin blood perfusion underneath the ITs [18]. A study suggested larger tilt angles to acquire evident pressure reduction [19], such as tilting the seat 65°; however, most power seat systems can only tilt the seat backward up to 45° and recline the backrest up to 165°. A recent study showed that *tilt 25° and recline 120°* can effectively enhance skin and muscle perfusion over the ITs [20]. Generally speaking, using the proper combination of tilt and recline functions to lean the trunk backward more than 145° (the sum of tilt and recline angles) can significantly shift the weight backward to unload the soft tissues underneath the weight bearing areas in a sitting position.

1.1.1.2 Recommended Duration and Frequency

Despite positioning using PSFs to decrease pressure, proper recommendation of pressure relief frequency and positioning duration is important to allow soft tissues to resume blood perfusion. However, existing evidence is not adequate to recommend a clear pressure relief regime which accommodates individual differences. Only general recommendations can be provided in clinical guidelines for wheelchair users, such as limiting the time spending in the chair without pressure relief [21, 22], or repositioning every 15-30 minutes [23] or at least every one hour [24, 25] based on clinical experience. The duration of pressure relief in sitting is seldom mentioned.

Ischemic-reperfusion injury is one of the factors causing tissue death and developing pressure ulcers. Peirce et al. tried to reveal the correlation between tissue damage and ischemia-reperfusion cycles in a rat skin model. When 50 mmHg of pressure was applied on rat skin and the number of reperfusion cycles stayed the same, longer ischemia duration caused more significant skin tissue damage. However, when the total ischemia duration stayed the same, they found that more reperfusion cycles induced severer skin tissue damage (10 cycles of reperfusion with ischemia for 1 hour and reperfusion for 0.5 hour versus 5 cycles of reperfusion with ischemia for 2 hours and reperfusion for 0.5 hour)[26]. With consideration of feasibility in daily living, the potential of reperfusion injury, and the possibility that the user may delay performing pressure relief due to the task that he is currently conducting, recommendation of performing pressure relief once every hour may be reasonable in clinical practice.

Blood reperfusion is the key factor to determine appropriate pressure relief duration. Makhsous et al. found that it took around 200-250 seconds after unloading the pressure to allow skin to reach maximum oxygen perfusion ($tcPO_2$ 5.8 mmHg to 54.7 mmHg) underneath the ITs when the average interface pressure was decreased to around 40 mmHg (the average peak interface pressure during normal sitting posture was around 80 mmHg). Although the speed of skin reperfusion must be affected by how fast the pressure decreased, $tcPO_2$ kept increasing after the interface pressure had reached the lowest point, shown in Figure 1 [27]. Another study found that it took around 1minute 51 seconds (range 42 s - 3 min 30 s) for tissues to regain $tcPO_2$ to the unloaded level [28]. No further evidence shows whether recovering $tcPO_2$ to the unloaded level periodically will successfully prevent pressure ulcer formation.

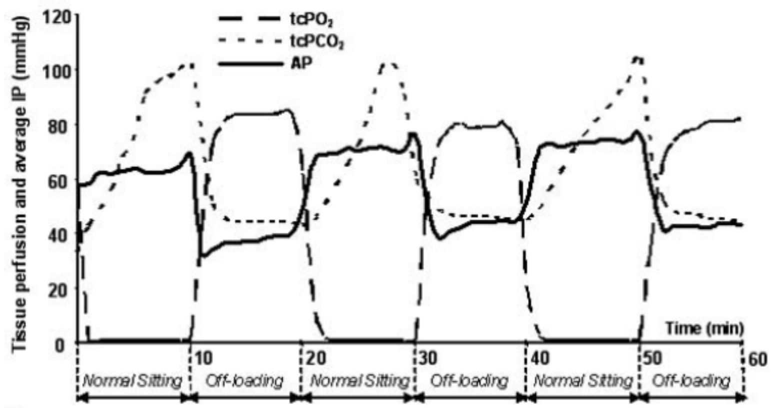


Figure 1. $tcPO_2$ kept increasing after the average interface pressure had reached the lowest point (Makhsous, 2007)

(AP: Average interface pressure)

1.1.2 Using PSFs To Minimize Fatigue and Seating Discomfort

Symptoms of fatigue may include increased malaise, problems with sleep, difficulties with memory and concentration, persistent muscle pain, joint pain, headache, etc [29]. Many neurological or neuromuscular disorders are associated with fatigue, such as multiple sclerosis, post stroke, Parkinson's disease, amyotrophic lateral sclerosis, etc [30, 31]. However, fatigue and pain resulted from prolonged static seating are common experiences for most people during long distant driving or flight and prolonged computer usage or gamming [32]. The same issue occurs in wheelchair users. A wheelchair provides the user with an independent means of mobility; however, wheelchair sitting tolerance profoundly affect how long a wheelchair user can move about independently and continuously for daily tasks or work. The duration of wheelchair users sitting in their wheelchairs can be less than 3 hours a day or more than 12 hours a day, depending on the user’s health condition, seating comfort, and user satisfaction [33]. Although there are no specific recommendations to manage fatigue, it has been found that providing adjustable class furniture and encouraging to move while sitting in the class made young students sit with less trunk and neck flexion, less lateral bending, more active in school, and experience less pain [34]. Besides, office workers are recommended to have a 5 minute break every hour, and individuals with musculoskeletal issues are recommended to have a break once every 20-30 minutes [35]. People who are not able to adjust their posture effectively should be provided with PSFs and encouraged to use PSFs to adjust their posture as frequently as they need to minimize fatigue and improve seating comfort.

1.1.3 PSF Usage by Electric Powered Wheelchair Users

Several studies found that most users reported to use PSFs for comfort, and small angles of tilt (5°-15°) and recline (95°-110°) are frequently utilized to increase sitting stability and assist with functional activities [36-40]. Some studies found that even when subjects claimed that they used PSFs for pressure relief, the tilt and recline angles they applied were not large enough to effectively relieve pressure [36, 38, 41].

1.1.4 Potential Challenges to Comply Repositioning Regime: Using Repositioning for Pressure Relief as an Example

Changing position periodically benefit electric powered wheelchair (EPW) users by assisting with preventing pressure sores and managing fatigue and pain. However, there are multiple challenges for an EPW user to follow a recommended repositioning regime. For example, to be compliant with a repositioning regimen for pressure relief, an EPW user has to go through a series of steps which require cognitive capabilities and sensory-motor functions:

1) be conscious of the need of performing pressure relief;

2) be aware how long he or she has stayed in an upright position;

3) remember the recommended pressure relief frequency;

4) determine that the environment is appropriate for performing pressure relief;

5) be willing to stop the activity that he or she is currently doing;

6) remember the pressure relief strategy or positioning;

7) be willing to adjust his or her position for pressure relief;

8) adjust him or herself into the position;

9) recognize whether his or her current position is matching with the recommended position;

10) remember the recommended duration for pressure relief;

11) be willing to stay in the position for the recommended duration;

12) be aware how long he or she has stayed in the pressure relief position;

13) stay in the recommended position for the recommended duration;

14) return to his functional position.

Besides sensory-motor functions for conducting pressure relief, proper setting of equipment and human-machine interface, and safe environment to tilt the seat and recline the backrest with large angles, several pieces of information are needed to be processed and registered appropriately in cognitive functions in advance to initiate and engage an individual to complete an effective pressure relief, as shown in Figure 2. These cognitive functions can be broadly categorized as retrieving information from long-term memories (recommended pressure relief regime and safety about PSF usage), tracking and comparing information from short-term memories (time, current activity, current environment, current body condition), decision making according to previous experience, collected information and personal preference. Lacking any one component of the information will prevent an EPW user from independently performing an effective pressure relief.

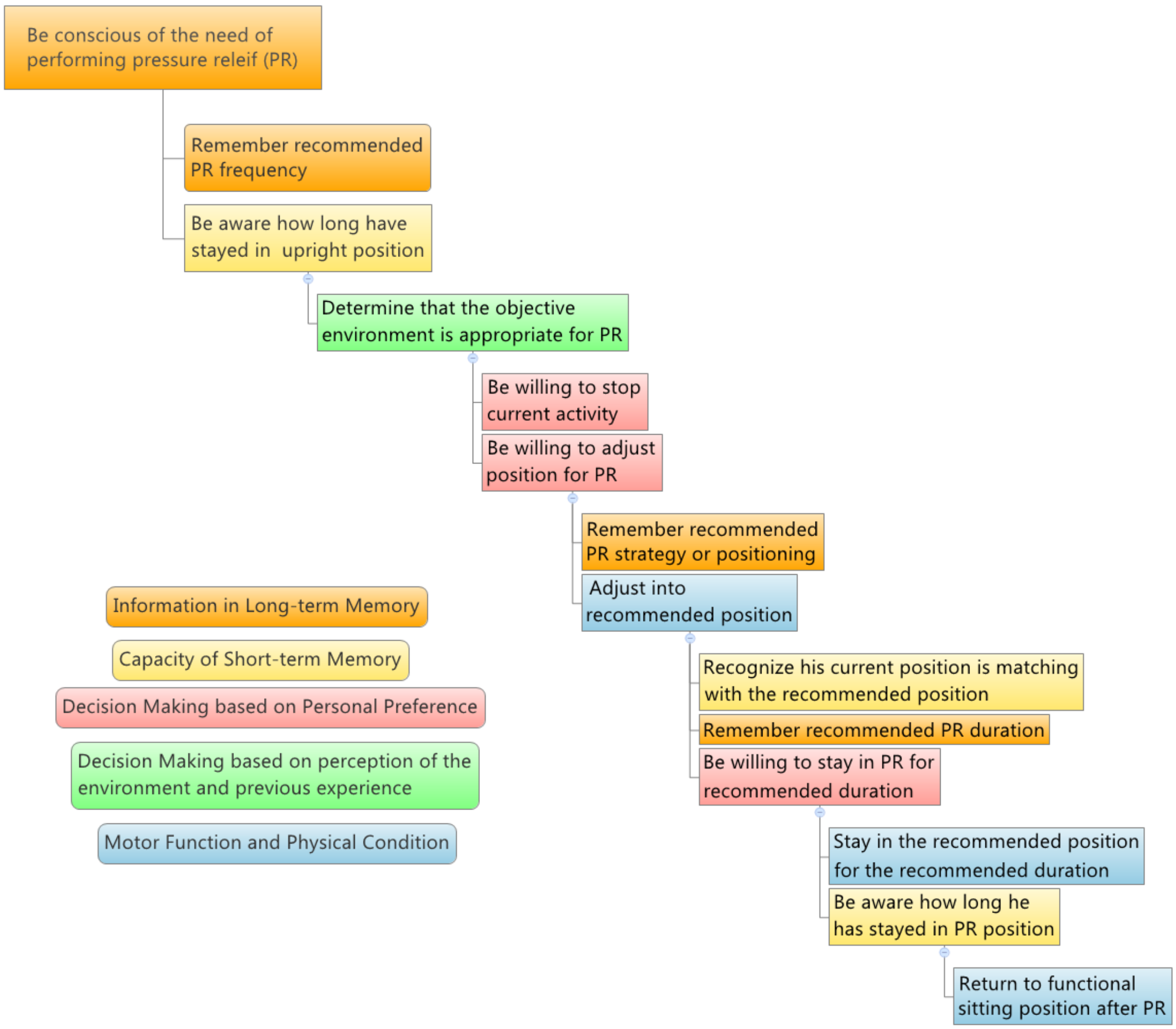


Figure 2. Process of Performing an Effective Pressure Relief Independently

1.1.4.1 Inadequate Knowledge about Pressure Ulcer Prevention in Long-Term Memory

For a novice power wheelchair user, the amount of information about a newly introduced powered mobility device is overwhelming to be digested within a 2-hour device delivery process.

In addition, no handy training or education material about PSF usage is available for EPW users, and the information about pressure relief is usually conveyed orally and found scattered over the internet. If a user is not self-motivate to discuss pressure sore prevention with clinicians and research the information about performing pressure relief, there is no external support or reinforcement for a user to install and consolidate the information in long-term memories, and therefore the thought of performing pressure relief will not be initiated. If the recommended pressure relief regime is not stored in the long-term memory, the person will not know the proper way to perform pressure relief even though he or she recognizes the importance of pressure relief. A study by Rintala et al. in 2008 showed that personalized pressure ulcer education and monthly telephone follow-up was effective to reduce the frequency and recurrence of developing pressure ulcers compared to providing quarterly follow-up without education content [15]. Accessible supportive materials and periodical discussion are the basic but plausible approach to facilitate new information being stored in long-term memories.

1.1.4.2 Unable to Keep Tracking Everything in Short-Term Memory

People attempt to shift their weight when feeling uncomfortable due to prolonged sitting. They do not need to remember "the need to perform pressure relief" because the feeling is the reminder. In contrast, individuals losing sensory functions due to diseases or injuries do not receive any trigger to initiate the action of performing pressure relief. With numerous activities and tasks happening during a day, it is very easy to lose track of time and forget to perform pressure relief even if the individual is aware of the importance of pressure ulcer prevention [42]. After a user adjusting himself into a pressure relief position, there is no convenient way for the user to track the time staying in the position compared to the recommended duration.

1.1.4.3 Decision Making Affected by Personal Preference and Perception of The Situation

Positions to achieve effective pressure relief are not functional, which means a wheelchair needs to stop what he or she is currently doing. A survey study showed that wheelchair users may choose to ignore the need to perform pressure relief and stay in a functional position for a prolonged period to accomplish more work or tasks, trading health for full participation [43]. People tend to prefer the options that are easy to process and bring instant outcomes [44, 45]. Being compliant with the pressure relief regime requires processing complex information, and does not bring any explicit outcome quickly. Compared with pressure relief, working on the activity in hand is fairly straightforward and can satisfy an immediate goal. Some wheelchair users felt being observed or watched when performing pressure relief [42]. Besides, people tend to feel unstable and vulnerable when the seat is tilted and backrest is reclined in large angles. Negative feelings about pressure relief will further increase the cognitive effort in order to follow the clinical recommendation, and therefore reduce the possibility that an individual would choose to stop a task to perform pressure relief or stay in the recommended position long enough.

1.2 FACILITATION OF HEALTH BEHAVIOR

Optimized PSF usage includes using the functions safely, appropriately, and repeatedly. Some behavior models provide insights on how to analyze the challenges of using PSFs following a recommended repositioning regime and develop strategies to enhance appropriate usage of PSFs.

1.2.1 Models and Theories of Individual Health Behavior

The Health Belief Model (HBM) (Hochbaum, 1958) and Transtheoretical Model (TTM) (Prochask, 1984) are widely adopted models because of their intuitive logic [46]. HBM was developed based on the expected value theories of cognitive psychology for decision making. The primary concept of HBM is that the individual will compare the perceived importance of a behavior (susceptibility and severity), the costs of performing the behavior (barriers and self-efficacy), and the outcome of the behavior (benefits), and then perform an action based on the combination of the beliefs. "Cues to action" is mentioned in the model construct, but the role of cues has not been studied systematically in this model [47]. How an individual analyzes the target behavior is the primary determinant leading to the behavior. TTM has been utilized extensively around the world because it provides explicit descriptions about the processes and principle of changes to guide interventions. One of the key assumptions of TTM is that specific principles of change need to be applied to specific stages to facilitate progress [48]. Therefore, accurately identifying the present stage of the individual and dynamically applying tailored interventions become the major challenges while adopting TTM in practice [46].

The Theory of Planned Behavior (TPB) (Icek Ajzen, 1985) emphasizes the causal relationship that attitude, subjective norm, and perceived control affect the intention to perform the intended behavior [49]. Similarly with HBM and TTM, TPB hold a basic assumption that the behavior can be modified by manipulating the underlying beliefs [50]. However, it has been found that the link between the change in intentions and the change in behavior is fairly weak when the behavior has become a habit or the individual is under social pressure [46]. Hence Montano and Kasprzyk proposes an Integrated Behavioral Model (IBM) in 2008 to include environmental constraints, knowledge and skills to perform the behavior, experience of performing the behavior, and salience of the behavior parallel with intention to determine the behavior [49]. "Salience of the behavior" can be explained as the salience of the cue reminding about the behavior. Considering the nature of performing periodical repositioning for pressure relief illustrated in Figure 2, IBM covers all the factors that could affect the possibility of an individual to reposition using PSFs following clinical recommendations.

1.2.2 Potential Application of a Modern Behavior Modification Models

Fogg's Behavior Grid (2010) defines 15 types of behavior according to behavior familiarity, duration of the behavior, and the direction of intended changes (desire to increase or to reduce) for persuasive design [51]. For example, the primary goal of prescribing an EPW with PSFs to a novice user with high risks of developing pressure sores is to facilitate the progress from Green Dot behavior (performing pressure relief using PSFs once under a clinician's supervision) to Green Path behavior (performing pressure relief using PSFs from now on). However, Green Path behavior cannot be achieved unless the individual has accomplished Green Span behavior (performing pressure relief using PSFs for the next month).

To achieve Green Span behavior, Fogg suggests that at least one of the three elements in the Fogg Behavioral Model (FBM) [51] need to be manipulated: motivation, ability, and triggers. Basically FBM simplifies IBM by grouping all the factors influencing an individual's belief/perception about the intended behavior into "motivation", grouping all the elements about how an individual analyze his own capability into "ability", and emphasizing the importance of triggers. It is possible that the behavior occurs when motivation is high and ability is low, but this is not a good option because motivation is difficult to be modified and monitored for multifactorial influence as illustrated in IBM.

An optimal intervention to prompt a behavior is to put triggers of easy tasks in the path of motivated people. Besides increasing awareness of the desired behavior, an effective trigger or reminder should allow the individual to take action right away. Feasibility of conducting the intended behavior can be modified by manipulating the "elements of simplicity", including time, money, physical effort, brain cycles, social deviance, and non-routine.

If modifying motivation is the focus of the design to initiate a new behavior, Fogg suggests that decreasing the fear about performing the new behavior is the most rewarding approach [51]. Although Fogg proposes "three core motivators" (sensation: pleasure/pain; anticipation: hope/fear; and belonging: social acceptance/social rejection) to understand and manipulate an audience's motivation profile, the three motivators are vague compared to the detail motivation factors described in IBM.

Maintaining the behavior is the primary issue for establishing a Green Path behavior [52], which is seldom emphasized in other health behavior models. Fogg believes that maintaining a behavior is all about proving persuasive triggers. Triggers should be provided at the time and location when the audience is with the highest ability to perform the behavior, and allow the audience can take action right after receiving the trigger. The sequence of triggers and actions should be repeated until the association is strong.

Although FBM may oversimplify the issues of behavior modification, it provides a straightforward guidance to start designing a persuasion system to facilitate health behaviors. Meanwhile, the frameworks of mainstream health behavior models should be considered to analyze the challenges of following pressure relief regime in order to facilitate better service delivery process besides developing a reminding system.

Researchers and designers propose numerous principles of persuasive design for various applications based on research findings and experiences. Marianne Lykke, a researcher in communication and psychology, suggests seven persuasive design principles for website activities [53]. Applying the principles of *reduction, tunneling,* and *reduction* may decrease the cognitive load and the stressfulness to search information on a user-interface. Principles of *suggestion*, *self-monitoring, surveillance,* and *conditioning* attempt to facilitate the user to utilize system features and provide users with the sense of control, supportive information, and reward. These principles are not revolutionary, but they are a useful tool for planning and analyzing information architecture. Interface Guidelines by Apple Inc. also provide straightforward but detail recommendations about how to develop user-friendly interfaces, such as using page control and consistent interface appearance through pages [54]. Although these design principles are for website interface, they are compatible with Fogg's Behavior Model and Rimer's Integrated Behavior Model in the elements about motivations and individual abilities behind the intended behavior. These persuasive design principles can serve to guide the development of a reminder device and evaluate its usability.

1.3 ELECTRONIC REMINDERS ASSISTING WITH HEALTH MANAGEMENT

1.3.1 Reminders for Time Routine

Reminder functions have been a basic and necessary function on a mobile phone. Many electronic medication reminders are on the market to alert the individual for the time to take medicine. For people needing to take complicated medication, simple reminder messages improved their adherence to the prescription [55]. However, health behaviors are much more about taking medication. Changing life styles is always intricate and challenging.

1.3.2 Reminders for Different Life Style

Customized web-pages or e-mail reminders have been applied to assist health management since 1980s [56]. However, limited accessibility to Internet due to locations and capability of the devices may baffle users to receive messages. Because of the high prevalence of mobile phones, short-message service (SMS) has been widely applied in health management interventions, and positive effects are shown for smoking cessation, weight loss, and diabetes management [57]. Dosages/frequencies of SMS were varied across the studies. SMS for diabetes management were delivered once every week in most studies, but SMS for smoking cessation were delivered as much as 5 times daily.

Wearable sensors, instant data upload using phone services, or periodical phone counseling sessions can be coupled with SMS for reliable outcome measurements and assembling tailored feedback. The content of reminders is mostly about the guidelines of healthy behaviors and strategies, and the user has a wide range of freedom to decide when the convenient time is to perform the desired health behavior. These reminders are mainly designed to facilitate motivation of the individual by reaffirming the goal and principles, as well as increase the ability by delivering tips and encouragement.

1.3.3 Reminders for Repositioning

Pressure relief needs to be performed with fairly high frequency (once every 15-30 minutes for manual wheelchair users; once every hour for power wheelchair users) compared to most of health behaviors mentioned above. A study by Yang et al. showed that monotonic ring tone alerts increased the frequency to perform pressure relief from 9.48 times to 12.30 times per day for manual wheelchair users, but the frequency was still much less than clinical recommendations at the time [58]. The alerts were delivered once every 20 minutes when the sensors detected continuous pressure on the rear part of the seat. 90% of the participants stated that they forgot to perform pressure relief even when receiving the alert; and 20% felt that the alerts were annoying and chose to ignore them [58]. The authors did not discuss why the participants refuse to perform pressure relief even though they received reminders. The result was accepted as the natural limitation of pressure relief, and therefore the authors propose that passive approaches, such as providing weight distribution cushions and devices to automatically unload the pressure for users, might be the better method for pressure ulcer prevention [58]. The authors seem to assume that the relationship between the alert and performing pressure relief was simple and straightforward; however, the timing of the alerts may not be appropriate for a participant to perform pressure relief. In addition, it was unknown whether the participants were annoyed and forgot to execute the task because of the monotonic ring tone, the frequency of the alert, or the timing of the alerts. There has not been a reminder device designed for power wheelchair users to perform pressure relief using PSFs. The system developed by Yang et al. was a time-routine reminder. For the purpose of facilitating using PSF to perform pressure relief, a reminder device needs to remind the timing of performing the task, as well as the procedure to complete the task. Many more factors should be considered when developing a reminder system for EPW users to facilitate periodical repositioning.

2.0 DEVELOPMENT OF POWERED SEATING FUNCTION USER GUIDE

To develop a tailored electronic reminder to facilitate appropriate powered seating function (PSF) usage, this interview study was conducted to understand how wheelchair seating clinicians recommended PSF usage. An internally-developed questionnaire to assess clinical recommendations of PSF usage was administered in an interview format to clinical seating and mobility specialists. A qualitative analysis was applied to codify the recommendations, and the findings were transformed into a PSF user guide. Specific but varied seating positions and temporal indication were recommended for performing pressure relief positioning. For several activities, appropriate seating positions should be determined according to the immediate physical condition of the user and/or the environmental settings. The findings provided general rules to plan the coaching function of the tailored reminder to facilitate appropriate PSF usage. The manuscript developed based on the findings from this study was accepted for publication in the journal, "Disability and Rehabilitation: Assistive Technology. [59]"

2.1 INTRODUCTION

Proper training in use of mobility devices has been identified as an important factor which may facilitate using devices in daily activities and in communities, and improve driving safety, user acceptance, and user satisfaction [7, 8]. Currently the recommendations for PSF usage are scattered and written in academic-scientific formats for clinicians and researchers. There is a need to gather and organize the information and develop a user guide to provide referable guidance and support to the end-users beyond clinical settings.

This paper described a pilot study on organizing and codifying clinical recommendations for PSF usage and developing a PSF user guide. An internally-developed questionnaire was used to interview experienced seating clinicians in order to capture the potential activities that PSFs can help with, and how clinicians would provide the instructions to the users. The clinical recommendations derived from this study guided the development of the coaching function of a tailored electronic reminder to facilitate PSF usage.

2.2 METHODS

2.2.1 Questionnaire and Structured Interview

A questionnaire was developed to interview each participant in order to capture how a clinician would recommend using PSFs to assist with daily tasks and health management to a user. Based on a literature review [1, 2, 37, 60, 61], potential activities that PSFs can assist with were listed in the questionnaire, including pressure relief, improving sitting stability (static sitting, during driving on a level surface, driving uphill on a ramp, and driving downhill on a ramp) to increase seating comfort and minimize fatigue, managing spasticity in lower extremities and trunk (positioning to decrease spasticity, positioning to accommodate the position change due to spasticity), pain management (neck pain and back pain), assisting with transfers (lateral transfer, standing-pivot transfer, and dependent transfer using a mechanical lift), facilitating reaching, edema management, taking care of contractures and muscle tightness in lower extremities and trunk, repositioning upright from a lying back position, realigning posture when sliding forward (sitting on the sacrum), facilitating physiological functions (orthostatic hypotension, respiration, oral function, digestion, bowel and bladder movements, and arousal level), helping the caregiver to use proper body mechanics. Each potential activity was followed by questions asking: (1) whether the participant would recommend using PSFs to assist with this activity; (2) which PSF(s) would be recommended for this activity; (3) what seating angle of each PSF are recommended for this activity; (4) in what order PSFs should be operated for this activity; (5) at what timing the user should use PSFs for this activity; (6) for how long the user should stay in the position achieved by using PSFs (duration); (7) how often the user should use PSFs to position for this activity (frequency); and (8) whether there are concerns about using PSFs for this activity. The last question of the questionnaire asked whether the participant had any notion or recommendation which was not captured in the questionnaire. Two seating clinicians reviewed the questionnaire to ensure that face validity was satisfied. An investigator interviewed each participant in person following the questions listed on the questionnaire, taking around 40-60 minutes. Participants were free to discuss in detail their recommendations or concerns about using PSFs at any time during the interview. The answers to the questionnaire and discussions during the interview were written down on an answer sheet and notes.

2.2.2 Participants

A convenient sample was obtained from the Center for Assistive Technology (CAT) at the University Medical Center. Five mobility and seating clinicians who are Assistive Technology Practitioners (ATPs) certified by Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) participated in the study. One has more than 20 years of experience in prescribing electric powered wheelchairs (EPWs) with PSFs, three have more than 10 years of experience, and one has more than 5 years of experience. All of them have a master degree in either physical therapy or occupational therapy, and one has a PhD degree in rehabilitation science.

2.2.3 Data Analysis

The answers and information collected by the questionnaire and interview were (1) categorized according to the activities that PSFs can assist with; (2) summarized to provide the instruction of using the seating functions, including the recommended seating functions, the recommended seating angles and/or seat height (seating positions), the recommended sequence that PSFs should be operated with (methods), and the recommended frequency and duration that PSFs should be used for the activities (temporal indications); and (3) labeled whether the recommended activities, seating positions, methods, and temporal indications are consensual among the five clinicians.

2.3 RESULTS

The activities that potentially can be assisted or facilitated by using PSFs are categorized and listed in Appendix A with the method for each activity and the variability in the method. The primary consensus across the five clinicians is the order of operating PSFs to incline backward and return to an upright sitting position from an inclined position. To incline backward for any purpose, the user should always tilt the seat first to ensure sitting stability, and then recline the backrest, followed by elevating the legrests as needed. To return to an upright position, the user should first make sure that the seat is tilted, and then lower the legrests followed by bringing the backrest forward, and then tilt the seat forward as needed. Instructions for some activities included specific seating positions or temporal indications. No specific instruction was given for physiological applications. Several precautions were highlighted by the clinicians in addition to recommendations for assisting with daily activities.

In Table 1, recommended activities were grouped according to the variability in the methods among the clinicians and whether specific seating positions were recommended. Specific seating positions and temporal indications were recommended for performing pressure relief positioning, but the seating positions and temporal indications were varied. The recommended methods of using the PSFs for assisting with standing pivot transfer and managing joint contractures and muscle tightness were different among clinicians. No specific seating position was recommended for several activities, whose appropriate seating positions should be determined according to either the immediate physical condition of the user and/or the environmental settings.

Table 1. Characteristics of recommendations: Activities of PSF usage are grouped based on the characteristics of the instructions in ATPs' recommendations

<table>
<tr><th colspan="2"></th><th>SIMILAR methods recommended</th><th>VARIED methods recommended</th></tr>
<tr><td colspan="2">Specific seating positions recommended</td><td>• Performing pressure relief
• Improving sitting stability in general
• Improving sitting stability while driving on level surfaces
• Repositioning if sliding forward
• Lying flat
• Assisting with dependent transfer</td><td></td></tr>
<tr><td rowspan="2">NO specific seating position recommended</td><td>IMMEDIATE PHYSICAL CONDITIONS are primary factors to determine proper seating angles</td><td>• Repositioning upright
• Pain management
• Spasticity management
• Edema management
• Managing physiological conditions</td><td>• Managing contractures and muscle tightness</td></tr>
<tr><td>ENVIRONMENTAL SETTINGS are primary factors to determine proper seating angles</td><td>• Facilitating reaching
• Assisting with lateral transfer
• Helping the caregiver to use proper body mechanics
• Improving sitting stability while driving on a ramp</td><td>• Assisting with standing pivot transfer</td></tr>
</table>

2.4 DISCUSSION

Besides providing recommendations for using PSFs for assisting with daily activities, clinicians emphasized the importance of educating users about the precautions for using some combination of seating functions and driving in certain positions. There are potential risks of tipping and blocking the driver's view if PSFs are used inappropriately. The number of wheelchair injuries treated in emergency departments has increased over the past years, mostly involving tips, falls and collision [62]. Several articles on expert opinion or investigating wheelchair injuries have emphasized the potential effect of proper training or education on decreasing wheelchair related accidents [63-65], and a study by Hoenig et al showed that better quality of wheelchair training would facilitate use of wheelchairs [66]. It is critical for clinicians and suppliers to provide training and education materials in order to promote effective and safe use of a mobility device.

Recommendations gathered from this study cover many daily activities. Specific seating angles and/or temporal indications were recommended only for a few activities, including pressure relief, improving sitting stability, repositioning if sliding forward, lying flat, and assisting with dependent transfer, which are performed in relatively predictable environments or have less interaction with the environment. However, the clinicians emphasized that proper seating angles or seat height for all of the activities should be modified based on desired tasks, current physiological conditions, environment settings, and individual characteristics (preferences, sensation, strength, movement control, range of motion, and body size) even though specific seating positions could be recommended for some activities. Therefore, the ability to properly and safely use PSFs to improve quality of life and health requires the knowledge about operating PSFs, the awareness of all the personal and environmental elements and their interactions that could affect the appropriate seating positions, and correct decision-making about when she/he should utilize which seating functions with what sequence, seating angles or seat height.

The clinicians reached consensus on most methods of applying PSFs, but a few differences were revealed. First was about using PSFs to manage contractures and muscle tightness in lower limbs. Some clinicians felt that PSFs can only be used to accommodate the limitation in the range of motion by positioning the lower limbs; but some would recommend the user to move the lower limb passively using PSFs under supervision. After discussing with clinicians, we concluded that the conservative recommendation of using PSFs to accommodate contractures and muscle tightness in lower limbs can be provided to every user, but the recommendation of using PSFs to provide range of motions should be determined according to the user's joint limitations, posture, sensory function, skin integrity, and cognitive function after careful clinical assessment. Second, the recommended methods of assisting with standing-pivot transfer were different in the order between elevating the seat and scooting forward before standing up from the seat. After discussing with the clinicians, we found that the order should be determined based on individual preference and characteristics (such as strength, range of motion, and limb length). These variations manifest the importance of clinical assessments to customize the training on PSF usage for each user.

Training in using PSFs is usually administrated during the wheelchair delivery process in the clinic with oral instructions, minimum practice, and limited length of time [67, 68]. For some individuals the cognitive process of using PSFs is overwhelming and difficult to learn. Although the RESNA position papers elaborate the rationales and positive impacts of using PSFs, they were written in technical terms and format for health care professionals and researchers [2, 6]. A user guide for PSF usage written in layman's terms would be beneficial for the users and caregivers to get familiar with PSFs and empowered to use PSFs to assist with daily activities. The booklets developed by the National Multiple Sclerosis Society are good examples of using layman's terms to convey knowledge involving medical terms and conditions [69, 70].

Based on the results from the structured interview, a PSF user guide was developed to provide non-tailored information about PSF usage (Appendix B). The angles were assigned into three categories, minimum, moderate, and maximum ranges to make it easier for the user to remember the instruction. Recommendations for all the potential activities and precautions were illustrated with figures and text in layman's terms. The importance of discussion with mobility and seating clinicians and physicians was emphasized in the user guide for customized recommendations.

Based on current evidence, tilt > 35° with mild recline (> 100°) or tilt > 15° with moderate recline (>120°) can significantly decrease interface pressure and regain perfusion over the weight bearing area [16, 18]. Only general recommendations of pressure relief positioning are provided in clinical guidelines for wheelchair users, such as limiting the time spent in the chair without pressure relief [21, 22], or repositioning every 15-30 minutes[23] or at least every one hour [24, 25]. The recommended duration for pressure relief while using a wheelchair is seldom mentioned. Some clinicians provide conservative recommendations to stay in the pressure relief position once every 15-30 minutes for 30 seconds or once every 60 minutes for 60 seconds according to an existing guideline [60]. A study by Coggrave et al. found that it took around 1minute 51 seconds (range 42 s - 3 min 30 s) for tissues to regain transcutaneous oxygen tension ($tcPO_2$) to the unloaded level [28]. Considering the feasibility of positioning for pressure relief, the frequency and duration was recommended as once every hour for 2 minutes, or once every 30 minute for 1 minute in the user guide.

Two wheelchair seating clinicians, two engineers, two clinical research coordinators, and seven PSF users were invited to review the draft of the PSF user guide to ensure that the information was correct and relevant to the purpose as a referable and educational material for customers, the wording and phrases were easy to be understood for people with various backgrounds and education, and the layout was reader-friendly. The seven PSF users who reviewed the draft of the user guide felt that this user guide was helpful, clear, and simple.

Limitations

Only five clinicians from the same clinic were recruited to participate in this study. Although the number of experts is small, they are RESNA certified ATPs and very experienced in seating assessments and prescription. However, variability in clinical decision making plus various guidelines and research findings may contribute to the differences in their recommendations for PSFs usage [17, 60, 71].

This article is a beginning of providing referable information for customers to extend user training beyond clinical settings, and provide an example of the methodology that can be replicated to develop user-friendly guides for other forms of assistive and rehabilitative technology. Because currently research finding about using PSFs in daily living is very limited, most recommendations are based on experts' experiences. The PSF user guide will be revised as more scientific evidence accumulates. Studies are needed to investigate the effectiveness of various training media, methods, and protocols to facilitate appropriate and safe PSFs usage to improve quality of life for EPW users.

Future Development

The guideline will need to be updated based on the latest scientific evidence. More seating & mobility clinicians from different clinics will be invited to share their experience in recommending PSF usage by in-person or phone interview. A structured survey and interview study on clinicians and PSF users will be conducted to establish the face and content validity of the guideline in the future.

2.5 CONCLUSION

PSFs are critical features on EPWs to allow an individual to adjust posture dynamically. The recommended methods and positions in using the seating functions should be determined with consideration for individual preferences, physical condition, environmental setting, and desired tasks after thorough clinical seating assessments. A PSF user guide was developed based on the findings from this interview study. Besides using PSFs to assist with daily tasks and managing physical conditions and health issues, precautions about positioning and driving safety, and the importance of discussing with clinicians are emphasized in the user guide. This article provided an example of the methodology to develop a user-friendly guide of an assistive device. The PSF user guide will be updated after more scientific evidence accumulates and be structurally evaluated for its face and content validity in the future. Besides, the recommendations collected from this study were applied to develop a tailored electronic reminder, Virtual Seating Coach, to facilitate appropriate PSF usage.

2.6 EDUCATIONAL MATERIALS DEVELOPED FROM THE SURVEY STUDY

2.6.1 Pamphlet

Since it was not practical to recommend specific seat angles for each application in a general guide book for a population with a wide variety, the movement range of each seat function were divided into three amplitudes: maximum, moderate, and minimum, according to previous research and clinical experience [37], shown in Table 2. Clinically zero degree of elevating legrests was defined as knees are fully extended, and 90 degrees as the knees were bent perpendicular with thighs, as shown in Figure 3 (a). In this case, the value of the legrest angle decreased when the legrests were being lifted up. To decrease the confusion when discussing the legrest angle with a user, the legrest angle position at 180 degrees was defined as knees were fully extended, as shown in Figure 3 (b). In this way the legrest angle value increased as the legrests were being elevated. The content of the pamphlet was written with 8th-grade reading level in second-person narrative mode to facilitate the engagement when reading the pamphlet.

Table 2. Three ranges of each seat function

	Minimum	Moderate	Maximum
Tilt	< 15 degrees	15-30 degrees	>30 degrees
Recline	< 110 degrees	110-130 degrees	>130 degrees
Elevating Legrests	< 110 degrees	110-130 degrees	>130 degrees
Seat Evelation	< 2 inches	2-4 Inches	> 4 inches

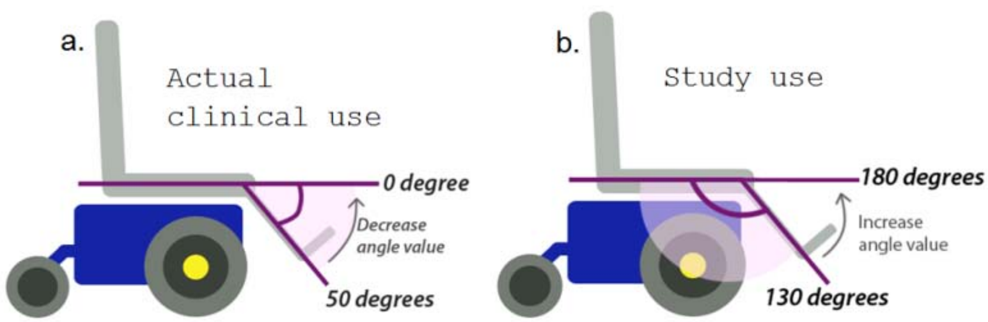


Figure 3. Definition of legrest angles

Illustrations of seating positions and the occupant corresponding to the application were included along side with the text. To decrease distraction and ease printing process, the pamphlet was developed in grayscale, and the illustrations only included outlines of wheelchairs and occupants created by computer programs, SolidWorks, Microsoft Paint, Corel Draw, or Adobe Photoshop. The size of the pamphlet was a half of a letter size paper, 5.5-inch wide and 8.5-inch long for portability.

2.6.2 Video

The first version (v1) of the educational video was created using Adobe After Effects and Adobe Premiere Pro according to the content of the pamphlet. The length of the video was around 29 minutes. Massive graphical effects and animations were applied to illustrate the seating angle changes and attract attention. Clinicians and PSF users were invited to review v1. Frequent comments included that the video was too long, and there were too many repetitions about the proper sequence to use the seat functions. For several applications, such as pain management, spasticity management, edema management, and managing limited flexibility in lower limbs, PSFs have to be utilized according to individual needs, and the recommendation only includes the proper sequence among tilt, recline, and elevating legrest functions. A clinician suggested that inserting bridging music between sections may help to decrease the feel of fatigue when viewing the video.

The second version (v2) was created based the feedback for v1. The length of the video was decreased to around 15 minutes by skipping the sections repeating the sequence of using PSFs, but the potential applications were mentioned at the end of the video with the reminder that the user should discuss with clinicians for appropriate use of PSFs. Unnecessary graphical effects and animations were removed to decrease distraction and delay between video clips. Short bridging music was inserted between sections to refresh the audience occasionally.

2.6.3 Flash Cards

Flash cards were created as a handy summary of the educational pamphlet. The size of the flash cards was 3 by 4 inches. The cards were printed one side on the paper, laminated and assembled with a ring. Each card included the summary of one application. The collection of the cards could be customized according to individual needs. For example, if the user was performing dependent transfer, the cards for standing pivot transfer and lateral transfer were removed. Color codes were applied to indicate that which seat function(s) were used for an application. For example, pink represents the tilt function, and the card explaining the tilt function was printed with pink background. A pink block was located at the top-right corner of the card about pressure relief to indicate that the tilt function was used to achieve pressure relief.

3.0 DEVELOPMENT OF VIRTUAL SEATING COACH (VSC)

The primary functions of the VSC were to trigger the behavior of repositioning using powered seating functions (PSFs) and support electric powered wheelchair (EPW) users to overcome the insufficiency in the information retrieved from long-term and short-term memory for time tracking and the steps to perform the repositioning. The concept of Participatory Action Design (PAD) [72] was applied to ensure the participation of end-users and clinicians starting from the early development stage. The design criteria were given by clinicians and verified by PSF users participating in a survey study and a pilot test study. Fogg's Behavior Model [51] was adopted to plan the timing of the reminders and the message to support and facilitate the desired behavior. The interface layout and displayed information were planned following Lykke's Persuasive Design Principles [53] and Apple Interface Guidelines [54] to encourage utilizing the VSC.

3.1 DESIGN CRITERIA

Repositioning Reminder Functions

- The VSC would periodically (frequency) give reminders to perform repositioning, instruction for the tilt and recline angles (position) and the duration to stay in the position (duration)
- The frequency, position, and duration of the reminder could be modified by the clinician
- The user could snooze or dismiss the reminder.
- If the user ignored the reminder, the VSC would snooze the reminder.
- The reminder would not be given when the user was driving the wheelchair.
- If the user performed a repositioning without the reminder, the VSC would reschedule the next reminder according to the last effective repositioning.
- The reminder would not be given when the wheelchair was unoccupied.

Warning Functions

- The VSC would give warnings when detecting inappropriate use of PSFs.
- The criteria to activate the warnings could be modified by the clinician.
- The user could dismiss the warning.
- If the user ignored the warning, the VSC would snooze the warning and repeat later if the user was still in the same event of appropriate use.
- The warning would not be given when the wheelchair was unoccupied.

User Interface

- The layout and sizes of the buttons on the touch screen should be easy for the users to access.
- The VSC would allow the user to personalize visual and auditory display effects for the reminders and warnings.
- The VSC would provide some supplemental information, such as how to access seat functions and contact research personnel.
- The VSC would allow the user to answer the daily questionnaire by pressing the buttons on the touch screen interface.

Software

- Data of seat position and wheelchair status would be recorded and saved with a timestamp constantly.
- Activation and compliance with reminder and warning would be recorded and saved with a timestamp.
- Changes of display effects, repositioning reminder setting, and warning criteria setting would be recorded and saved with a timestamp.
- The answers to the daily questionnaire would be recorded and saved with timestamp.
- A report program would be developed to display the summary of PSF and wheelchair usage history, which should easily be understood by the clinician and user.

Hardware

- The hardware should be able to withstand vibration and stresses during normal wheelchair use.
- The hardware should be as low-profile as possible and should not increase the dimensions of an EPW.
- The hardware should cause no harm to the user.
- The hardware should not interfere with the user's daily tasks.
- The energy consumption of the VSC should not affect the user's regular driving routine.

3.2 PROTOTYPE: V0

3.2.1 Hardware Structure

A series of sensors and encoders were mounted on a conventional EPW equipped with PSFs, as shown in Figure 4, to monitor how PSFs were used. A computer box was attached at the backrest to protect a single-board computer. A 7-inch touch screen was mounted at the end of the armrest with swing away mechanism and a variety of adjustability. The computer and touch screen were powered by the wheelchair batteries. Every effort was made to build the system as small as possible. Except the touch screen and the computer at the back, a wheelchair with the VSC looked no different from a regular EPW.

Figure 4. Instrumentation of Virtual Seating Coach System

3.2.2 Software

C# was used to develop the prototype of the VSC program, which detected seating angle changes and display feedback with synthetic voice and animation of the seating movements, as shown in Figure 5. The reaction between the event being detected and the feedback being displayed was round 15 seconds.

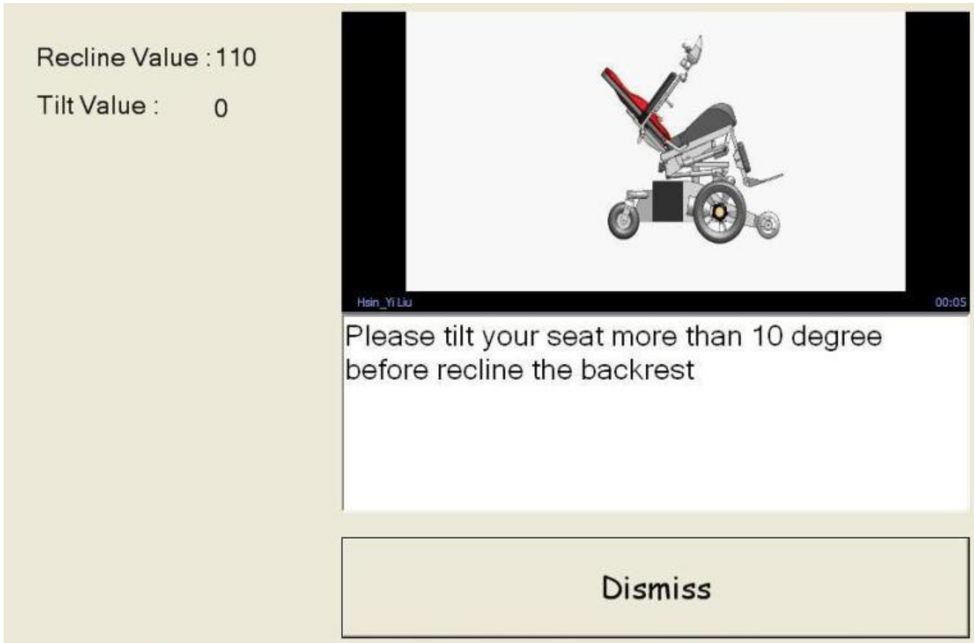


Figure 5. Prototype of VSC program

3.3 SURVEY STUDY ON USERS' PREFERENCE ON DISPLAY EFFECT AND USABILITY

In order to design the interface and the coaching program for the VSC that would display user-friendly feedback, a survey study was conducted to understand EPW users' preference for feedback modalities and gather their suggestions and concerns about the VSC. EPW/PSF users and some clinicians were recruited to participate in this survey study. They reviewed modalities with various features using a computer demonstration program, and then answered a questionnaire and were interviewed. Trends of preferences for indicator and feedback modalities were observed, but some diversity was also found. Findings from this survey study guided the selection of feedback modalities and remind us to build the VSC with the capacity to accommodate individual differences.

3.3.1 Introduction

Selections of feedback modalities for a computer-based coaching program can influence users' adherence and learning outcome. There have been numerous studies trying to identify feedback modalities and their formats which may optimize learning effect and experience for a computer-based training or coaching program, but it is not rare to find the study results seem to conflict with each other. For example, one study found that narration facilitated learning significantly [73], but another study showed that providing either narration or on-screen text would not affect learning outcome [74]. Subjective perception and learning effect can be affected by display modalities.. The VSC was meant to be installed on an EPW and accompany the user for a relatively long period in order to implant the new knowledge and modify health behavior. It was highly possible that the user may be interrupted by the VSC during daily activities even though the user could choose to ignore or dismiss feedback delivered by the VSC. The nature of our desired tasks and human-machine interaction was different from performing a task in a learning session. The interaction between the VSC and user was illustrated in Figure 6. Although some general rules could be drawn from previous studies, we decided to conduct a preliminary survey study to ensure that our design of the prototype would match users' expectation and preference of a coaching system that would work closely with them. Wheelchair seating clinicians were also being recruited as our participants because we would like to know medical experts' comments and suggestions on the design of display effects and the tailored reminders.

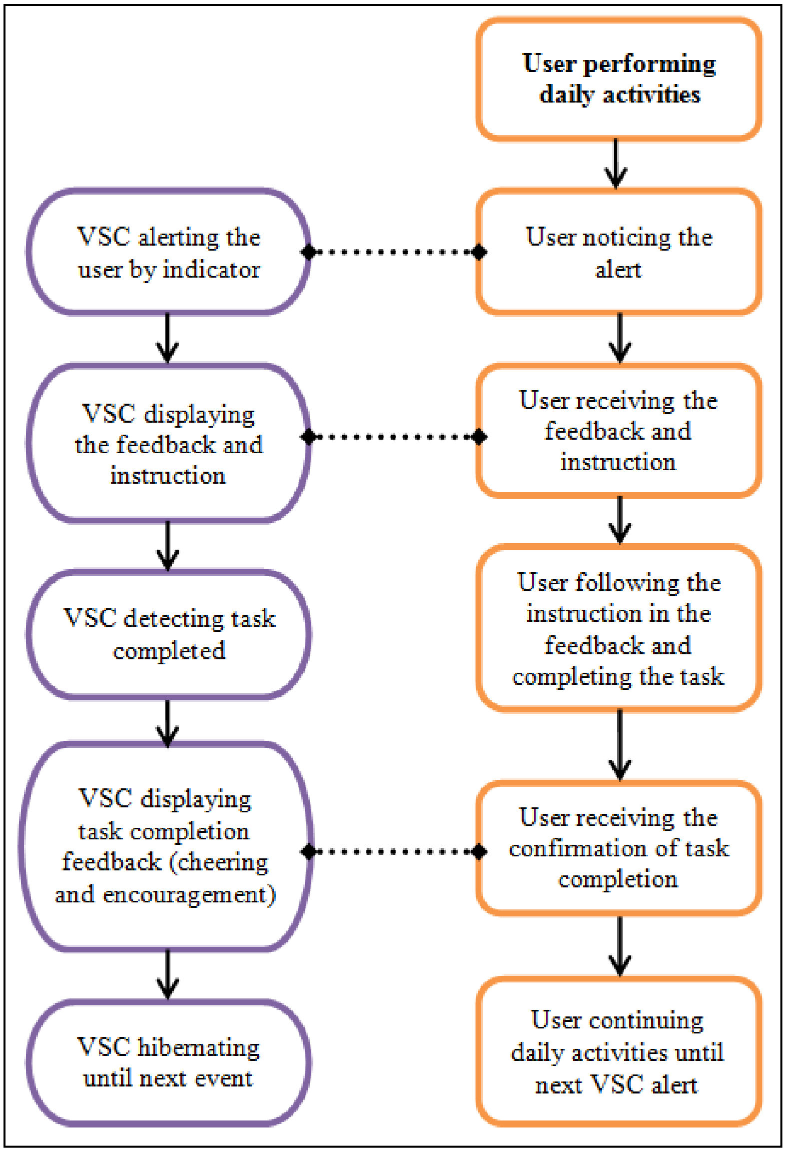


Figure 6. Interaction between the VSC and the user when the user was successfully following the coaching message. The three dash lines indicate the three stages that the VSC needed to generate understandable and acceptable outputs (alerts and feedback) for users

3.3.2 Methods

3.3.2.1 Participants

PSF users and clinicians were recruited to participate in this survey study. The PSF user participants had to be over 18 years of age, experienced with using PSFs, and able to operate seating functions independently. The clinician participants had to be experienced with prescribing EPWs with PSFs. There were no exclusion criteria for both groups of participants. The information about this study was distributed through study flyers were posted in the Center for Assistive Technology and the Human Engineering Research Laboratories (HERL) newsletter. Participants' demographic information is showed in Table 3.

Table 3. Participants demographic information

		PSF users (n=9)	Clinicians (n=5)
Gender	Female	3	3
	Male	6	2
Age (years)	<30	2	1
	30-50	5	3
	>50	2	1
Profession	Physical Therapist	--	4
	Occupational Therapist	--	1
Diagnosis	Spinal Cord Injury	4	--
	Muscular dystrophy	2	--
	Cerebral Palsy	2	--
	Multiple Sclerosis	1	--

3.3.2.2 Equipment

Computer Program

A computer demonstration program with graphical user interface was used to present example feedbacks which were going to be provided by the VSC, and also allowed the participant to change feedback modalities in different forms and features. Indicator and feedback modalities, forms, and features are listed in Table 4. They were chosen because they were commonly used in daily electronics, computer and gaming interface to provide feedbacks interacting with users. The program presented feedbacks in four different themes: reminding, warning, giving guidance, and giving encouragement. In the reminding theme, the feedback message was to inform the participant that it was time to perform pressure relief. In the warning theme, the message cautioned the participant about sitting in a static position for too long. In the giving guidance theme, the message provided detail about how to perform pressure relief using PSFs. In the giving encouragement theme, the message gave cheering that the task had been completed. Participants could choose to use the tablet monitor, keypad, or joystick as the pointing device. To review the example feedbacks, the participant needed to select the forms and features of feedback modalities on a menu, showed in Figure 7, and then hit the "Preview" button to play the combination of selection. The on-screen text, speech, and animation of PSF task output were congruent with the theme. Only one animation or static sign was displayed with on-screen text each time because the size of the display could be added onto a wheelchair was very limited. Human animation agents were not included at this stage of development. Static female and male faces [75] were used to simulate the effect of animated coaching agents, showed in Figure 8. Cartoon animations were from Microsoft Agent Animations, and animations of PSF task were generated from mechanical design software SolidWorks. Examples of cartoon and PSF task animations were showed in Figure 9. The demonstration program was running on a tablet computer, and audio feedbacks were played over a set of speakers. The equipment set-up was showed in Figure 10.

Table 4. The indicator and feedback modalities in the demonstration program

Modality	Form	Feature
Audio	Beeping	Beeping frequency is around 1.5 Hz, lasting for 5 seconds.
	Melody	Simple
	Speech	Type: Cartoon, Female, Male, Synthetic(monotonic) Tone: Professional (Calm) and Enthusiastic (emotional) for female and male voices Dialogue Content and length: Short: Direct command and key information Long: Full sentence of polite social communication and including more detail information
Visual	Light (supplement device)	Steady red light
	Static sign	Collective signs commonly used in daily human-machine interfaces (such as electronics, computer, or gaming program), showed in Figure 7.
	Animation	Cartoon, Female face, Male face, Task of using PSFs
	On-screen Text	Dialogue Content and Length: Short: Direct command and key information Long: Full sentence of polite social communication and including more detail information
Somatic	Vibration (supplement device)	Steady 60 Hz vibration (supplement device)

Note: Contents for speech and on-screen text feedbacks were matching with each other. For example, the short dialogue of the warning theme for both speech and text was "Pressure relief now!!" The long dialogue was "You should perform pressure relief now. You have been sitting in a static position for more than an hour."

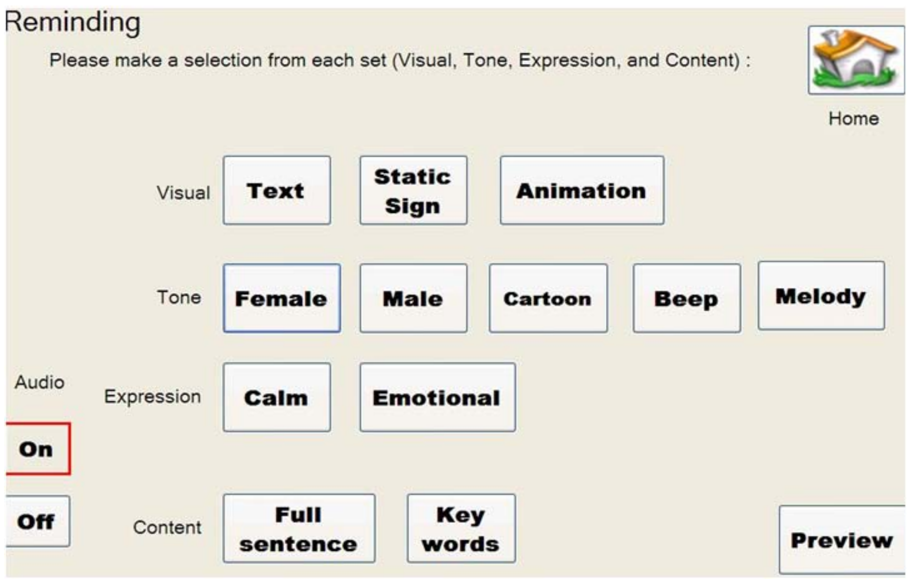


Figure 7. Menu for the participant to select forms and features of feedback modalities for the reminding theme. The participant can go back to Home Menu to choose the other theme

Female Face Image

Male Face Image

Figure 8. Human face images used to simulate the effect of animated coaching agents

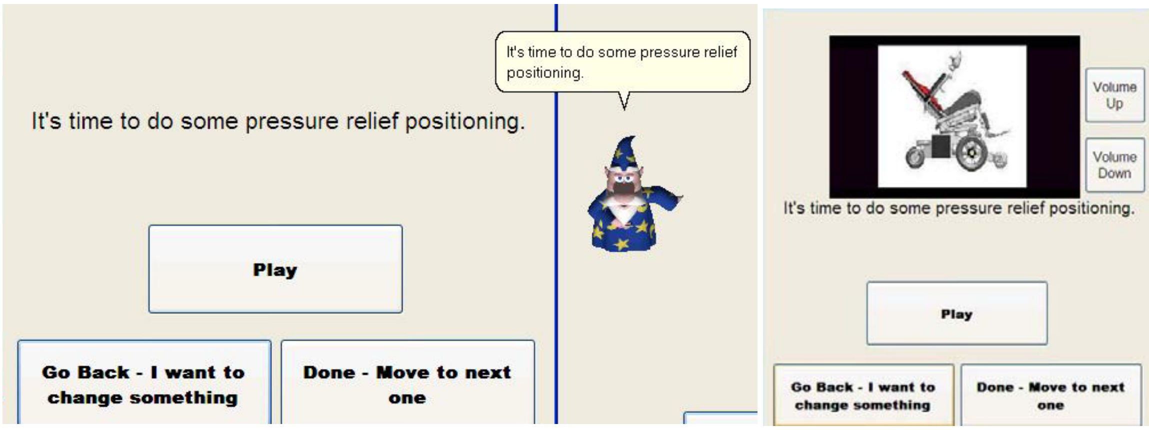


Figure 9. Examples of cartoon and PSF task animations for the reminding feedback

Figure 10. Equipment setup for participants to review example feedback

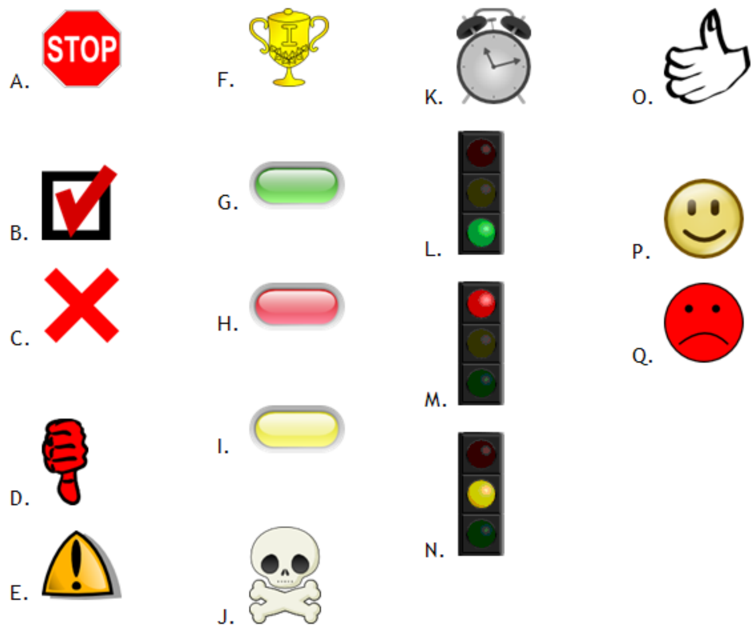


Figure 11. Collection of commonly seen icons that participants need to select one for each of reminding, warning, and guidance themes

Supplement Device

A supplement device independent from the tablet computer allowed participants to turn on light and vibration alerts using toggle switches. Steady red light was generated from a LED indicator light bulb (12 V DC, 5 milliamperes). Steady 60 Hz vibration was generated from a mini motor (length: 14.2 mm; diameter: 6.0 mm) housed in a flat case (6.5 cm x 6.5 cm x 1 cm). This device is showed in Figure 10.

Questionnaire

A paper-based questionnaire was developed to collect participant preferences for modalities. The first part of the questionnaire needed participants to select one appropriate form of indicator modalities for reminding and warning feedbacks in five scenarios, including noisy restaurant, park, office, class or meeting, home. In the second part, participants were asked to rank modality features of animations and speech, and then ranked locations for vibrating indicator. They were also encouraged to note the reason of ranking and provide any suggestions or concerns. In the third part, participants were asked to select one static sign from a collection of 17 icons for reminding, warning, and encouragement feedbacks. These icons were commonly seen on daily human-machine interfaces, showed in Figure 11. They were also the options of static signs in the demonstration program.

Interview

A semi-structured interview was conducted with some standard questions to know how participants expect a coaching system, and was open for discussing any concerns or suggestions. The standard questions are listed as follows:

1. What are your major concerns about using or developing this device?
2. Do you think of any feedback features that could be acceptable and useful to be added on the VSC interface?
3. What other functions could be useful to be included with the VSC?
4. Do you want the control to turn off the VSC?
5. Would you allow the VSC to control your power seat functions?
6. Please provide any your suggestions for developing or design the VSC?

Protocol

An investigator started with giving an introduction of the purpose and concept of developing the VSC, and then demonstrated how to use the program to select modality features and display example feedback. The participant could select or change the pointing device and the volume of audio output. They were directed to review the reminding theme first, followed by the warning, guidance, and encouragement themes. Necessary assistant was provided if the participant had difficulty to use the pointing device. There was no time limit for participants to review the modality features. After the participant reported that he had finished reviewing modalities in each theme, the investigator would show him the LED indicator light for the effect of alert for reminding and warning. Then, the vibration box was turned on and placed on the participant's shoulder, back of mid upper trunk, back of head, and forearm. After reviewing feedback modalities, the participant would go on to answer the questionnaire. The participant could go back to review the feedback and indicator modalities if he needs to refresh his memory. The participant would be informed that this study was to understand users' preference for indicator and feedback modalities rather than evaluate the quality of the example feedbacks demonstrated in the program. If the participant preferred certain modality feature but was not satisfied with the example feedback, the participant should confirm his preference for the feature in the questionnaire and note his suggestion or expectation. The interview was conducted at the end and audio-recorded, lasting around 15 minutes. The whole protocol lasted about 40 minutes, but might be extended according to how fast the participant is reviewing feedback modalities and answering the questionnaire. The diagram in Figure 8 illustrates the study protocol. This study was reviewed and approved by the Institutional Review Board of the University of Pittsburgh.

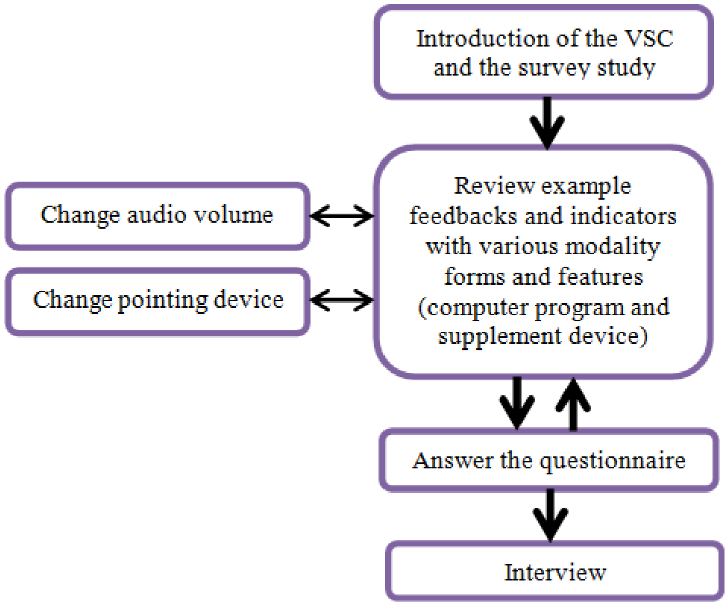


Figure 12. The protocol of the survey study on display effects and usability

Data Analysis

Because the small sample size due to a relative small population and limitation in transportation for PSF users, frequencies were reported for observing the trend toward modality selections. Qualitative data collected by the questionnaire were described in the result and discussion session. Frequent comments collected interviews are listed in a table with their frequencies presented.

3.3.3 Results and Discussion

3.3.3.1 Selection of Indicator Modality for Reminding and Warning Feedback

User participants preferred to receive audio alert, especially beep and speech, for reminding and warning feedbacks, but seldom selected vibration. They recognized that audio feedbacks can be annoying, but they wanted to be alerted when the VSC was sending important messages. Clinicians thought that vibration was an appropriate modality to alert the user in most occasions because it was low-profile. They rarely selected beep because it was obtrusive and so the user may get annoyed by the VSC. The top three choices of modality forms for indicating reminding and warning feedbacks are showed in Table 5 Table 6.

Table 5. Top three choices of indicator modality forms for reminding feedback in different scenarios (number of participants selecting the modality form)

Reminding	User (n=9)	Clinician(n=5)
Noisy Restaurant	Beep(5) Speech(1), Static sign(1), Vibration(1)	Vibration(4) Light(1)
Park	Speech(3) Beep(2), Melody(2) Static Sign(1), Animation(1)	Melody(2), Vibration(2) Speech(1)
Class or Meeting	Light(3) Melody(2), Text(2) Beep(1), Speech(1)	Vibration(4) Light(1), Text(1)
Home	Speech(7) Beep(1), Animation(1)	Melody(2) Beep(1), Speech(1), Light(1)
Office	Speech(3) Beep(2), Melody(2), Light(2)	Vibration(3) Light(2)

Table 6. Top three choices of indicator modality forms for warning feedback in different scenarios (number of participants selecting the modality form)

Warning	User (n=9)	Clinician(n=5)
Noisy Restaurant	Beep(4) Speech(2) Light(1), Animation(1)	Vibration(3) Light(1), Animation(1)
Park	Speech(4) Beep(3) Melody(1), Animation(1)	Vibration(2) Beep(1), Melody(1), Speech(1)
Class or Meeting	Beep(4) Text(3) Light(1), Vibration(1)	Vibration(2) Light(1), Animation(1), Text(1)
Home	Speech(5) Beep(2) Light(1), Animation(1)	Speech(2) Beep(1), Melody(1), Vibration(1)
Office	Beep(3), Speech(3) Light(1), Animation(1), Vibration(1)	Vibration(4) Light(1)

There were some factors that may influence the selection of indicator modalities can be observed from the result. Although participants had their own interpretation of what indicator modality was appropriate to alert the user, accessibility to the modality could be the primary factor. PSF users may have impaired or absent sensation and cannot sense vibration effectively. Visual modalities should be less revealing, but the user would easily miss them if the display was not in the view. Audio modalities were chosen by PSF users for most occasions. They were not strictly directional, and therefore participants felt that they could detect audio alerts more easily than visual alerts. Another factor could be the sense of inter-person distance and being noticed. For the scenarios in a noisy restaurant and office, where the user was sharing the space with others but the people were doing individual activities, user participants were open to choose beep to indicate reminding and warning messages. Beep was bold enough to alert the user but would not disclose personal affairs. The distance among people was even larger in the park, and therefore user participants were not worry about confidentiality issues. It was efficient to apply speech indicator because the user was receiving feedback messages while being alerted without looking at the display.

3.3.3.2 Preference for Speech Modality Features

Most participants preferred human and cartoon voices rather than synthetic voice, showed in Table 4. User participants especially preferred the female voice because female was related with considerate and flexible personality, which made the participants feel that the system was easy to work with. User gender may have played some influence because 5 out of 6 male user participants ranked the female voice as their first or second preference. Female user participants' preference was not clear because of small sample size (n=3), and 2 out of 3 female user participants actually preferred cartoon and synthetic voices compared to human voices. Similar results were found in other studies. In a study investigating cuing feedback modalities for elders with dementia, conducted by Mihailidis, Barbenel, and Fernie, the male voice evoked negative emotion in some male participants because it reminded participants of the time in the army [76]. Baylor noticed that if virtual agents had been with professional manner and authoritative speech, learners would prefer female agents although participants had higher reported positive effects while working with male virtual agents [77]. The combination of a coaching ambiance and a male voice, even in a virtual environment, may induce certain level of stress on users.

Table 7. Preference for features of speech and animation, listed according to number of participants ranking each modality feature as their first or second choice. (number of participants ranking the feature as their 1st or 2nd choice)

Feedback Modality Forms	User (n=9)	Clinician (n=5)
Speech	Female Voice (6) Cartoon Voice (5) Male Voice (4) Synthetic Voice (3)	Male Voice (3), Female Voice (3), Cartoon Voice (3) Synthetic Voice (1)
Animation	PSF task animation (8) Cartoon Agent (7) Female Agent (2) Male Agent (1)	PSF task animation (4), Cartoon Agent (4) Female Agent (1), Male Agent (1)

3.3.3.3 Preference for Animation Modality Features

Participants preferred cartoon agents and animation showing how PSFs should move to complete the task, showed in Table 4. Both clinicians and users agreed that PSF task animations were very useful because they were illustrating messages matching with the feedback messages, and users feel that PSF task animations made them feel serious about the feedbacks and more convinced to perform the task. Cartoon animations were chosen because participants felt they are more entertaining and relaxing than virtual human agents. Some user participants suggested that a virtual agent animating someone they know, such as their clinicians or family members, may be more effective; but some thought that this idea would make them more annoyed because of feeling being under surveillance of an acquaintance.

Presents of virtual pedagogical agents may not always bring positive effects in multimedia learning environments. Many studies showed that learners felt more interested and less stressful when interacting with virtual agents [78, 79]. However, Moreno et al found that removing the image of the pedagogical agent did not affect learning [74], and providing audio feedback with tailored dialogue was the main factor facilitating learning effect [73]. Baylor, Ryu, and Shen noticed that virtual agents brought negative effect on satisfaction with the training program and self-efficacy in their participants [80]. The characters of the tasks and users may the learning outcome with virtual agents. Because the size and location of a display that can be added onto an EPW without blocking driving view was very limited, presenting animations of PSF tasks accompanied with tailored feedback messages may be a safe and dependable decision.

3.3.3.4 Preference for Length and Tone of Feedback Message

Both user and clinician participants preferred similar speech length and tone and on-screen text length for warning, guidance, and encouragement scenarios, except the remiding scenario. The results are showed in Table 8. Clinician participants felt that reminding feedbacks need to be detailed in professional tone to convince users to follow the recommendations, or be short and enthusiastic to motivate users. On the other hand, user participants just wanted short and calm feedbacks to tell them what they need to do. The role of using the VSC may contribute this difference. Clinicians may consider that the VSC was an education tool and an extension of themselves interacting with users. Therefore, they expected that this system should explain detail of the recommendations to novice PSF users, or enthusiastically convince them to follow commands when the reasoning behind the recommendation is too complicated for the user to understand, just like interacting with clients in clinics. However, the user participants recruited in this study are experienced in using PSFs, and thus they felt it is not necessary for them to receive tedious information about PSFs. The most important function of the VSC for them is to remind when to perform pressure relief instead of how to use PSF.

Table 8. Speech length and tone and on-screen text length selection that most number of participants chose for different themes. (number of participants choosing the feature)

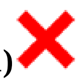
	User (n=9)	Clinician (n=5)
Speech length and tone		
Reminding	Short + Professional (5)	Long + Professional (2) Short + Enthusiastic (2)
Warning	Long + Enthusiastic (4)	Long + Enthusiastic (3)
Guidance	Long (6)	Long (3)
Encouragement	Short + Professional (3) Short + Enthusiastic (3)	Short + Enthusiastic (3)
On-screen text length		
Reminding	Short (5)	Short (4)
Warning	Short (7)	Short (4)
Guidance	Long (6)	Long (4)

Providing detailed information supports beginners to learn new tasks, but may be redundant after the user gradually memorized the procedures to perform the tasks. Decreasing the amount of information provided by the VSC program according to the user's compliance may avoid information redundancy after a user has gradually learned how to use PSFs. In addition, a "Help" tool on the interface can be a useful resource to allow the user accessing supplemental information and keep feedback messages succinct.

3.3.3.5 Selection of Static Sign

Eleven participants chose the clock sign to represent reminding messages, and 8 participants chose the smiling face for encouragement messages. The choice for warning messages was varied. The results are showed in Table 6.

Table 9. Selection of static signs to represent reminding, warning, and encouragement feedbacks. (number of participants selecting each sign)

	User (n=9)	**Clinician (n=5)**
Reminding	 **(6)**  **(1)**  **(1)**  **(1)**	 **(5)**
Warning	 **(3)**  **(2)**  **(2)**  **(1)**  **(1)**	 **(1)**  **(1)**  **(1)**  **(1)**  **(1)**
Encouragement	 **(6)**  **(1)**  **(2)**	 **(2)**  **(1)**  **(1)**  **(1)**

The clock and smiling face icons will be used to represent reminding and warning feedbacks respectively according to the result, but we need to assign a warning icon because no obvious trend is observed. The icons with soothing colors and shapes, which are Icons G, H, and I in Figure 11, were not chosen because participants felt that their literal representations were not clear. The attention sign with an exclamation mark may be applied in the VSC instead of the stop sign because we want to avoid confusing users with the action of pause (the common response after seeing the stop sign) and the task emphasized in the VSC feedback message. A study showed that participants could learn and memorize assigned warning icons and even demonstrated satisfying accuracy to recognize assigned icons [81]. Users should be able to recognize the attention sign as a warning sign with a short period of training.

3.3.3.6 Preference to Vibration Alert Locations

The survey results are showed in Table 7. Most user participants preferred forearm or back of mid upper trunk to be the location receiving vibration alerts, but clinician participants thought that armrests is not a good location to install vibration alerts because EPW users are not always contacting with armrests according to their experience. One user participant specifically stated that armrests are not a good choice for her for the same reason. Proper locations for vibration alert can be varied based on users' preference and sensory function. For instance, most user participants in this study did not frequently need headrests to support their heads except tilting and reclining the seat. As a result, participants disagreed with locating vibrations on headrests. However, a significant number of PSF users rely on headrests to support their head position and lose sensory in their limbs and trunks, headrests may be the only option for installing vibration alert. Armrests can be set as the default locations for vibration alerts, but the vibration location should be modified for different user needs.

Table 7. Preference for vibration location, listed according to number of participants ranking each location as their first or second choice (number of participants ranking the location as their 1st or 2nd choice)

Feedback Modality Forms	User (n=9)	Clinician (n=5)
Vibration Location	Armrest/Forearm (8) Back of mid upper trunk (5) Shoulder blade (3) Back of head (1)	Shoulder blade (5) Back of mid upper trunk (4) Armrest/Forearm (1) Back of head (0)

3.3.3.7 Interview Results: Concerns and Suggestions

Common concerns and suggestions stated during the interview are presented in Table 9. All of the participants felt that the VSC can be beneficial to novice PSF users, but reported some concerns and suggestions similar to regular mobile phone users: size, flexibility for personalization, and additional functions. The size and location of the VSC was a common concern because any additional device on an EPW can further decrease users' accessibility to the environment. However, a display that is too small is difficult for the user to read displayed messages. The size of each component needs to be decided with caution, but one size and one location may not fit all user. Some participants would like to have more options of feedback modality features to personalize the device. Although most mobile phone users set up their ring tones and alerts at the beginning and will rarely change them, a reasonable number of alert options should be provided so that a user will not dislike the device when just starting to use it. Several participants suggested that the VSC could include more reminder functions, such as nutrition and medicine reminders. However, some clinicians expressed concerned the complexity of adding more technologies on an EPW. They suggested that the VSC should be kept simple and straightforward, avoiding information overload. Although the VSC has the potential to be a personal digital assistant on a wheelchair, building a coaching system with an uncomplicated and friendly interface and functions should be the goal for our development.

Table 10. Frequent statements reported during the interview

Concern/Suggestion		N	
		PSF User (n=9)	Clinician (n=5)
1.	Concerned about the size and location of the SVC on a wheelchair	9	2
2.	More options for interface modality properties should be provided	4	2
3.	More reminder functions can be included	7	4
4.	Worrying that the SVC will increase the complexity of a wheelchair system	0	2
5.	The user is willing to share PSF data with clinicians and caregivers	8	--
6.	The clinician would like to review the user’s PSF usage data with the frequency according to individual needs (e.g., risks of developing pressure sores)	--	4

User autonomy was another intriguing issue when developing this coaching system for assisting with health management. Most users wanted to have the control to turn off the coaching program even though ideally it can detect proper timing to provide reminders. Participants felt that there may be certain occasions that they wanted to be sure that the VSC would not disturb in anyway. However, some clinicians felt that users should not be allowed to turn off the coaching program because they may forget to turn it on, and thus the purpose of providing tailored feedbacks would be missed. Both concerns were critical, but no clear conclusion can be drawn because no EPW user has used the VSC. For the purpose of investigating the effect of tailored feedback provided by the VSC, the prototype would not allow the participants to turn off the coaching program in a three-day pilot trial study, but will provide the options of snoozing or dismissing the feedback. More specific findings from the pilot study may suggest a better decision on this issue.

The potential of machine automaticity was controversial for EPW users. Many participants did not agree with the idea to allow the VSC operating PSFs automatically. Even though the VSC knew the schedule and position for the recommended repositioning regime, it may not be able to detect whether the user was ready for changing position. Some users specifically stated that they have lost a lot of control in their lives, and therefore they wanted to maintain as much independence and control as possible in spite of the convenience of using technology. In contrast, some participants thought that that was a good idea because the system can position the users with cognitive issues or very limited functional movements for pressure relief according to the prescribed schedule. Simplifying the process to use PSFs for periodical repositioning by automatic control can be a potential method to facilitate health management, and allowing the user to initiate positioning may help to eliminate users' worry of losing control over the device. Our goal was to investigate the effectiveness of the VSC compared to use of traditional health education materials, such as pamphlets, flash cards, and videos. The development of an automatic seating positioning device can be the future project after we obtained more knowledge about the nature PSF usage and EPW users' response to a machine that was closely monitoring and interacting with them from this study.

Although the investigator asked each participant to express their preferences without being limited by our examples, some bias was difficult to be avoided. For example, it was unknown whether participants would prefer virtual agents if we had presented them as animations. This was a cross-sectional study, and participants were entertained by changing feedback modalities and features using the computer program. Users' preference may change after using the VSC for a period of time when reminding and warning feedback would pop up several times a day. The investigation on users' preferences and satisfaction with the interface and feedback should be conducted in the future clinical trial. The follow-up studies would reveal more information about the appropriate multimedia interface modalities for real-time interactive reminder devices.

3.3.4 Conclusion

The trend of participants' preference to feedback modalities was observed, but some diversities are showed. Differences in preferences may result from different considerations from clinicians and wheelchair users, various personalities, and individual needs. The findings from this study gave us an explorative guide to design friendly feedback and build the prototype of the coaching system with flexibility to accommodate individual differences. This findings of this study was published in IEEE Pervasive Computing [82].

3.4 REVISED SYSTEM: V1

3.4.1 Software Structure

The software was divided into two parts: a kernel and a configuration. These two parts were written in different programming languages. The kernel was written in a compiled language, such as C++ or C#, and consisted of the basic components of the system, such as functions for sensory data acquisition and showing objects on the display. The configuration part was written in a scripting language, which was interpreted to shape and define the application. Interpreted languages, such as Lua, were highly flexible and provided capability for modification without stopping the application. This type of design provided for flexibility in the reminding system.

3.4.2 Coaching Program and Displayed Message

The coaching program was developed according to the content of the PSF user guide described in Chapter 2.0 and the comments and suggestions received from the survey study described in Section 3.3. Eleven events were identified to be included: repositioning reminder and ten PSF usage safety warnings. Flow charts of estimated interactions between VSC and the user were created by clinicians to facilitate discussions with engineers on programming the coaching protocol. An example is shown in Figure 13.

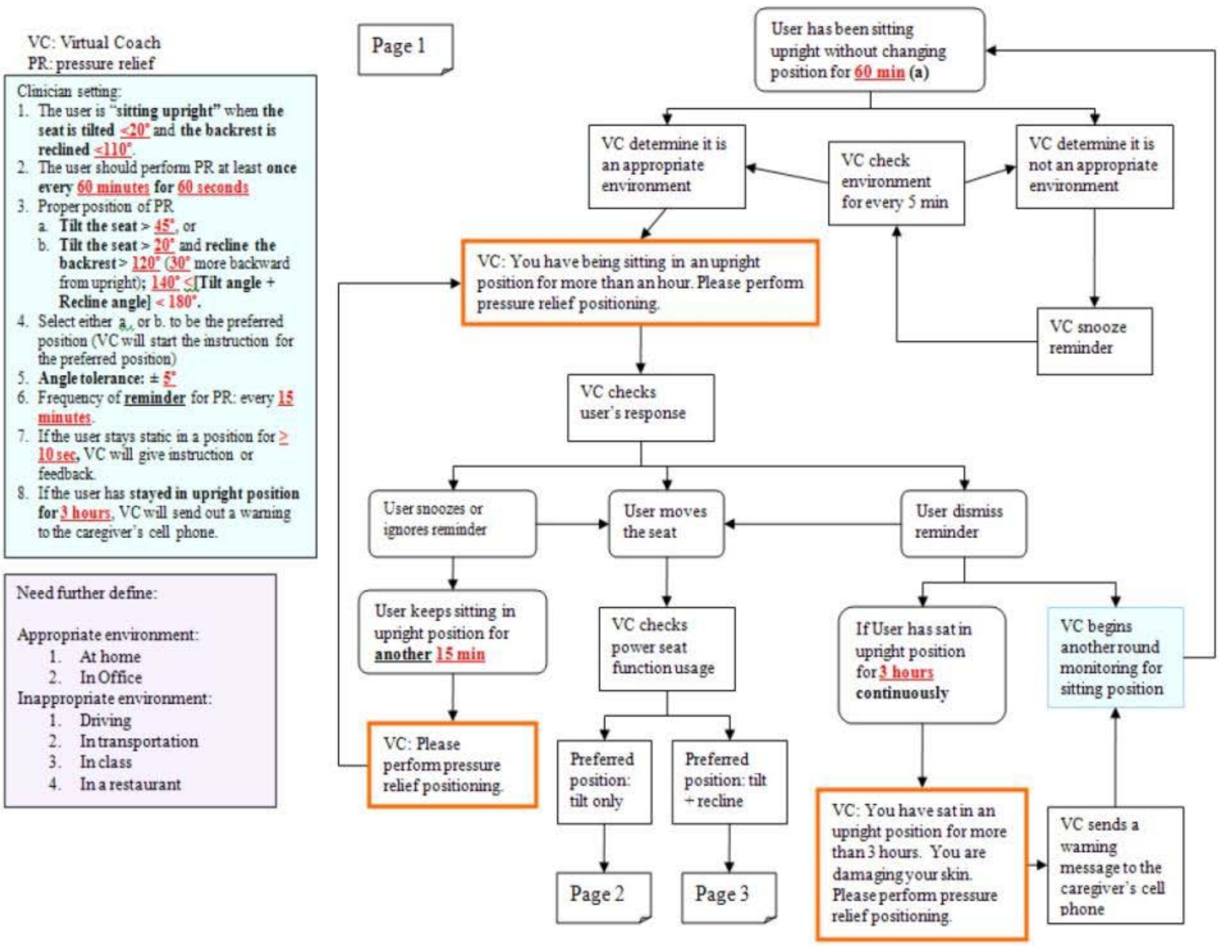


Figure 13. Example of VSC-User interaction flow chart to remind repositioning

<u>Repositioning Reminder:</u> If the user had not performed repositioning for a prescribed duration, a reminder would alert the user (Figure 14 a). The user could press the "OK" button or start operating the seat functions, and then the instruction for positioning was shown (Figure 14 b). Once the user adjusted the tilt and/or recline angles to the "green zones", the prescribed duration that the user needed to stay in the position for releasing muscle stress and sufficient tissue reperfusion would show in the text window with time counting down, which was also indicated by color and fill changes of the progress bar on the top of the display (Figure 14 c). After the user completed the prescribed repositioning, a confirmation message would show

(Figure 14 d). If the user pressed the “Snooze” button or ignored the reminder for more than 15 seconds, the reminder would hibernate for 5 minutes and then come out again. If the user chose to “Dismiss” the reminder, the current scheduled repositioning reminder would be skipped, and therefore the reminder would show after 1 hour.

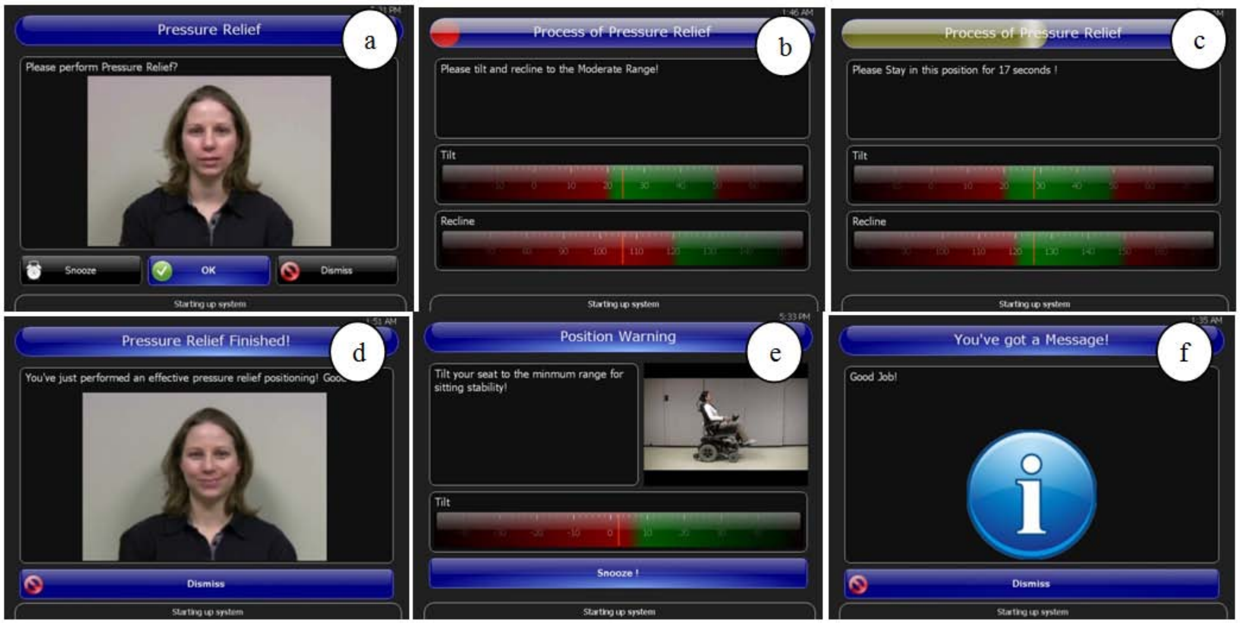


Figure 14. Repositioning reminder and warning

Power seat function usage warnings: Clinicians identified ten conditions that the VSC could give warnings to avoid adverse effects. For example, the user was encouraged to sit with the seat tilted mildly for better sitting stability. The warning would show when the user sat in the wheelchair but the tilt angle was less than the recommended angle (Figure 14 e). After the user followed the instruction and adjusted the seat angle to the “green zone”, a confirmation message would be displayed (Figure 14 f). If the user ignored the warning, the warning would subside until the user changed seat angles and the same condition was detected again. The ten warning events are listed in Table 11.

Table 11. Ten warning conditions that the Virtual Seating Coach will detect; and day averages of activated frequency and participant compliance of each warning

	Trigger Condition	Adverse Effect of the Condition
W1	Reclined the backrest when the seat was not tilted	The user would tend to slide forward
W2	Sat without the seat tilted	The user would slide forward easily
W3	Elevated legrests without reclining the backrest	Hamstring muscles might be stretched over range, which may cause tissue damage
W4	Tilted the seat and reclined the backrest excessively	The user might slide backward in this extreme position
W5	Drove the wheelchair when the seat was tilted too much or the backrest was reclined too much	The driving view was limited in an excessive inclining position, and the increased turning radius might cause crashing accidents
W6	Drove the wheelchair when the seat was not tilted	The user might slide forward
W7	Drove the wheelchair when the legrests were elevated too high	The increased turning radius might cause crashing accidents
W8	Drove the wheelchair when the seat was elevated too high	The risk of flipping over was increased because of the higher center of mass
W9	Drove uphill when the seat was tilted and backrest was reclined	The risk of flipping backward was increased because the center of mass moves backward
W10	Drove downhill when the seat was not tilted	The user might slide forward

The messages displayed in the reminders and warnings were kept as succinct as possible. Clinicians could modify the settings (seating angles, frequency, and positioning duration) of repositioning reminders and criteria to activating the warnings.

Repositioning reminders was displayed when the user was not driving the wheelchair. If the user had performed repositioning without receiving a reminder, the VSC would offset the next scheduled repositioning time.

3.4.3 Display Effects

Based on the findings and comments from the survey study described in Section 3.3, the interface provided mode selection and user setting functions to allow the user to modify the alert and display modalities for personalization. <u>Mode Selection Function:</u> Each mode was a collection of display modalities. Six mode buttons (Home, Office, Class/Meeting, Outdoor, Noisy Place, Other) were always displayed on the homepage when there was no event, shown in Figure 15 (a). The user could switch between different modes by simply pressing the buttons. <u>User Setting Function:</u> After pressing the “Setting” button on the homepage, the user could modify the selection of display modalities in each mode, shown in Figure 15 (b) and (c).

Figure 15. Screen shots of feedback mode and feature selecting functions

3.4.4 In-Lab Reliability Test

Double-Drum Test (Vibration): It was unknown whether instrumentation of the VSC was durable enough to withstand the vibration during daily use. The electronics on an EPW would receive much more intensive vibration than on a regular vehicle. The encoders to detect seating angles and the touch screen were subject to vibration damage. The ANSI/RESNA Double-Drum Test was conducted with a 100 kg dummy loaded on the VSC study chair during the test. Due to time limitation and cost of the research equipment, the Double-Drum Test only ran for 1 hour while VSC was working. VSC functioned well during and after the test.

Energy Consumption Test: Energy consumption of a wheelchair was a critical safety issue for EPW users. Users may get stuck in bad weather or have traffic accidents due to unexpected depletion of wheelchair battery power. The VSC was powered by wheelchair batteries, and therefore it was important to know how much battery energy the VSC would consume in daily use. We conducted an ANSI/RESNA Wheelchair Energy Consumption Test to compare the energy use with and without the VSC running. With the occupancy of a 60-kg user, the VSC, the touch screen and the wheelchair consumed 40.4 Wh/km (theoretical range: 23.2 miles). When the VSC and the touch screen were turned off, the wheelchair alone consumed 35.8 Wh/km (theoretical range: 26.2 miles). The average daily traveling distance of active EPW users was around 10.7 miles [83]. The test results showed that the addition of the VSC on a wheelchair should not affect regular use of an EPW.

Others: On the VSC Version 1.0, the touch screen was mounted on a conventional ball joint for infinite angle adjustment. However, we found that the ball joint got loosed very frequently due to vibration, and the edge of the screen was the most lateral part of the whole wheelchair system. The increased width of the system may affect indoor maneuverability, and the touch screen was at risks to be crashed by a doorway. Our engineers designed and manufactured an angle and height adjustable mount to bring the touch screen inward to keep the VSC within the footprint of an EPW, shown in Figure 16. All the encoder mounts on Version 1.0 were modified to increase reliability of data reading and avoid the possibility of pinching the user. Therefore, it was very difficult to find where the encoders and sensors were in Figure 16.

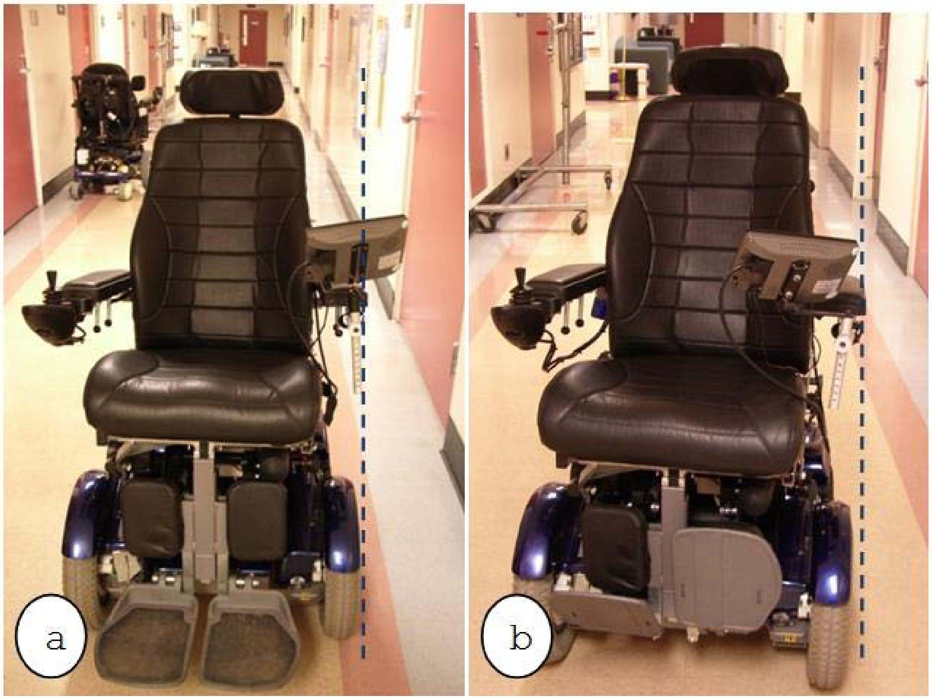


Figure 16. Improvement of the touch screen mount to decrease the width of the system and prevent equipment damage. The dash lines indicate the lateral edge of the wheelchair

3.5 PILOT STUDY: EVALUATE RELIABILITY OF VSC

The primary purposes of this study were to test whether the prototype of the VSC could survive outside of the lab environment and to debug the coaching program. EPW users who operated their power seat functions independently were recruited to participate in this study. The investigators first introduced the VSC and administered the survey and questionnaire about the attitude of using assistive technology and first impressions about the VSC. If the clinician identified that the participant could be fitted in the study wheelchair, the participant could decide whether he/she wanted to take the study wheelchair home and use it for up to three days. At the end of the in-home trial, another set of surveys were administered to gage the participant's attitude toward the VSC after using it for 3 days. The study finding was published in the proceeding of RESNA conference in 2012 [84].

3.5.1 Methods

EPW users who can operate PSFs independently were recruited to participate in this study. The investigators first introduced the VSC, and administered a survey and interview about their first impressions of the VSC. If the clinician identified that the participant could be fitted in the study wheelchair, the participant could decide whether he/she wanted to take our study wheelchair home and use it for up to three days. The reminders were set by the clinician, based on the participant's preferences and general rules recommended by wheelchair seating clinicians. Participants could dismiss or snooze reminders by pressing a button on the touch screen, and personalize the display effects. At the end of the 3 days, a follow-up survey and interview were administered to gage the participant's attitude toward the VSC.

3.5.2 Results

Seven participants evaluated the VSC. Their demographics are listed in Table 12. Five of them participated in the in-home trial. Participants B and D declined to participate in the 3-day in-home trial because the study wheelchair was front-wheel drive, whose maneuver behavior was very different from the two participants' personal wheelchairs (rear-wheel drive and mid-wheel drive chairs). Participant B even expressed his concern with recording PSF and EPW usage for privacy reasons. Although Participant E agreed to enter the in-home trial, she felt that the reminders were very annoying, and chose to turn off the monitor, but kept using the study wheelchair for 3 days. Daily wheelchair occupancy durations were varied among 5 participants, as shown in Table 12.

Table 12. Demographics of the participants. Gray fill indicates the participants who declined to participate in the in-home trial or turned off the VSC interface

Participant	Age	Gender	Diagnosis	Type of Personal Wheelchair	Occupancy Duration (hr/day)
A	24	M	Spinal Cord Injury	Front-Wheel Drive	15.9
B	67	M	Spinal Cord Injury	Mid-Wheel Drive	--
C	31	M	Muscular Dystrophy	Front-Wheel Drive	7.4
D	62	M	Multiple Sclerosis	Rear-Wheel Drive	--
E	56	F	Spina Bifida	Front-Wheel Drive	14.2
F	62	F	Post-Polio	Front-Wheel Drive	7.4
G	62	M	Spinal Cord Injury	Front-Wheel Drive	9.8

Participant A was the first wheelchair user to conduct the in-home trial. Although the repositioning reminder was set to deliver once every 60 minutes, the reminder was actually delivered once every 30 minutes with auto-snooze interval of every one minute (if the participant ignored the reminder, VSC would display the reminder again after one minute) because of programming problems. The VSC program was debugged and the reminder was delivered as the frequency set by the clinician for the participants. The auto-snooze interval was set to be 5 minutes for the participants C, F, and G.

The repositioning reminder setting for the four participants and their compliance are listed in Table 13. The number of reminders delivered by VSC included the reminders repeating after the auto-snooze intervals. Participant C performed repositioning with the frequency matching the reminder frequency setting, and on average the snooze function was activated at most twice before he complied with the reminder and performed an effective repositioning. The snooze function was activated at least 3 times for Participants A, F, G before they performed the recommended repositioning. Participant A dismissed reminders 3-6 times each day. Others rarely dismissed reminders, for example once per day. Only Participant A chose to turn off the audio output all the time. Others kept receiving audio alerts.

Table 13. Repositioning reminder setting and participants' compliance

Participant	Reminder Frequency Setting	Position and Duration Setting	Counts of Reminders Delivered by VSC (times/day)	Counts of effective repositioning (times/day)	Average repositioning frequency
A	Once every 30 min*	Tilt 30° for 60 s	95	28.5	Once every 33 min
C	Once every 60 min	Tilt 30° for 120 s	19	7.5	Once every 59 min
F	Once every 120 min	Tilt 20° + Recline 120° for 120 s	20	2.5	Once every 171 min
G	Once every 30 min	Tilt 30° for 120 s	43	11	Once every 53 min

Before the in-home trial, all four participants felt that they would not benefit from VSC because they knew very well how to use PSFs. After the in-home trial, Participants A and C reported that they felt more comfortable sitting in the EPW because of following the repositioning regimen reminded by VSC. Participants F and G felt that the position of the monitor was in their way of conducting many daily tasks, and VSC was redundant since they had their own methods of performing repositioning. However, they recognized the potential benefit of emphasizing repositioning by repeating reminders for novice EPW users to habituate the repositioning regimen.

3.5.3 Discussion

VSC hardware functioned reliably during the 3-day in-home trial. VSC malfunctioned only a few times due to software problems, but the study wheelchair itself functioned normally without impeding participants' daily activities. When the participant received a reminder, he/she might not be able to perform repositioning immediately. The snooze function provided a buffer period to allow the user to wrap up her/his current task temporarily before performing the recommended repositioning. If reminders had really annoyed participants, we should have observed frequent use of the dismiss function. It was not clear whether the infrequent use of the dismiss function resulted from the participants wish to be reminded even though they were not available or they just ignored reminders. Although it seemed that reminders did facilitate users to perform the recommended repositioning and the participants recognized the benefit of it, users' compliance could be affected by each individual's attitude toward a constant monitoring system and tolerance toward frequent reminders. Besides the appropriateness of the reminder protocol and quality of the interface, belief and attitude of the user toward the technology should be considered when evaluating the outcome of using a tailored monitoring and reminding system.

3.6 REFINED SYSTEM: V2

3.6.1 Adding New Interface Functions And Modifying Hardware To Improve Usability

Accessing repositioning instructions after a reminder was dismissed or snoozed: A button would appear on the interface, as shown in Figure 17, after a repositioning reminder was dismissed or snoozed. This button notified that there was an over-due repositioning, and the user can press the button to access the instruction of performing an effective repositioning anytime when the user felt that the occasion was appropriate to perform.

Error handling program: An error handling program was developed and embedded with the VSC program to detect abnormal data reading from the sensors and encoders. When error sensor readings were detected, the program would display a message to notify the user and restart the computer and VSC program, as shown in Figure 18.

Retractable display mount: EPW users commented that the display mounted on the swing-away mount got into their way because the display would extend laterally from the armrest when it was swung away, and the swing-lock was underneath the armrest and relatively inaccessible. Retractable display mounts were built to allow the user to simply put the display away but minimize the distance that the display would laterally extend from the armrest.

Figure 17. The red button indicates that there is an over-due pressure relief

Figure 18. A message informs the user that VSC system detects errors and is going to re-start

3.6.2 Updating The Computer System With The Latest Tablet Computer Technology

Tablet computer technology has become much more mature, stable, and affordable nowadays. We revised our computer system to use the HP Slate 500, a commercialized tablet computer running Windows 7, to be the computer as well as the display. In this way, the VSC system evolved closer to a real product which minimized the basic computer technical detail that engineers needed to take care of, and they could focus on the reliability of the sensors, data collection, and VSC program. For the need of monitoring PSF and EPW usage during the baseline period in the efficacy study, the electronic box needed to store and protect the tablet computer. For this revision, the mount and computer box were redesigned and rebuilt to accommodate the changes as shown in Figure 19 and Figure 20. The prototype with this revised VSC system, Version 2.0, was tested on the double-drum system for an hour of exposure to vibration, and the system functioned well during the test. And an ANSI-RESNA energy consumption test was done. Although the VSC Version 2.0 consumes 40% more energy compare to Version 1.0 with a single-board computer and separate touch screen, its theoretical range (15.7 miles) was still more than the average driving distance a day of real use (10 miles per day).

Figure 19. The electronic box which can accommodate the tablet computer if needed

Figure 20. The revision of VSC with a tablet computer

3.6.3 Installing VSC System on Powered Wheelchairs of Different Models

The user feedback from the 3-day pilot test study indicated that EPW users were sensitive to different driving types of EPWs. Our first prototype was installed on a front-wheel-drive chair, Permobil C500. Two Pride Quantum 6400Z (mid-wheel drive EPWs), one Invacare TDX (mid-wheel drive EPW), one Permobil Street (rear-wheel drive EPW), and three additional Permobil C500 were purchased and instrumented with VSC Version 2.0. Engineers in the Human Engineering Research Laboratories had to redesign the encoder and sensor enclosures to accommodate mechanical structures and available spaces on different wheelchair models. Each encoder enclosure had to be individually designed to couple an encoder and a certain seat function joint together, as shown in Figure 21. An electronic technician carefully planned how to draw power from the wheelchair batteries to run the VSC and ensure the safety and functionality of the wheelchair. For each wheelchair model, research clinicians were invited to review the design to confirm that these additional components on the wheelchair would not hurt or interfere with users. This redesign process took our engineer team around 3 month to allow the VSC to run on a different wheelchair model.

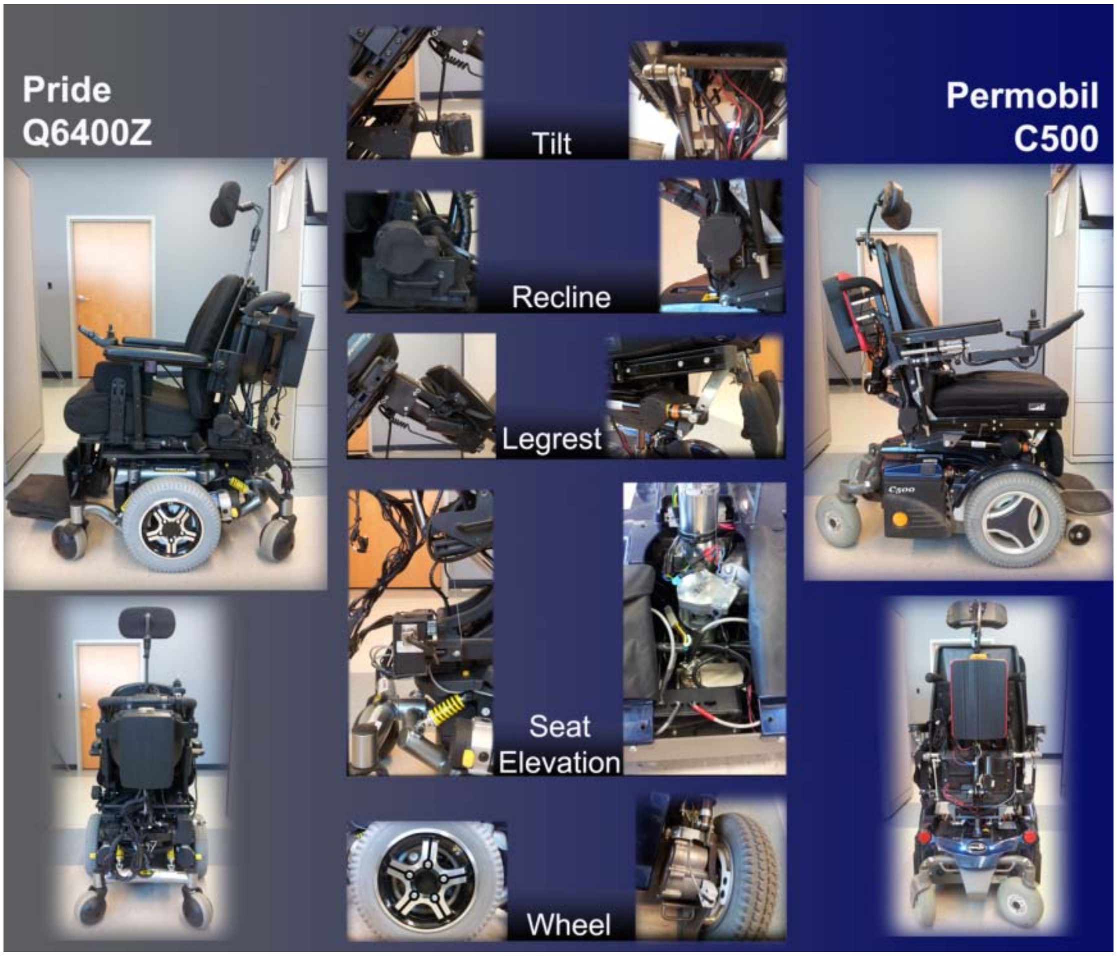


Figure 21. The VSC system accommodates differences among powered wheelchair models

4.0 CHALLENGES IN RECRUITING POWERED WHEELCHAIR USERS FOR AN INTERVENTION STUDY TO EVALUATE VIRTUAL SEATING COACH

4.1 INTRODUCTION

To evaluate the efficacy of the Virtual Seating Coach (VSC), a tailored reminder to facilitate powered seating function (PSF) usage and compliance with recommended repositioning regimes for improving health and seating comfort, PSF users were recruited from wheelchair seating clinics to participate in the study. Participants were randomized into two study groups: the instruction (INS) group and VSC group. Participants in the INS group received a user training program during the intervention period, and the participants in the VSC group received the same training program plus the use of VSC to remind PSF usage for repositioning. The number of participants recruited in the study was much lower than the expected sample size. A high attrition rate also occurred during the study. This chapter describes the challenges and lessons learned from the recruitment process of the study.

4.2 METHODS

4.2.1 Participant Recruitment

Potential participants were recruited at the UPMC Center for Assistive Technology (CAT) or the VA Pittsburgh Healthcare System (VAPHS) wheelchair seating clinic by clinicians directly involved in the participants' care. The clinicians directly involved in the participants' care introduced the potential participant to a study investigator to provide additional information, answer any questions, and administer informed consent. The clinician could also identify potential participants among the previous clients of the seating clinic and contacted them via phone call or mail to invite them to participate in the study. If the previous client expressed interest in the study during the phone call, the clinician would inquire her/his consent to share contact information with the study investigators, and then the investigator would call the previous client for further questions or scheduling the visit.

After written informed consent was obtained, a research investigator would verify and document whether or not the participant met inclusion/exclusion criteria for the study. If the participant did not meet the inclusion criteria for the study, the participant would be withdrawn from the study. The inclusion criteria included: 1) Participants were 18 years of age or older; 2) A electronic powered wheelchair (EPW) with one or more power seat functions (tilt in space, recline, elevating legrests, seat elevator) was recommended as medically necessary by a wheelchair seating clinician from the VAPHS Wheelchair and Seating Clinic or the CAT; 3) Participants were able to be properly fitted with one of the study EPWs; 18” or 20” seat widths were available. Cushions and backrests were made available to meet participant’s clinical needs; 4) Participant’s home was accessible to accommodate use of a power w/c; 5) Participants were determined to be fully capable of examining his/her sitting surface daily for redness or pressure ulcers or if not that another individual could be designated as able and willing to-do this; and 6) Participants were able to conveniently access a compact disc player.

The exclusion criteria include: 1) Participants who had active pelvic, gluteal or thigh wounds or who have had a pressure ulcer in these regions within the past 30 days; and 2) Participants who reported more than 5 days of hospitalization in the previous month.

4.2.2 Study Design And Study Protocols

Clinicians identified potential participants among their current and past clients of the seating clinics and recruited them into the study. Participants needed to use a study EPW equipped with the VSC system for around 8 weeks, including 5 study visits. The first two weeks were baseline data collection. The rest of 6 weeks were the intervention period. Participants were consented at the first visit. Additional visits were conducted for solving technical problems on the wheelchair or the VSC system.

Visit 1 occurred on the same day as the wheelchair assessment or was scheduled at a time convenient to the participant. Visit 1 was expected to last a maximum of two hours. By drawing envelops, participants would be randomized into one of two study groups: Instruction Group (INS group) or Instruction & Virtual Coach Group (VSC group).

A study EPW with PSFs was fitted and tuned to the participant's needs by a clinician. All participants were provided with the "standard of care" training on driving of the EPW and usage of PSFs. All study participants received verbal instruction and a demonstration on the importance of using their PSFs by a clinician. Participants were instructed to go about their daily activities as they normally would for two weeks, while the VSC instrumented on the study EPW was tracking their EPW and PSF usage. This two-week period allowed participants to become familiar with the study EPW while baseline data on all participants were recorded by the tablet computer stored in the customized electronic box. Participants were asked to complete a general questionnaire to obtain information about demographics, health status, and experience using assistive mobility devices. They were also ask to answer a daily questionnaire about seating discomfort at the end of day for the following two weeks.

Visit 2 was scheduled two weeks after Visit 1. All follow up visits were scheduled at a location that both investigators and the participant agreed with. Visit 2 was expected to last a maximum of 1 hour for the INS group and a maximum of 1 ½ hours for the VSC group.

All participants were asked to turn in the daily questionnaire for the past two weeks, and a research clinician would provide a package of the daily questionnaire for the following two weeks. The investigator checked the condition of the VSC monitoring system and downloaded the data from the computer. The clinician reviewed the PSF user guide video with the participant, discussed PSF usage recorded by the VSC monitoring function in the previous two weeks, and provided the PSF user guide in several formats including a pamphlet, pocket-sized reminder cards, and a compact disk. Participants were asked to complete two other standardized assessment questionnaires about psychosocial impacts of using the assistive device and community participation. All participants received the same training and instructional materials.

For the participants in the VSC group, the VSC tablet computer would be taken out of the electronic box and mounted to the armrest with a retractable mount accessible to the participant. Participants were instructed in use of the VSC coaching functions. The daily questionnaire had been built in the VSC, and therefore participants could choose to answer the daily questionnaire on the VSC interface in the following weeks. The function of the daily questionnaire was enabled after 4pm every day to ensure that the participant answered the daily questionnaire at the end of the day.

For the participants in the INS group, the VSC tablet computer was remained in the electronic box to monitor EPW and PSF usage throughout the study.

Visit 3 and Visit 4 were scheduled two weeks after the previous visit, and were expected to take a maximum of 1 hour. The participants were asked to answer a standardized assessment questionnaire about psychosocial impacts of using the assistive device and return the package of the daily questionnaire. The research clinician would discuss PSF usage recorded by the VSC monitoring function in the previous two weeks.

Visit 5 was scheduled two weeks after Visit 4 and was expected to take a maximum of 1 hour. The procedures were the same as Visits 3 & 4. In addition, we interviewed participants in the VSC group about their perspective of the utility of the VSC.

4.2.3 A Priori Power Analysis

Using data from 11 participants included in the study of Leister et al. [61], correlations were calculated between the frequency of accessing tilt and three other variables: 1) total time occupying the EPW per day (r^2=.49, p=0.13); 2) longest duration of single occupation of the EPW (r^2=.58, p=0.06); and 3) frequency of transfers per day (r^2= -0.16, p=0.64). Thus, these variables were used to calculate the power of the proposed study sample. Using "PS: Power and Sample Size Calculation" software, sample sizes were calculated for powers of both .80 and .90, as shown in Table 14. Delta's and standard deviations from the previous study were used for the calculations. Based on our power calculations, 21 per group, and alpha of 0.05, and groups of equal size, would provide us with greater than 90% power to detect differences in the majority of outcome variables. Being a longitudinal study, we targeted for a power of .90 as a way to accommodate possible attrition, and still have a power of .80. Based on the power analysis, the study sample was expected to be composed of 25 individuals per group (25 for controls, 25 for instruction group, and 25 for instruction + virtual coach group), giving us an n=75.

Table 14. Power Calculation Table

Variable	.80 Power	> .90 Power
Frequency tilt was accessed	6 per group	8 per group
Total time occupying EPW/day	12 per group	16 per group
Longest single time of occupying EPW	16 per group	21 per group

4.3 RESULTS

4.3.1 Modification of Study Protocol

We started recruiting participants on 11/29/2011. The original study design was planned to include three treatment group: Control, INS and VSC groups. After 6 months, we found that there were significant challenges to recruit participants, and the rate of withdrawal was much higher than expected. Therefore, we modified the study protocol to removed the control group and performed block randomization to ensure the group size were similar. The first 14 participants were randomized by drawing one out of 30 envelops, which consisted of 10 envelops for the control group, 10 for the INS and 10 for the VSC group. After the protocol modification was approved by IRBs in October 2012, the randomization block was set to be 10, and the numbers of the envelops for the two groups were adjusted by the number of participants who successfully finished the study in the previous block.

Two participants withdrew from the study because they could not use the VSC independently or the VSC could not fit appropriately in the participant's living environment, but they indicated interest in continuing in the study. Considering the challenges in recruiting participants and clinical benefit for the participants from participating in the study, another modification was made to allow the participants in the VSC group to switch to the INS group when the VSC was not appropriate for them. This modification was approved in December 2012. The progress of participant recruitment and protocol modifications is illustrated in Figure 22.

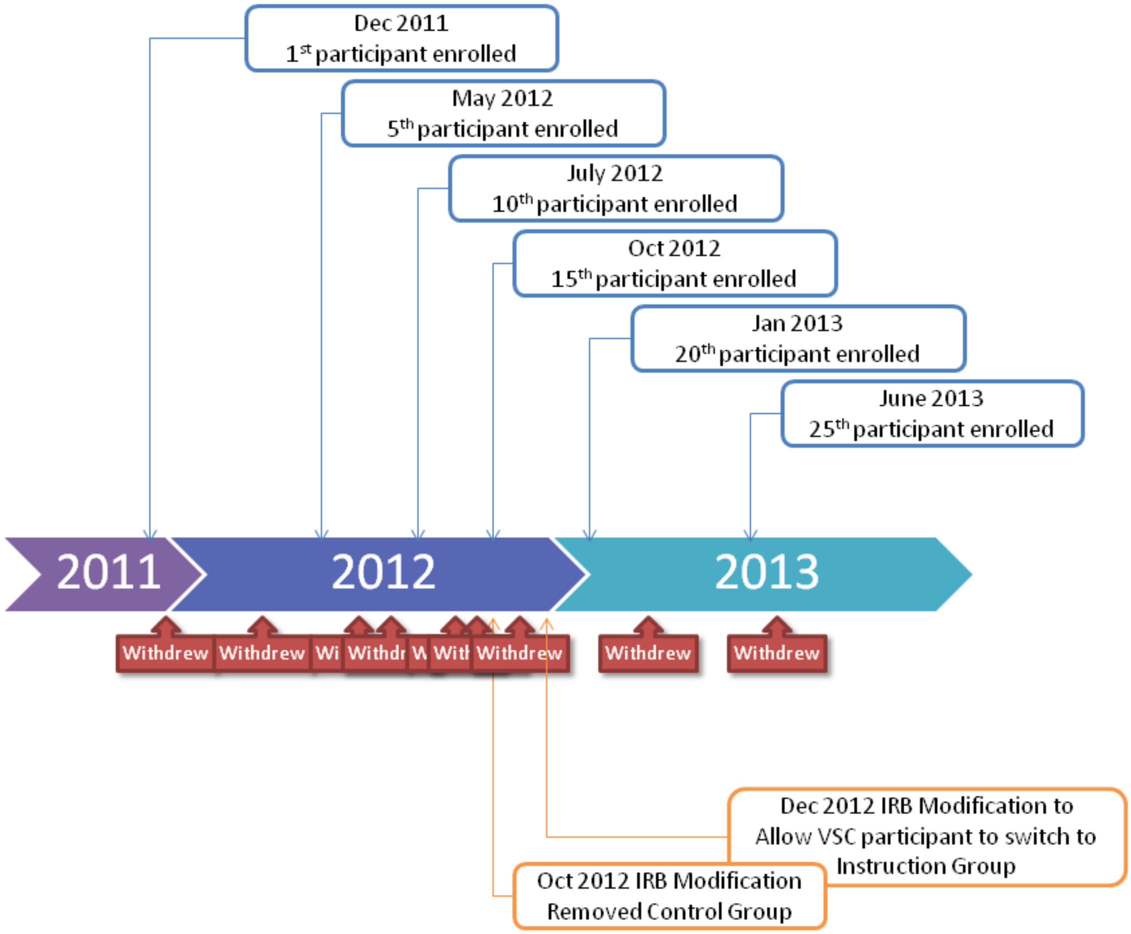


Figure 22. Progress in participant recruitment and protocol modifications

4.3.2 Participant Recruitment

Clinicians in the seating clinics assisted with participant recruitment, and investigators also reviewed the seating assessment reports of CAT to identify potential participants. Between 11/29/2011 to 6/5/2013, CAT made 690 recommendations of EPWs, 258 (37% of 690) of them were with PSFs, as shown in Figure 23. One-hundred and fifteen clients who received recommendation of using PSFs were not eligible in pre-screening to participate in the study. The reasons of ineligibility in pre-screening were shown in Figure 24. Forty percent of ineligibility resulted from the needs of special seating or controls. Every attempt was made to position the participant appropriately in study chairs by basic adjustments (armrest height and tilting angle, headrest position, footrest height and tilting angle, and controller position), posture support accessories (thigh guides, chest belts, lateral chest supports, etc.), and cushions (gel cushions, air-capsule cushions, air-foam cushions, and regular foam cushions). However, many individuals needed more specialized features and modifications on the chair, such as custom molded seats, seat dimensions other than 20x20 inches and 18x18 inches, wheelchair bases for bariatric users, customized footrests/legrests/armrests, swing-away legrests, standing features, special mounts for communicating devices, mini-joysticks, foot controls, head controls, chin controls, and sip-and-puff controls. It is time and cost prohibitive to configure study chairs to equip these advanced and highly customized features. Forty-nine of 102 eligible CAT clients were not in an appropriate condition to participate in the study. The reasons of not being appropriate were shown in Figure 25. At the beginning of participant recruitment, only three front-wheel drive wheelchairs were equipped with VSC. The research team was still working on install VSC on the rest of five study chairs. Some potential participants who needed mid-wheel or rear-wheel drive wheelchairs at the time could not be recruited in the study. Twenty-eight of 54 CAT clients who were in an appropriate condition did not participate in the study. Available reasons of deciding not participating were shown in Figure 26. Three potential participants did not participate in the study because they could not use the study chair independently because of insufficient driving skill or the house was not built with accessible design. Around 10% of CAT clients who were recommended to use PSFs participated in the study (25 out of 258. One participant was recruited from VA wheelchair seating clinic).

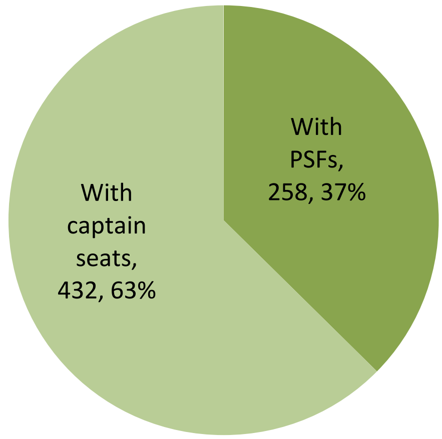


Figure 23. Number of CAT clients received recommendation of using PSFs

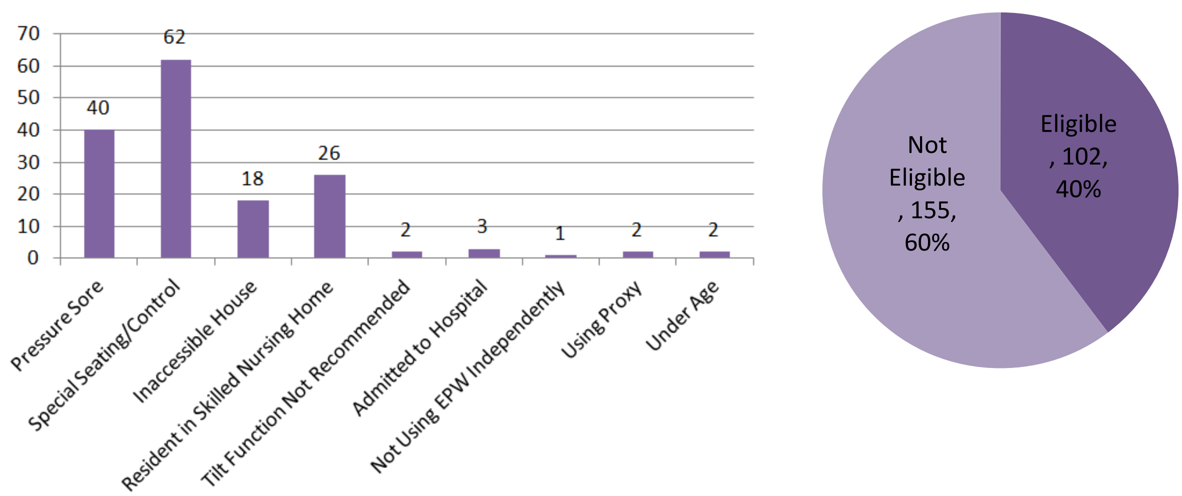


Figure 24. Number of clients who were "eligible" / "not eligible" in pre-screening to participate in the study and the reasons of ineligibility

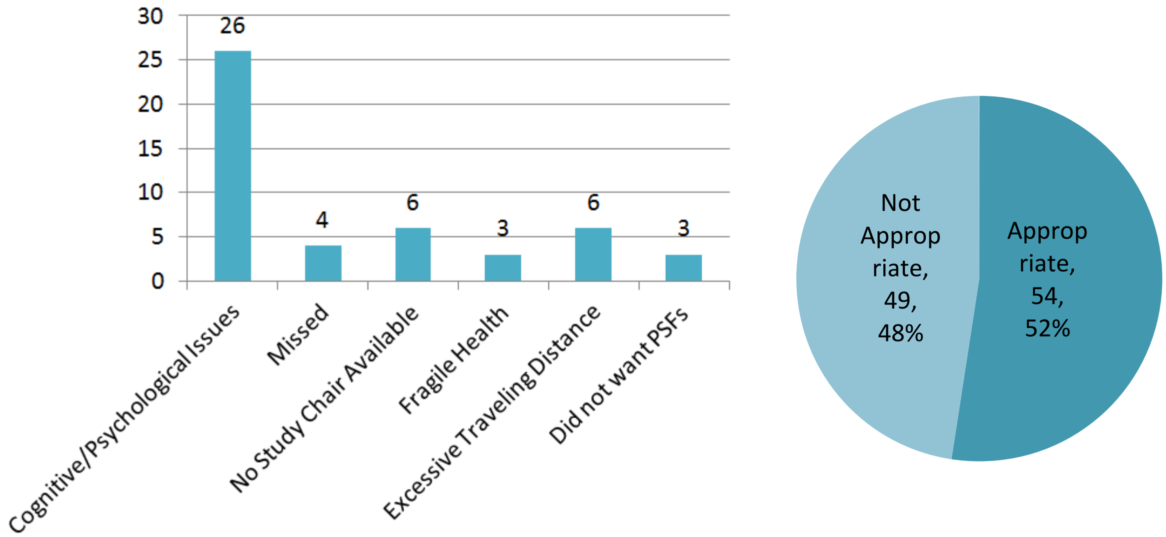


Figure 25. Number of clients who were eligible and "not in an appropriate condition" / "in an appropriate condition" to participate in the study and the reasons of being not appropriate

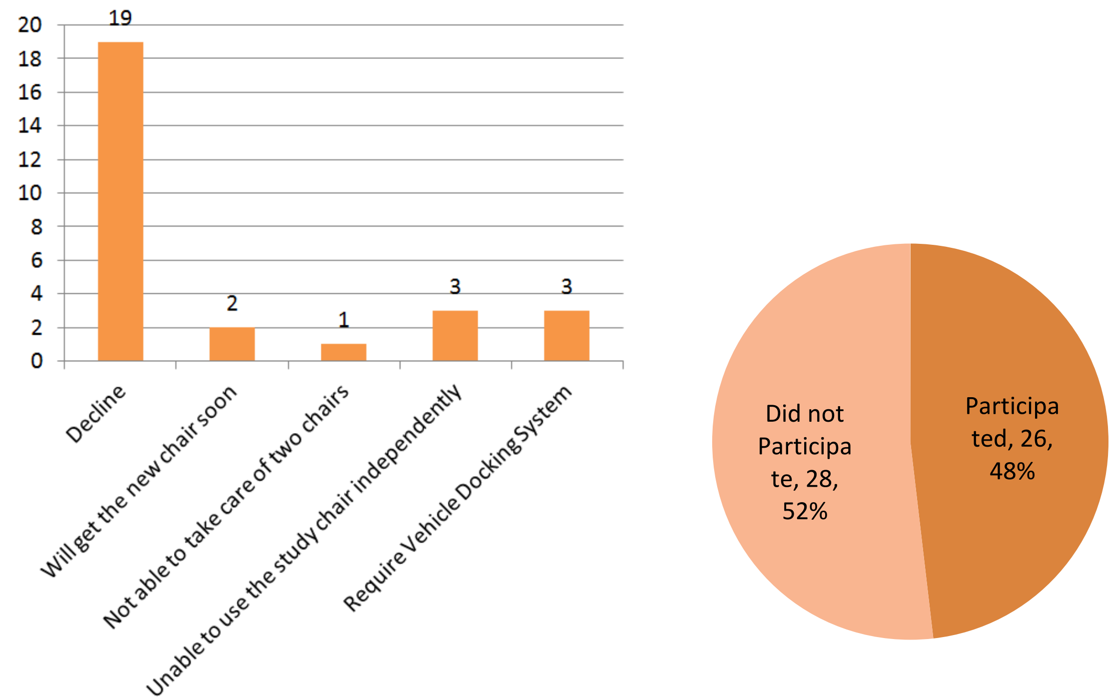


Figure 26. Number of clients who were eligible, in an appropriate condition, and "participated" / "did not participate" in the study and the reasons of not participating

4.3.3 Participation and Withdrawal

From 11/29/2011 to 6/5/2013, 26 individuals participated in the study. Two participants in the control group and 7 in the VSC group withdrew from the study. The progress in participant recruitment and the number of participants completing the study is illustrated in Figure 27. One hundred and twenty people who were eligible by being pre-screened based on the inclusion criteria. Fifty four individuals were referred by seating clinicians considering that their overall conditions were appropriate to participate in a research study. The causes and time point of withdrawal were listed in Table 15.

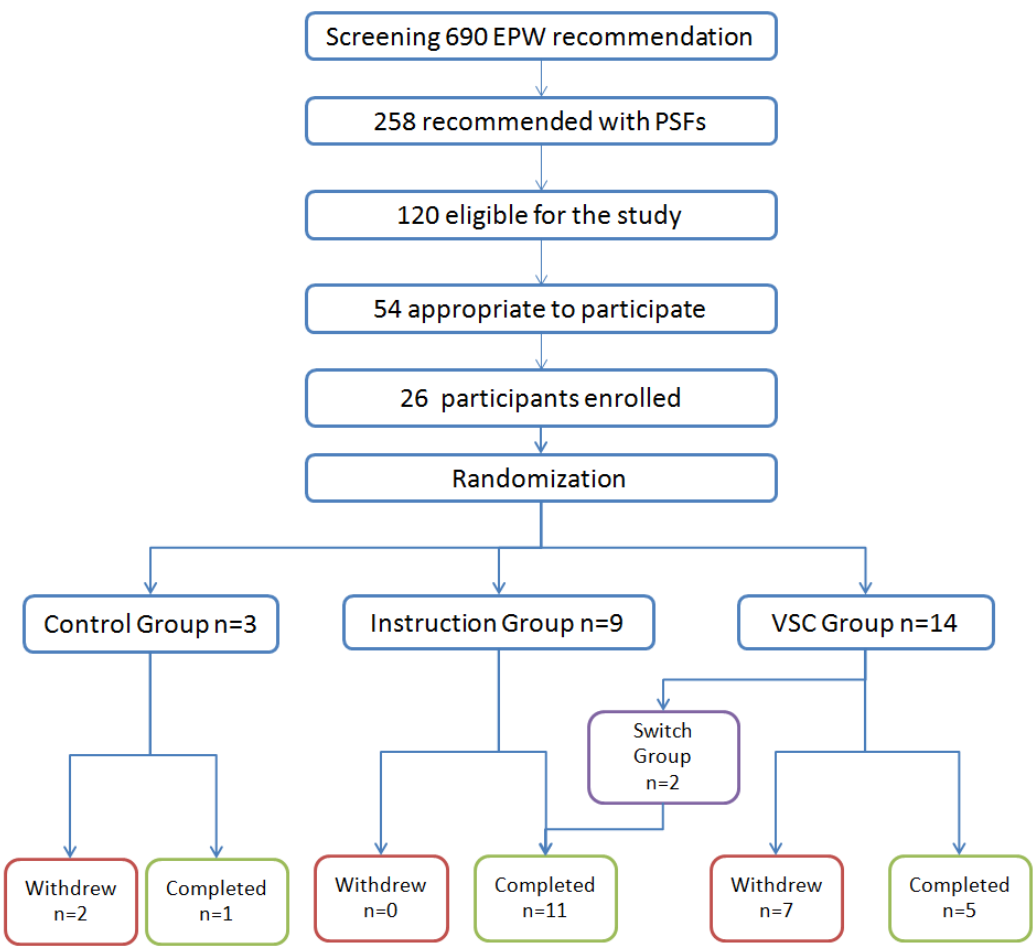


Figure 27. Progress in conducting the study from 11/29/2011 to 6/5/2013

Table 15. Causes of withdrawal

ID	Group	Time Point of Withdrawal	Cause of Withdrawal
01	Control	2nd week	The only available study chair was a group-4 front-wheel drive chair. His personal chair was a rear-wheel drive chair. He was not able to get used to the moving behavior of the study chair, which created difficulties for him to drive the study chair indoor. The study wheelchair base was 6" longer and 0.5" wider than his personal wheelchair base.
02	Control	4th week	Her declining vision and the size of the study chair relative to the tight space of her bathroom made it very difficult for her to use the study chair. Besides, her health condition was deteriorating, and was admitted to hospital. The study wheelchair base was 2.3" wider than her personal wheelchair base.
06	VSC	3rd week	The size and location of VSC interfered his transfers and driving the chair through the narrow doorway to the bathroom. The study wheelchair base was 2.8" wider than his personal wheelchair base.
07	VSC	2nd week	The caregivers felt that the daily questionnaire and learning to use the study chair required too much additional time.

Table 15. (Continued)

11	VSC	1st week	The study chair was not comfortable for her. She needed a larger space between the armrests, but the adjustability of the study chair could be configured to meet her needs.
12	VSC	3rd week	The size and location of the VSC interfered with him getting close to the dining table.
13	VSC	5th week	The size and location of the VSC interfered with him driving indoors, and it was very difficult for him to read the text on the display. The study wheelchair base was 2.8" wider than his personal wheelchair base.
18	VSC	6th week	She was still ambulatory indoors, and used the study chair rarely because she and her family were still processing the changes of using an EPW.
26	VSC	2nd week	The size of the study chair was too large to fit his house, especially when making 90° turns from hallways to get into rooms. He never used his scooter indoors.

Participants' demographics of the INS group, VSC group, who switched from the VSC group to the INS group, and who withdrew from the study were shown in Table 16. Participants who performed standing-pivot transfer and could walk between furniture indoors were categorized as being limited ambulatory. Whether or not participants performed pressure relief was determined based on their self-report. Participant 19 switched from the VSC group to the INS group at Visit 2 (the beginning of the intervention period) because she found that the size and location of the VSC could not fit in the narrow hallway in her kitchen and laundry. Participant 21 switched to the INS group at Visit 3 (after two weeks in the intervention period) because the size and location of the VSC interfered with lateral transfer which he had to perform several times a day for driving his vehicles to multiple business locations. Compared to the participants who completed the study, participants who withdrew from the study were older, with higher percentages of living with attendant care, and with lower percentages of experience with smartphones and computers.

Table 16. Demographics of INS group, VSC group, participants who switched from VSC group to INS group, and participants who withdrew from the study

	Completed (n=16)			Withdrew (n=9)
	INS Group (n=9)	VSC Group (n=5)	Switch to INS Group (n=2)	
Gender: Female	44% (4)	40% (2)	50%(1)	44% (4)
Average Age (y/o)	53 ± 9.7	49 ± 18.7	51 ± 9.2	60 ± 13.6
Age: >60 y/o	22% (2)	40% (2)	0% (0)	56% (5)
Received Education More Than Some College	67% (6)	40% (2)	50% (1)	56% (5)
Years after Diagnosis	25 ±16.3	19 ± 14.6	13 ± 0.7	19 ± 17.5
Years Using EPW	8 ± 7.7	3 ± 2.8	9 ± 5.0	5 ± 6.7
First time EPW User	22% (2)	40% (2)	0% (0)	33% (3)
Group of previous EPWs	Group-2: 5 Group-3: 0 Group-4: 2	Group-2: 1 Group-3: 0 Group-4: 2	Group-2: 1 Group-3: 0 Group-4: 1	Group-2: 4 Group-3: 2 Group-4: 0
First time PSF User	78% (7)	80% (4)	50% (1)	100% (9)
Dependent Transfer	22% (2)	60% (3)	0% (0)	33% (3)
With Attendant Care	44% (4)	0% (0)	0% (0)	56% (5)
Limited Ambulatory	33% (3)	20% (1)	0% (0)	33% (3)
Using Smart Phone	56% (8)	40% (2)	50% (1)	0% (0)
Using Computer	67% (6)	40% (2)	100% (2)	22% (2)
Perform Pressure Relief	33% (3)	40% (2)	50% (1)	11% (1)

4.3.4 Technical and Usage Problems Required Additional Visits

Besides 104 regular visits made as planned in the study protocol, 13 visits were made to pre-screen the home accessibility and discuss with potential participants about the study, 27 visits were made to solve technical problems on the VSC, 9 visits were made to solve technical problems on the study EPW, and 5 visits were made to solve PSF or EPW usage problems. All the technical problems and usage problems during the study are listed in Table 17. Some technical problems were solved at the regular visits. Some technical problems required repair at the shop and therefore two additional visits were made to pick up the study EPW from the participant and deliver it back to the participant once the problem was solved.

Table 17. Technical and usage problems during the study

Number of Events	Technical and Usage Problems
VSC Technical Problems	
10	Wheelchair batteries were drained because of no charge for 3 day. (5 events x 2 visit; 4 events x 1 visits; 1 event at the end of study)
2	SEI-USB split board failed. (2 events x 1 visit)
2	There was error in encoder reading. (2 events x 1 visit)
1	USB connectors were pulled from the tablet computer. (1 event x 1 visit)
1	The touch screen of the tablet computer malfunctioned. (solved at the regular visit)
1	VSC stopped working because the power connector was loose from the tablet computer. (1 event x 1 visit)
1	The encoder for reading recline angle failed to rotate while the backrest was moving. (1 event x 2 visit)
1	A bolt was loose from a gear of the wheel encoder. (1 event x 2 visit)
1	A bolt on the retractable tablet mount was snapped. (1 events x 1 visit)
1	The VSC tablet frame was broken. (1 events x 2 visit)

Table 17. (Continued)

EPW Technical Problems	
1	The turning acceleration needed to be decreased. (1 event x 1 visit)
1	The legrest retraction belt was torn. (1 event x 1 visit)
1	The tilt actuator failed. (1 event x 2 visit)
1	The seat dimension needed to be adjusted. (1 event x 2 visit)
1	The controller wire was torn. (1 events x 1 visit)
1	The armrest was broken. (solved at the regular visit)
1	The controller malfunctioned due to water damage. (solved at the regular visit)
1	The controller malfunctioned due to electronic failure. (1 event x 2 visits)
EPW / PSF Usage Problem	
1	The seat was not upright enough to navigate in narrow spaces. (1 event x 1 visit)
1	Footrests were too low and caught carpet. (1 event x 1 visit)
1	Did not remember how to adjust speed. (1 event x 1 visit)
1	The chair was not working because the backrest recline angle was too large. (1 event x 1 visit)
1	The seat cushion was not comfortable. (1 event x 1 visit)

The problem of wheelchair batteries being drained occurred several times because the tablet computer continuously used the battery power. When the participants did not use the chair for several days, they would plug the regular EPW charger on the chair. The charger would stop charging the chair once it sensed that the chair was fully charged. However, the tablet was still consuming the battery power and the charger could not detect the drop of the battery power. The participants had to unplug the charger and plug it onto the chair again to activate the charging function within 3 days, or the batteries would be drained. For the participants who used and charged the study EPW every day, this problem never occurred. This problem happened to the participants who were sick for a few days, left town for a vacation, or not using the chair as a regular means of mobility. Depending on the structure of wheelchair models, the investigator could pay one visit to replace batteries at the participant's home for some study EPWs, but had to bring some study EPWs back to the lab to revive the batteries.

4.4 DISCUSSION

4.4.1 Challenge of Requiring Participants to Use Study EPWs

The study protocol requiring participants to use study EPWs limited the number of individuals who could participate in the study. Around 24% of individuals recommended to use PSFs required special seating and/or control, which would be too costly to equip the study chairs with these advanced positioning or control features. Wheelchair fitting is very personalized. Generic EPWs prepared for the study could only satisfy the needs of a few EPW users. Besides, 1) taking care of two EPWs during the 8 weeks and 2) getting used to a study EPW for 8 weeks and then getting used to the new personal chair may require additional effort for some experienced EPW users whose old personal EPW were still functional. Some EPW users were very sensitive and specific about the support and positioning of the seat and driving setting, and therefore the idea of using a less custom study EPW temporarily could be linked with changes in seating comfort and driving behavior of the chair.

Furthermore, participants in the VSC group had to go through the intervention phase with the VSC installed in front of the armrest, which was a significant change on the chair. Because of being unable to cope for the changes resulting from adding the VSC on the chair, three participants in the VSC group withdrew from the study before modifying the study protocols to allow participants switching from the VSC group and INS group, and two participants switched to the INS group after the protocol modification. Level of disabilities, coping behaviors, expectation levels, changes in medical conditions, cognitive demand to use the device, aesthetics of the chair, changes in the living environment, etc, can all play roles in accommodating a new EPW or changes on a chair [85]. The study EPWs were like loaner chairs, which were not custom ordered for specific participants. Participants were willing to ignore some minor fitting issues for the study, but using the study chair with the VSC mounted at the location often interfering with transfers, desk tasks, and navigation in tight spaces might be too stressful for some participants. Two studies were found that required participants to use study wheelchairs. A study by Olson asked participants to use a newly developed folding manual wheelchair as much as possible for 4 weeks, and the participants at most used the study chair for 0-14 days during the 4-week take-home trial [86]. Another study by Makhsous et al. required participants to sit in the study chair at least 4 hour per day for 4 weeks; however, it was unknown how many participants were EPW or manual wheelchair users, and whether every participant successfully followed the study protocol according to the published article [87]. Besides, some participants had to deal with technical problems by spending time and effort to communicate and meet the study investigators, which could further increase the stress level of using the study EPW and VSC. User acceptance of VSC was an outcome from a dynamic balance among numerous factors surrounding the end-user, and should not be simply attributed to the size and location of the VSC. Future development of revising the VSC to be a smartphone application is aiming to enable the VSC to be installed on virtually any EPWs, which will eliminate the requirement of using a study EPW, and therefore user acceptance and effect of the VSC can be evaluated without the interference from the rejection of the EPWs.

4.4.2 Technical Problems of VSC

Thirteen out of 26 participants had experienced technical problems due to the VSC system. The problem that the wheelchair batteries were drained by the VSC system occurred 10 times throughout the study. The research team was aware of the problem during the development, but could not apply any feasible modification on the study EPW or the VSC to prevent this problem. This problem is the similar to the issue of forgetting to turn off the light in a vehicle for several days will drain the vehicle batteries. Participants were asked not to turn off the tablet computer to be sure that EPW and PSF usage were recorded continuously during the study.

Although study EPWs equipped with the VSC were tested in the lab and in three-day pilot study for their reliability, repetitive usage and vigorous vibration while driving outdoors could deteriorate the integrity of VSC. Although rotary encoders provided accurate reading of seating angles, the mechanism to couple the encoder axis and the rotation axis of the seating movement were vulnerable to bending force and vibration, and so are the retractable mounts and VSC tablet frames.

Based on the experience in the technical problems found in this study, the research team is working on revising the VSC, which will be a personal reminder application installed on a smartphone connected with external accelerometers to detect seating position. The new version of the VSC will allow the user to remove the smartphone while the EPW is not in use to prevent the problem of the wheelchair batteries being drained, will require only hand tools to attach the sensors without modifying the EPW, and will be much lighter than the tablet version to decrease the influence from bending force and vibration.

4.4.3 Challenges from Home Accessibility

Group-4 EPWs were purchased as our study chairs. Their durability and quality were expected to sustain repeated usage throughout the study. However, the size of the study chair plus the electronic box on the backrest was commonly a concern for users in getting into the bathroom, shower, bedroom, and vehicles. Although there are only less than 7 inch difference in length and less than 2 inch difference in width between Group-4 and Group-3 wheelchairs, users reported that the difference in the dimension impacted the effort they spent to navigate through doorways and even affected accessibility. The problem often occurred when making a 90° turn through doorways. The International Residential Code for One- and Two- Family Dwelling requires the minimum hallway should not be less than 36 inches [88]. Bathroom doorways of less than 27" wide are commonly seen in Pittsburgh area. A study by Koontz et al. found that 37% of EPW users could not complete the 90° turn in the hallways of 29.5 inch wide following the

Accessibility Guidelines for Buildings and Facilities, and the minimum space for mid-wheel drive and front-wheel drive EPWs to make 90° turn was around 34.6 inches (88.0 and 87.7 cm, respectively) [89]. Fifteen out of 16 participants who participated and completed the study did not need to make tight 90° turn to access bathrooms or bedrooms. One participant used the study chair in open areas like the living room and kitchen. For EPW users who already have to navigate through tight spaces daily and have visual and/or motor control issues affecting driving performance, any increase the chair dimension would raise the level of difficulty in driving and decrease their motivation to participate in or spend effort to continue the study. Novice EPW users may not acquire sufficient EPW driving skills to navigate narrow spaces. The level of difficulty in driving increases if their houses were not built with accessible design.

4.4.4 Challenges for Novice EPW Users to Participate in the Study

It was the first time for many individuals to receive recommendations to use EPWs with PSFs. The information about the device, accompanied with modifications in their daily living and environment to accommodate the chair, and the perceived image of using an EPW for mobility and repositioning were too overwhelming for some individuals to participate in a study. Participant 10 was happy to use the study chair for mobility for longer distances, but was reluctant to use PSFs as a regular means to reposition herself. Participant 18 participated in the study, but had talked about her hesitation of using the chair at home and the avoidance of her family to discuss use of the EPW. The study EPW was abandoned and not used for many days. These two participants might not be ready to accept their disabilities, which would affect their coping skills for the idea of using EPWs in daily living [85]. Individuals may perceive using an EPW as giving up ambulation and loss independence [90], and even worry about bullying and mugging [91]. Some expressed the struggle that they would rather not use an EPW but were left with no alternatives due to their disabilities [92]. It may take some users years to identify the EPW as a great support to allow them having more energy and options to perform the activities they like [93]. A survey study found that individuals with Amyitrophic Lateral Sclerosis (ALS) used EPWs 0-3 hours per day after they received the chairs, and used the chair 1-3 hours or 11-15 hours per day at the time answering the survey, on average about 28.8 months after the EPW was delivered [94], which implied that users need time to figure out how to incorporate a mobility device in their life. Participating in a research study that required the use of a study EPW may be too stressful for some novice EPW users.

The struggles of novice users to accommodate an EPW with PSFs observed during the process of participant recruitment indicate that it is important to conduct longitudinal studies to understand the process and challenges experienced by a person to use an EPW with PSFs as her/his primary means of locomotion. The study findings will further reveal the factors affecting PSF usage and facilitate clinical service to provide appropriate supports, follow-up or referral to encourage people to use EPW and PSFs to improve quality of life.

4.4.5 Challenges in Recruiting Participants for the Sample Size Satisfying Randomized Control Trials

Studies on EPW users with randomized control trials, repeated measurements or evaluating a new device or intervention for a extended period of time may face similar challenges that occurred in this study. A study about prevention of pressure ulcers by Guihan et al. faced critical challenges because the design of a randomized control trial could not fit in clinical practice, resulting in slow participant recruitment and early termination of the study [95]. Well-planned single subject designs or small-N designs can be an alternative approach to evaluate the effectiveness of treatments [96, 97]. The basic elements of small-N designs include: 1) studying a small group of people, 2) dependent variables are measured repeatedly, and 3) phases/periods to apply and withdraw treatments/interventions. Phase designs include at least two testing periods: a baseline period and an intervention period. Baseline data provides a standard of comparison for evaluating the potential cause-and-effect relationship between the intervention and target behavior [98, 99]. With these elements, researchers can observe response patterns induced by the intervention through repeated measurement controlling for the variability between and within participants. The study procedures involving small-N designs are similar with and more comparable to documenting treatment progress in day-to-day clinical practice. Besides, small-N study designs are less cost- and time- consuming compared to large-N randomized clinical trials for their sample sizes and difficulties in recruiting participants with disabilities. Applying small-N designs coupling with appropriate statistic analyses to study interventions or new devices for people with disabilities may be helpful to accumulate the evidence base for clinical practice.

Randomized control trials are powerful to determine the efficacy of interventions. Although they require large numbers of participants and inclusion / exclusion criteria controlling for the variations between and within study groups before randomization, the study design and the randomization process ensures that the only difference between the study groups is the intervention. If the goal is to conduct a randomized control trial on participants with disabilities, the population size, inclusion / exclusion criteria, the estimated sample size, variability among participants, and the effort needed for the participants to follow the study protocol need to be carefully investigated and analyzed while planning the study protocol and interventions.

4.5 CONCLUSION

This study aimed to evaluate the efficacy of the VSC through randomized groups and repeated measurements. However, the requirement that the participants had to use study EPWs resulted in several challenges in recruiting participants and for the participants to conduct the study protocol. Besides, the VSC started to deteriorate due to repetitive usage and vigorous vibration from driving outdoors and transportation. The lessons learned from this study enable the research team to develop a new version of the VSC which will be flexible and portable to be installed on virtually any personal EPWs. The small-N design can be considered to apply for studying the effect of new devices or interventions on people with disabilities by accommodating their naturally small populations and high individual variability.

5.0 EFFICACY OF VIRTUAL SEATING COACH

5.1 INTRODUCTION

In 2007, 173,300 Medicare beneficiaries received electric powered wheelchairs (EPWs). EPWs equipped with powered seating functions (PSFs) are considered complex rehabilitation wheelchairs, accounting for about 7% of Medicare power wheelchair claims [100], and the number is growing. EPW users who have impaired or absent sensation over weight-bearing area are at high risk of developing pressure ulcers. Prevalence of pressure ulcers in wheelchair users ranges between 10 to 40% [12-14]. While users reported being satisfied with EPWs [94, 101, 102], the majority of EPW users also experienced pain [103]. Fatigue and pain resulting from prolonged static sitting are common experiences for most people during long distant driving or flight and prolonged computer usage or gamming [32]. The same issue occurs in wheelchair users. PSFs allow EPW users the ability to change their position, however most PSF users used tilt and recline functions only within minimum ranges for comfort [104, 105]. In other words, only a small proportion of the users benefit from the maximum ranges of powered tilt and recline functions. Literature has shown that to achieve adequate pressure relief, a person must incline the trunk backward more than 45° using the combination of tilt and recline functions (from 90° as the trunk is in an upright position) [20, 106, 107]. Unfortunately, these recommendations are not always followed. A similar example of seating guidelines that aren't followed includes office workers. This population also has issues related to sitting statically, and they are recommended to have a break from sitting once every hour for 5 minutes, but only around 8% of office workers comply with this recommendation everyday [35].

The goal of this study was to investigate the efficacy of the new technology, known as the Virtual Seating Coach (VSC). The VSC was developed to facilitate EPW users to utilize PSFs for health management and reminds users to reposition with seating angles, frequency, and positioning duration recommended by clinicians. We evaluated the VSC on compliance with clinical recommendations of periodical repositioning with specific seating position, frequency, and positioning duration compared to a training program providing educational material and recurrent meetings with a clinician.

5.2 HYPOTHESES

<u>Question</u>: Would adding a training program or the VSC in conjunction with a training program to the delivery and educational process of an EPW with PSF provide improvement in adherence by users to clinical practice guidelines for pressure relief and discomfort management?

Hypothesis 1 - Comparison of Intervention to Base-Line: Users who received the training program the proper usage of PSF would show greater adherence to the recommended repositioning regime and less discomfort.

Hypothesis 2 – Comparison of Virtual Coach to Instruction Only: Users who received the training program on the proper usage of PSFs combined with VSC would show greater adherence to the recommended repositioning regime and less discomfort than the users who only received the training program.

5.3 METHODS

5.3.1 Study Design

This was a mixed design study to evaluate and compare the efficacy of two interventions: Instruction (INS) and Virtual Seating Coach (VSC). Please refer to Chapter 4 Section 4.2 for the methods of participant recruitment and study protocol. The tablet computer and sensors on each study EPW monitored and recorded EPW and PSF usage and compliance with recommended repositioning regime all the time during the study. Assessment tools were administered to measure perceived seating discomfort, perceived psychological impact of using the study chair, and community participation at various time scales, as shown in Table 18. This study included EPW and PSF usage, compliance rates, and seating discomfort as outcome variables to evaluate the efficacy of the VSC.

Table 18. Mixed design of the study

		A. Time: Repeated Measures • Daily for EPW and PSF usage, compliance rates, and seating discomfort • Once every two weeks for perceived psychosocial impacts • At the end of the baseline, intervention, and follow-up periods for independence and community participation
B. Intervention: Groups	INS	
	VSC	

5.3.2 Independent Variables

5.3.2.1 Intervention Groups

The content of the two interventions are listed in Table 19. Participants received regular care during the baseline period of two weeks, and then received interventions according to the group which they were randomized into.

Table 19. Content of two treatment

Treatments	Receive Educational Materials (DVD, pamphlet, flash cards)	Recurrent Meeting with a Clinician to review PSF usage in previous weeks	Use VSC to remind repositioning and PSF usage safety
INS	✓	✓	
VSC	✓	✓	✓

5.3.2.2 Time: Repeated Measurements

Outcome variables were measured repeatedly with different intervals during the study as illustrated in Figure 28. Time variables included Date_centered, Time Sections, and baseline/intervention periods. These time variables may affect the study outcomes, but they are neither independent nor dependent variables. They served as covariates in the mixed mode trajectory analysis and were used to report study results. The time section between visits was at least 2 weeks. In order to meet the participants at their time of convenience, time sections varied within and between participants. The time variable "Date_centered" aligned the day of staring the intervention period as Day 1 to make it clearer to compare the results between baseline and intervention periods.

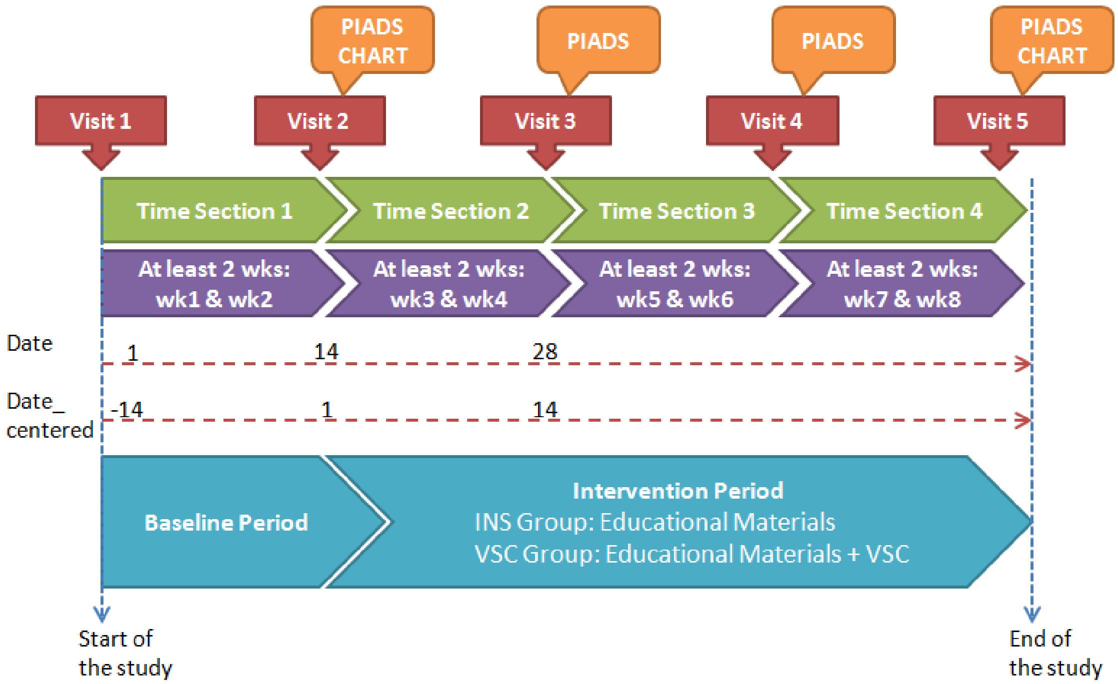


Figure 28. Time table of the study

5.3.3 Outcome Variables

5.3.3.1 Qualitative Variables

Tool For Assessing Wheelchair Discomfort (TAWC)- This tool was used to measure daily wheelchair sitting discomfort [108, 109]. The TAWC consists of three sections. Section I is to collect general information about the activities that the participant had performed during the day. The following two section are two subscales, General Discomfort Assessment (GD) and Discomfort Intensity Rating (DI) [109]. For both subscales, a higher score indicates greater discomfort. GD consists of eight statements related to discomfort and five statements related to comfort. The statement are rated on a seven-point Likert scale with 1=strongly disagree and 7=strongly agree. GD scores range from 13 to 91. DI includes seven body areas (back, neck, buttocks, legs, arms, feet, and hands) and overall discomfort level, that are rated for a degree of discomfort intensity on a scale of 0 (no discomfort) to 10 (severe discomfort). Space is also included for the user to list additional body areas. DI scores may range from 8 to more than 88, depending on whether the participant reported additional areas of discomfort.

PIADS & CHART: Theses are two standardized assessment tools to measure users' perceived psychological impacts about using the device and community participation. Findings regarding these two variable are presented in Chapter 6.0 .

5.3.3.2 Quantitative Variables

EPW Usage- Wheelchair Occupancy (hr/day) and Driving Distance were two measures used to represent EPW usage. As the wheelchair occupancy of a day affects driving distance, driving distance was normalized by the wheelchair occupancy of a day (km/hr).

PSF Usage- One time access of PSF was defined as staying in a seating angle more than 30 seconds (error range ±3 degrees) after adjusting the seating angle. The duration and frequency of PSF usage were categorized into three ranges: minimum, moderate, and maximum ranges, as shown in Table 2. The wheelchair occupancy of a day controls frequency and duration of PSFs. Therefore, variables of PSF usage were normalized by the wheelchair occupancy of the day and include:

1. Frequency of Repositioning: the frequency of accessing any ranges of tilt, recline, or elevating legrests per hour, normalized by wheelchair occupancy (times/hr)

2. Frequency of Repositioning with Mod & Max Ranges: the frequency of accessing the moderate and maximum ranges of tilt, recline, or elevating legrests functions per an hour, normalized by wheelchair occupancy (times/hr)

Compliance with clinical recommendations on repositioning- A research clinician recommended a repositioning regime for each participant. The regime included the frequency of repositioning, the desired seating position (seating angles), and the duration that the participant should stay in the desired position for optimized effects. For example, the clinician may have recommended that a participant reposition once every hour with a desired position of tilting the seat more than 30 degrees, and the participant staying in that position for more than 2 minutes. The participant had to follow the recommended position, duration, and frequency to be considered as compliant. Examples of one participant's performance and compliance with recommended repositioning regime is illustrated in Figure 29: a) The participant repositioned once every hour. Her compliance rate was 100%; b) The participant repositioned 40 minutes after the previous repositioning. As long as the participant repositioned once every hour or less than an hour, her compliance rate was 100%; c) The participant did not reposition one hour after the previous repositioning, and then she repositioned an hour later. Her compliance rate was 67% (=(2/3)x100%); d) The participant did not reposition one hour after the previous repositioning, she repositioned 40 minutes later, and then again an hour later. Her compliance rate was 75% (=(3/4)x100%); e) The participant repositioned 42 minutes after the previous repositioning, but did not reposition one hour later. She repositioned another one hour later. Her compliance rate was 75% (=(3/4)x100%); and f) The participant did not reposition for more than 2 hours, and then she repositioned 40 minutes later, and again another 40 minutes later, and performed again an hour later. Her compliance rate was 60% (=(3/5)x100%).

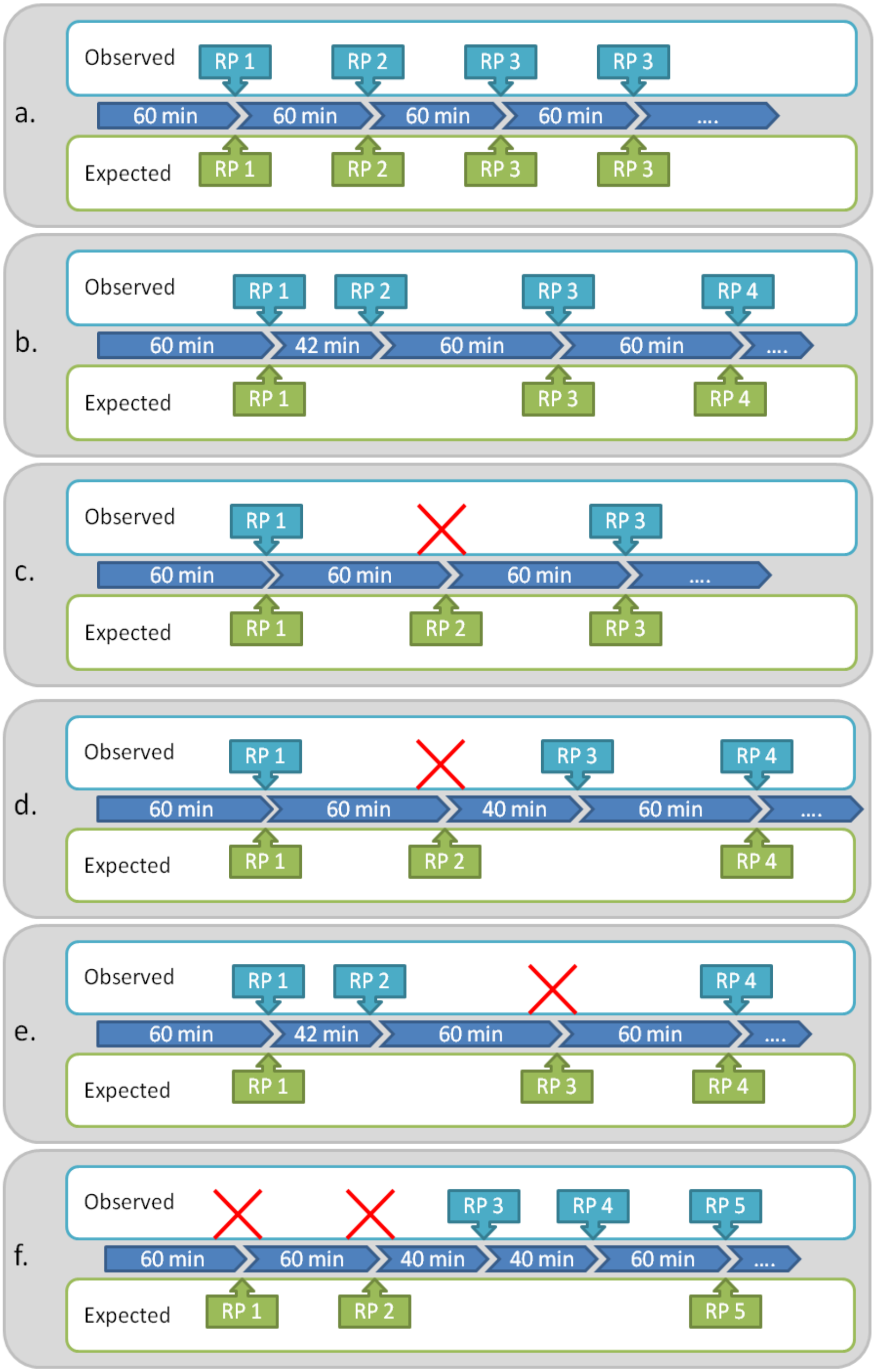


Figure 29. Participant's performance and compliance with clinical recommendation on repositioning regime

5.3.4 Data Analysis

Means and standard deviations are shown either in tables (Table 20 and Table 21) or bar charts (Figure 30, Figure 32, and Figure 33). Data were categorized by Groups and Time Sections. If the data were normally distributed, 2x4 mixed MANOVA would be used to test the difference. Alpha level would be set as .01 (.05/5) based on Bonferroni adjustment for 5 outcome variables. If the data were not normally distributed, Friedman test would be used to test the main effect of time; and Mann-Whitney-U test would be used to test the main effect of groups. If the main effects were found, custom simple comparisons would be performed, using Wilcoxon Signed Ranked test and Mann-Whitney-U test, to test the differences between Time Sections 1 and 2, 1 and 3, and 1 and 4, and the differences between groups in each Time Section.

Mixed model trajectory analysis was used to investigate the efficacy of interventions in compliance rates over time (days). The analysis was conducted to establish multiple regression models for the aggregate outcomes. The following factors were tested as predictors in each model for both fixed and random effects: Date Centered, Time Sections, Intervention of INS, Intervention of VSC, Wheelchair Occupancy, Driving Distance, and interactions between factors. Wheelchair Occupancy and Driving Distance were included in the analysis because these two factors are virtually available in clinical settings by users' report and may interact with the opportunity of performing repositioning. Spearman's correlation was used to evaluate the correlation between observed and estimated compliance rates.

5.4 RESULTS

Twenty-six participants were recruited in the study to evaluate the efficacy of the INS and VSC intervention, and 16 of them completed the intervention protocol. The data were not normally distributed. Non-parametric statistic analysis was applied to analyze the data.

5.4.1 Baseline Differences

The means and standard deviations of EPW and PSF usage, compliance rates, and seating discomfort of the two groups in the baseline are shown in Table 20. There were large variations between participants, especially in compliance rates. The compliance rates of each participant of the VSC group were listed in Table 21. Significant differences were found in the compliance rates between the INS and VSC groups (U = 2091.50, z = -3.46, p = .0005, r = -0.25).

Table 20. Means and standard deviations of EPW and PSF usage, compliance rates, and seating discomfort during the baseline period

	INS Group (n=11)	VSC Group (n=5)	All (n=16)
Wheelchair Occupancy (hours)	7.01 ± 4.64	6.11 ± 4.99	6.74 ± 4.75
Driving Distance (km/hr)	1.19 ± 1.68	1.18 ± 1.13	1.19 ± 1.53
Compliance Rates (%)*	8.46 ± 20.90	21.75 ± 32.84	12.02 ± 25.26
Frequency of Repositioning (times/hr)	1.77 ± 2.05	2.52 ± 2.76	1.99 ± 2.30
Frequency of Repositioning with Mod & Max Ranges (times/hr)	0.81 ± 1.14	1.14 ± 1.26	0.91 ± 1.18
General Discomfort (GD) Score	42.43 ± 11.80	40.36 ± 13.92	41.99 ± 12.25
Discomfort Intensity (DI) Score	19.10 ± 8.90	18.38 ± 11.17	18.95 ± 9.38

* $p < .05$

Table 21. Means and standard deviations of compliance rate of the participants in the VSC group in the baseline.

Participant	Compliance Rate of Each Participant
08	28.6 ± 48.8
09	6.6 ±12.8
15	0 ± 0
17	25.4 ± 27.4
24	51.0 ± 40.4

5.4.2 Effect of Interventions

Main effects of time were found in compliance rates (p <.001), frequency of repositioning (p <.001), frequency of repositioning using moderate and maximum ranges (p = .004), and general discomfort (p <.001). Main effects of groups were found in compliance rates (p <.001), frequency of repositioning (p <.001), frequency of repositioning using moderate and maximum ranges (p <.001), and discomfort intensity (p <.001). Custom simple comparisons were performed between Time Sections 1 and 2, 1 and 3, and 1 and 4 for each group in compliance rates, frequency of repositioning, frequency of repositioning using moderate and maximum ranges, general discomfort; and between groups in each Time Section in compliance rates, frequency of repositioning, frequency of repositioning using moderate and maximum ranges, discomfort intensity. Alpha level was set at .00125 (.05/40) based on Bonferroni adjustment for multiple comparisons.

5.4.2.1 Compliance Rates

The research clinician recommended a repositioning regime for each participant at Visit 2. Participants received individualized recommendations on seating angles and all the participants were recommended to reposition once every hour, and stay in the desired position for 2 minutes. The recommended positions for repositioning regimes are listed in Table 22. The diagnosis, transfer strategy, and status of being a novice EPW user or a novice PSF user of each participant are listed in Table 23.

Table 22. Recommended position for each participant

Participant		Position
INS Group	03	Tilt > 20 degrees for decreasing fatigue
	04	Tilt > 20 degrees for decreasing fatigue
	10	Tilt > 20 degrees for decreasing fatigue
	14	Tilt > 20 degrees for decreasing fatigue
	16	Tilt > 30 degrees for decreasing fatigue and pressure relief
	19	Tilt > 20 degrees for decreasing fatigue
	20	Tilt > 20 degrees + Recline > 120 degrees for pressure relief
	21	Tilt > 30 degrees for pressure relief (During Time Sections 3 and 4)
	22	Tilt > 20 degrees for decreasing fatigue
	23	Tilt > 20 degrees for decreasing fatigue
	25	Tilt > 20 degrees for decreasing fatigue
VSC Group	08	Tilt > 30 degrees for decreasing fatigue
	09	Tilt > 30 degrees for pressure relief
	15	Tilt > 30 degrees for decreasing fatigue
	17	Tilt > 30 degrees for decreasing fatigue and pressure relief
	21	Tilt > 30 degrees for pressure relief (During Time Section 2)
	24	Tilt > 30 degrees for decreasing fatigue and pressure relief

Table 23. Diagnoses, transfer strategies, and experience in using EPWs and PSFs of each participant

Participant		Diagnosis	Transfer Strategy	Novice EPW user	Novice PSF user
INS Group	03	Muscular Dystrophy	Dependent		
	04	Multiple Sclerosis	Standing pivot		✓
	10	Multiple Sclerosis	Standing pivot	✓	✓
	14	Multiple Sclerosis	Standing pivot		✓
	16	T-level SCI	Standing pivot		✓
	19	Multiple Sclerosis (switched from VSC group)	Standing pivot		✓
	20	C-level SCI	Dependent		
	21	T-level SCI (switched from VSC group)	Lateral		
	22	Stroke	Standing pivot		✓
	23	Degenerative Joint Disease	Standing pivot		✓
	25	Multiple Sclerosis	Standing pivot	✓	✓
VSC Group	08	Cerebral Palsy	Standing pivot		✓
	09	C-level SCI	Dependent		
	15	Muscular Dystrophy	Standing pivot	✓	✓
	17	Muscular Dystrophy	Dependent		✓
	24	Multiple Sclerosis	Dependent	✓	✓

Means and standard deviations of compliance rates over Time Sections are shown in Figure 30. Time Section 1 was the baseline period, and Time Sections 2, 3, and 4 were the intervention period. The baseline data of Participant 21 were included in the INS group in the bar chart. Significant differences were found in the compliance rates between the INS and VSC groups during Time Section 2 (U = 621.00, z = -9.31, p = .0000, r = -0.72), Time Section 3 (U = 1329.50, z = -7.25, p = .0000, r = -0.55), and Time Section 4 (U = 555.00, z = -6.94, p = .0000, r = -0.62). No significant differences were found in the compliance rates of the INS group between Time Section 1 (8.46 ± 20.90 %) and Time Section 4 (15.43 ± 26.46 %). Significant differences were found in the compliance rates of the VSC group between Time Section 1 (21.75 ± 32.84 %) and Time Section 2 (54.41 ± 32.13 %) (T = 599.5, p = .0000, r = -0.68), and between Time Section 1 and Time Section 4 (62.24 ± 34.12 %) (T = 489.50, p = .0000, r = -0.70). The effect sizes (Cohen's D, d) of INS and VSC interventions were 1.37 and 4.69, respectively.

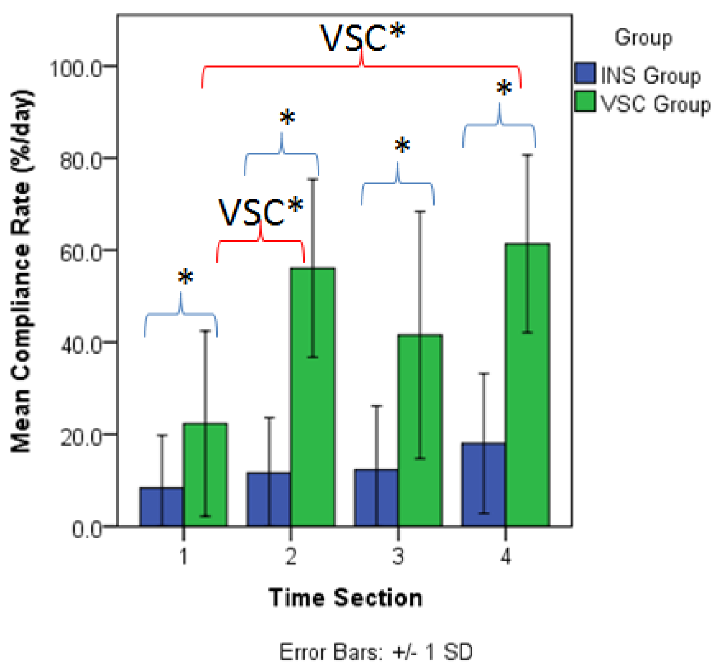


Figure 30. Means and standard deviations of compliance rated across Time Sections

* $p < .00125$

Mixed Model Trajectory Analysis for Compliance Rates

To investigate the changes in the compliance rates associated with interventions, compliance rates were further analyzed using mixed model trajectory analysis. The fit statistics of the aggregate model are shown in Appendix C. The line chart of the mean estimated compliance rates by the best fit models for the two groups is illustrated in Figure 31. The best fit model to estimate compliance rates for the aggregate outcome was:

$$
\begin{aligned}
&\text{Compliance Rate} = \\
&20.91 + (5.80)(10^{-5})(\text{Date Centered})^3 + \\
&(-4.31)(\text{Intervention: INS, Yes=1, No=0}) + \\
&(38.64)(\text{ Intervention: VSC, Yes=1, No=0}) + \\
&(-1.16)(\text{Wheelchair Occupancy: hr/day})
\end{aligned}
$$

The estimated compliance rate was significantly correlated with the observed compliance rate (r_s = .534, p =.000).

Based on the aggregate model, the VSC intervention showed a much larger positive impact on the compliance rates by increasing the compliance rates 38.6 % at the beginning of the intervention period. For the INS group, the intervention did not result in significant impact on the compliance rates; however, the learning effect contributed to the improvement in the compliance rates by the end of the intervention period. In addition, compliance rates were inversely related with wheelchair occupancy, which contributed to mild variations in the compliance rates from day to day.

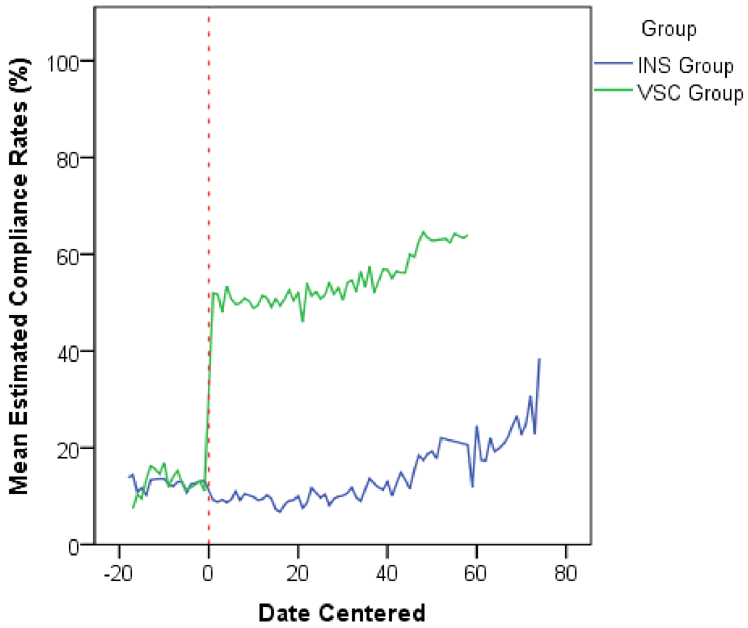


Figure 31. Mean estimated compliance rate by the best fit model, with red dash lines indicating the start of the intervention period

The reasons that participants gave about non-compliance with repositioning regimes are listed in Table 24.

Table 24. Explanations that the INS participants gave about non-compliance with repositioning recommendations

Participant	Explanation
03	He was not used to the tilted position. The tilted position sometimes made it difficult for him to reach the EPW joystick.
04	He felt that moving in the chair should be enough to decrease fatigue and release pressure. He felt that he had performed repositioning.
10	She wanted to adjust posture by herself as long as possible before the disease took her mobility away.
14	She thought she did. She did not know the tilt angle was not large enough.
16	He simply forgot to perform repositioning.
19	She thought she did. She thought that tilting for half hour at the end of a day was comparable to reposition periodically.
20	He insisted he knew when he needed to reposition for pressure relief.
21	He followed the repositioning reminders during the 2 weeks in the VSC group. After he switched to the INS group, he insisted he knew when he needed to reposition for pressure relief and insisted on performing push-up for pressure relief.
22	He did not know the seat could tilt. (He had significant memory issues.) He forgot to perform repositioning.
23	She insisted she knew when she needed to tilt.
25	She forgot the recommendation for repositioning.

5.4.2.2 Powered Seating Function Usage

Means and standard deviations of Frequency of Repositioning and Frequency of Repositioning using moderate and maximum ranges were shown in Figure 32. Significant differences were found in the frequency of repositioning using PSFs (tilt, recline, and elevating legrests) between the two groups during Time Section 2 (U = 1420.50, z = -7.62, p = .0000, r = -0.56), and in the frequency of repositioning using PSFs with moderate and maximum ranges between the two groups during Time Section 2 (U = 1515.00, z = -7.45, p = .0000, r = -0.56), Time Section 3 (U = 2761.00, z = -3.29, p = .0010, r = -0.24), Time Section 4 (U = 1962.5, z = -4.26, p = .0000, r = -0.33). No significant difference was found in the frequency of repositioning using PSFs between Time Section 1 and Time Section 4 for both groups. Large variations in PSF usage were shown within groups.

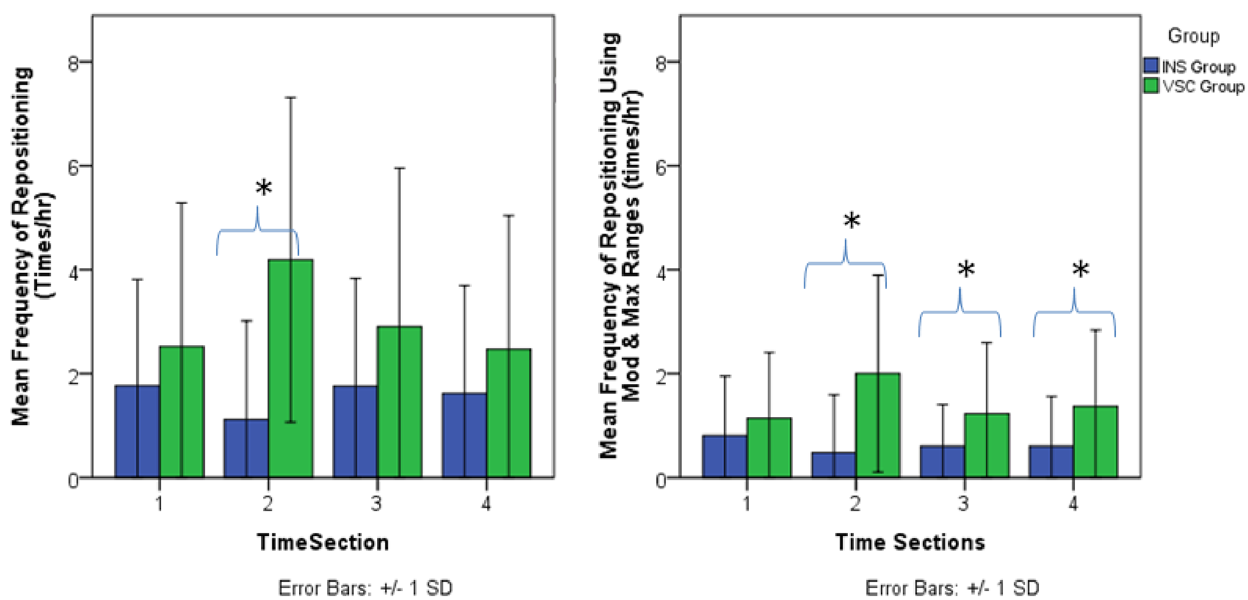


Figure 32. Means and standard deviations of repositioning using tilt, recline, and elevating legrest functions over Time Sections.

* $p < .00125$

5.4.2.3 Seating Discomfort

Means and standard deviations of General Discomfort (GD) and Discomfort Intensity (DI) scores measured by TAWC were shown in the bar charts in Figure 33. Significant differences were found in the GD scores between INS and VSC groups during Time Section 2 (U = 1421.00, z = -3.43, p = .0006, r = -0.30), in the GD scores of the INS group between Time Section 1 (42.43 ± 11.80) and Time Section 4 (44.14 ± 13.67) (T = 592.50, p = .0003, r = -0.58), and in the DI scores between INS and VSC groups during Time Section 2 (U = 1684.00, z = -3.53, p = .0004, r = -0.29), Time Section 3 (U = 1436.00, z = -3.99, p = .0001, r = -0.32), and Time Section 4 (U = 389.50, z = -6.13, p = .0000, r = -0.56).

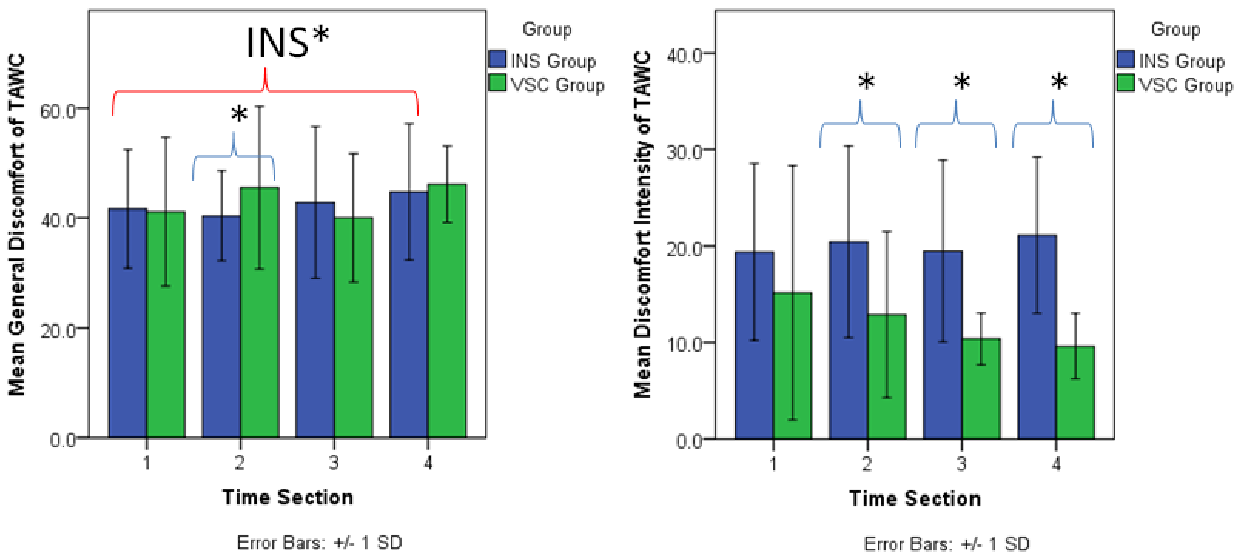


Figure 33. Means and standard deviations of General Discomfort and Discomfort Intensity over Time Sections

* $p < .00125$

5.4.3 Preference for Display Effects

Patterns of user preference for display effects were observed in the study. **1) Participants preferred default settings**: Participants 8, 15, 21, and 24 kept using the default display effect and "Home" mode, seeing and hearing a female clinician to remind about repositioning. **2) Participants liked to hear and see the female clinician:** Participants 8 and 24 specifically said that they liked to see and hear the female clinician and therefore did not change the setting. **3) Not all participants liked the encouragement after the complying the reminder:** Participant 15 said that he just did not feel the need to change it, but he specifically pointed out that he disliked the encouragement with the final confirmation. He felt that the confirmation of task completion alone was sufficient. **4) Participants who were not familiar with touch screen interface may hesitate to change display effects:** Participant 17 also did not change the display setting because she was afraid to break the VSC. She stayed in "Home" mode, seeing and hearing the female clinician, for a week, and then switched to stay "Noisy Place" mode, seeing a static sign and hearing a short piece of piano melody, for the most of time because she wanted to hear the melody. However, when interviewing her at the end of the intervention period, she kept emphasizing her preference for seeing and hearing the female clinician. **5) Not all participants preferred multi-media display effects:** Participant 9 was the only individual who modified the display settings. He used the default "Home" mode, seeing and hearing the female clinician to give reminders and warnings, for 7 hours, and then modified "Home" mode to display text and turn off sound effect. He said that he preferred the simple text and no sound effect, and just periodically checked the VSC to see whether he had an overdue repositioning. **6) Some mode buttons may be accidentally activated due to their locations on the interface:** Although he kept using "Home" mode for the most of time, he would switched to "Other" mode, whose default setting was to display the image of the female clinician and text and beep sound, several time for a few minutes. At the 5th day into the intervention period, he modified "Other" mode to display text and turn off sound effect, which was the same with his setting for "Home" mode. For the rest of the intervention period, he kept using either "Home" mode or "Other" mode.

5.4.4 Comments about VSC

Participant 8 and 24 did not report any concerns about the design of the VSC. Participant 9, 15, 17, and 21 commented that it would be much easier to use the VSC if its size could have been smaller. Even though it was retractable, the additional steps to move it away were reported to be annoying. Sometimes its retracted position was still in the way of performing tasks. All the VSC participants recognized the benefit of reminding them to repositioning regularly. Participant 17 reported that her feet and buttocks were not as sore as before, and her husband stated that he felt his wife became happier. Participant 24 reported that the VSC made her quickly adjust to using the maximum range of tilt, and she felt that the pressure over the buttock and hip pain were decreased by repositioning. Participant 15 felt that he did not need the VSC, but it could be very helpful for elders. None of the participants who had used the VSC felt the need of increasing the options of display effects.

5.5 DISCUSSION

5.5.1 Efficacy of the VSC

Providing educational materials and recurrent meetings, discussions, or training sessions are popular strategies for health education or health promotion, focusing on facilitating motivations and increase knowledge about the health issues of the target audience [110]. Upper limb preservation, transfer strategies, propulsion techniques, and pressure ulcer prevention are primary topics of health education for wheelchair users, and well-designed education programs enhance wheelchair users' health status and compliance with desired health behavior [111, 112]. Yang et al. showed the potential of pervasive computing to facilitate health behaviors of wheelchair users in a study that simply provided audio alerts increasing the compliance rate by 10% in manual wheelchair users to perform push-ups for pressure relief [58].

Although there were differences in the compliance rates between the INS and VSC groups in the baseline period, the VSC group showed significant increase in the compliance rates in Time Sections 2 and 4 compared to Time Section 1 (the baseline period). The regression model also estimated that the compliance rates would increase 39% once the participants received the VSC intervention. Additionally, there was improvement in the compliance rates of the INS group, but it relied on the learning effect accumulated through the intervention period. The optimized intervention with VSC showed a large effect size (r= 0.70; d= 4.69) compared to other studies using mobile phone short-message service (SMS) to deliver interventions to change health behaviors (d= 0.09-1.38 of six studies) [113]. Although the efficacy of VSC alone is unknown from this study, VSC did demonstrate a very promising potential to extend health education and user training beyond clinical settings. Compared to interventions delivered by

SMS or e-mails, the VSC was equipped with data-logger technology developed in HERL to increase user engagement by providing real-time feedback on positioning change. The VSC features of displaying the detected seating angles in contrast with the desired seating angles and giving confirmations about the completion of the desired repositioning tasks likely played an important role in guiding and reinforcing the desired behaviors.

A pattern of large improvement during Time Section 2 and then declined in Time Section 3 was observed in both PSF usage and compliance rates for the VSC group. Besides the intervention effect, the Hawthorne effect, or the observation effect, might play a role in the efficacy of the VSC intervention [114]. The Hawthorne effect is defined as the tendency of people to change their behavior while being observed. The increase in the performance during the first two weeks of the intervention period (Time Section 2) could be the result of receiving a lot of attention from the VSC and the study clinician on the use of PSFs. The intervention of receiving education materials and recurrent meetings with the study clinician (the INS intervention) did not induce the Hawthorne effect because the performance was not improved until the last two weeks in the intervention period. In the rest of the weeks in the intervention period, participants in the VSC group just followed the reminders to reposition once every hour, which might make them feel that they had complied the recommendation and therefore decreased the frequency of using PSFs. Alternatively, the repositioning regimes might have improved their seating comfort, and therefore the participants did not need to reposition as frequently as in the early weeks in the intervention period. The VSC was developed to monitor and coach PSF usage, which was in a sense to facilitate compliance and PSF usage by inducing the feeling about being observed. The Hawthorne effect has been applied to enhance adherence to medication and hand hygiene guidelines [115, 116]. For the purpose of the VSC, the potential influence of the Hawthorne effect can be considered as part of the efficacy of VSC. Further studies are needed to investigate whether the performance induced by the VSC will decline after withdrawing the VSC.

The efficacy of the VSC intervention in decreasing discomfort intensity during the intervention period could be the results of increasing PSF usage and/or the Hawthorne effect, which could not be parted with this current study deign. Further studies are needed to investigate the effect of PSF usage and psychological support on perceived discomfort intensity for EPW users.

5.5.2 Users' Interaction And Comments After Using VSC

All the participants recognized the VSC's benefits of reminding them about appropriate repositioning. Three participants, two females and one male, liked the default setting with seeing and hearing a female clinician to give reminders with text displayed. Four out of six participants, including the one later switched to the INS group, did not feel the need to change the display effects. All VSC participants felt that there was no need to increase the options of display effects. One common design principle of computer interface or applications is to provide users with the capacity to personalize their interface, which is similar to the participants' comments in our survey study about preference for display effects [82]. However, Spool found that less than 5% of the Microsoft Word users changed the settings, and users assumed that the program was already in its optimal settings [117]. Information overload and the anxiety about the possibility of breaking a research device while exploring the settings may have affected participants' motivation subconsciously to personalize display effects [118]. In this condition, the default settings become an important element that can influence users' satisfaction and usage of the device.

Participants 15 and 21 felt that they did not need repositioning reminders because they knew how to use the wheelchair and take care of themselves. Participant 15 especially disliked the encouragement "Good job!" after the VSC detected that he had completed a successful repositioning. He felt that a confirmation of task completion would be sufficient for him. It is very common to find in studies that encouragement of animated agents facilitate users to engage in the learning program and increase motivation [119, 120]. However, some details in the agent's characters, as simple as nodding, may trigger negative effects [121]. Although only one participant expressed negative perception about this particular element, this finding is a reminder that users' reactions and satisfactions to animated agents could be influenced by many detail characters of the agent and the user.

5.5.3 Limitations

5.5.3.1 Study Design

The study was designed to provide quality clinical care to research participants in the study. As such, a group using the VSC without any user training program was not included in the study, and the efficacy of VSC alone remains unknown.

The intervention period of this study lasted 8 weeks, which was short compared to the majority of the studies using mobile phones as a media to deliver behavior change intervention lasting 3-12 months [113, 122, 123]. The current version of the VSC involved permanent modifications on EPWs for the purpose of research, which required participants to use study EPWs instead of their personal chairs. The duration that the participants could use the study

EPW was limited because these study EPWs were purchased for general use, and did not fit participants as well as their personal chairs.

5.5.3.2 Small Sample Size With Larger Variability Between Participants

Only 40% of 258 clients who were recommended to use EPWs with PSFs were eligible for the study, and around half of eligible individuals were in an appropriate condition to be recruited to participate in the study. Only 10% of 258 individuals recommended to use PSFs participated in the study. Providing a study chair could be beneficial for some individuals while waiting for their new chairs, but could also be stressful for the majority of individuals to get used to another chair and participate in the study during the process of getting a new chair. Additionally, the study requirement of using the VSC may not be feasible for all the participants because it may interfere with transfers and performing desk tasks. Although the results showed that the VSC intervention generated a large effect size in increasing the compliance rate, most researchers would suggest recruiting more participants in order to increase the power of the study. Revising the VSC to be smaller in dimensions and to be simple / portable to be installed on any personal wheelchairs may help to increase the motivation of the potential participants to join the study. There is large variability in ages, motor functions, cognitive functions, sensory functions, living environments, etc., among people with disabilities. These variations would decrease the power of the statistic analyses comparing between groups. A well-planned single subject design or small-N design study might be more feasible to provide the evidence base of the effectiveness of the intervention.

5.5.4 Future Studies

Foreseeing the potential impact of VSC on improving quality of life of EPW users and effectiveness of health care, it would be valuable to develop a smartphone version of the VSC. Primary design goals of the Smartphone Based Virtual Seating Coach (SP-VSC) are: 1) the system only requires simple hand tools for installation; 2) the system can be installed on most EPWs; 3) the interface is user-friendly and incorporated into regular smartphone usage; 4) the size of the system should be minimized compared to the VSC of the tablet version. A small-N design study can be utilized to analyze the effect on facilitating compliance with recommended repositioning regimes.

The VSC consisted with a series of encoders and sensors to maximize its capacity of monitoring and recording EPW and PSF usage, and therefore it needed extensive work to modify the study chairs. In order to apply the VSC in clinical practice, it is important to know how much complexity of a tailored reminder is needed to facilitate satisfying compliance rates. A SP-VSC connected with external sensors to detect seating angles and a SP-VSC using smartphone built-in Gyro sensors to estimate seating angles should be compared to investigate the appropriate level of device complexity to induce clinical significant effects.

5.6 COCLUSION

Twenty six participants were recruited in the study to evaluate the efficacy of the INS and VSC interventions, and 16 of them completed the intervention protocol. The VSC intervention of providing educational materials, recurrent meetings with a clinician and using the VSC increased the compliance rates with recommended repositioning regimes around 40%, while the INS intervention of providing educational materials and recurrent meetings with a clinician increased the compliance rates around 18%. The VSC intervention also increased PSF usage and decreased discomfort intensity. The participants recognized the benefit of the VSC in reminding periodical repositioning and provide instructions. With the significant efficacy in facilitating compliance rates shown in the study, the smartphone version of the VSC is developed in hope to provide more flexibility to be installed on personal chairs, and therefore benefit more EPW users.

6.0 REALTIONSHIPS BETWEEN POWERED SEATING FUNCTION USAGE AND QUALITY OF LIFE

6.1 INTRODUCTION

Powered seating functions (PSFs) are important features to assist users with health management, enhance seating comfort, and functional performance with activities of daily living (ADL) [22, 124]. Usage of electronic powered wheelchair (EPW) was shown to have positive impact on quality of life (QoL) [125-128]. Users reported that they were satisfied with PSFs [94, 104, 105, 129]; however, there were only a few studies looking into the relationships between PSF usage and QoL. The earliest study dated back to 1999 [130], and the investigators found participants who received EPWs with PSFs gave high ratings on the Psychosocial Impact of Assistive Devices Scale (PIADS). Another study in 2004 attempted to explore the impact of powered tilt and/or recline by interviewing participants, and concluded that powered tilt improved seating comfort, but involved issues with funding and transportation [129]. Other studies focused on how PSFs were applied in ADL based on participants' self-report and the patterns of PSF usage [104, 105, 131]. The relationships between the intensity of PSF usage and QoL for EPW users was unknown. The Virtual Seating Coach (VSC) was developed to be an electronic tailored reminder to facilitate PSF usage, and it was also capable to monitor and record daily EPW and PSF usage. The relationships between the intensity of PSF usage and QoL were explored and investigated through the objective measure of PSF and EPW usage by the VSC and QoL measured using standardized assessment tools in the study.

6.2 HYPOTHESES

Question 1: What was the relationship between PSF usage and four measures of QoL, including wheelchair seating tolerance, seating discomfort, satisfaction with the assistive device, independence, and community participation?

Hypothesis 1: Users who used their PSFs more frequently would also demonstrate higher levels of wheelchair usage (wheelchair occupancy and driving distance) due to their increased seating tolerance.

Hypothesis 2: The intensity of PSF usage would be inversely correlated to wheelchair seating discomfort, measured by Tool for Assessing Wheelchair disComfort (TAWC).

Hypothesis 3: The intensity of PSF usage would be positively correlated to user satisfaction with the device, measured by the Psychological Impacts of Assistive Devices Scale (PIADS).

Hypothesis 4: The intensity of PSF usage would be positively correlated with independence and community participation, measured by the Craig Handicap Assessment and Reporting Technique Scale (CHART).

Question 2: What user-specific factors may influence the relationship between PSF usage and QoL?

6.3 METHODS

6.3.1 Participant Recruitment And Study Protocol

The participant recruitment process and study protocol were the same as described in Chapter 4 Section 4.2 for the methods of participant recruitment and study protocol. Participants used study EPWs equipped with the VSC to monitor their PSF and EPW usage for 8 weeks, and were visited by a study clinician once every 2 weeks. Participants were asked to answer TAWC at each evening, answer PIADS at Visit 2, Visit 3, Visit 4, and Visit 5; and answer CHART at Visit 2 and Visit 5 (the end of baseline and intervention period).

6.3.2 Outcome Variables

Wheelchair seating tolerance, wheelchair seating discomfort, satisfaction with the assistive device, and community participation were measured to reflect QoL of EPW users. The intensity of EPW usage represented wheelchair seating tolerance, indicating the quantity of users' mobility independence in terms of duration and distance. EPW and PSF usage were recorded by the data logging function of the VSC on study EPWs. Wheelchair seating discomfort, satisfaction with the assistive device, and community participation were measured by standardized assessment tools as qualitative measures.

6.3.2.1 Quantitative Variables

EPW Usage- Wheelchair Occupancy (hr/day) and Driving Distance were two variables to measure EPW usage. The wheelchair occupancy of a day controls driving distance. Therefore, Driving Distance was normalized by the wheelchair occupancy of a day. The unit of normalized driving distance was km/hr.

PSF Usage- One time access of PSF was defined as staying in a certain seating angle more than 30 seconds (error range ±3 degrees) after adjusting the seating angle. The duration and frequency of PSF usage were categorized into three ranges: minimum, moderate, and maximum ranges, as shown in Table 2. The wheelchair occupancy of a day also governed the frequency of using PSFs. Therefore, variables of PSF usage were normalized by the wheelchair occupancy of the day. The variables of normalized PSF usage included:

1. Frequency of Repositioning: the frequency of accessing any ranges of tilt, recline, or elevating legrests per an hour (times/hr)
2. Frequency of Accessing Seat Elevation (times/hr)

6.3.2.2 Qualitative Variables

General Discomfort and Discomfort Intensity by TAWC- TAWC is used to measure daily wheelchair sitting discomfort [108, 109]. The TAWC consists of three sections. Section I is used to collect general information about the activities that the participant had engaged in over a day. The following two sections are two subscales, General Discomfort Assessment (GD) and Discomfort Intensity Rating (DI) [109]. For both subscales, a higher score indicates more discomfort. GD consists of eight statements related to discomfort and five statements related to comfort. The statement will be rated on a seven-point Likert scale with 1=strongly disagree and 7=strongly agree. GD scores may range from 13 to 91. DI includes seven body areas (back, neck, buttocks, legs, arms, feet, and hands) and overall discomfort level, that are rated for a degree of discomfort intensity on a scale of 0 (no discomfort) to 10 (severe discomfort). Space is also included for the user to list additional body areas. DI scores may range from 8 to more than 88, depending on whether the participant reported additional areas of discomfort.

PIADS- This tool is to measure perceived psychological impact of using an assistive device. It consists of three subscales, Competence (12 items), Adaptability (6 items), and Self-esteem (8 items)[132]. Each item receives a score from -3 to +3.

CHART- This tool is to measure independence and community participation. It consists of six subscales, Physical Independence, Cognitive Independence, Mobility, Occupation, Social Integration, and Economic Self Sufficiency [133]. The scores of Economic Self Sufficiency were not included in the analysis because many participants chose to skip this subscale.

6.3.3 Data Analysis

If the data were normally distributed, Pearson's correlation would be used to test the relationships between PSF usage measures of QoL. If the data were not normally distributed, Spearman's correlation would be used to test the relationships.

Correlations between PSF usage and measures of QoL were computed also for each participant. Although using Spearman's or Pearson's correlation violated the assumption of independent observation and ignoring the influence of autocorrelation, it has been a exploratory method to reveal the trend of correlations between longitudinal data [134, 135]. Correlation coefficients were treated as scores in this study to investigate the patterns of relationships between PSF usage and measures of quality of life.

Participants were categorized into two groups for each of the following user characteristics: the average of their ages, gender, level of education, the average years after diagnoses, the average years of EPW usage experience, PSF usage experience, transfer strategies, presence of daily attendant care, and ambulatory ability, to analyze the possible factors which may influence the patterns of correlations between PSF usage and QoL measures. These categorical factors were shown in Table 26. Because there were only a few participants with experience in using PSFs, participants were categorized based on whether or not they had experience in PSF usage, instead of the average years in PSF usage experience. Participants who performed standing-pivot transfer and were able to walk between furniture were categorized as "limited ambulatory". Mann-Whiteney U Test was used to test the effects of user characteristics on correlation coefficients. Because this an explorative analysis, an alpha level of 0.05 was set.

6.4 RESULTS

6.4.1 General Correlations between PSF Usage and Measures of QoL

Twenty-six participants were enrolled in the study, and 16 of them completed the study protocol. Because the data were not normally distributed, Spearman's correlation was used to analyze the relationships. Participants showed large variations in the strength and directions of their correlations between PSF usage (frequency of repositioning using PSFs and frequency of accessing seat elevation) and measures about QoL. Means and standard deviations of PSF usage and measures of QoL in Time Section 1 and Time Section 4 were listed in Table 25. The ranges of Spearman's correlation coefficients were shown in box plots of Figure 34 and Figure 35.

Table 25. Means and standard deviations of PSF usage and measures of QoL at Time Sections 1 and 4

	Time Section 1	Time Section 4
Frequency of Repositioning (times/hr)	1.99 ± 2.30	1.91 ± 2.28
Frequency of Accessing Seat Elevation (times/hr)	0.31 ± 1.30	0.34 ± 1.17
Wheelchair Occupancy (hr/day)	6.74 ± 4.75	6.59 ± 4.41
Driving Distance (km/hr)	1.19 ± 1.53	1.43 ± 1.80
TAWC: General Discomfort	41.99 ± 12.25	44.52 ± 12.31
TAWC: Discomfort Intensity	18.95 ± 9.38	17.08 ± 8.22
PIADS: Competence	19.56 ± 12.81	21.47 ± 13.15
PIADS: Adaptability	11.25 ± 5.50	11.53 ± 7.69
PIADS: Self-Esteem	12.06 ± 7.56	12.33 ± 8.86
PIADS: Total	42.88 ± 24.11	45.33 ± 29.24
CHART: Physical Independence	67.82 ± 25.33	67.55 ± 26.46
CHART: Cognitive Independence	70.75 ± 23.75	70.25 ± 26.08
CHART: Mobility	76.50 ± 24.17	75.69 ± 21.41
CHART: Occupation	39.00 ± 30.77	47.06 ± 34.61
CHART: Social Integration	80.50 ± 21.17	75.19 ± 22.22

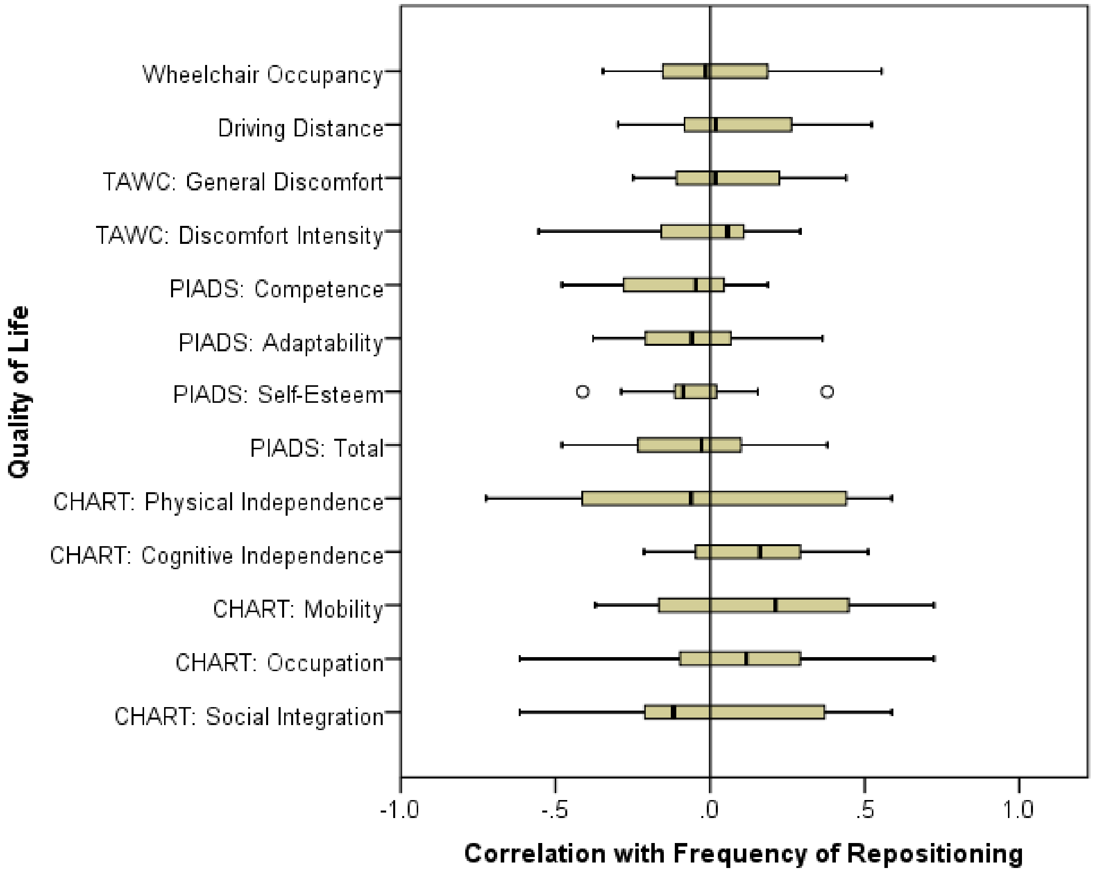


Figure 34. Correlation coefficients between frequency of repositioning using PSFs and measures of QoL

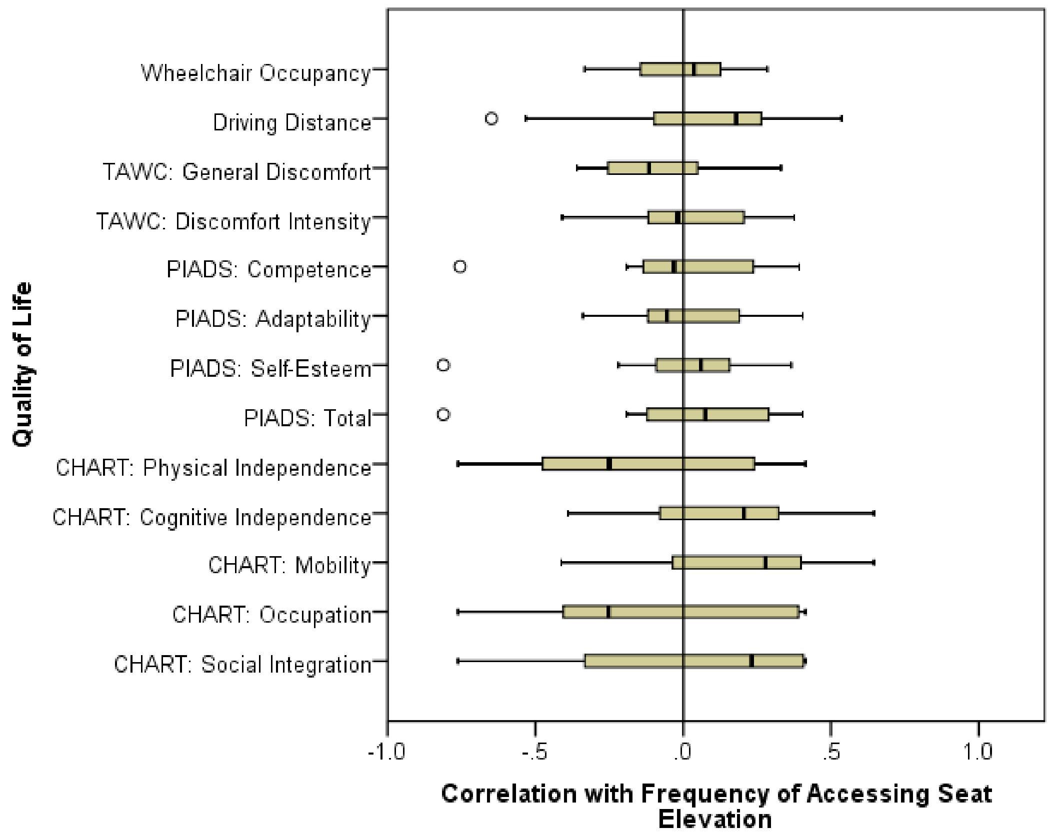


Figure 35. Correlation coefficients between frequency of accessing seat elevation and measures of QoL

6.4.2 Potential Factors Affecting Correlations between PSF Usage and Measures of QoL

Percentages of participants in each group factors were shown in Table 26. No significant differences were found when grouping participants based on age, level of education, years since diagnoses, transfer strategies, and presence of daily attendant care. The group factors, including gender, experience in EPW and PSF usage, and ambulatory ability, were found to show significant impacts in the correlations between PSF usage and PIADS score and CHART scores. No significant differences were found in correlations between PSF usage and wheelchair seating tolerance and seating discomfort when categorizing participants with any of the factors. The impacts of gender, experience in EPW usage, experience in PSF usage, and ambulatory ability were presented in the following sections.

Table 26. Percentages of participants in each categorical factor

Potential Factors	Percentage (count) (Total n = 16)
Gender: Female	44% (7)
Age	51.5 ± 12.4 years old
> 52 years old	50% (8)
Received Education More Than Some College	56% (9)
Years since Diagnoses	19.5 ± 10.6 years
>20 years	38% (6)
Experience in EPW Usage	6.9 ± 7.0 years
> 7 years	38% (6)
Novice EPW User	25% (4)
Experience in PSF Usage: Novice PSF User	75% (12)
Dependent Transfer	31% (5)
With Daily Attendant Care	25% (4)
Limited Ambulatory	44% (7)

6.4.2.1 Gender

A significant difference was found in the correlation coefficients between CHART Mobility scores and frequency of accessing seat elevation between female and male participants (U = .00, z = -2.24, p = .036, r = -0.79). Male users tended to show positive correlations between CHART Mobility scores and frequency of accessing seat elevation, as shown in Figure 36.

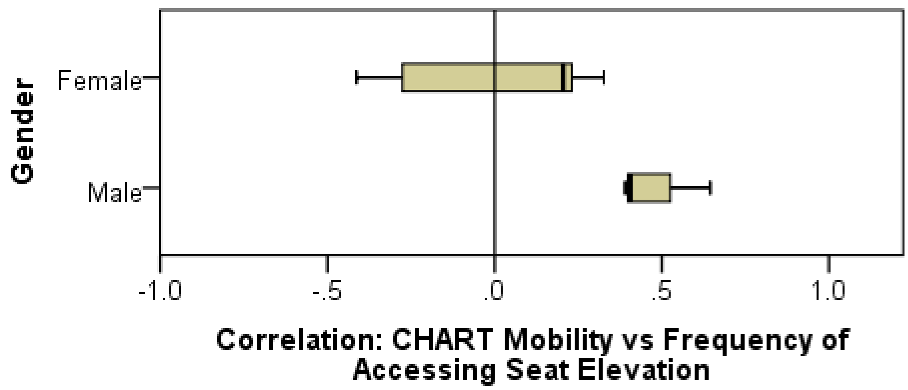


Figure 36. Correlation between CHART Mobility scores and frequency of accessing seat elevation for female and male participants

A significant difference was found in the correlation coefficients between CHART Occupation scores and frequency of repositioning using PSFs between female and male participants (U = 3.00, z = -2.19, p = .030, r = -0.66). Female users tended to show positive correlations between CHART Occupation scores and frequency of accessing seat elevation, as shown in Figure 37.

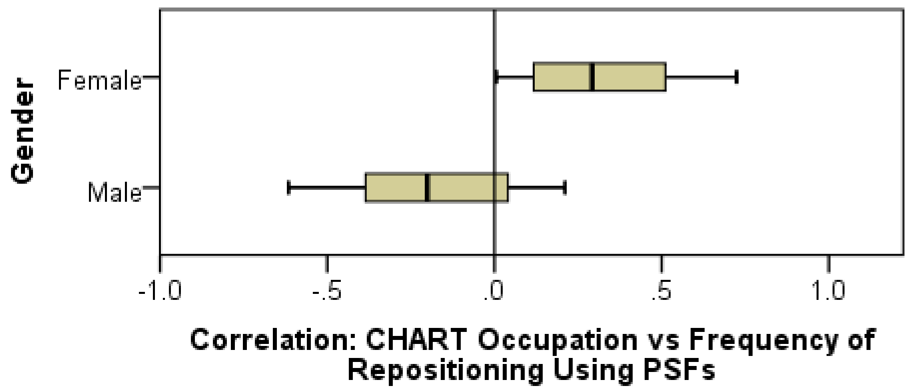


Figure 37. Correlation between CHART Occupation scores and frequency of repositioning using PSFs for female and male participants

6.4.2.2 Experience in EPW Usage

A significant difference was found in the correlation coefficients between PIADS Adaptability scores and frequency of repositioning using PSFs between participants with EPW usage experience more than 7 years and less than 7 years (U = 10.00, z = -2.17, p = .030, r = -0.54). Participants with more years of EPW usage tended to show positive correlations between PIADS Adaptability scores and frequency of repositioning, as shown in Figure 38.

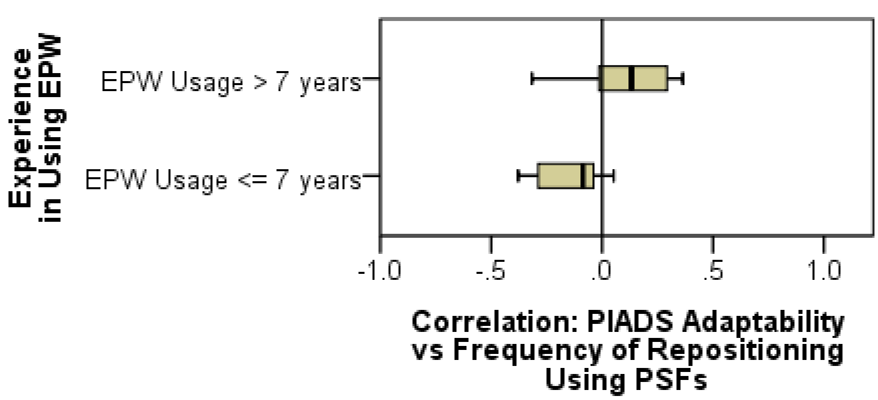


Figure 38. Correlation between PIADS Adaptability scores and frequency of repositioning using PSFs for participants with EPW usage experience more than 7 years and less than 7 years

A significant difference was found in the correlation coefficients between PIADS Total scores and frequency of repositioning using PSFs between participants with EPW usage experience more than 7 years and less than 7 years (U = 8.00, z = -2.39, p = .016, r = -0.60). Participants with more years of EPW usage tended to show positive correlations between PIADS Total scores and frequency of repositioning, as shown in Figure 39.

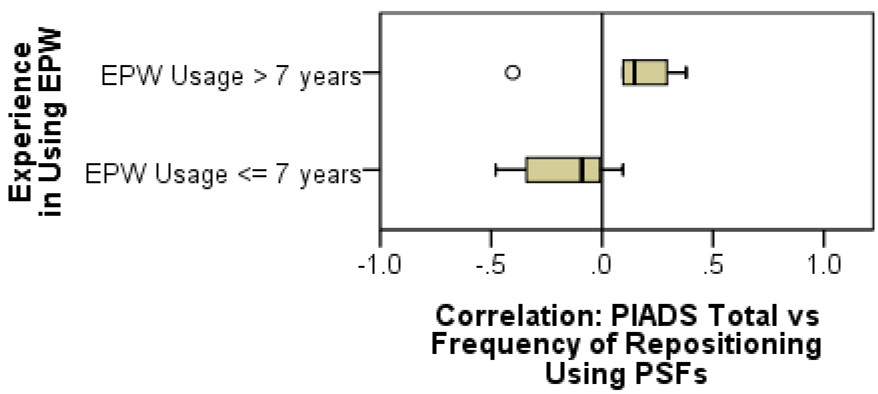


Figure 39. Correlation between PIADS Total scores and frequency of repositioning using PSFs for participants with EPW usage experience more than 7 years and less than 7 years

A significant difference was found in the correlation coefficients between CHART Social Integration scores and frequency of repositioning using PSFs between participants with EPW usage experience more than 7 years and less than 7 years (U = 1.00, z = -2.07, p = .048, r = -0.69). Participants with more years of EPW usage tended to show positive correlations between CHART Social Integration scores and frequency of repositioning, as shown in Figure 40.

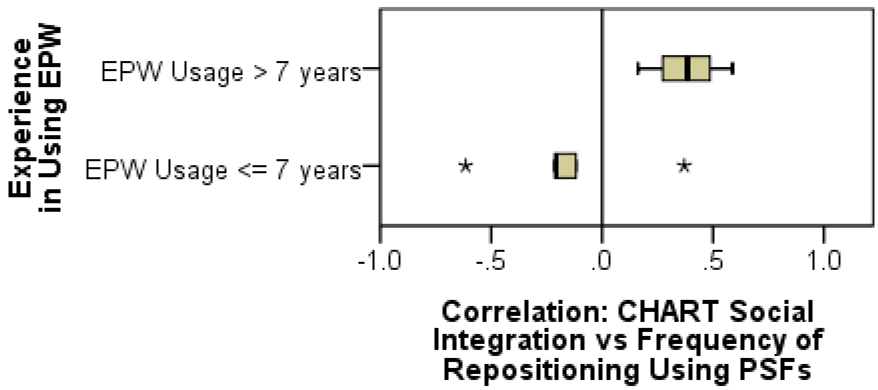


Figure 40. Correlation between CHART Social Integration scores and frequency of repositioning using PSFs for participants with EPW usage experience more than 7 years and less than 7 years

6.4.2.3 Experience in PSF Usage

A significant difference was found in the correlation coefficients between PIADS Adaptability scores and frequency of repositioning between novice PSF users and experienced PSF users (U = 6.00, z = -2.18, p = .030, r = 0.55). Experience PSF users tended to show positive correlations between PIADS Adaptability scores and frequency of repositioning, as shown in Figure 41.

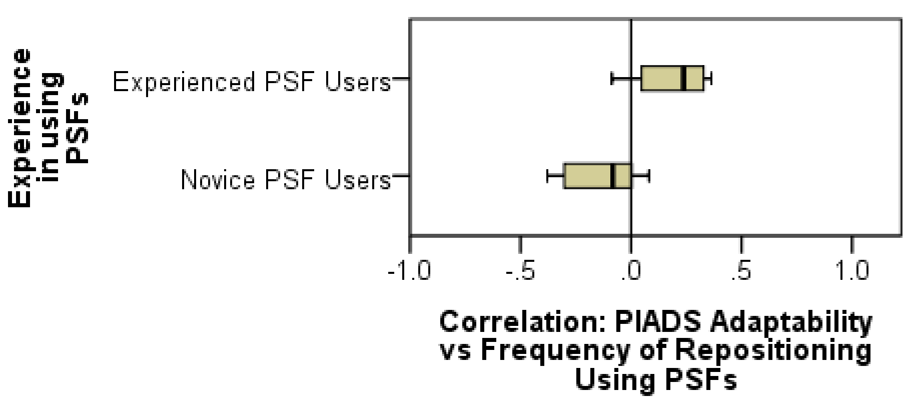


Figure 41. Correlation between PIADS Adaptability scores and frequency of repositioning using PSFs for participants who were experienced and novice PSF users

A significant difference was found in the correlation coefficients between PIADS Total scores and frequency of repositioning between novice PSF users and experienced PSF users (U = 7.00, z = -2.06, p = .042, r = 0.52). Experienced PSF users tended to show positive correlations between PIADS Total scores and frequency of repositioning, as shown in Figure 42.

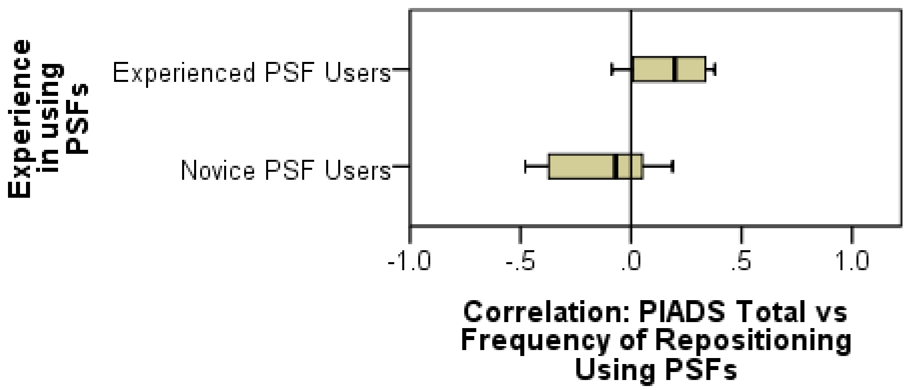


Figure 42. Correlation between PIADS Total scores and frequency of repositioning using PSFs for participants who were experienced and novice PSF users

6.4.2.4 Ambulatory Ability

A significant difference was found in the correlation coefficients between PIADS Competence scores and frequency of accessing seat elevation between participants who were not ambulatory and limited ambulatory (U = 6.00, z = -2.32, p = .020, r = 0.62). Participants who were not ambulatory tended to show positive correlations between PIADS Competence scores and frequency of accessing seat elevation, as shown in Figure 43.

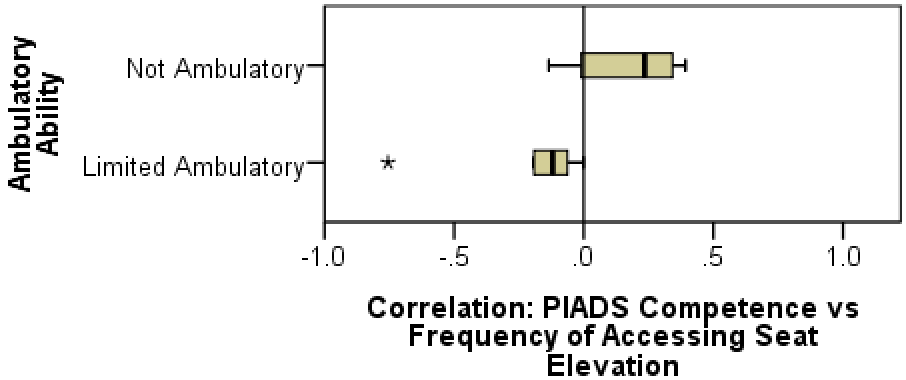


Figure 43. Correlation between PIADS Competence scores and frequency of accessing Seat elevation for participants who were not ambulatory and limited ambulatory

A significant difference was found in the correlation coefficients between PIADS Total scores and frequency of accessing seat elevation between who were not ambulatory and limited ambulatory (U = 6.00, z = -2.48, p = .012, r = 0.64). Participants who were not ambulatory tended to show positive correlation between PIADS Total scores and frequency of accessing seat elevation, as shown in Figure 44.

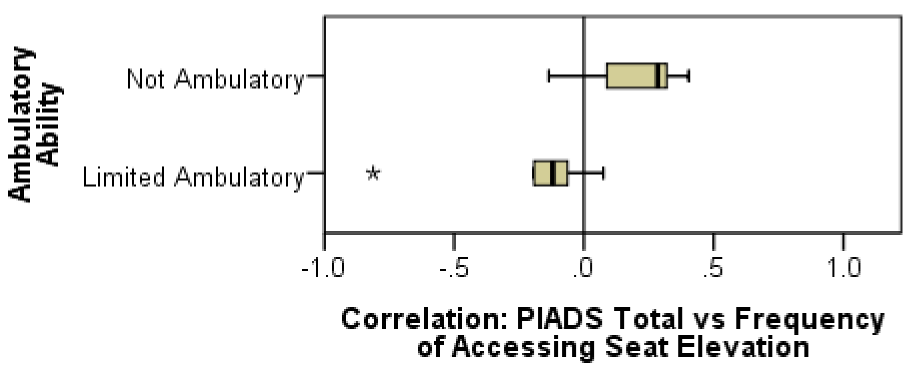


Figure 44. Correlation between PIADS Total scores and frequency of accessing Seat elevation for participants who were not ambulatory and limited ambulatory

6.5 DISCUSSION

6.5.1 Relationships among PSF Usage, Perceived Seating Discomfort, and Wheelchair Seating Tolerance

Our findings showed that correlations between PSF usage and seating discomfort (general discomfort and discomfort intensity), and between PSF usage and wheelchair seating tolerance (wheelchair occupancy and driving distance) were different among participants in their directions and strength. Even though the subscale Discomfort Intensity is asking the discomfort when sitting in the wheelchair, it had been reported that the Discomfort Intensity Rating is highly correlated with pain intensity rating measured by McGill Pain Questionnaire [136]. Pain experienced by EPW users can be affected by EPW usage or other underlying medical issues [103]. In a qualitative study by Frank et al., 59% (38 out of 64) participants felt that their pain was influenced by their EPW, and only 5% reported that they used recline and/or tilt to reduce pain [103]. Besides, duration of EPW usage had been reported to be positive correlated with seating discomfort or pain [103, 137]. Based on a comfort model proposed by Vink et al., as shown in Figure 45, EPW and PSF usage (I, Interaction between human, device, and usage) will affect human effects (H, human effects, such tactile sensation and posture change). Human effects and expectation (E) will affect how the individual perceive the effects (P, perceived effects), and then result in the feeling of comfort (C), nothing (N), and discomfort (D). E and C are circled because expectations are often linked to comfort. Discomfort may further develop into musculoskeletal complaints (M). And, discomfort will affect the usage of the device [138]. Clinically it is commonly assumed that individuals who use PSFs with higher frequency would experience less seating discomfort, and therefore would show increased wheelchair seating tolerance, as hypothesized in the study. However, it was found in this study that, some individuals who experienced more seating discomfort might use PSFs with higher intensity, and some participants who stayed in the EPW longer and travel further might use PSFs with less intensity. More in-depth data analyses was needed to reveal the relationship among PSF usage, seating discomfort, and wheelchair seating tolerance.

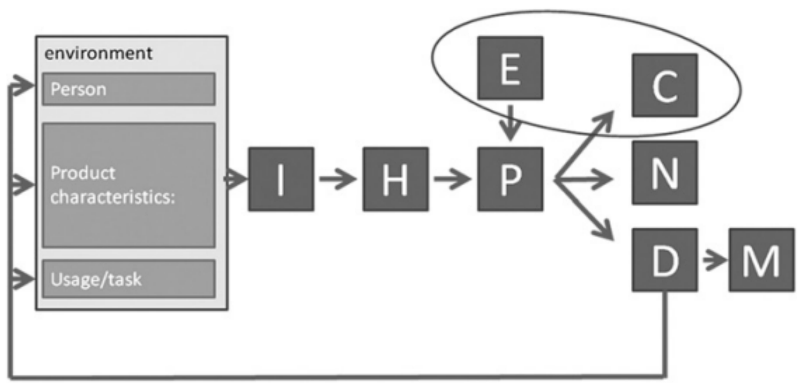


Figure 45. Comfort model proposed by Vink et al. in 2012

6.5.2 Relationships between PSF Usage and Community Participation

Participants showed wide ranges of directions and strength in correlations between PSF usage and CHART scores. CHART Cognitive Independence and Social Integration scores could be inversely correlated with fatigue [139], Occupation scores could be inversely correlated with caregiver distress [140], Physical Independence and Occupation scores could be affected by education on device usage [111], and scores of all the subscales could be affected by the changes in motor function [141], family function, depression, and anxiety [142]. The wide range of correlations found in the study implied that each users may have her/his own dynamics among PSFs, independence, and community participations. More studies are needed to determine how to evaluate and interpret independence and community participation as outcome measurements of recommending EPWs with PSFs.

6.5.3 Impact of Gender

Men tended to experience fewer barriers when facing the usage of medical devices and a more positive attitude than women [143]; however, men also showed more negative correlation between their disabilities and QoL and social function [144, 145]. Similar findings emerged when examining gender difference in this study. Male participants showed clear and positive correlation between CHART Mobility scores and usage of seat elevation. The more male participants used the powered seat elevation function, the more they moved around. On the contrary, female participants showed positive correlation between CHART Occupation scores and frequency of repositioning using PSFs. This finding may indicate that female users may be more open to use PSFs while they were participating in work and recreational activities.

6.5.4 Impact of Experience In Using EPWs And PSFs

It was shown in the study that the participants who were more experienced in using EPWs and PSFs tended to show positive correlations between PSF usage and measures of QoL. The study by Harvey et al. found that higher intensity of assistive device usage was related to more satisfaction [146]. Our findings implied that familiarity with the EPW and PSFs would affect satisfaction and QoL. Users may also need a significant amount of time to digest the changes required or resulted from an EPW with PSFs. A study compared the usage of EPW and pushrim-activated powered-assisted wheelchair (PAPAW), and found that, even participants received higher performance scores rated by clinicians while using PAPAW, participants gave lowered PIADS scores for PAPAW than they did for EPWs [147]. Another study comparing two control modes for robotic arms found that users had lower tolerance for decline in the device performance than they had for decline in their own performance [148]. Both studies showed the anxiety of users facing new devices or technology. How a user interprets the usage of a mobility device and expects the change resulted from the usage may affect the perspective about using the device [92], and familiarity and usage history with the device may affect the interpretation and expectation toward the device.

6.5.5 Impact of Ambulatory Ability

Although some studies have found that users were positive about the transition to use EPWs [127, 128], some users and caregivers worried about losing ambulation functions by using EPWs, especially shown in the studies on children and adolescences with cerebral palsy [149-151] and progressive neuromuscular diseases [152-154]. Parents reported the mixed feeling about their son's transition to a EPW because they mourned their child's loss of ambulation but also felt optimistic as their children had mobility independence [155, 156]. It is a process of negotiating, beginning with self-awareness of symptoms, subsequent fear of falling, decision regarding assistive devices, and then transitioning to wheelchair usage, marked by loss and discovery of independence and freedom [156]. The study participants who had limited ambulation might be in this negotiating process, and therefore they tended to show inverse correlations between perceived psychosocial impacts of the device and usage of seat elevation. Users who are in the transition between ambulation and EPW usage may need some time and support to accept the usage of powered seat elevation.

6.5.6 Limitations

Spearman's correlation was a liberal method to explore the trend of correlations between PSF usage and QoL. However, serial dependency in the outcomes of repeated measurements may confound the correlation analysis. Furthermore, the potential effect of study interventions were not included in data analysis in this chapter. Findings from this study provide a foundation to estimate potential causal relationships between PSF usage, seating discomfort, wheelchair seating tolerance, and interventions of user training in order to perform more detail analysis, such as Structure Equation Modeling, controlling for serial dependency.

6.6 CONCLUSION

Participants showed large variations in the directions and strength of correlations between PSF usage and measures of QoL, which implies that there was a large variability among participants' behaviors, perspectives, and experience in using EPWs related to PSF usage. Although PSFs assist user to perform activities and manage health issues, gender, experience and history in using EPWs and PSFs, and status of motor functions could affect the relationship between PSF usage and perceived QoL. Customized user training and support may be needed to facilitate positive and smooth experience in EPW and PSF usage.

7.0 CONCLUSION

7.1 SUMMARY

Based on the results from this research project described in this dissertation, the Virtual Seating Coach (VSC) in conjunction with educational materials and recurrent meetings with a clinicians significantly increased participants' compliance with recommended repositioning regimes for health management using powered seating functions (PSFs). It was challenging to recruit electric powered wheelchair (EPW) users to participate in the study; however, this experience supported the need to revise the VSC to become smaller and portable in order to be applied in clinical practice. The study participants demonstrated various relationships between PSF usage and measures of quality of life (QoL), indicating the need of personalized educational programs to enhance PSF usage and QoL for EPW users.

Findings from the interview study described in Chapter 2 showed that the recommended methods and positions in using PSFs should be determined with consideration for individual preferences, physical condition, environmental settings, and desired tasks after thorough clinical seating assessments. A PSF user guide was developed based on the findings from this interview study. Besides using PSFs to assist with daily tasks and managing physical conditions and health issues, precautions about positioning and driving safety, and the importance of discussing with clinicians are emphasized in the user guide. The recommendations collected from this study were applied to develop the VSC.

Findings from Chapter 4 showed that people who were recommended to use a EPW with PSFs might go through a transition process to change their life style and modify living environments, and some individuals may need additional user education and psychological supports to make the best use of the device. The study wheelchairs were too large for some EPW users to navigate in their houses. Participating in a study requiring to use a study EPW may be stressful for them. Many participants who required customized configuration and modifications on their personal wheelchairs. They were not eligible to participate in the study because the study chairs could not be modified for advanced customized features. For some participants, the tablet version of the VSC interfered with transfers and desk tasks, and therefore they withdrew from the study or switched to the other study group. Technical problems of the VSC may result from repetitive usage and vigorous vibration while driving outdoors. The VSC is revised to be smaller and able to be installed on virtually any personal EPWs without permanent modifications on the chairs. When planning studies on people with disabilities to evaluate the effect of an intervention or a device, small-N design can be considered to overcome the challenges of large variability among participants and small sample sizes.

Findings from Chapter 5 showed that participants who received a training program, including providing instructions through educational materials and recurrent meetings with a clinician to discuss PSF usage (the INS intervention), progressed slowly in the improvement of their compliance with repositioning regimes and no changes in the level of seating discomfort. The intervention of the VSC in conjunction with the training program (the VSC intervention) increased the compliance rates by 38.6% and decreased wheelchair seating discomfort.

Participants received the INS intervention reported that they forgot to reposition, thought they had followed the recommended regime, or insisted that they knew when and how to reposition for health management. Participants who had used the VSC recognized the benefit of being reminded for periodical repositioning, and were satisfied with the interface design and display effects. Although the participants in the survey study suggested that the VSC should provide more options of display effects for personalization, only one out of five participants who had used the VSC in the efficacy study changed the display effects. None of them felt the need to increase the selections of display effects. Revising the VSC to be smaller was the consensus that the participants recommended after using the VSC for the study.

Findings from Chapter 6 showed that participants had large variability in the directions and strength of correlations between PSF usage and measures of QoL. Gender, experience in EPW and PSF usage, and ambulatory ability may affect the relationships between PSF usage and QoL. Male participants showed positive correlations between powered seat elevation usage and Mobility scores measured by CHART; and females showed positive correlations between Occupation scores measured by CHART. Participants with more experience in EPW and PSF usage tended to show positive correlations between PSF usage and satisfaction with the device. Participants who were limited ambulatory tended to show negative correlations between PSF usage and satisfaction with the device. More studies are needed to determine how to interpret the measures of QoL as outcome measurements for the effect of PSF usage. More in-depth analyses, such as structural equation modeling, can be performed to investigate relationships between PSF usage and measures of QoL, controlling for the serial dependency in repetitive measured variables.

7.2 FUTURE WORK

The VSC had showed its potential to extend user education beyond clinical settings and efficacy in increasing compliance with recommended repositioning regimes. In order to broaden the applicability of the system and adapt it to the day-to-day lives of EPW users, the need is identified to develop a smartphone-based VSC (SP-VSC) system for more user-friendly experience and efficient application in clinical settings. Primary design goals of the SP-VSC are: 1) the system only requires simple hand tools for installation; 2) the system can be installed on most EPWs; 3) the interface is user-friendly and incorporated into regular smartphone usage; 4) the size of the system should be minimized compared to the VSC of the tablet version. A usability study will be conducted to ensure end-users' participation in the design process. The effect of the SP-VSC will be evaluated by a long-term intervention study with a small-N and A-B-A-B design to reveal the behavior change, usage of the SP-VSC, and the efficacy of the intervention on a personal level.

The VSC of the tablet version consisted with a series of encoders and sensors to maximize its capacity of monitoring and recording EPW and PSF usage. In order to apply the VSC in clinical practice, it is important to know how much complexity of a tailored reminder is needed to induce a satisfying compliance rate. A study can be conducted to compare the efficacy of a SP-VSC connected with external sensors to detect seating angles and another SP-VSC using smartphone built-in Gyro sensors to estimate seating angles. This study may help to indicate the appropriate level of complexity for a tailored coaching device to induce clinical significant effects.

The challenges of recruiting EPW users to participating in the study and the various relationships between PSF usage and measures of QoL may imply the need to conduct qualitative studies to reveal and document the challenges that novice users may face throughout the process from preparing for accommodations to use an EPW with PSFs to regularly use the EPW in daily living. This information will provide the foundation to plan more effective user training and support programs to facilitate smooth and positive user experience for novice users and encourage them to make the best use of an EPW with PSFs.

APPENDIX A

RECOMMENDATIONS COLLECTED FROM THE QUESTIONNAIRE AND INTERVIEW

Category	Activity	Method	Variability in the methods
Pressure Relief	Positioning for effective pressure relief	(1) For users at high risk of developing pressure sores: A large angle of tilt or the combination of tilt and recline should be used to perform effective pressure relief on a regular basis. Elevating legrests are used as needed. (2) For users not at high risk of developing pressure sores: Keep doing whatever they do for pressure relief	**Positions:** • >45º of tilt • 45º of tilt + 120º of recline • 45º of tilt + 105º of recline • 35º of tilt + 100º of recline • 20º of tilt + 120º of recline **Duration and frequency:** • 30 seconds per 30 minutes • 1 minute per hour • 2 minutes per hour • ≥5 minutes per 0.5-1 hour • 10 minutes per hour

Category	Activity		Method	Variability in the methods
Environment	Driving		Small angle of tilt is necessary to improve sitting stability.	Tilt angles: • 5°-15° • 10°-15° • 10°-20° • 10°-25°
	Ramp	Driving Downhill	Depending on how steep the slope is, tilt the seat to make the seat level.	
		Driving Uphill	The seat and backrest should be upright.	
	Reaching		Depending on how high the target is, increase seat height to avoid elevating arms over shoulder.	

Category	Activity	Method	Variability in the methods
Assist with Transfers	Lateral transfer	Adjust the seat height using seat elevation to perform gravity-assisted transfer.	
	Standing pivot transfer	Adjust the seat height using seat elevation to decrease the moving distance and strength demand while standing up or lowering down into the seat.	Timing to adjusting the seat height during standing up: • Scoot forward to the edge of the seat, and then elevate the seat • Elevate the seat, and then scoot forward to the edge of the seat • Adjust seat height while scooting forward

Category	Activity	Method	Variability in the methods
Assist with Transfers	Dependent transfer (Mechanical lift)	Use PSFs to adjust the positions to ease the transfer process.	Position while lifting up the user: • Tilt + recline according to the need • 0° of tilt + 0° of recline • 10° -15° of tilt • 30° of tilt Position while lowering the user into the seat: • 10°-20° of tilt • 10°-20° of tilt + 100° of recline • 20° of tilt + recline according to the need • 30° of tilt • tilt + recline according to the need

Category	Activity	Method	Variability in the methods
Basic Body Position	Sitting	Tilt the seat to increase stability in a seated position and leverage gravity to save energy for maintaining an upright posture.	Tilt angle: • 5°-15° • 10°-15° • 10°-20° • 10°-25°
	Lying flat	Tilt the seat first to increase stability, and then recline the backrest as far as the user needs to lie down.	Tilt angle before reclining the backrest: • 10°-20° • 20°
	Reposition upright	Make sure that the seat is tilted, and then decrease the recline angle of the backrest. Decrease the tilt angle as needed to get a functional position.	

Category	Activity	Method	Variability in the methods
Basic Body Position	Reposition if sliding forward	Use PSFs to help the user shift backward into the seat.	Tilt and recline angles: • 5°- 10° of tilt • 20° of tilt • 15°- 20° of tilt • 45° of tilt + 100° of recline • 40°- 45° of tilt + 100°-115° of recline + 45° of legrest elevation
	Help your caregiver to use proper body mechanics	Adjust the seat height to minimize the bending movement of the caregiver.	

Category	Activity	Method	Variability in the methods
Special Considerations	Neck or back pain	PSFs should be used according to individual preferences to obtain the position that will decrease discomfort. The user should use PSFs to change his position whenever he needs.	
	Spasticity in lower limbs or trunk	(1) General position: Sitting in a tilted position will help to improve stability and comfort. The actual angle varies according to individual preference. (2) Accommodation posture change: Using powered tilt and recline to obtain a lying position for accommodating extensor thrust to prevent falling and increase comfort. The actual angle varies according to individual preference.	

Category	Activity	Method	Variability in the methods
Special Considerations	Swelling in lower limbs	Use PSFs to elevate feet above heart level to facilitate fluid return. Clinical assessment is needed to determine the proper positioning using PSFs to achieve the posture.	
	Contractures and/or muscle tightness in lower limbs or trunk	Use PSFs to accommodate or provide range of motion. Clinical assessment is needed.	Three clinicians suggested that PSFs can be used to provide range of motion with careful assessment and under supervision. Two recommended that PSFs should be used to accommodate the limitation of range of motion.
	Other physiological conditions	Using PSFs appropriately may help to improve breathing, swallowing, coughing, speaking, bladder or bowl functions, and symptoms of orthostatic hypotension. The proper positions vary according to individual conditions and preferences.	

Category	Activity	Method	Variability in the methods
Precautions about Using Powered Seating Functions		(1) It is not advisable to sit in a 90-90-90 posture all the time. (2) Tilt the seat before reclining the backrest to maintain sitting stability and decrease shear force on the skin. (3) Recline the backrest before elevating the legrests to release the tension in hamstrings. (4) The user needs to drive carefully while the seat is tilted and/or the backrest is reclined because of the increase in turning radius. (5) When the seat is elevated, the user needs to drive carefully around the table because the legs may get caught by the table. (6) Some wheelchairs would go slowly when using PSFs.	

APPENDIX B

POWERED SEATING FUNCTION USER GUIDE

University of Pittsburgh &
Human Engineering Research Laboratories

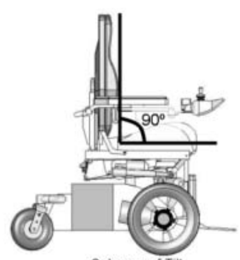
Powered Seating Functions User Guide

CONTENTS

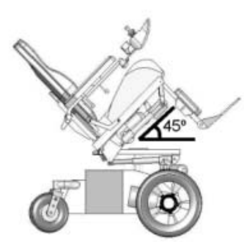
What are Powered Seating Functions?

Powered Seating Functions are optional features of a wheelchair seating system. These functions include tilt-in-space, recline, elevating legrests, and seat elevation. All of them can be equipped with a wheelchair at the same time, but it can also be just one or some of the functions equipped with the wheelchair.

Tilt indicates that the entire seating system is shifted backward, but the angle between the back and seat remains constant.



0 degree of Tilt



45 degree of Tilt

What are powered seating functions?

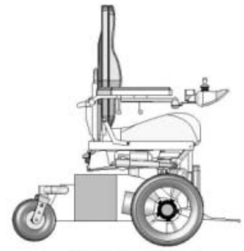
Three categories to indicate the TILT position:

	Degrees
Minimum	5-15
Moderate	15-30
Maximum	>30

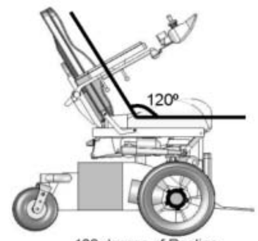
2

What are powered seating functions?

Recline is the change in seat to back angle, but the seat angle with the ground remains constant.



90 degree of Recline



120 degree of Recline

3

What are powered seating functions?

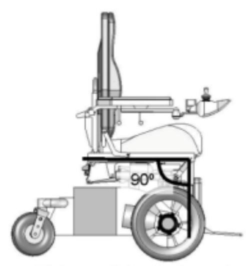
Three categories to indicate the RECLINE position:

	Degrees
Minimum	95-110
Moderate	110-130
Maximum	>130

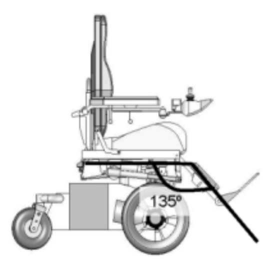
4

What are powered seating functions?

Elevating legrests will raise and lower the individual's lower legs in a seated position.



90 degree of Elevating Legrest



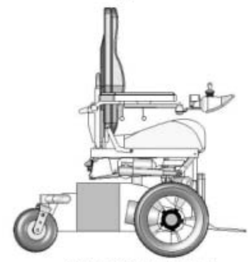
135 degrees of elevating legrests

5

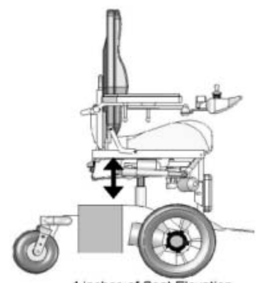
Three categories to indicate the LEGREST ELEVATION position:

	Degrees
Minimum	**<110**
Moderate	**110-130**
Maximum	**>130**

Seat elevation will raise or lower the individual in a seated position through the use of an electro-mechanical lift system.



0 inch of Seat Elevation



4 inches of Seat Elevation

What can Powered Seating Functions do for you?

Powered Seating Functions provide you with access to independent and dynamic posture adjustments. These functions can assist you with many activities and needs in your daily living:

- pressure relief
- assist functional activities
  - maintain sitting stability
  - facilitate reaching
  - assist with transfers
    - lateral transfer
    - pivot transfer
    - transfer with hoist lift
    - help your caregiver to use proper body mechanics
  - obtain lying back position
  - realign posture
- manage neck pain and back pain
- manage spasticity in lower limbs or trunk
- manage swelling in lower limbs
- manage muscle tightness in lower limbs and trunk
- help to facilitate body functions

The following content are recommendations for using power seat functions to assist with daily activities and needs. While using power seat functions, there are some precautions that will help to insure your safety. These precautions are listed at the end of this guideline.

Please consult your therapist or clinician when you have any questions about power seat function usage.

PRESSURE RELIEF

You may be considered at high risk of developing pressure sores, if you...

1. Currently have open wounds or pressure sores
2. Have a history of pressure sores
3. Have a loss of sensation or impaired sensation
4. Are extremely thin
5. Have uneven weight bearing due to an slanted pelvis, hip dislocation, scoliosis, or amputation
6. You cannot shift your weight and reposition yourself with your arms

If you are at high risk of developing pressure sores...

The following are commonly recommended positioning options for pressure relief:

1. Tilt only: Maximum Tilt
2. Combination of tilt and recline: Moderate Tilt + Moderate Recline; elevate the legrests as needed

- Since everyone has a unique body shape, your positioning for pressure relief may not be the same as others. Your clinician or therapist will work with you to find out the proper positions for pressure relief.

To have sufficient pressure relief, you should perform positioning on a regular basis:

1. once every hour for 2 minutes, or
2. once every 30 minutes for 1 minute

- ❖ If you have any questions, your clinician or therapist will work with you to find out the frequency and duration at which you should perform pressure relief.

If you are not at high risk of having pressure sores:

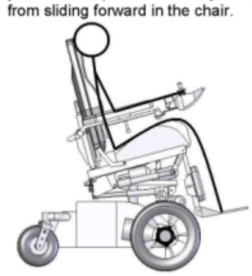
Keep doing your current method of pressure relief. Change your sitting posture using power seat functions as frequently as possible.

ENVIRONMENTAL CONSIDERATIONS

Driving

While you are driving the chair,

TILTING to the MINIMUM RANGE will help you maintain postural stability and prevent you from sliding forward in the chair.



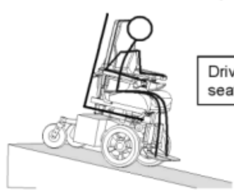
Driving with the seat tilted 15°.

Caution: Turning radius is increased when using tilt function. Be careful while driving in a narrow space, turning, and backing up as you may not turn as tightly as you do when not using the tilt function.

Ramp

While you are driving downhill on a ramp,

TILTING the seat within MINIMUM to MODERATE RANGE will prevent you from leaning forward and make you feel more stable. The proper tilt angle depends on how steep the ramp is. The steeper the ramp, the more tilt is needed for your seat to be level.



Driving downhill with the seat in upright position.

Driving downhill with the seat in 15º of tilt.

Caution: Before you drive uphill on a ramp, return the seat to an upright position to prevent from tipping over.

Reaching

If you would like to reach something above shoulder level,

Raise the seat height to a level so that the target object is about chest level. This helps to eliminate an extreme over head reach.

Reaching **without** the use of seat elevation.

Reaching **with** the use of seat elevation.

Caution: Be careful while driving close to a table or desk when using seat elevation. Your knees may hit the edge of the table due to increased seat height.

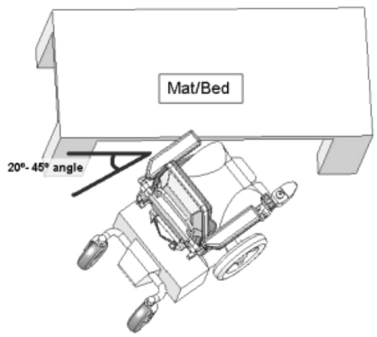
ASSIST WITH TRANSFERS

Lateral transfer

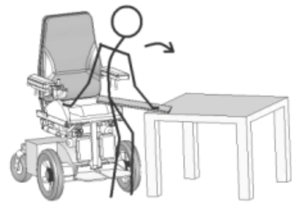
If you would like to transfer out of the chair using lateral transfer skills, there are a few things you should do before starting to transfer:

1. Return the seat to the upright position;

2. Position the chair as close to the target transfer surface as possible at approximately a 20-45° angle.



3. Adjust seat elevation such that **the seat of the chair is 1-2 inches higher than the target transfer surface** to allow for gravity to help you **(downhill transfer)**. If it is not possible to be higher than the target surface, the seat of your wheelchair should at least be level with the target surface.



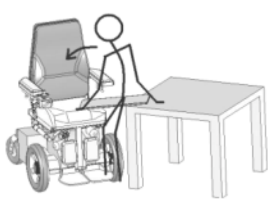
❖ The actual height should be determined according to your functional level and environmental settings. For example, the downhill side will sink in more if you are transferring to a softer surface (e.g. tempurpedic mattress) than to a firmer surface (e.g. foam mattress).

If you would like to transfer back to the chair using lateral transfer skills, there are a few things you should do before starting to transfer:

1. Make sure that the seat is level;

2. Position the chair as close to the starting surface as possible at approximately a 20-45° angle (as the figure shown on page 7);

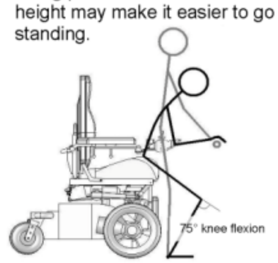
3. Adjust seat elevation such that **the seat is 1-2 inches lower than the starting surface** to allow for gravity to help you **(downhill transfer).** If it is not possible for the seat of the wheelchair to be lower than the target surface, both surfaces should at least be level with each other.



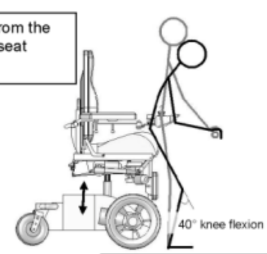
❖ The actual height should be determined according to your individual functional level and environmental setting. For example, the downhill end will sink in more if you are transferring back to a softer surface (e.g air cushion) than to a firmer surface (e.g. honeycomb cushion).

Standing pivot transfer

Using power seat elevation to adjust the seat height may make it easier to go from sitting to standing.



Standing up from the chair with no seat elevation.



Standing up from the chair with 4 inches of seat elevation.

<u>If you want to transfer out of or stand up from the chair.</u>

1. Return to an upright position if you were using tilt or recline, and make sure the seat is level before starting to transfer

2. Make sure the footrests are moved out of the way.

3. Scoot forward to the edge of the seat. Make sure that both of your feet are positioned flat on the ground in a stable position. Hold onto the armrests of the wheelchair to insure your sitting balance.

4. Increase the seat height using seat elevation. The seat height is adjusted according to your functional level and preference (e.g. muscle strength, leg length, or the height of the grab bar)

5. Hold onto the armrests of the wheelchair, and then stand up

6. Make sure you are stable in the standing position, and then move your hands onto the walker.

❖ The order of steps 3 and 4 can be reversed according to what is more comfortable and safer for you. Your clinician or therapist will work with you to practice and figure out the proper seat height and method.

<u>If you want to transfer back to the chair with the assistance of a caregiver</u>

1. Move the footrests out of the way and make sure the seat is level before starting to transfer

2. Raise the seat height using seat elevation. The seat height is adjusted according to your functional level and preference (e.g. muscle strength, leg length, or the height of the grab bar)

3. Carefully step back as close as possible to your wheelchair (you may want your caregiver to drive the chair as close to you as possible)

4. Move your hands onto the armrests of the wheelchair.

5. Lower yourself and sit on the edge of the seat

6. Lower the seat height (you may need assistance from your caregiver).

7. Scoot backward into the seat.

❖ The order of steps 5 and 6 can be reversed according to what is more comfortable and safer for you. Your clinician or therapist will work with you to practice and figure out the proper seat height and method.

Dependent transfer

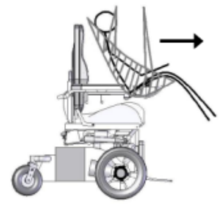
While your caregiver is setting up the sling

1. To help your caregiver to slide the sling behind you, return the seat to an upright position and lean your trunk forward if you can tolerate.
2. Recline the backrest as needed to give more space to help your caregiver to tuck the sling underneath your hips.

To be lifted up and transferred out,

1. To have better alignment with the sling when being raised by the lift, you may **TILT** the seat to the **MODERATE RANGE** as needed.

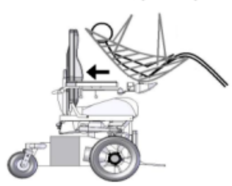
2. To clear your buttocks from the seat, tilt the seat forward.



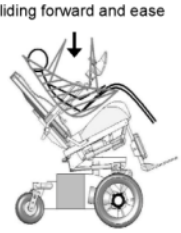
3. Now, your caregiver can transfer you out of the chair.

To be transferred back and lowered in the seat,

1. To clear your buttocks from the seat, you may tilt the seat forward.
2. Your caregiver can transfer you back to the seat.



3. To prevent you from sliding forward and ease your initial positioning in the wheelchair, **TILT** the seat to the **MODERATE RANGE** and recline the backrest as needed.



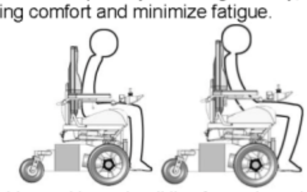
4. Now, your caregiver can lower you into the seat.
5. It would be easier to take off the sling if the seat was tilted forward.

❖ Since everybody has a unique body shape and condition, you may find your own way of using power seat functions to assist with hoist lift transfer. Please consult with your therapist and clinician if you have any question.

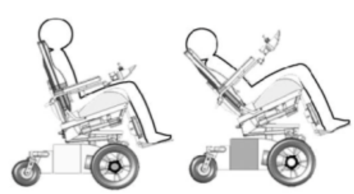
BASIC BODY POSITION

Sitting in General

TILT the seat and **RECLINE** the backrest as you need to improve your sitting stability, seating comfort and minimize fatigue.



Slouching and buttocks sliding forward are the indications that you are fighting the gravity to sit upright.

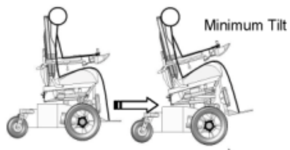


By using Tilt and Recline functions, the gravity will assist to improve your sitting stability, increase seating comfort, and saving energy to perform more daily tasks.

Lying flat

If you would like to lie back in the seat,

1. To maintain sitting stability, **TILT** the seat to the **MINIMUM RANGE**



2. Recline the backrest as far as needed

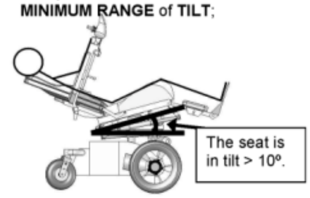
3. Elevate the legrests as high as needed

⚠ Caution: Elevate the legrests with caution. Excessive elevation may cause undue tightness in your hamstrings. Please consult with your therapist and clinician to insure safety use of this function.

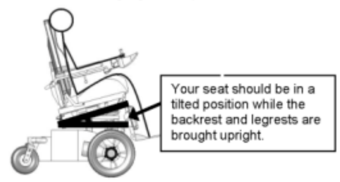
Reposition upright

If you want to return to functional sitting from recline or supine (lying back) posture,

1. First, make sure that the seat is in the **MINIMUM RANGE** of **TILT**;

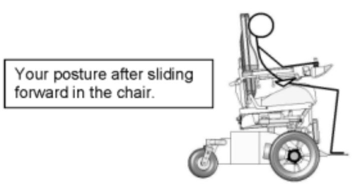


2. Then, lower the legrests and return the backrest from recline (Recline and legrest should be adjusted in turn according to individual hamstring tightness);

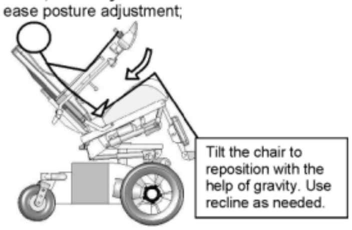


3. Last, bring the seat back from tilt as needed to obtain functional sitting position.

Reposition if sliding forward



1. First, **TILT** the seat to the **MODERATE TO MAXIMUM RANGE** will allow gravity to help you with scooting or sliding backward;
2. Then, **recline your backrest as needed** to ease posture adjustment;



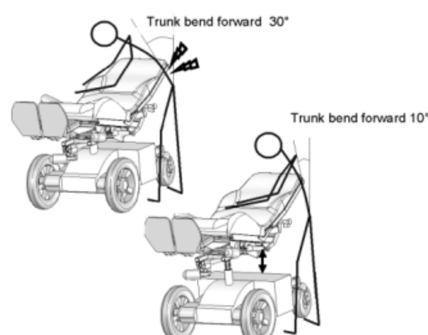
3. Last, return the seat from tilt as needed to obtain a functional sitting position. If you added some recline, remember to bring the backrest up before sitting upright (return the seat from a tilting position).

Help your caregiver to use proper body mechanics

If your caregiver would like to assist you with dressing or bladder/ bowel management,

You may want to ask your caregiver to adjust the seat height according to his/her needs.

- ❖ Adjusting the seat height properly will help your caregiver to decrease the degree of bending and prevent the occurrence of back pain.



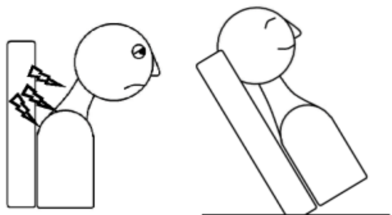
SPECIAL CONSIDERATIONS

Neck Pain and Back Pain

<u>If you have neck pain,</u>

Rest your head on the headrest, and tilt the seat as you feel comfortable.

Gravity will help you in supporting your neck. The degree of tilt is determined according to how you feel in the current position.



Everybody tends to slouch naturally while sitting on an upright seat.

While sitting in the tilted seat, gravity helps your head to rest against the headrest without effort.

<u>If you have back pain,</u>

1. Tilt the seat so that gravity helps you to rest your trunk against the backrest, so that your trunk muscles can relax. The tilted seat also helps to maintain sitting stability when the backrest is reclined and the legrests are elevated.

2. Recline the backrest and elevate legrests as needed.

❖ The angles of tilt, recline, and legrests are decided according to how comfortable you feel in the position.

<u>If you want to improve comfort while sitting in the chair,</u>

Use the powered seating functions to adjust your posture as frequently as you want. Just remember to make sure that the seat is tilted before you recline your backrest.

Spasticity in Lower Limbs or Trunk

<u>If you have spasticity in your lower limbs and/or trunk,</u>

Using the powered seating functions properly to adjust your position may help to control tone or the discomfort associated with it.

General positioning

- **TILTING** the seat to the **MINIMUM RANGE** will help you <u>maintain sitting stability</u> and thus may improve your upper limb function.
- **TILTING** the seat to the **MODERATE TO MAXIMUM RANGE** with larger angles may <u>let you relax</u> in the chair. You may use recline function and legrest elevation as needed. The degree of tilt is determined according to how you feel in the seat. Your clinician and therapist will help you to find the proper tilt angle.

Accommodate posture change

<u>When you are in extensor thrust (your back tends to arch due to spasticity),</u>

You may want to lay back in the seat to help you to relax and prevent you from sliding out of the seat due to an extremely extended posture. In the section ***"Obtain supine (lying back) position (p16)"*** there are instructions about how to use the powered seating functions to obtain supine/recumbent (lying back) position.

Caution: The powered seating functions should be used according to how you feel in the seat. In some cases, a reclined position might not help to ease extensor tone. Please consult with your clinician or therapist, and they will work with you to find out the proper positioning while you are in extensor thrust.

Swelling in Lower Limbs

If you have swollen feet (dependent edema),

Positioning your feet above heart level helps to decrease fluid accumulation in your feet and legs:

1. **TILT** the seat to the **MAXIMUM RANGE**;
2. **Elevate the LEGRESTS** to the **MAXIMUM RANGE OR** as high as possible;
3. While the legrests are elevated, recline the backrest as needed to release tightness in hamstrings.

Feet-up positioning for managing edema in lower extremities.

Caution: Although a temporary feet-up position is encouraged for managing dependent edema, head-down position should be avoided since it can make you dizzy and affect your blood pressure. Your clinician or therapist will work with you to find out the most proper positioning for managing edema.

Muscle Tightness in Lower Limbs and Trunk

If you have **hip joint** contracture or tightness,

You can **RECLINE** the backrest to accommodate your hip position.

- ❖ Remember to TILT your seat to the **MINIMUM RANGE** before reclining the backrest in order to maintain sitting stability. Your clinician will work with you to find out the proper recline and tilt angles.
- ❖ If you would like to use the recline function to assist with range of motion in your hip joints, please consult your clinician or therapist. Inappropriate usage of recline function may affect sitting stability.

If you have **knee joint** contracture or tightness,

You can adjust the legrests angles to accommodate your knee position.

- ❖ You may want to recline the backrest to decrease the tightness in your hamstrings. Remember to tilt the seat using a small angle before reclining the backrest in order to maintain sitting stability. Your clinician will work with you to find out the proper angles in using functions.
- ❖ If you would like to elevate the legrests in order to have some range of motion in your knee joints, please consult your clinician or therapist. Inappropriate usage of legrest elevation may cause undue tightness in your hamstrings and affect sitting stability.

If you **tend to slump** or **slouch in the seat**,

1. you may want to **TILT** your seat to the **MINIMUM RANGE** to allow gravity to assist you in maintaining a functional sitting posture, or
2. you may want to **TILT** your seat to the **MINIMUM OR MDERATE RANGE** to rest, adjust your posture, or stretch your neck and chest muscles.

OTHER APPLICATIONS

Proper positioning may help you to improve some body functions. You should use powered seating functions to adjust your posture or positioning whenever needed.

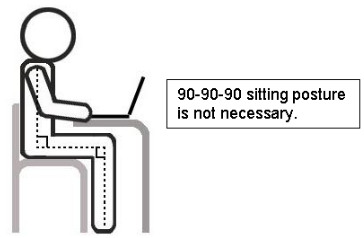
The body functions that could be improved through positioning include:

Breathing
Swallowing
Coughing
Speaking
Bladder or bowel functions, especially catheterizing
Or sitting upright to treat symptoms of dizziness due to low blood pressure

❖ Since everyone has a unique body shape and physical condition, your proper position for improving body functions may be different from others. Your clinician and therapist will work with you to find out the proper positioning.

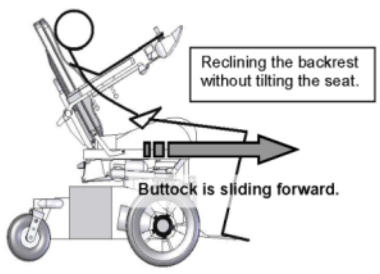
Precautions about Using Powered Seating Functions

1. ***90-90-90 sitting posture is a functional position, but it is not advisable to sit in this posture all the time.*** Everybody changes posture and moves all the time. You should change posture as frequently as needed.



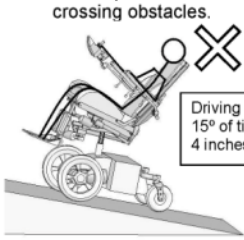
2. ***TILTING your seat to the MINIMUM RANGE is a very useful and important position.*** Small degrees of tilt can help you maintain sitting stability especially while you are driving and using other powered seating functions.

3. ***Using recline function alone may cause some hazardous effects.*** Using recline function alone will increase shear force (friction between your body and the wheelchair) on your skin and the likelihood of sliding forward. When you return to an upright from a recline position, bringing the backrest up without tilting the seat may cause you to slide forward due to the friction between the body and backrest.

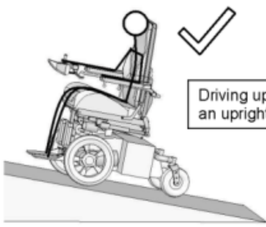


4. ***Elevating legrests should be used with caution.*** Elevating your legrests without reclining the backrest will increase tightness in your hamstrings, and may increase the pressure on your sit-bone (ischial tuberosities). Please consult your clinician and therapist about the proper use of elevated legrests.

5. ***Return the seat to an upright position before you drive uphill on a ramp or drive over small obstacles in order to prevent from tipping over.*** The upright position will move your center of gravity forward while driving uphill on a ramp and will keep the chair more balanced while crossing obstacles.



Driving uphill with the seat in 15º of tilt, 110º of recline, and 4 inches of seat elevation.



Driving uphill with the seat in an upright position.

6. ***Turning radius is increased when using tilt, recline, and elevated legrests.*** Be careful while driving in a narrow space, turning, and backing up as you may not turn as tightly as you do when not using these features.

7. ***Be careful while driving close to a table or desk when using seat elevation.*** Your knees may hit the edge of the table due to increased seat height.

8. ***If your wheelchair doesn't go as fast as you expect it should, try to decrease the tilt angle, recline angle, legrest angle, or seat elevation***. Some wheelchairs may be programmed to decrease the driving speed while using powered seating functions.

Quality of Life Technology Center

a National Science Foundation Engineering Research Center

APPENDIX C

MAXIMUM LIKELYHOOD ESTIMATIONS

	Models (data point= 636)		AIC	BIC	$LR\chi^2$	df	$LR\chi^2$ difference, df
	Fixed	Random					
1	Intercept,	Intercept	6270.155	6279.072	6266.155	3	--
2	Intercept, Date Centered	Intercept	6258.311	6276.144	6250.311	4	15.844, 1
3	Intercept, Date Centered, Intervention: INS	Intercept	6114.291	6236.583	6104.291	5	146.02, 1
4	Intercept, Date Centered, Intervention: INS, Intervention: VSC	Intercept	6020.754	6047.504	6008.754	6	95.537, 1

	Models (data point= 636)		AIC	BIC	LRχ^2	df	LRχ^2 difference, df
	Fixed	Random					
5	Intercept, Date Centered, Intervention: INS, Intervention: VSC, Wheelchair Occupancy,	Intercept	5962.566	5993.752	5948.566	7	60.188, 1
6	Intercept, (Date Centered)^2, Intervention: INS, Intervention: VSC, Wheelchair Occupancy,	Intercept	5957.880	5989.067	5943.880	7	4.766, 0
7	Intercept, (Date Centered)^3, Intervention: INS, Intervention: VSC, Wheelchair Occupancy,	Intercept	5955.805	5986.991	5941.805	7	2.075, 0

Best Fit Model
Compliance Rate = 20.91 + $(5.80)(10^{-5})(\text{Date Centered})^3$ + (-4.31)(Intervention: INS, Yes=1, No=0) + (38.64)(Intervention: VSC, Yes=1, No=0) + (-1.16)(Wheelchair Occupancy: hr/day)   Correlation with Observed Compliance Rate r_s= .534, p=.000

BIBLIOGRAPHY

1. Cook AM and Hussey SM, *Seating Systems As extrinsic Enablers for Assistive Technologies*, in *Assistive Technology: Principles and Practice*. 2002, Mosby. p. 165-211.
2. Dicianno BE, Margaria E, Arva J, Lieberman JM, Schmeler M, Souza A, Philipas K, Lange M, Cooper R, Davis K, and Betz K, *RESNA Position on the Application of Tilt, Recline, and Elevating Legrests for Wheelchairs,* in *Rehabilitation Engineering & Assistive Technology Society of North America*. 2008, Rehabilitation Engineering & Assistive Technology Society of North America: Arlington, VA.
3. O'Brien JG, Chennubhotla SA, and Chennubhotla RV, *Treatment of edema.* American Family Physician, 2005. **71**(11): p. 2111-7.
4. Littleton SR, Heriza CB, Mullens PA, Moerchen VA, and Bjornson K, *Effects of positioning on respiratory measures in individuals with cerebral palsy and severe scoliosis.* Pediatric Physical Therapy, 2011. **23**(2): p. 159-169.
5. Park B-H, Seo J-H, Ko M-H, and Park S-H, *Effect of 45° Reclining Sitting Posture on Swallowing in Patients with Dysphagia.* Yonsei Medical Journal, 2013. **54**(5): p. 1137-1142.
6. Arva J, Schmeler M, Lange M, and Lipka D, *RESNA Position on the Application of Seat-Elevating Devices for Wheelchair Users*, in *Rehabilitation Engineering & Assistive Technology Society of North America*. 2005, Rehabilitation Engineering & Assistive Technology Society of North America: Arlington, VA.
7. Edwards K and McCluskey A, *A survey of adult power wheelchair and scooter users.* Disability and Rehabilitation: Assistive Technology, 2010. **5**(6): p. 411-419.
8. Karmarkar AM, Collins DM, Wichman T, Franklin A, Fitzgerald SG, Dicianno BE, Pasquina PF, and Cooper RA, *Prosthesis and wheelchair use in veterans with lower-limb amputation.* Journal of Rehabilitation Research & Development, 2009. **46**(5): p. 567-576.
9. Lueder R, *Ergonomics of seated movement- A review of the scientific literature*. 2007, Board of Certification of Professional Ergonomists.
10. Hedge A and Ruder M. *Dynamic sitting—how much do we move when working at a computer?* in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 2003: SAGE Publications.
11. Linder-Ganz E, Scheinowitz M, Yizhar Z, Margulies S, and Gefen A, *How do normals move during prolonged wheelchair-sitting?* Technology and Health Care, 2007. **15**(3): p. 195-202.

12. Brienza D, Kelsey S, Karg P, Allegretti A, Olson M, Schmeler M, Zanca J, Geyer MJ, Kusturiss M, and Holm M, *A Randomized Clinical Trial on Preventing Pressure Ulcers with Wheelchair Seat Cushions.* Journal of the American Geriatrics Society, 2010. **58**(2): p. 308.
13. Chen Y, DeVivo MJ, and Jackson AB, *Pressure Ulcer Prevalence in People With Spinal Cord Injury: Age-Period-Duration Effects.* Arch Phys Med Rehabil, 2005. **86**: p. 1208-1213.
14. Garber SL and Rintala DH, *Pressure ulcers in veterans with spinal cord injury: A retrospective study.* Journal of Rehabilitation Research & Development, 2003. **40**(5): p. 433-442.
15. Rintala DH, Garber SL, Friedman JD, and Holmes SA, *Preventing Recurrent Pressure Ulcers in Veterans With Spinal Cord Injury: Impact of a Structured Education and Follow-Up Intervention.* Arch Phys Med Rehabil, 2008. **89**: p. 1429-1441.
16. Giesbrecht E, Ethans K, and Staley D, *Measuring the effect of incremental angles of wheelchair tilt on interface pressure among individuals with spinal cord injury.* Spinal Cord, 2011: p. 1-5.
17. Aissaoui R, Lacoste M, and Dansereau J, *Analysis of sliding and pressure distribution during a repositioning of persons in a simulator chair.* IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2001. **9**(2): p. 215-224.
18. Jan Y-K, Brienza D, Boninger M, and Brenes G, *Comparison of skin perfusion response with alternating and constant pressures in people with spinal cord injury.* Spinal Cord, 2011. **49**: p. 136-141.
19. Dicianno BE, Margaria E, Arva J, Lieberman JM, Schmeler M, Souza A, Cooper R, and Davis K, *RESNA Position on the Appilication of Tilt, Recline, and Elevating Legrests*. 2008, Rehabilitation Engineering & Assistive Technology Sciety of North America: Arlington, VA.
20. Jan Y-K, Crane BA, Liao F, Woods JA, and Ennis WJ, *Comparison of muscle and skin perfusion over the ischial tuberosities in response to wheelchair tilt-in-space and recline angles in people with spinal cord injury.* Archives of physical medicine and rehabilitation, 2013.
21. *Guideline for prevention and management of pressure ulcers.* 2003, Wound, Ostomy, and Continence Nurses Society (WOCN).
22. Dicianno BE, Arva J, Lieberman JM, Schmeler MR, Souza A, Phillips K, Lange M, Cooper R, Davis K, and Betz KL, *RESNA position on the application of tilt, recline, and elevating legrests for wheelchairs.* Assistive Technology: The Official Journal of RESNA, 2008. **21**(1): p. 13-22.
23. *Pressure Ulcer Prevention and Treatment Following Spinal Cord Injury: A Clinical Practice Guideline for Health-Care Professionals*. 2000, Consortium for Spinal Cord Medicine. Paralyzed Veterans of America.
24. *Pressure Ulcers in Adults: Prediction and Prevention*. 1992, Agency for Health Care Policy and Research.
25. McCaskey MS, Kirk L, and Gerdes C, *Preventing Skin Breakdown in the Immobile Child in the Home Care Setting.* Home Healthcare Nurse, 2011. **29**(4): p. 248-255.
26. Peirce SM, Skalak TC, and Rodeheaver GT, *Ischemia-reperfusion injury in chronic pressure ulcer formation: A skin model in the rat.* Wound Repair and Regeneration, 2000. **8**(1): p. 68-76.

27. Makhsous M, Priebe M, Bankard J, Rowles D, Zeigler M, Chen D, and Lin F, *Measuring Tissue Perfusion During Pressure Relief Maneuvers: Insights Into Preventing Pressure Ulcers.* Journal of Spinal Cord Medicine, 2007. **30**: p. 497-507.
28. Coggrave M and Rose L, *A specialist seating assessment clinic: changing pressure relief practice.* Spinal Cord, 2003. **41**: p. 692-695.
29. *Chronic Fatigue Syndrome (CFS).* 2013 [cited 2013; Available from: http://www.cdc.gov/cfs/index.html.
30. Staub F and Bogousslavsky J, *Fatigue after stroke: a major but neglected issue.* Cerebrovascular Diseases, 2001. **12**(2): p. 75-81.
31. Chaudhuri A and Behan PO, *Fatigue in neurological disorders.* The Lancet, 2004. **363**(9413): p. 978-988.
32. Gillespie R, Nordin M, Halpern M, Koenig K, Warren N, and Kim M, *Musculoskeletal impact of computer and electronic game use on children and adolescents.* Available from: ww w. iea. cc/ergonomics4children/pdfs/art0235. pdf [Accessed 20 February 2008], 2006.
33. Ward AL, Sanjak M, Duffy K, Bravver E, Williams N, Nichols M, and Brooks BR, *Power Wheelchair Prescription, Utilization, Satisfaction, and Cost for Patients With Amyotrophic Lateral Sclerosis: Preliminary Data for Evidence-Based Guidelines.* Arch Phys Med Rehabil, 2010. **91**: p. 268-272.
34. Cardon G, De Clercq D, De Bourdeaudhuij I, and Breithecker D, *Sitting habits in elementary schoolchildren: a traditional versus a "Moving school".* Patient education and counseling, 2004. **54**(2): p. 133-142.
35. Ryan CG, Dall PM, Granat MH, and Grant PM, *Sitting patterns at work: objective measurement of adherence to current recommendations.* Ergonomics, 2011. **54**(6): p. 531-538.
36. Ding D, Leister E, Cooper RA, Cooper R, Kelleher A, Fitzgerald SG, and Boninger ML, *Usage of tilt-in-space, recline, and elevation seating functions in natural environment of wheelchair users.* Journal of Rehabilitation Research & Development, 2008. **45**(7): p. 973.
37. Lacoste M, Weiss-Lambrou R, Allard M, and Dansereau J, *Powered tilt/recline systems: why and how are they used?* Assistive Technology, 2003. **15**(1): p. 58-68.
38. Sonenblum S, Sprigle S, and Maurer CL, *Use of power tilt systems in everyday life.* Disability and Rehabilitation: Assistive Technology, 2009. **4**(1): p. 24-30.
39. Dewey A, Rice-Oxley M, and Dean T, *A Qualitative Study Comparing the Experiences of Tilt-in-Space Wheelchair Use and Conventional Wheelchair Use by Clients Severely Disabled with Multiple Sclerosis.* British Journal of Occupational Therapy 2004. **67**(2): p. 65-74.
40. Sonenblum SE and Sprigle S, *Distinct tilting behaviours with power tilt-in-space systems.* Disability and Rehabilitation: Assistive Technology, 2011. **6**(6): p. 526-535.
41. Schofield R, Poerter-Armstrong A, and Stinson M, *Reviewing the Literature on the Effectiveness of Pressure Relieving Movements.* Nursing Research and Practice, 2013. **2013**: p. 1-31.
42. Vaishampayan A, Clark F, Carlson M, and Blanche EI, *Preventing Pressure Ulcers in People with Spinal Cord Injury: Targeting Risky Life Circumstances through Community-Based Interventions.* Advances in Skin & Wound Care, 2011. **24**(6): p. 275-284.

43. Fogelberg D, Atkins M, Blanche EI, Carlson M, and Clark aF, *Decisions and Dilemmas in Everyday Life: Daily Use of Wheelchairs by Individuals with Spinal Cord Injury and the Impact on Pressure Ulcer Risk.* Top Spinal Cord Inj Rehabil, 2009. **15**(2): p. 16-32.
44. Medin DL, Ross BH, and Markman AB, *Judgment and Decision Making*, in *Cognitive Psychology 4th Edition*, R. Flahive, Editor. 2005, John Wiley & Sons, Inc.
45. Wickens CD and Hollands JG, *Decision Making*, in *Engineering Psychology and Human Performance 3rd Edition*, N. Boberts, Editor. 2000, Prentice Hall: Upper Saddle River, New Jersey.
46. Brewer NT and Rimer BK, *Perspectives on Health Behavior Theories that Focus on Individuals*, in *Health Behavior and Health Education. Theory, Research, and Practice. 4th Edition*, K. Glanz, B.K. Rimer, and K. Viswanath, Editors. 2008, Jossey-Bass: San Francisco, CA. p. 149.
47. Champion VL and Skinner CS, *The Health Belief Model*, in *Health Behavior and Health Education. Theory, Research, and Practice. 4th Edition*, K. Glanz, B.K. Rimer, and K. Viswanath, Editors. 2008, Jossey-Bass: San Francisco, CA. p. 45.
48. Prochaska JO, Redding CA, and Evers KE, *The Transtheoretical Model and Stages of Change*, in *Health Behavior and Health Education. Theory, Research, and Practice. 4th Edition*, K. Glanz, B.K. Rimer, and K. Viswanath, Editors. 2008, Jossey-Bass: San Francisco, CA. p. 97.
49. Montaño DE and Kasprzyk D, *Theory of Reasoned Action, Theory of Planned Behavior, and the Integrated Behavioral Model*, in *Health Behavior and Health Education. Theory, Research, and Practice. 4th Edition*, K. Glanz, B.K. Rimer, and K. Viswanath, Editors. 2008, Jossey-Bass: San Francisco, CA. p. 67.
50. Baban A and Craciun C, *Changing health-risk behaviors: a review of theory and evidencebased interventions in health psychology.* Journal of Cognitive and Behavioral Psychotherapies, 2007. **7**(1): p. 45-66.
51. Fogg BJ, Hreha J, Krieglstein R, Chanasyk K, and Krishna G, *Green Span Behavior Guide version 0.50*. 2010, Stanford Persuasive Tech Lab.
52. Fogg B, Hreha J, Krieglstein R, Chanasyk K, and Krishna G, *Green Span Behavior Guide version 0.50*. 2010, Stanford Persuasive Tech Lab.
53. Lykke M. *Persuasive design strategies: means to improve the use of information organisation and search features in web site information architecture?* in *American Society for Information Science and Technology SIG-Classification Research 20th Workshop*. 2009.
54. *iOS Human Interface Guidelines*. 2013, Apple Inc.
55. Wu AW, Snyder CF, Huang I-C, Richard Skolasky J, McGruder HF, Celano SA, Selnes OA, and Andrade AS, *A Randomized Trial of the Impact of a Programmable Medication Reminder Device on Quality of Life in Patients with AIDS.* AIDS Patient Care and Studies, 2006. **20**(11): p. 773-781.
56. Chatterjee S and Price A, *Healthy Living with Persuasive Technologies: Framework, Issues, and Challenges.* Journal of the American Medical Informatics Association, 2009. **16**(2): p. 171-178.
57. Cole-Lewis H and Kershaw T, *Text Messaging as a Tool for Behavior Change in Disease Prevention and Management.* Epidemiologic Reviews, 2010. **32**: p. 56-69.

58. Yang Y-S, Chou Y-C, Hsu J-J, and Chang J-J, *Effects of Audio Feedback on Sitting Behaviors of Community-Dwelling Manual Wheelchair Users With Spinal Cord Injuries.* Assistive Technology, 2010. **22**(2): p. 79-86.
59. Liu H-Y, Cooper R, Kelleher A, and Cooper RA, *An Interview Study For Developing A User Guide for Powered Seating Function Usage.* Disability and Rehabilitation: Assistive Technology. **In Press**.
60. *Pressure Ulcer Prevention and Treatment Following Spinal Cord Injury: A Clinical Practice Guideline for Health-Care Professionals*. 2000, Paralyzed Veterans of America.
61. Leister EP, *The Effectiveness and Use of Seat Tilt, Backrest Recline, and Seat Elevation in Adult Powered Wheelchair Users*, in *Rehabilitation Science and Technology*. 2004, University of Pittsburgh. p. 94.
62. Xiang H, Chany A-M, and Smith GA, *Wheelchair related injuries treated in US emergency departments.* Injury Prevention, 2006. **12**: p. 8-11.
63. Kirby RL, Coughlan SG, and Christie M, *Could Changes in the Wheelchair Delivery System Improve Safety?* Canadian Medical Association Journal, 1995. **153**(11): p. 1587-1591.
64. Gavin-Dreschnack D, Nelson A, Fitzgerald S, Harrow J, Anguiano AS, Ahmed S, and Powell-Cope G, *Wheelchair-related Falls Current Evidence and Directionsm for Improved Quality Care.* Journal of Nursing Care Quality, 2005. **20**(2): p. 119-127.
65. Opalek JM, Graymire VL, and Redd D, *Wheelchair Falls: 5 Years of Data From a Level I Trauma Center.* Journal of Trauma Nursing 2009. **16**(2): p. 98-102.
66. Hoenig H, Landerman LR, Shipp KM, Pieper C, Pieper C, Richardson M, Pahel N, and George L, *A Clinical Trial of a Rehabilitation Expert Clinician Versus Usual Care for Providing Manual Wheelchairs.* Journal of the American Geriatrics Society, 2005. **53**(10): p. 1712-1720.
67. Sprigle S, Lenker J, and Searcy K, *Activities of suppliers and technicians during the provision of complex and standard wheeled mobility devices.* Disability and Rehabilitation: Assistive Technology, 2012. **7**(3): p. 219-225.
68. Sund T, Iwarsson S, Andersen MC, and Brandt Å, *Documentation of and satisfaction with the service delivery process of electric powered scooters among adult users in different national contexts.* Disability and Rehabilitation: Assistive Technology, 2013. **8**(2): p. 151-160.
69. King M, Jaffee C, Frankel D, Laroche B, and Dick P, *Someone You Know Has MS. A Book For Families: For Children and Teenagers*. 2012, National Multiple Sclerosis Society.
70. Frankel D and Schneider DM, *Mininize Your Risk of Falls*, in *National Multiple Sclerosis Society*. 2011.
71. Pellow TR, *A comparison of interface pressure readings to wheelchair cushions and positioning: a pilot study.* Canadian Journal of Occupational Therapy - Revue Canadienne d Ergotherapie, 1999. **66**(3): p. 140-9.
72. *An introduction to rehabilitation engineering*, ed. R.A. Cooper, H. Ohnabe, and D.A. Hobson. 2007, Boca Raton, FL: Taylor & Francis Group.
73. Moreno R, Mayer RE, and Lester JC. *Life-Like Pedagogical Agents in Constructivist Multimedia Environments: Cognitive Consequences of their Interaction*. in *World Conference on Educational Multimedia Hypermedia, and Telecommunications*. 2000. Chesapeake, VA.

74. Moreno R, Mayer RE, Spires HA, and Lester JC, *The case for social agency in computer-based teaching: do students learn more deeply when they interact with animated pedagogical agents?* Cognition and Instruction, 2001. **19**(2): p. 177-213.
75. Braun C, Gruendl M, Marberger C, and Scherber C, *Beautycheck - Ursachen und Folgen von Attraktivitaet.* 2001.
76. Mihailidis A, Barbenel JC, and Fernie G, *The efficacy if an intelligent cognitive orthosis to facilitate handwashing by persons with moderate to severe dementia.* Neuropsychological Rehabilitation, 2004. **14**(1): p. 134-171.
77. Baylor AL. *The impact of pedagogical agent image on affective outcomes*. in *International Conference on Intelligent User Interfaces*. 2005. San Diego, CA.
78. Bickmore TW, Pfeifer LM, and Paasche-Orlow MK, *Health Document Explanation by Virtual Agents*, in *Lecture Notes in Computer Science*. 2007, Springer. p. 183.
79. Woolf B, Arroyo I, Muldner K, Burleson W, Cooper D, Dolan R, and Christopherson R. *The Effect of Motivational Learning Companions on Low Achieving Students and Students with Disabilities*. in *International Conference on Intelligent Tutoring Systems*. 2010. Pittsburgh, PA: Springer.
80. Baylor A, Ryu J, and Shen E. *The Effects of Pedagogical Agent Voice and Animation on Learning, Motivation and Perceived Persona*. in *World Conference on Educational Multimedia, Hypermedia and Telecommunications*. 2003. Chesapeake, VA.
81. Stevens CJ, Brennan D, Petocz A, and Howell C, *Designing informative warning signals: Effects of indicator type, modality, and task demand on recognition speed and accuracy*. Advancements in Cognitive Psychology, 2009. **5**: p. 42-48.
82. Liu H-Y, Grindle G, Chuang F-C, Kelleher A, Cooper R, Siewiorek D, Smailagic A, and Cooper R, *A Survey of Feedback Modalities for Wheelchair Power Seat Functions.* IEEE Pervasive Computing, 2012. **11**(3): p. 54-62.
83. Cooper RA, Thorman T, Cooper R, Dvorznak MJ, Fitzgerald SG, Ammer W, Song-Feng G, and Boninger ML, *Driving characteristics of electric-powered wheelchair users: how far, fast, and often do people drive?* Archives of physical medicine and rehabilitation, 2002. **83**(2): p. 250-255.
84. Liu H-Y, Wu Y-K, Kelleher A, Cooper R, Seiwiorek D, and Cooper R. *Case Study: Pilot Test of Virtual Seating Coach Evaluated by Power Seat Function Users*. in *Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference*. 2012. Baltimore, MD.
85. Batavia AB, R. Friedman, M, *Changing chairs: Anticipating problems in prescribing wheelchairs.* Disability & Rehabilitation, 2001. **23**(12): p. 539-548.
86. Olson JJ, *Redesign, Clinical Testing and Evaluation of the Endeavor Folding Wheelchair*. 2009, University of Pittsburgh.
87. Makhsous M, Lin F, Knaus E, Zeigler M, Rowles DM, Gittler M, Bankard J, and Chen D, *Promote pressure ulcer healing in individuals with spinal cord injury using an individualized cyclic pressure-relief protocol.* Advances in skin & wound care, 2009. **22**(11): p. 514.
88. *International Residential Code for One- and Two- Family Dwelling*, I. International Code Council, Editor. 2012: Country Club Hills, IL.
89. Koontz AM, Brindle ED, Kankipati P, Feathers D, and Cooper RA, *Design features that affect the maneuverability of wheelchairs and scooters.* Archives of physical medicine and rehabilitation, 2010. **91**(5): p. 759-764.

90. Mortenson WB, Miller WC, Boily J, Steele B, Odell L, Crawford EM, and Desharnais G, *Perceptions of power mobility use and safety within residential facilities.* Canadian Journal of Occupational Therapy, 2005. **72**(3): p. 142-152.
91. Frank A, Neophytou C, Frank J, and de Souza L, *Electric-powered indoor/outdoor wheelchairs (EPIOCs): users' views of influence on family, friends and carers.* Disability & Rehabilitation: Assistive Technology, 2010. **5**(5): p. 327-338.
92. Barker DJ, Reid D, and Cott C, *Acceptance and meanings of wheelchair use in senior stroke survivors.* The American journal of occupational therapy, 2004. **58**(2): p. 221-230.
93. Blach Rossen C, Sørensen B, Würtz Jochumsen B, and Wind G, *Everyday life for users of electric wheelchairs-a qualitative interview study.* Disability and Rehabilitation: Assistive Technology, 2012. **7**(5): p. 399-407.
94. Ward AL, Sanjak M, Duffy K, Bravver E, Williams N, Nichols M, and Brooks BR, *Power wheelchair prescription, utilization, satisfaction, and cost for patients with amyotrophic lateral sclerosis: preliminary data for evidence-based guidelines.* Archives of physical medicine and rehabilitation, 2010. **91**(2): p. 268-272.
95. Guihan M, Garber SL, Bombardier CH, Durazo-Arizu R, Goldstein B, and Holmes SA, *Lessons learned while conducting research on prevention of pressure ulcers in veterans with spinal cord injury.* Archives of physical medicine and rehabilitation, 2007. **88**(7): p. 858-61.
96. Graham JE, Karmarkar AM, and Ottenbacher KJ, *Small Sample Research Designs for Evidence-Based Rehabilitation: Issues and Methods.* Archives of Physical Medicine and Rehabilitation, 2012. **93**(12): p. 2384-2384.
97. Barnett SD, Heinemann AW, Libin A, Houts AC, Gassaway J, Sen-Gupta S, Resch A, and Brossart DF, *Small N designs for rehabilitation research.* Journal of rehabilitation research and development, 2012. **49**(1): p. 175-186.
98. Horner RH, Carr EG, Halle J, McGee G, Odom S, and Wolery M, *The Use of Single-Subject Research to Identify Evidence-Based Practice in Special Education.* Exceptional Children, 2005. **71**(2): p. 165-179.
99. Portney LG and Watkins MP, *Single-Subject Designs*, in *Foundations Of Clinical Research: Applications To Practice*. 2009, Julie Levin Alexander: Upper Saddle River, New Jersey. p. 235-278.
100. Levinson DR, *Power Wheelcairs in the Medicare Program: Suppier Acquisition Costs and Services*. 2009, Office of Inspector General, Department of Health and Human Service.
101. Samuelsson K and Wressle E, *User satisfaction with mobility assistive devices: An important element in the rehabilitation process.* Disability & Rehabilitation, 2008. **30**(7): p. 551-558.
102. Wressle E and Samuelsson K, *User satisfaction with mobility assistive devices.* Scandinavian journal of occupational therapy, 2004. **11**(3): p. 143-150.
103. Frank AO, De Souza LH, Frank JL, and Neophytou C, *The pain experiences of powered wheelchair users.* Disability and Rehabilitation, 2012. **34**(9): p. 770-778.
104. Ding D, Leister E, Cooper RA, Cooper R, Kelleher A, Fitzgerald SG, and Boninger ML, *Usage of tilt-in-space, recline, and elevation seating functions in natural environment of wheelchair users.* Journal Of Rehabilitation Research And Development, 2008. **45**(7): p. 973-983.

105. Lacoste M, Weiss-Lambrou R, Allard M, and Dansereau J, *Powered tilt/recline systems: why and how are they used?* Assistive Technology: The Official Journal of RESNA, 2003. **15**(1): p. 58-68.
106. Giesbrecht EM, Ethans KD, and Staley D, *Measuring the effect of incremental angles of wheelchair tilt on interface pressure among individuals with spinal cord injury.* Spinal cord, 2011. **49**(7): p. 827-31.
107. Jan YK, Brienza DM, Boninger ML, and Brenes G, *Comparison of skin perfusion response with alternating and constant pressures in people with spinal cord injury.* Spinal cord the official journal of the International Medical Society of Paraplegia, 2011. **49**(1): p. 136-141.
108. Crane B, Holm M, Hobson D, Cooper R, Reed M, and Stadelmeier S, *Test-retest reliability, internal item consistency, and concurrent validity of the wheelchair seating discomfort assessment tool.* Assistive Technology, 2005. **17**(2): p. 98-107.
109. Crane BA, Holm MB, Hobson D, Cooper RA, and Reed MP, *Responsiveness of the TAWC tool for assessing wheelchair discomfort.* Disability & Rehabilitation: Assistive Technology, 2007. **2**(2): p. 97-103.
110. Seifert CM, Chapman LS, Hart JK, and Perez P, *Enhancing Intrinsic Motivation in Health Promotion and Wellness.* American Journal of Health Promotion, 2012. **January/February**: p. TAHP 1-12.
111. Rice LA, Smith I, Kelleher AR, Greenwald K, and Boninger ML, *Impact of a Wheelchair Education Protocol based on Practice Guidelines for Preservation of Upper Limb Function: A Randomized Trial.* Archives of physical medicine and rehabilitation, 2013.
112. Rintala DH, Garber SL, Friedman JD, and Holmes SA, *Preventing recurrent pressure ulcers in veterans with spinal cord injury: impact of a structured education and follow-up intervention.* Archives of physical medicine and rehabilitation, 2008. **89**(8): p. 1429-41.
113. Fjeldsoe BS, Marshall AL, and Miller YD, *Behavior change interventions delivered by mobile telephone short-message service.* American journal of preventive medicine, 2009. **36**(2): p. 165-173.
114. Bouchet C, Guillemin F, and Briancon S, *Nonspecific effects in longitudinal studies: impact on quality of life measures.* Journal of clinical epidemiology, 1996. **49**(1): p. 15-20.
115. Mertz D, Dafoe N, Walter SD, Brazil K, and Loeb M, *Effect of a Multifaceted Intervention on Adherence to Hand Hygiene among Healthcare Workers: A Cluster-Randomized Trial.* Infection Control and Hospital Epidemiology, 2010. **31**(11): p. 1170-1176.
116. Pladevall M, Brotons C, Gabriel R, Arnau A, Suarez C, de la Figuera M, Marquez E, Coca A, Sobrino J, and Divine G, *Multicenter Cluster-Randomized Trial of a Multifactorial Intervention to Improve Antihypertensive Medication Adherence and Blood Pressure Control Among Patients at High Cardiovascular Risk (The COM99 Study) Clinical Perspective.* Circulation, 2010. **122**(12): p. 1183-1191.
117. Spool J. *Do users change their settings?* User Interface Engineering 2011 [cited 2013 Oct 1]; Available from: http://www.uie.com/brainsparks/2011/09/14/do-users-change-their-settings/.
118. Bawden D and Robinson L, *The dark side of information: overload, anxiety and other paradoxes and pathologies.* Journal of information science, 2009. **35**(2): p. 180-191.

119. Wiekens A, *Feedback presentation for physical activity coaching: by an embodied conversational agent or by a simple e-mail?* 2011.
120. Chen G-D, Lee J-H, Wang C-Y, Chao P-Y, Li L-Y, and Lee T-Y, *An Empathic Avatar in a Computer-Aided Learning Program to Encourage and Persuade Learners.* Educational Technology & Society, 2012. **15**(2): p. 62-72.
121. Von der Puetten AM, Krämer NC, Gratch J, and Kang S-H, *"It doesn't matter what you are!" explaining social effects of agents and avatars.* Computers in Human Behavior, 2010. **26**(6): p. 1641-1650.
122. Cole-Lewis H and Kershaw T, *Text messaging as a tool for behavior change in disease prevention and management.* Epidemiologic Reviews, 2010. **32**(1): p. 56-69.
123. Shapiro JR, Bauer S, Andrews E, Pisetsky E, Bulik-Sullivan B, Hamer RM, and Bulik CM, *Mobile therapy: Use of text-messaging in the treatment of bulimia nervosa.* International Journal of Eating Disorders, 2010. **43**(6): p. 513-519.
124. Arva J, Schmeler MR, Lange ML, Lipka DD, and Rosen LE, *RESNA position on the application of seat-elevating devices for wheelchair users.* Assistive Technology: The Official Journal of RESNA, 2005. **21**(2): p. 69-72; quiz 74-75.
125. Bourret E, Bernick L, Cott C, and Kontos P, *The meaning of mobility for residents and staff in long-term care facilities.* Journal of Advanced Nursing, 2002. **37**(4): p. 338-345.
126. Devitt R, Chau B, and Jutai JW, *The effect of wheelchair use on the quality of life of persons with multiple sclerosis.* Occupational Therapy in Health Care, 2004. **17**(3-4): p. 63-79.
127. Brandt A, Iwarsson S, and Stahle A, *Older people's use of powered wheelchairs for activity and participation.* Journal of rehabilitation medicine, 2004. **36**(2): p. 70-77.
128. Buning ME, Angelo JA, and Schmeler MR, *Occupational performance and the transition to powered mobility: A pilot study.* The American journal of occupational therapy, 2001. **55**(3): p. 339-344.
129. Dewey A, Rice-Oxley M, and Dean T, *A qualitative study comparing the experiences of tilt-in-space wheelchair use and conventional wheelchair use by clients severely disabled with multiple sclerosis.* The British Journal of Occupational Therapy, 2004. **67**(February): p. 65-74.
130. Gryfe P and Jutai J. *The impact of power positioning devices on quality of life*. in *The Canadian Seating and Mobility Conference*. 1999. Toronto, Ontario.
131. Sonenblum SE, Sprigle S, and Maurer CL, *Use of power tilt systems in everyday life.* Disability and rehabilitation: Assistive technology, 2009. **4**(1): p. 24-30.
132. Day H and Jutai J, *Measuring the psychosocial impact of assistive devices: The PIADS.* Canadian Journal of Rehabilitation, 1996. **9**: p. 159-168.
133. Hall KM, Dijkers M, Whiteneck G, Brooks C, and Stuart Krause J, *The Craig handicap assessment and reporting technique (CHART): metric properties and scoring.* Topics in spinal cord injury rehabilitation, 1998. **4**(1): p. 16-30.
134. McGorry RW, Shaw WS, and Lin J-H, *Correlations between pain and function in a longitudinal low back pain cohort.* Disability & Rehabilitation, 2011. **33**(11): p. 945-952.
135. Einarsson EJ, Petersen H, Wiebe T, Fransson PA, Grenner J, Magnusson M, and Moëll C, *Long term hearing degeneration after platinum-based chemotherapy in childhood.* International journal of audiology, 2010. **49**(10): p. 765-771.

136. Crane BA, Holm MB, Hobson D, Cooper RA, Reed MP, and Stadelmeier S, *Test-retest reliability, internal item consistency, and concurrent validity of the wheelchair seating discomfort assessment tool.* Assistive Technology, 2005. **17**(2): p. 98-107.
137. Gibson J and Frank A, *Pain experienced by electric-powered chair users: a pilot exploration using pain drawings.* Physiotherapy Research International, 2005. **10**(2): p. 110-115.
138. Vink P and Hallbeck S, *Editorial: Comfort and discomfort studies demonstrate the need for a new model.* Applied ergonomics, 2012. **43**(2): p. 271-276.
139. Englander J, Bushnik T, Oggins J, and Katznelson L, *Fatigue after traumatic brain injury: association with neuroendocrine, sleep, depression and other factors.* Brain Injury, 2010. **24**(12): p. 1379-1388.
140. Sander AM, Maestas KL, Sherer M, Malec JF, and Nakase-Richardson R, *Relationship of Caregiver and Family Functioning to Participation Outcomes After Postacute Rehabilitation for Traumatic Brain Injury: A Multicenter Investigation.* Archives of physical medicine and rehabilitation, 2012. **93**(5): p. 842-848.
141. Riggins MS, Kankipati P, Oyster ML, Cooper RA, and Boninger ML, *The relationship between quality of life and change in mobility 1 year postinjury in individuals with spinal cord injury.* Archives of physical medicine and rehabilitation, 2011. **92**(7): p. 1027-1033.
142. Ponsford J and Schoenberger M, *Family functioning and emotional state two and five years after traumatic brain injury.* Journal of the International Neuropsychological Society, 2010. **16**(2): p. 306.
143. Wilkowska W, Gaul S, and Ziefle M, *A Small but Significant Difference–The Role of Gender on Acceptance of Medical Assistive Technologies*, in *HCI in Work and Learning, Life and Leisure*. 2010, Springer. p. 82-100.
144. Casetta I, Riise T, Nortvedt MW, Economou NT, De Gennaro R, Fazio P, Cesnik E, Govoni V, and Granieri E, *Gender differences in health-related quality of life in multiple sclerosis.* Multiple Sclerosis, 2009. **15**(11): p. 1339-1346.
145. Miller A and Dishon S, *Health-related quality of life in multiple sclerosis: the impact of disability, gender and employment status.* Quality of life research, 2006. **15**(2): p. 259-271.
146. Harvey L, Chu J, Bowden J, Quirk R, Diong J, Batty J, Thompson A, and Barratt D, *How much equipment is prescribed for people with spinal cord injury in Australia, do they use it and are they satisfied 1 year later&quest.* Spinal cord, 2012. **50**(9): p. 676-681.
147. Giesbrecht EM, Ripat JD, Quanbury AO, and Cooper JE, *Participation in community-based activities of daily living: comparison of a pushrim-activated, power-assisted wheelchair and a power wheelchair.* Disability & Rehabilitation: Assistive Technology, 2009. **4**(3): p. 198-207.
148. Kim D-J, Hazlett R, Godfrey H, Rucks G, Portee D, Bricout J, Cunningham T, and Behal A. *On the relationship between autonomy, performance, and satisfaction: Lessons from a three-week user study with post-SCI patients using a smart 6DOF assistive robotic manipulator*. in *Robotics and Automation (ICRA), 2010 IEEE International Conference on*. 2010: IEEE.
149. Henderson S, Skelton H, and Rosenbaum P, *Assistive devices for children with functional impairments: impact on child and caregiver function.* Developmental Medicine & Child Neurology, 2008. **50**(2): p. 89-98.

150. Palisano RJ, Hanna SE, Rosenbaum PL, and Tieman B, *Probability of walking, wheeled mobility, and assisted mobility in children and adolescents with cerebral palsy*. Developmental Medicine & Child Neurology, 2010. **52**(1): p. 66-71.
151. Day SM, Wu YW, Strauss DJ, Shavelle RM, and Reynolds RJ, *Change in ambulatory ability of adolescents and young adults with cerebral palsy*. Developmental Medicine & Child Neurology, 2007. **49**(9): p. 647-653.
152. Bray P, Bundy AC, Ryan MM, North KN, and Burns J, *Health status of boys with Duchenne muscular dystrophy: A parent's perspective.* Journal of Paediatrics and Child Health, 2011. **47**(8): p. 557-562.
153. Erby LH, Rushton C, and Geller G. *"My Son Is Still Walking": Stages of Receptivity to Discussions of Advance Care Planning Among Parents of Sons With Duchenne Muscular Dystrophy*. in *Seminars in Pediatric Neurology*. 2006: Elsevier.
154. Kohler M, Clarenbach CF, Bahler C, Brack T, Russi EW, and Bloch KE, *Disability and survival in Duchenne muscular dystrophy*. Journal of Neurology, Neurosurgery & Psychiatry, 2009. **80**(3): p. 320-325.
155. Gravelle AM, *Caring for a child with a progressive illness during the complex chronic phase: parents' experience of facing adversity*. Journal of Advanced Nursing, 1997. **25**(4): p. 738-745.
156. White VB, Leib JR, Farmer JM, and Biesecker BB, *Exploration of transitional life events in individuals with Friedreich ataxia: Implications for genetic counseling.* Behavioral and Brain Functions, 2010. **6**(1): p. 65.