THE EFFECTIVENESS AND USE OF SEAT TILT, BACKREST RECLINE, AND SEAT ELEVATION IN ADULT POWERED WHEELCHAIR USERS

by

Elizabeth Powell Leister

BS, Washington University, 2004

Submitted to the Graduate Faculty of

Rehabilitation Science and Technology in partial fulfillment

of the requirements for the degree of

Masters in Rehabilitation Science and Technology

University of Pittsburgh

2006

UNIVERSITY OF PITTSBURGH

FACULTY OF REHABILITATION SCIENCE AND TECHNOLOGY

This thesis was presented

by

Elizabeth Powell Leister

It was defended on

September 15, 2006

and approved by

Rory A. Cooper, PhD

Shirley G. Fitzgerald, PhD

Rosemarie Cooper, MPT

Dan Ding, PhD

Thesis Director

THE EFFECTIVENESS AND USE OF SEAT TILT, BACKREST RECLINE, AND SEAT ELEVATION IN ADULT POWERED WHEELCHAIR USERS

Elizabeth P. Leister, BS

University of Pittsburgh, 2006

This study examined how adults use power wheelchair seat features such as seat tilt, backrest recline, and seat elevation, during typical daily activities. A Seat Feature Data Logger (SFDL) was attached to 11 subject's wheelchairs for 10-14 days to gather data regarding daily usage of the wheelchair and these features. Subjects occupied their wheelchairs for 12.0 ± 3.0 hours per day and transferred in/out of their wheelchairs 5.0 ± 5.3 times per day. An average of 0.7 ± 1.5 hours per day was spent in an upright position. The tilt feature was accessed 18.4 ± 14.4 times per day for 8.5 ± 5.2 hours per day, and recline was accessed 11.5 ± 8.4 times per day for 8.6 ± 4.6 hours per day. Tilt and recline were used in combination for a total of 4.8 ± 4.6 hours per day. Subjects accessed the seat elevation feature 4.3 ± 4.1 times per day on average for 2.8 ± 4.6 hours day. Based on these data it was found that subjects spent significantly more time in a tilted versus an upright position ($p<0.025$), but that tilt was not used significantly more than recline ($p=0.155$) or seat elevation ($p=0.046$). In addition, comparison of SFDL data with pressure-mapping data revealed that subjects were more likely to use small and intermediate amplitude tilt and recline angles, and positions known to result in low peak pressure were accessed more frequently and for longer durations than intermediate and high pressure positions. While subjects did not always use large angles of tilt and recline – as many clinicians recommend – these features were used frequently and their use resulted in lower peak pressures.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ix

1.0 INTRODUCTION 1

1.1 PRESSURE ULCERS AND THEIR PREVENTION 1

1.1.1 Definition and Cause of Pressure Ulcers 1

1.1.2 Cost and Prevalence of Pressure Ulcers 2

1.1.3 Prevention of Pressure Ulcers 2

1.2 SEAT TILT, BACKREST RECLINE, AND SEAT ELEVATION 3

1.2.1 Tilt and Recline for Pressure Relief 3

1.2.2 Tilt and Recline for Comfort 6

1.2.3 Seat Elevators 8

1.3 DATA LOGGERS AND RECORDING WHEELCHAIR USE 9

2.0 SPECIFIC AIMS 11

3.0 METHODS 12

3.1 SUBJECTS AND RECRUITMENT 12

3.1.1 Demographic Information 12

3.1.2 Recruitment Procedures 14

3.2 INSTRUMENTATION 14

3.3 PROTOCOL 17

3.4 DATA ANALYSIS AND REDUCTION 20

3.4.1 Data Collection Program 20

3.4.2 Data Analysis and Reduction Program 20

3.4.3 Statistical Analysis 25

4.0 RESULTS 27

4.1 CHAIR OCCUPANCY TIME 27

4.2 SEAT FEATURE USAGE 28

4.2.1 Seat Tilt Usage 28

4.2.2 Backrest Recline Usage 29

4.2.3 Simultaneous Usage of Seat Tilt and Backrest Recline 30

4.2.4 Seat Elevation Usage 31

4.2.5 Most Common Tilt and Recline Angles 32

4.3 EFFECTIVENESS OF SEAT FEATURE USAGE 35

4.4 QUESTIONNAIRE 38

5.0 DISCUSSION 42

5.1 CHAIR OCCUPANCY 42

5.2 SEAT TILT USAGE 44

5.3 BACKREST RECLINE USAGE 46

5.4 SIMULTANEOUS SEAT TILT AND BACKREST RECLINE USAGE 47

5.5 SEAT ELEVATION USAGE 47

5.6 EFFECTIVENESS OF SEAT FEATURE USAGE 48

5.7 LIMITATIONS 50

5.8 FUTURE STUDIES 51

APPENDIX A: RECRUITMENT FLYER 52

APPENDIX B: DEMOGRAPHIC INFORMATION 53

APPENDIX C: QUESTIONNAIRE 54

APPENDIX D: MATLAB CODE 56

BIBLIOGRAPHY 80

LIST OF SUPPLIERS 84

LIST OF TABLES

Table 1 Demographic information for each subject 13

Table 2 Characteristics of wheelchairs used in the study 13

Table 3 Chair occupancy results 27

Table 4 Frequency and duration of tilt accesses and upright time 29

Table 5 Frequency and duration of recline accesses 30

Table 6 Duration of simultaneous tilt and recline use 31

Table 7 Frequency and duration of seat elevation accesses 32

Table 8 The most common tilt angles and percent of time spent in these angles 33

Table 9 The most common recline angles percent of time spent in these angles 33

Table 10 Access frequency of positions known to achieve low, intermediate and high pressures 35

Table 11 Duration of accessing positions known to achieve low, intermediate and high pressures 36

Table 12 Estimated and actual frequencies of seat feature accesses 38

LIST OF FIGURES

Figure 1 The Seat Feature Data Logger (SFDL) 15

Figure 2 (A) Placement of tilt sensors on a wheelchair. (B) Definition of seat tilt and backrest recline angles 16

Figure 3 Seat tilt angles before and after the reduction algorithm 22

Figure 4 An example of one day's use of the seat elevation feature 23

Figure 5 A close-up of SFDL data plotted over pressure-mapping (PM) data 25

Figure 6 Tilt angle ranges accessed by subjects during the study 34

Figure 7 Recline angle ranges accessed by subjects during the study 34

Figure 8 Tilt and recline angle combinations (wide angle ranges) 37

Figure 9 Tilt and recline angle combinations (consistent angle ranges) 37

Figure 10 Estimated and actual frequency of tilt accesses per day 39

Figure 11 Estimated and actual frequency of recline accesses per day 39

Figure 12 Estimated and actual frequency of seat elevation accesses per day 40

Figure 13 Reasons for using seat features 41

Figure 14 Reswick and Rogers' pressure versus time curve (1976) 43

ACKNOWLEDGEMENTS

First and foremost I would like to thank my primary advisor, Dr. Dan Ding for her support throughout the research process. I am especially indebted to her for teaching me new ways of thinking, writing, and approaching problems – essential skills in any field. I would also like to thank all the students and staff at the Human Engineering Research Laboratories (HERL) for helping me in a variety of ways. Finally, thanks to Mitch and my family and friends for their love and support.

1.0 INTRODUCTION

1.1 PRESSURE ULCERS AND THEIR PREVENTION

1.1.1 Definition and Cause of Pressure Ulcers

Pressure ulcers, also known as pressure sores or decubitus ulcers, are wounds on the skin caused by “unrelieved pressure upon weight-bearing tissues” (Brienza, Geyer & Karg, 2001). As the name suggests, excessive external pressures are the primary culprit in the development of pressure ulcers. However there are also many intrinsic and extrinsic factors which contribute to pressure ulcer formation (Brienza *et al.*, 2001; Koo, Mak & Lee, 1996). Intrinsic risk factors include tissue age, humidity, location, metabolism, and temperature (Sprigle & Dunlop, 2003; Henderson, Price, Brandstater & Mandac, 1994). Extrinsic factors include compression and shear which can lead to capillary occlusion (Ceelen, 2003; Brienza *et al.*, 2001), disruption of interstitial fluid and lymph flow (Ceelen, 2003; Brienza *et al.*, 2001), or cell deformation (Ceelen, 2003). But the exact pathway of pressure ulcer formation is unknown (Brienza *et al.*, 2001; Koo *et al.*, 1996; Stinson, Porter-Armstrong & Eakin, 2003a).

With respect to wheelchair users, “any seated position is recognized to be unacceptable if it is held for too long, no matter how well the spinal vertebrae are positioned and the body supported” (Lacoste, Weiss-Lambrou, Allard & Dansereau, 2003). Thus full-time wheelchair users who are unable to independently relieve pressure on the buttocks and thighs frequently are at high risk for sustaining ulcers in these regions. Compounding this problem, some wheelchair users do not have sensation and cannot perceive the need to shift weight (Lacoste *et al.*, 2003). Clinicians and scientists have responded by offering numerous methods of pressure management.

1.1.2 Cost and Prevalence of Pressure Ulcers

Pressure ulcers are a frequent and costly problem in the United States. It is estimated that the yearly cost of treating pressure ulcers is between 1.3 (Xakellis & Frantz, 1996) and 6.4 billion U.S. dollars (Brienza *et al.*, 2001). Furthermore, it can cost approximately $30,000 to treat a single ulcer (Shields & Cook, 1988). Among persons with complete quadriplegia and paraplegia, it is estimated that 60% and 50%, respectively, develop pressure ulcers (Shields & Cook, 1988) – making it important to provide adequate pressure-relieving mechanisms to those who are at risk.

1.1.3 Prevention of Pressure Ulcers

Most wheelchair users are fitted for a seat cushion to help alleviate pressure on the buttocks and thighs. Cushions help to reduce interface pressure on bony prominences, such as the ischial tuberosities (bony part of the buttocks) and/or the trochanters (bony part of the upper femur). While many different kinds of cushions are available – foam, air-filled, gel/gel-foam, fluid flotation, and dynamic – they do not solve the problem of pressure ulcers. Indeed, “even the best seating system can be harmful if an individual remains in it for too long without a change of position” (Lacoste *et al.*, 2003). Therefore some combination of a cushion and pressure relieving methods is necessary for adequate ulcer prevention (Henderson *et al.*, 1994). Many wheelchair users perform arm “push-ups”, or change postures (forward, or side-to-side leaning) to alleviate pressure (Koo *et al.*, 1996). But not all individuals who use wheelchairs have the arm strength or trunk control required to perform these relief methods independently (Lacoste *et al.*, 2003).

1.2 SEAT TILT, BACKREST RECLINE, AND SEAT ELEVATION

1.2.1 Tilt and Recline For Pressure Relief

Many studies have shown (Hobson, 1992; Aissaoui, Lacoste, & Dansereau, 2001; Henderson *et al.*, 1994; Shields & Cook, 1988) that seat tilt can significantly reduce static seating pressure, a key component in the development of pressure sores (Sprigle & Sposato, 1997), and that combining tilt with backrest recline has been shown to achieve greater pressure reduction than tilt alone (Aissaoui *et al.*, 2001; Lacoste *et al.*, 2003). Using tilt with recline can allow for a change in position in the wheelchair, reducing pressure and improving the user's comfort. Clinicians typically prescribe tilt and recline accessories for power wheelchairs based on these arguments. Yet it is unclear if once prescribed these systems are effectively used, and it is unknown if the tilt and/or recline angles used provide adequate pressure relief.

Previous research was conducted largely in laboratory settings, and did not investigate everyday usage of seating systems. Pope (1985) studied the instability of wheelchair users in relation to posture. The primary results of the study indicated that reclining helps reduce stress on the lumbar region of the back, but that reclining also tends to encourage shear stress (sliding). Such shear stress is another recognized culprit in pressure ulcer formation (Ceelen, 2003).

Shields et al. (1988) compared the effects on seat pressure of a lumbar support at 0º and 10º seat tilt angles (recline, or the seat-to-back angle was fixed at 95º). The lumbar support reduced high pressures significantly for both seat tilt angles, but there was no significant difference between the 0º and 10º positions without the lumbar support. This does not necessarily indicate that use of a lumbar support would solve the problem of pressure ulcers. Individuals who lack trunk control would not be able to effectively use a lumbar support unless they could achieve a tilted position. Furthermore, individuals with contraindications, such as tight hamstrings, might be unable to use a lumbar support at all.

In a study incorporating a wider range of angles, Gilsdorf, Patterson, Fisher & Appel (1990) examined sitting forces at different angles and with different cushions. A force plate mounted on the test wheelchair seat was used to measure the sitting forces of five able-bodied subjects at varying angles of backrest recline. The backrest was varied from 5º to 58º (seat-to-back angles of 95º and 148º, respectively), with force measurements taken only at the 5º and 58º positions. This study showed that recline helps to reduce normal force, but can add shear forces on the back. The researchers found that leaning forward helped to reduce the shear forces caused by returning the backrest to the 5º position.

Hobson (1992) conducted an extensive study that compared the pressure and shear at nine different seated positions. In addition, he compared able-bodied subjects and subjects with spinal cord injury (SCI). Comparison of the two different subject types revealed that people with SCI experienced larger maximum pressures in all positions tested, with a 26% higher average pressure in the neutral position. Researchers who measure sitting pressures in able-bodied subjects therefore cannot assume that their results will correlate to pressures experienced by individuals who have a disability. The author suggests this could be due to asymmetrical loading on the buttocks caused by spinal and/or pelvic deformities and atrophy of tissue over this area. Results from this study indicated that leaning the trunk left or right reduced maximum buttock pressure the most (by 32-38%), reclining 120º reduced it by 12%, tilting 20º reduced it 11%, and a 50º forward lean reduced it by 9%. Hobson also investigated shear forces at the nine postures and found that reclining to 110º and 120º increased shear by 7% and 25%, respectively. Reductions in shear were achieved with the 50º forward lean (133% reduction), and 20º of tilt (85% reduction). By extrapolating the tilt angle results, the author found that tilting 25º would theoretically reduce shear by 100%, and tilting more would cause shear to increase rather than decrease. So for wheelchair users who are unable to lean forward, tilt might partially replace the effects leaning forward.

Henderson *et al.* (1994) studied three positions: 35º of tilt (called "tip" in the report), 65º of tilt, and a forward lean. The forward lean offered the greatest pressure relief, 65º of tilt offered significant relief, and 35º of tilt provided only minimal pressure reduction. Again, not all individuals who use wheelchairs are capable of leaning forward.

More recently Aissaoui *et al.* (2001) published a study that examined seat pressures in able-bodied subjects at different angles of tilt and recline. Tilt angles of 0º, 15º, 30º, and 45º were combined with recline angles of 90º, 100º, and 120º. The biggest reduction in maximum pressure was found with 45º of tilt and 120º of recline, while the highest pressure was found with 0º of tilt and 90º of recline (fully upright). Because recline had less of an effect when tilt was 0º than when tilt was 45º, the authors concluded that tilt is more important than recline in reducing maximum seat pressure. In addition, they concluded that only when tilt is greater than 15º is an effective weight shift achieved.

In another study, which examined only recline angle, it was found that reclining 30º significantly reduced average pressure, while recline angles of 10º and 20º had no effect (Stinson *et al.*, 2003a). Coggrave and Rose (2003) describe the measurement of transcutaneous oxygen tension as an effective means to determine when pressure relief is adequate. The authors measured the time taken for subjects to return their tissue oxygen to unloaded levels. They found that brief (15-30 seconds) pressure lifts did not relieve pressure for most people, while longer lifts (average: 1 minute and 51 seconds) were required to return tissue oxygen to unloaded levels.

Finally, Lacoste *et al.* (2003) used a questionnaire for tilt and recline users to find out what ranges of tilt and recline angles were used, and how frequently they were used. They found that 97.5% of respondents used their tilt/recline systems everyday. 70% said they used their systems primarily to rest, relax, increase comfort, and decrease pain. Surprisingly, a minority (≤ 35%) said they used their system to prevent skin redness and/or pressure sores. Of the angle ranges used, small- and middle-sized angles were used more often than larger angles; small angles were used for comfort, while larger angles were used to rest or reduce pain. It should be noted that the reliability and validity of the questionnaire were not established.

1.2.2 Tilt and Recline for Comfort

As mentioned above, Lacoste *et al.* (2003) found that some individuals may use tilt and/or recline for comfort, rather than using it explicitly for pressure relief. There is some disagreement in the literature as to the exact definition of comfort (de Looze, Kuijt-Evers, & van Dieën, 2003). However, researchers do agree that comfort is a perception unique to individuals, can be altered by many different variables within the body (mental and physical), and is a response based on surroundings (de Looze *et al.*, 2003). Although comfort is difficult to define and measure, it is a very real issue in the realm of seating. With regard to wheelchair users, feelings of discomfort can have serious consequences including “equipment abandonment, decreased consumer satisfaction, and an inability to function throughout the day” (Crane & Hobson, 2003).

Researchers have attempted to correlate comfort with quantitative measures. de Looze and colleagues (2003) reviewed the literature to determine how various quantifiable measures related to comfort. They found that studies examining the relationship between posture and comfort did not yield statistically significant results, but "associations" between posture and comfort/discomfort were found (de Looze *et al.*, 2003). In studies which investigated the relationship between pressure distribution and comfort, a few found a statistically significant relationship while others yielded correlations, but without statistical significance (de Looze *et al.*, 2003). Other relationships were considered as well, including the relationship between muscle activation level (using electromyography) and comfort. It was concluded from this review that, compared to other quantitative measures, pressure distribution correlates best with comfort and/or discomfort. In addition, Goossens, Teeuw, & Snijders (2005) found a strong relationship between high pressures at the body-seat interface and discomfort. This might indicate that although wheelchair users in the Lacoste *et al.* (2003) study said they use power seat features for comfort, the underlying reason for their discomfort is high pressure.

Qualitative research has also been undertaken with respect to seating and comfort. A Wheelchair Seating Discomfort Assessment Tool (WcS-DAT) was recently developed to quantify seating discomfort in wheelchair users who occupy their chairs for over 8 hours per day and who have intact sensation in the buttocks (Crane, Holm, Hobson, Cooper, Reed, *et al.*, 2004). The reliability of this tool was verified in another study by the same research group (Crane, Holm, Hobson, Cooper, Reed, *et al*., 2005) and has the potential to provide researchers and clinicians with important information regarding wheelchair seating discomfort.

Whatever the reason for using power seat features, wheelchair users who have difficulty moving independently can benefit greatly from tilt and recline. These features help users shift weight, relieve pressure, and adjust posture. Although the studies in the de Looze *et al.* (2003) review did not find a statistically significant relationship between posture and comfort, the reality is that most individuals find it necessary to shift weight and posture to achieve comfort, and the needs of wheelchair users are no different.

1.2.3 Seat Elevators

Wheelchair seat elevators do not help relieve pressure, but they are important in helping users accomplish mobility related activities of daily living (Arva, Schmeler, Lange, & Lipka, 2005). Seat elevators can help the user perform transfers out of their wheelchair to another surface, reach objects at different surface heights, or achieve eye-to-eye contact in social situations (Cooper, Boninger, Cooper, Fitzgerald, & Kelleher, 2004; Arva *et al.*, 2005). While it may not seem obvious to able-bodied individuals, the ability to achieve eye-to-eye contact with people during conversations can be very important for those who spend a large portion of their day in a seated position. In a pilot study of the Independence™ 3000 IBOT™, Cooper and colleagues (2004) found that during a half-workday subjects preferred to use the wheelchair in an elevated position to facilitate eye-to-eye interactions with peers. Children can also benefit greatly from a seat elevator as they explore their environment and develop learning skills (Arva *et al.*, 2005). Caregivers can benefit as well; helping a person transfer or stand from a low seated position places greater strain on the caregiver's back, possibly leading to future injury (Edlich, Heather, & Galumbeck, 2003). In addition, studies concerning sit-to-stand transfers at different heights have found that rising from a lower position is biomechanically more demanding on the body (Janssen, Bussmann, & Stam, 2002). A seat elevator is thus a valuable feature which helps promote independence and improve transfer biomechanics.

1.3 DATA LOGGERS AND RECORDING WHEELCHAIR USE

A data logger is an electronic device that collects data over a period of time (Onset Computer Corporation, 2003). Usually they are portable and battery-powered, enabling researchers to capture data outside of the laboratory. This is advantageous in studies of human/animal behavior, when an accurate portrayal of activities is desired. Individuals have a tendency to change behaviors if they are aware of being observed, such as in a laboratory setting. This phenomenon is known as the Hawthorne effect (Portney & Watkins, 2000). An ideal data logger therefore travels silently and unobtrusively with a subject and collects data independently.

Numerous studies of animal behavior have been made possible through the use of portable, remote data logging devices. Andrews (1998) described a system which remotely monitored physiological and behavioral variables in elephant seals. Another group collected brain activity information from homing pigeons via a custom-built data logging device (Vyssotski, Serkov, Itskov, Dell'Omo, Latanov, *et al.*, 2006).

Data loggers can also be used by doctors and clinicians as a compliance tool, which can be helpful in planning the course of a patient's therapy. For instance, data logging technology has been used in orthodontic appliances, such as headgear and retainers, to determine if patients wear the devices as frequently as they claim (U.S. Patent, No. 6,099,303, 2000). This information can affect future compliance with therapy – if little progress is observed while a patient claims to use their appliance as prescribed, the orthodontist will increase the forces on the teeth. If the patient is non-compliant, this can lead to discomfort and a reduced desire to continue therapy. Data loggers have been used in other clinical compliance applications including scoliosis bracing (Helfenstein, Lankes, Ŏhlert, Varoga, Hahne, *et al.*, 2006) and brushing teeth (McCracken, Janssen, Steen, deJager, & Heasman, 2002).

Data loggers have also been used to measure wheelchair usage. The Human Engineering Research Laboratories (HERL) has developed many different types of data loggers, improving their design with each phase of development. Speath, Arva, & Cooper (2000) describe the application of a speed and distance data logger to compare how subjects used their personal manual wheelchairs versus a power assist wheelchair. A magnet and reed switch tracked wheel turns, and the resulting time-date stamps were used to calculate distance and speed. This data logger was used in many different studies from the same research group. In another study the data loggers were used to measure distance traveled, speed, and frequency of use in 17 power wheelchair users (Cooper, Thorman, Cooper, Dvorznak, Fitzgerald, *et al.*, 2002). Kaminski (2004) explored manual and power wheelchair usage in children between 6 and 17 years old. And more recently the data loggers were used to examine usage patterns of a group of athletes at the National Veterans Wheelchair Games (Tolerico, 2005).

HERL also recently developed a weather-proof data logger which monitors seat feature usage on power wheelchairs (Leister, Ding, Cooper, Kelleher, Cooper, *et al.*, 2005). A separate group validated an instrument that collects information regarding tilt and distance traveled (Lankton, Sonenblum, Sprigle, Wolf & Oliveira, 2005). The data logger described by Leister *et al.* (2005) collects real-time information from pressure, tilt, and seat height sensors. The data are downloaded and analyzed to determine how the seat features are being used. Clinicians can utilize the information generated from the data logger to quantify the use of tilt, recline and seat elevation and examine the effectiveness of using these features.

2.0 SPECIFIC AIMS AND HYPOTHESES

The principal goal of this study was to examine how individuals use power wheelchair seat features such as seat tilt, backrest recline, and seat elevation, during typical daily activities. Data related to usage were collected with a seat feature data logger, which was unobtrusively mounted to each participant's wheelchair. The information collected by the seat feature data logger allows for a novel and quantitative description of the effectiveness and use of power seat features. This information can also be used as a clinical compliance tool, or to construct better wheelchairs.

This study addresses three specific aims:

1. To quantify how people use power seat features by calculating the frequency and duration of accessing each feature, and determining the most common tilt and recline angles used and the amount of time spent in these angles. Simultaneous use of tilt and recline will also be examined.
2. To investigate if people use tilt and recline effectively by calculating the use of these features at positions known to reduce seat interface pressure.
3. To explore whether perceived usage is consistent with actual usage.

In this study we also tested two hypotheses:

1. Wheelchair users will spend more time in a tilted rather than an upright position.
2. Wheelchair users will use seat tilt significantly more than backrest recline or seat elevation.

3.0 METHODS

3.1 SUBJECTS AND RECRUITMENT

3.1.1 Demographic Information

A total of 12 subjects were recruited to participate in the study; results are reported for 11 subjects (data from one subject was not used due to inconsistencies). Subjects were included in the study if they 1) were between the ages of 18 and 70; 2) used an electric powered wheelchair (EPW) equipped with functioning seat tilt and/or backrest recline and/or seat elevation; and 3) were able to independently control the seat tilt and/or backrest recline and/or seat elevation options. Individuals were not eligible to participate if they had open pressure sores. There were 6 males and 5 females in the study with a mean age of 44.4 ± 14.5 years. Four different types of disability were represented in this sample: 4 subjects with a spinal cord injury (SCI), 3 with cerebral palsy (CP), 3 with multiple sclerosis (MS), and 1 with muscular dystrophy (MD). Table 1 shows demographic information for each subject. Nine participants used Permobil wheelchairs, and the remaining two used power wheelchairs from Invacare. The average age of these wheelchairs was 2.5 ± 2.0 years. The characteristics of the EPWs used in this study are presented in Table 2.

Table 1: Demographic information for each subject.

Subject	Age	Gender	Disability
1	44	F	SCI / dwarfism
2	38	M	SCI (C4-C5)
3	52	F	CP (athetoid)
4	48	M	SCI (C5)
5	44	M	SCI (C5)
6	55	F	MS
7	60	F	MS
8	25	F	CP
9	69	M	MS
10	29	M	CP
11	24	M	MD

Table 2: Characteristics of wheelchairs used in the study (tilt and recline ranges are approximate).

Subject	Wheelchair Make	Wheelchair Model	Wheelchair Age	Seat Cushion	Seat Tilt Range (degrees)	Backrest Recline Range (degrees)
1	Permobil	C500 (super low)	3 weeks	Varilite	0 to 20	85 to 115
2	Permobil	Chairman 2K	4 years	Roho	2 to 45	90 to 130
3	Permobil	Chairman Entra	1 year	Permobil*	0 to 45	95 to 140
4	Permobil	Street	1 month	Permobil*	0 to 45	100 to 145
5	Permobil	Chairman Entra	4.5 years	Roho	0 to 46	100 to 145
6	Permobil	Chairman Entra	3 years	Permobil*	0 to 38	96 to 140
7	Permobil	C300	8 days	Varilite	0 to 46	95 to 150
8	Permobil	Street	16 months	Varilite	1.5 to 45	93 to 140
9	Invacare	Storm TDX3	4 years	Jay	0 to 60	N/A
10	Permobil	Chairman	5 years	Contour U (custom foam)	0 to 23	N/A
11	Invacare	Ranger X	4 years	Cloud	4 to 44	90 to 150

* Permobil cushions are a car seat type foam cushion.

3.1.2 Recruitment Procedures

Individuals utilizing EPWs equipped with any combination of seat tilt, backrest recline, or seat elevation were recruited to participate in this study. Subjects were recruited through mailings to EPW users in the Human Engineering Research Laboratories (HERL) wheelchair users registry (see Appendix A for the flyer approved by the University of Pittsburgh IRB); or through therapists working at the Center for Assistive Technology (CAT) at the University of Pittsburgh.

3.2 INSTRUMENTATION

A Seat Feature Data Logger (SFDL) was constructed to record the usage of EPW seat features including seat tilt, backrest recline, and seat elevation. It consists of a commercial programmable data logger from Onset Computer Corp.[a] with 19 analog channels and 2MB flash EEPROM, three tilt sensors from Crossbow Technologies Inc.[b], three pressure sensors from Interlink Electronics, Inc.[c], and one linear position transducer from Unimeasure Inc.[d]. The SFDL is a modular system (see Figure 1) powered by three 9-volt batteries in parallel, which can be mounted on a variety of power wheelchairs without additional modifications to the EPWs and does not interfere with daily activities of wheelchair users.

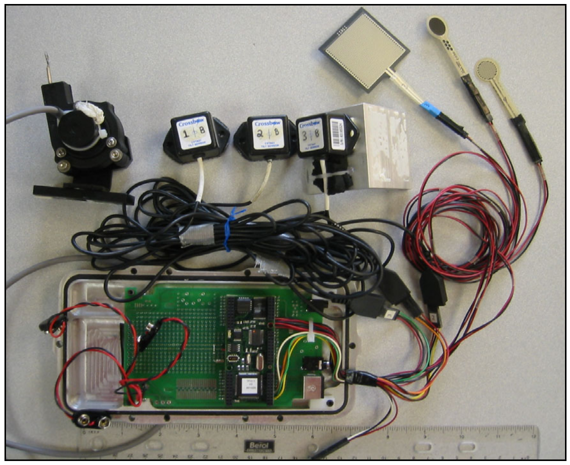

Figure 1: The Seat Feature Data Logger (SFDL)

The solid-state, analog tilt sensors used in the study have an angular range of ± 75º with respect to gravity. The angle of tilt (θ) for each sensor was calculated as:

$$\theta = \sin^{-1}\left[\frac{Vout_T - Vzero}{Sensitivity}\right]$$

Where $Vout_T$ is the output voltage of the tilt sensor, *Vzero* is the voltage of the tilt sensor at 0º (approximately 2.5 Volts), and *Sensitivity* is approximately 35 mV/degree. The tilt sensors were attached to the wheelchair using double-sided tape and duct tape at three different locations (see Figure 2) on the wheelchair (i.e., the wheelchair base, the seat pan and the backrest). These sensors are referred to as the base, seat, and backrest sensors, respectively. The base sensor was used to eliminate the effect of slopes in calculating the seat tilt and backrest recline angles. The seat tilt angle *SA* was obtained by subtracting the seat sensor reading from the base sensor reading. The backrest sensor was mounted to the chair using a 90° bracket so that it was oriented roughly parallel to the ground. The backrest recline angle *RA* was calculated as the angle between the seat and backrest as follows:

$$RA = 90° - SA + BA$$

where *BA* is the reading from the backrest sensor.

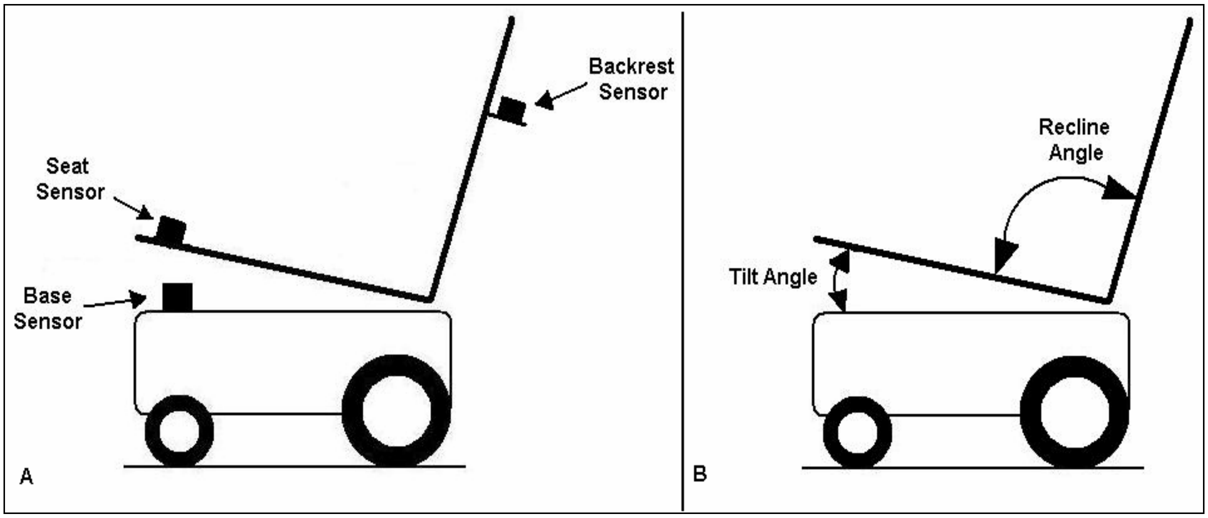

Figure 2: (A) Placement of tilt sensors on a wheelchair. (B) Definition of seat tilt and backrest recline angles.

The pressure sensors are made of a polymer thick film, and exhibit a reduced resistance when a force is applied to their active surface. One 1.5” x 1.5” square sensor and two 0.5” diameter circular sensors were utilized to detect wheelchair occupancy. They were attached to the seat pan of the wheelchair, underneath the cushion. The square sensor was attached to the seat pan in an area where one of the subject’s ischial tuberosities would approximately rest, and the two circular sensors were affixed in an area where the subject’s thighs would rest. The sensors and trailing wires were secured using duct tape and electrical tape. In order to reliably detect chair occupancy, the sensitivity of each pressure sensor was adjusted with a proper series resistor. The resistor was chosen based on the requirement that it enabled the pressure sensors to reliably detect chair occupancy under a variety of seat cushions. Five cushion types were tested including 1) a non-contoured nylon/foam cushion, 2) a car seat type synthetic leather-covered foam cushion, 3) an Independence Max Pro (a cushion packed with triangular, air-filled nylon cells), 4) an Invacare Comfort Mate contoured foam cushion, and 5) a Jay fluid cushion. During the test, three pressure sensors were affixed to the seat pan of a test wheelchair and a different cushion was used for each test. Different resistance values were tested where pressure sensor readings were recorded with an able-bodied investigator in upright and forward-leaning positions, and with the chair unoccupied. As a result, the 120 kΩ resistor chosen allowed for chair occupancy detection and prevented heavier cushions from falsely triggering the sensors.

The linear position transducer was used to measure seat elevation. The model of the transducer used in the study has a linear range of 50 cm and has an average sensitivity of approximately 0.19 mV/V/cm. A resistor can also be placed in series with this sensor to control sensitivity and current consumption. Different resistance values were tested for the full range of the sensor, and a value of 4.7 kΩ was determined to yield the best sensitivity while also limiting current consumption. The sensor was calibrated with this resistor value and the following equation was used to calculate seat height:

$$Height = 9.9916 \times Vout_H$$

Where *Height* is the length of the wire rope (i.e. height of the EPW seat) in centimeters, $Vout_H$ is the voltage output of the linear position transducer, and 9.9916 is a conversion factor. The swivel base of the transducer was attached to the wheelchair base. The wire rope of the transducer was secured to a location underneath the seat on the wheelchair frame using a cable tie. The attachment point was chosen such that the wire rope exited perpendicular to the sensor body, and so the sensor would not be activated when tilt and/or recline were used.

3.3 PROTOCOL

The VA Pittsburgh Healthcare System Institutional Review Board (IRB) and the University of Pittsburgh IRB approved the protocol for this study. The nature of the study was explained and written informed consent was obtained from all subjects before the start of data collection. Subject testing was conducted at one of three locations: 1) the Human Engineering Research Laboratories, located at the Highland Drive, VA Pittsburgh Healthcare System, 2) the Center for Assistive Technology, located on the University of Pittsburgh campus, or 3) the participant's home.

The protocol was described as follows:

- **First Visit**

  After obtaining informed consent, demographic information for the subjects and their wheelchairs were collected (see Appendix B) including age, gender, ethnic origin, date of birth, disability, wheelchair make and model, wheelchair age, ranges of seat tilt and backrest recline angles, and seat elevation.

- **SFDL mounting**

  Once documentation was completed, the subject was transferred out of his/her wheelchair with proper clinical assistance. While the subject was out of the chair, the SFDL pressure sensors were attached to the seat pan of the wheelchair.

- **Pressure-mapping at various seat tilt and backrest recline positions**

  Before the subject was transferred back to his/her wheelchair, a pressure-mapping device (a force sensing array (FSA) from Vista Medical Ltd.[e]) was placed on top of the subject's wheelchair cushion for the pressure-mapping procedure. The FSA mat consists of 256 pressure-sensitive sensors in a 16-by-16 array. The mat can record peak pressures on the buttocks, with a maximum reading of 200 mmHg for each sensor. The FSA was calibrated according to the manufacturer's product manual before the study began. The same calibration was used throughout the study to maximize comparability of results.

The procedure began with the wheelchair fully upright. For a majority (n=8) of EPWs in the study, a "fully upright" position was at a tilt angle of approximately 0º, and a recline angle between 90º and 95º. However, a few subjects (n=4) began the procedure at a different initial position, either because their EPWs were equipped different tilt and/or recline ranges, or because they were physically uncomfortable with the upright initial position (e.g. one individual lacked trunk control and never used a tilt angle below 10º). During the procedure each subject was asked to go through the full range of tilt and recline angles in 5º increments. Peak pressure readings from the FSA were recorded at each position after the subject settled.

- **Data collection**

  Once the pressure-mapping was completed, the SFDL and the remaining sensors were secured to the wheelchair and the logging program was started. The subject was sent away and instructed to go about their daily activities as usual for 10-14 days.

- **Mid-study visit**

  At the end of one week (5-7 days) subjects returned to the center or a research associate visited their home to check sensor placement, download data from the previous week, replace the batteries of the SFDL, and restart the data acquisition program to collect data for an additional week.

- **Final visit and completion of a brief questionnaire**

  At the end of the study, subjects returned to the center or a research associate visited their homes to remove the SFDL and its sensors. Subjects were asked to complete the rest of the questionnaire (see Appendix C) related to their perceived usage of seat features and the purposes of accessing these features. The questionnaire was completed at the end of the study to ensure that questions on the questionnaire did not influence subject's use of seat features during the study period.

3.4 DATA ANALYSIS AND REDUCTION

3.4.1 Data Collection Program

The data collection program running on the SFDL was written in TFBASIC from Onset Computer Corp[a]. The pressure sensors were sampled every 15 seconds to determine wheelchair occupancy. If the subject was in the chair (i.e., at least one pressure sensor reading was over 1 volt), the readings from the pressure sensors, tilt sensors, linear position transducer, and current time stamp were stored every 15 seconds. Otherwise, the program stored all sensor readings and the time stamp when the subject left the wheelchair, and continued sampling the pressure sensors until wheelchair occupancy was detected.

3.4.2 Data Analysis and Reduction Program

The data analysis and reduction program was written in MATLAB[f]. It read the data file downloaded from the SFDL, and converted the digital data into voltage for the pressure sensors, angles (in degrees) for the tilt sensors, and length (in centimeters) for the linear position transducer. The MATLAB program was also used for data reduction and calculation of all the variables of interest related to seat feature usage.

- **Chair occupancy and transfer frequency**

  Three variables related to chair occupancy were calculated based on pressure sensor readings, including total occupancy time per day, duration of the longest single continuous occupancy per day, and the transfer frequency per day. The wheelchair was considered to be occupied if at least one pressure sensor was above 1 volt. A transfer activity was counted whenever the subject left his/her wheelchair for at least 10 minutes or returned to and stayed in the wheelchair for at least 2 minutes. A 10 minute out-of-chair time interval was chosen to account for brief transfer periods (such as when transferring to perform ADLs). In addition, this interval was selected to ensure that leaning or other weight shift activities were not mistaken for wheelchair vacancy. The 2 minute in-chair time interval was chosen to account for brief periods of noise or momentary movements that might falsely trigger the pressure sensors.

- **Frequency and duration of seat tilt, backrest recline, and seat elevation accesses**

  Based on the sensitivity of the sensors and examination of the data from subjects, we established the following definitions for a seat tilt access, a backrest recline access, and a seat elevation access. A seat tilt access was defined as a tilt angle change of greater than 2.5° in either fore or aft directions. Similarly, a backrest recline access was defined as a recline angle change of greater than 2.5° in either fore or aft directions. A seat elevation access was defined as a seat elevation change greater than 1 cm in either direction.

  Because the tilt sensors were noisy (a static fluctuation of approximately ± 1°), and could be perturbed by wheelchair vibration introduced by terrain changes and accidental movements of the subject, we developed a data reduction algorithm to filter the raw data. The algorithm searched for the peaks and valleys of the seat tilt angles, averaged the adjacent angles (peak or valley), and summed the durations if the difference was less than 2.5°. We further reduced the data if the duration between adjacent angles was smaller than 1 minute. The top plot in Figure 3 depicts a portion of tilt data. The bottom plot is an enlarged view of the circled peak in the top plot, demonstrating sensor fluctuation and showing the difference between seat tilt angles before and after the reduction algorithm.

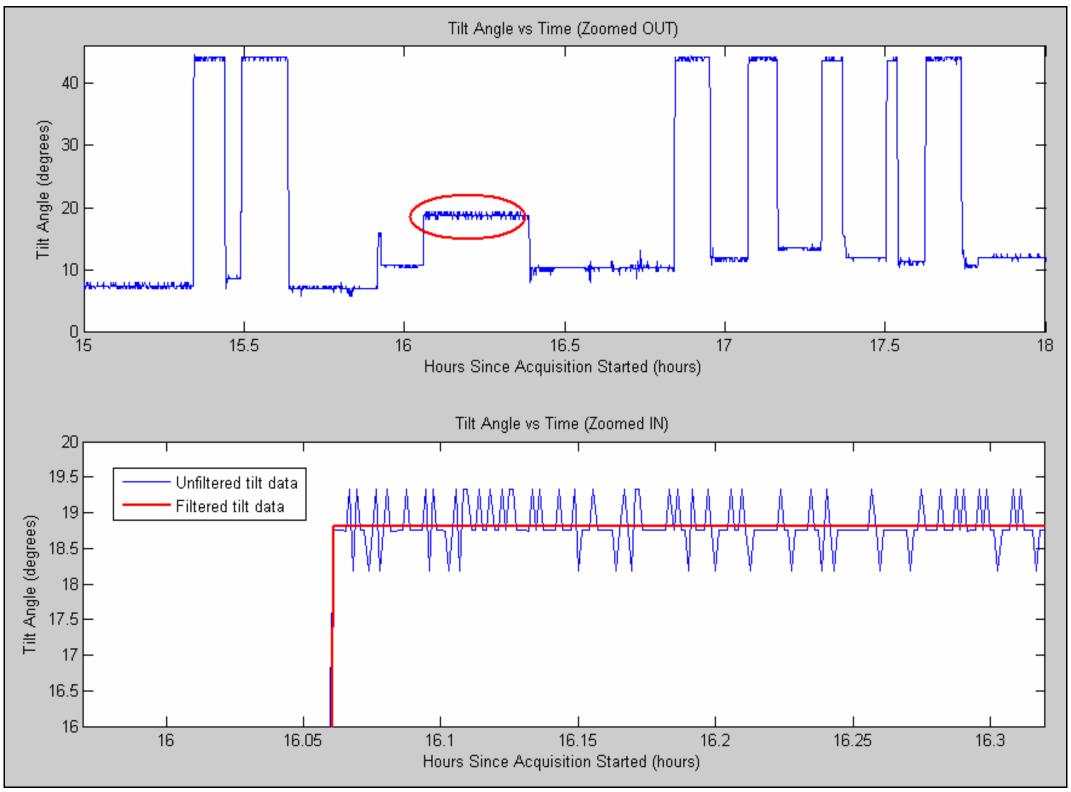

Figure 3: Seat tilt angles before and after the reduction algorithm.

The seat elevation sensor was less susceptible to noise from vibration. Furthermore, seat elevation is commonly used for functional tasks, which can be of short duration. Therefore, we chose not to use a duration threshold to reduce the data from the seat elevation sensor. Figure 4 shows an example of one day's use of the seat elevation feature.

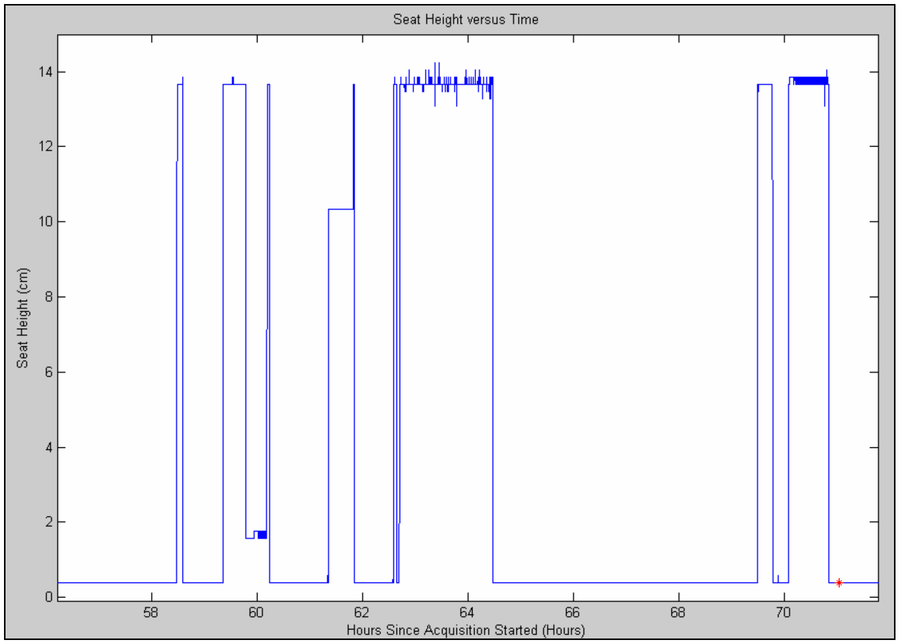

Figure 4: An example of one day's use of the seat elevation feature.

- **Simultaneous tilt and recline accesses**

  The duration of simultaneous tilt and recline use was calculated by combining tilt and recline angles into a single array. This tilt/recline array was reduced using tilt angle parameters then further reduced by searching the array for overlapping recline usage. Simultaneous tilt and recline use was defined as the coincident occurrence of a tilt angle above 2.5° and a recline angle above 95°. This variable was obtained for those subjects having EPWs equipped with both seat tilt and backrest recline features.

- **Most common tilt and recline angles and time spent in these angles**

  For both the seat tilt and backrest recline features, we calculated the most common tilt/recline angles based on the duration of access and the frequency of access, respectively. The percent of time spent in these angles was also calculated. In addition, we grouped the tilt angles into several ranges, i.e., 2.5°-15°, 15°-30°, 30°-45°, 45° and higher, and calculated the access frequency of these ranges. For the recline angles, we calculated the access frequency of the following ranges: 95°-100°, 100°-120°, 120°-140°, 140° and higher.

- **Frequency and duration of accessing positions known to relieve pressure**

Based on clinical practice, peak seat interface pressures can be classified as low, intermediate, or high if they are below 80 mmHg, between 80 and 120 mmHg, and above 120 mmHg, respectively (Shapcott & Levy, 1999). Seat positions (i.e., tilt and recline angles) known to yield low, intermediate and high peak pressures were identified from the pressure-mapping procedure. The frequency and duration of accessing these angle combinations known to fall within the three categories were calculated, and the effectiveness of using these seat features was examined.

To calculate the frequency and duration of accessing positions known to relieve pressure, tilt and recline angle combinations recorded by the SFDL were compared to combinations recorded during the pressure-mapping (PM) procedure. Figure 5 is a close-up of SFDL data plotted over PM data. Many SFDL data points did not exactly match PM data points, so the distances between data points were calculated (i.e. the black arrows in Figure 5) and distances less than 2.5º were considered an approximate match. The following equations, based on the Pythagorean Theorem, were used to calculate the distance between points:

$$\Delta x = Tilt_{DL} - Tilt_{PM}$$

$$\Delta y = \mathrm{Re}cline_{DL} - \mathrm{Re}cline_{PM}$$

$$Dist = \sqrt{\Delta x^2 + \Delta y^2}$$

where $Tilt_{DL}$ is the tilt angle recorded by the SFDL, $Tilt_{PM}$ is the tilt angle measured during the pressure-mapping procedure, and Δx is the difference between the two. Δy is calculated similarly for the recline angles. For subjects whose wheelchairs were not equipped with recline, Δy was assumed to be zero. Once data points were matched the frequency and duration of accessing low, intermediate, and high pressure positions were determined for each day of the trial.

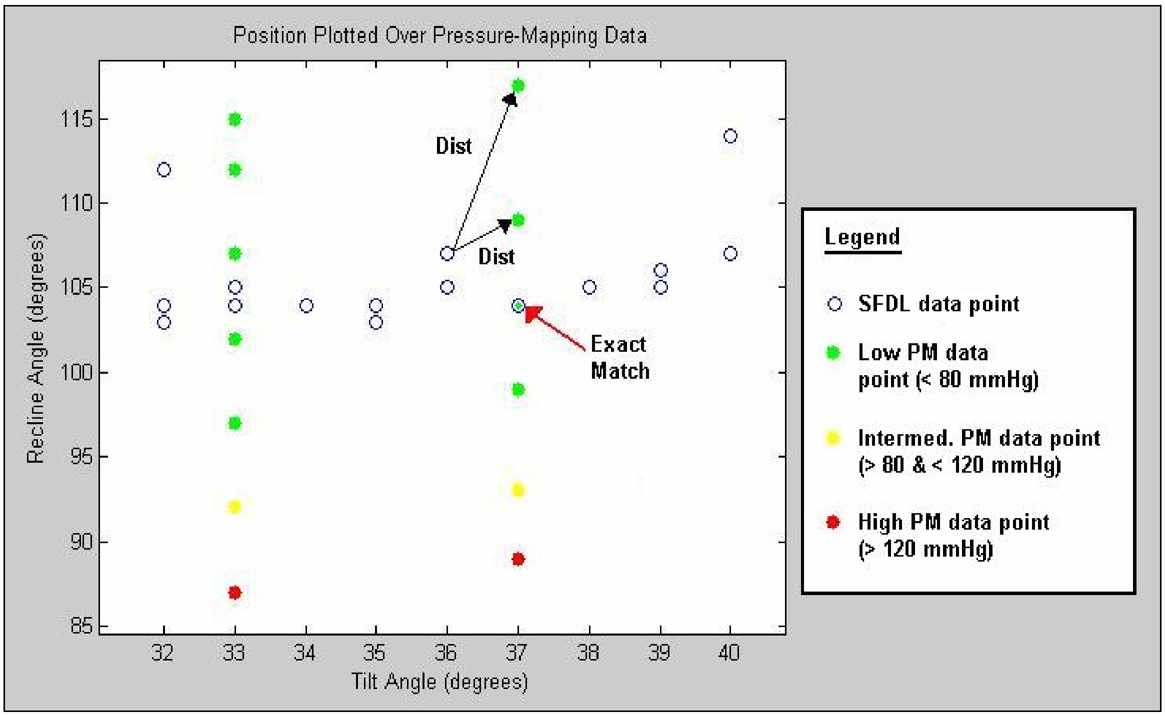

Figure 5: A close-up of SFDL data plotted over pressure-mapping (PM) data.

3.4.3 Statistical Analysis

Averages and standard deviations were calculated for all variables described. To determine if subjects spent more time in a tilted versus an upright position a Wilcoxon signed ranks test was calculated. This test was also used to determine if seat tilt was used significantly more than backrest recline and/or seat elevation. Using a Bonferroni correction, statistical significance was set at the $p<0.025$ level to account for using multiple tests on the same data. The Wilcoxon signed ranks test was also used to determine if subjects significantly over- or underestimated their frequency of accessing seat features. This test was not repeated for multiple tests, so a *p*-value of 0.05 was chosen. Finally, to determine if a relationship existed between transfer frequency and the frequency of seat elevation accesses, Spearman's rho correlation was calculated for these variables. All statistics were analyzed using SPSS[g] statistical software.

4.0 RESULTS

4.1 CHAIR OCCUPANCY TIME

Chair occupancy data are shown in Table 3 including the total occupancy time, the longest single occupancy time, and transfer frequency per day. On average subjects occupied their wheelchairs for 12.0 ± 3.0 hours per day, with an average longest single continuous occupancy of 10.6 ± 3.6 hours. Subjects transferred in and out of their wheelchairs for an average of 5.0 ± 5.3 times per day.

Table 3: Chair occupancy results.

Subject	Total occupancy time (hours/day)	Longest single continuous occupancy (hours/day)	Transfer frequency (#/day)
1	15.4 ± 3.9	10.7 ± 5.2	11.3 ± 4.2
2	10.5 ± 0.8	10.5 ± 0.8	2.0 ± 0.0
3	14.2 ± 3.4	11.5 ± 4.1	6.0 ± 1.6
4	11.5 ± 4.9	11.4 ± 5.0	0.6 ± 1.8
5	14.3 ± 1.4	14.3 ± 1.4	2.0 ± 0.0
6	13.3 ± 1.9	13.3 ± 1.9	2.0 ± 0.0
7	5.5 ± 2.4	2.2 ± 1.5	17.9 ± 5.5
8	7.9 ± 2.7	5.7 ± 2.0	5.1 ± 3.3
9	13.1 ± 0.4	13.0 ± 0.4	0.8 ± 1.5
10	13.4 ± 1.9	13.4 ± 1.9	2.0 ± 0.0
11	13.1 ± 2.7	10.5 ± 4.0	5.1 ± 2.4

4.2 SEAT FEATURE USAGE

Results of statistical analysis indicated that subjects spent significantly more time in a tilted versus an upright position ($p=0.003$). In addition, it was found that seat tilt was not used significantly more than backrest recline ($p=0.155$) or seat elevation ($p=0.046$).

4.2.1 Seat Tilt Usage

Table 4 shows the frequency and duration of tilt accesses. Tilt access frequency is defined as the number of times the seat tilt feature was accessed per day, and tilt duration is the total length of time seat tilt was accessed per day. The table also shows the total time subjects spent in an upright position, defined as a seat tilt and backrest recline angle below 2.5° and 95°, respectively. This was chosen since most subjects' tilt and recline features were capable of going below these values (see Table 2). Subjects accessed the tilt feature 18.4 ± 14.4 times per day for 8.5 ± 5.2 hours per day. Little time was spent in a fully upright position: 0.7 ± 1.5 hours per day. Note that subjects 7 and 8 did not utilize the tilt feature frequently. Subject 7 had MS and fatigued easily, and therefore spent much of the day in bed. In addition her wheelchair was less than one week old and she was learning how to use the seat features. Subject 8 has CP and moves around quite a bit while in a seated position (which in and of itself can help relieve pressure). Furthermore, subject 8 usually transferred out of her wheelchair into a rocking chair in the afternoons when she returned home from a daycare program.

Table 4: Frequency and duration of tilt accesses and upright time.

Subject	Tilt Accesses (#/day)	Tilt Duration (hours/day)	Upright time (hours/day)
1	15.4 ± 10.2	4.6 ± 2.6	0.1 ± 0.2
2	41.3 ± 7.1	10.1 ± 0.8	0.0 ± 0.0
3	30.1 ± 11.7	11.3 ± 3.0	0.3 ± 0.3
4	10.2 ± 6.6	3.6 ± 2.7	0.0 ± 0.0
5	38.0 ± 11.2	13.1 ± 1.7	0.0 ± 0.0
6	32.2 ± 4.8	13.0 ± 1.7	0.0 ± 0.0
7	2.4 ± 2.2	0.7 ± 0.7	0.2 ± 0.4
8	0.4 ± 0.9	0.4 ± 1.2	1.9 ± 2.4
9	9.3 ± 4.9	13.4 ± 1.9	0.0 ± 0.0
10	9.3 ± 4.9	13.4 ± 1.9	0.0 ± 0.0
11	13.6 ± 6.6	10.1 ± 2.5	5.0 ± 2.5

4.2.2 Backrest Recline Usage

Table 5 shows frequency and duration of recline accesses. The frequency of recline accesses is defined as the number of times the recline feature was accessed per day, and the recline duration is the total length of time the recline feature was accessed per day. This feature was accessed on average 11.5 ± 8.4 times per day, for 8.6 ± 4.6 hours per day. Note that subject 11 did not use recline as much as the other subjects. This subject had a severe spinal deformity and usually did not sit with his back against the backrest, therefore limiting his need to use recline. However, he indicated that when he wanted to stretch his spine, rest, or improve comfort he would lean back against the backrest and use the recline feature.

Table 5: Frequency and duration of recline accesses.

Subject	Recline Accesses	Recline Duration (hours/day)
1	9.0 ± 3.0	13.1 ± 3.8
2	5.9 ± 2.5	10.0 ± 0.8
3	12.1 ± 5.2	9.0 ± 3.0
4	28.2 ± 18.4	9.7 ± 5.1
5	14.4 ± 2.8	13.1 ± 1.4
6	19.5 ± 8.3	13.0 ± 1.7
7	10.2 ± 5.8	5.0 ± 2.3
8	2.9 ± 1.4	4.2 ± 2.2
9*	N/A	N/A
10*	N/A	N/A
11	1.7 ± 1.7	0.2 ± 0.3

* The seat feature was not present.

4.2.3 Simultaneous Usage of Seat Tilt and Backrest Recline

Table 6 shows the total duration of simultaneous tilt and recline use. This was not calculated for subjects 9 and 10 because their wheelchairs were not equipped with the recline function. On average, subjects accessed tilt and recline together for 4.8 ± 4.6 hours per day. Note that subjects 7, 8, and 11 did not use tilt and recline simultaneously because of the reasons discussed previously.

Table 6: Duration of simultaneous tilt and recline use.

Subject	Duration of Simultaneous Tilt and Recline Use (hours/day)
1	3.3 ± 2.4
2	9.9 ± 0.9
3	7.1 ± 2.6
4	2.2 ± 1.7
5	8.4 ± 2.1
6	11.9 ± 3.0
7	0.5 ± 0.6
8	0.0 ± 0.1
9*	N/A
10*	N/A
11	0.1 ± 0.2

* The seat feature was not present.

4.2.4 Seat Elevation Usage

Table 7 shows the frequency and duration of seat elevation accesses. The frequency of seat elevation accesses is defined as the number of times the seat elevation feature was accessed per day, and the seat elevation duration is the total length of time the seat elevation feature was accessed per day. Seat elevation usage was recorded for six subjects: 2 subjects did not have the feature and three subject's EPWs did not accommodate the sensor. This feature was accessed 4.3 ± 4.1 times per day on average, for 2.8 ± 4.6 hours. No significant correlation was found between transfer frequency and frequency of seat elevation accesses (r=0.541, p=0.268).

Table 7: Frequency and duration of seat elevation accesses.

Subject	Seat Accesses	Seat Duration (hours/day)
1	C/A*	C/A
2	8.8 ± 2.4	5.1 ± 2.0
3	9.3 ± 4.2	11.2 ± 5.3
4	C/A	C/A
5	2.3 ± 0.5	0.4 ± 0.5
6	0.1 ± 0.3	0.0 ± 0.0
7	4.8 ± 2.8	0.1 ± 0.1
8	C/A	C/A
9	N/A†	N/A
10	0.2 ± 0.4	0.0 ± 0.0
11	N/A	N/A

* C/A = The seat elevation sensor could not be attached.

† N/A = The seat elevation feature was not present.

4.2.5 Most Common Tilt and Recline Angles

The most common tilt and recline angles used through out the trial are shown in Tables 8 and 9. “MCTA” is the most common tilt angle based on *duration* of accesses; “% time MCTA” is the percent of time spent in MCTA, and is based on the total duration of that angle divided by the total in-chair time. “MCTB” is the most common tilt angle based on *frequency* of accesses; % time in MCTB is the percent of time spent in MCTB. Similarly, MCRA is the most common recline angle based on duration of accesses, while MCRB is the most common recline angle based on frequency of accesses. MCTA ranged from 2.5 to 15 degrees and MCTB ranged from 2.5 to 45 degrees, while % Time MCTA ranged from 2.2 to 77.0 percent and % Time MCTB ranged from 1.6 to 77.0 percent. MCRA ranged from 95 to 122.5 degrees and MCRB ranged from 95 to 137.5 degrees, while % Time MCRA ranged from 0.5 to 74.8 percent and % Time MCRB ranged from 0.4 to 74.8 percent.

Table 8: The most common tilt angles and percent of time spent in these angles.

Subject	MCTA (degrees)	% Time MCTA	MCTB (degrees)	% Time MCTB
1	2.5 to 5	9.3	2.5 to 5	9.3
2	12.5 to 15	30.6	42.5 to 45	13.8
3	10 to 12.5	11.7	17.5 to 20	5.1
4	2.5 to 5	15.2	2.5 to 5	15.2
5	2.5 to 5	38.0	2.5 to 5	38.0
6	7.5 to 10	34.3	7.5 to 10	34.3
7	12.5 to 15	2.2	10 to 12.5	1.6
8	2.5 to 5	7.7	2.5 to 5	7.7
9	10 to 12.5	50.0	10 to 12.5	50.0
10	2.5 to 5	77.0	2.5 to 5	77.0
11	5 to 7.5	34.4	5 to 7.5	34.4

Table 9: The most common recline angles and percent of time spent in these angles.

Subject	MCRA	% Time MCRA	MCRB	% Time MCRB
1	102.5 to 105	22.1	107.5 to 110	17.7
2	102.5 to 105	43.0	135 to 137.5	4.7
3	97.5 to 100	13.0	102.5 to 105	9.8
4	107.5 to 110	19.2	107.5 to 110	19.2
5	100 to 102.5	37.4	100 to 102.5	37.4
6	95 to 97.5	74.8	95 to 97.5	74.8
7	102.5 to 105	36.9	102.5 to 105	36.9
8	97.5 to 100	21.2	97.5 to 100	21.2
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	120 to 122.5	0.5	107.5 to 110	0.4

Access frequencies of several ranges of tilt and recline angle were also calculated. Figures 6 and 7 show the average number of times that subjects accessed small, intermediate, and large amplitude tilt and recline angles per day. Subjects generally used small and intermediate amplitude angles for both tilt and recline, and seldom used larger angles. For some subjects the range of angles accessed can be explained by the seat feature ranges present on their wheelchair (i.e. tilt angle ranges accessed by subjects 1 and 10, see Table 2).

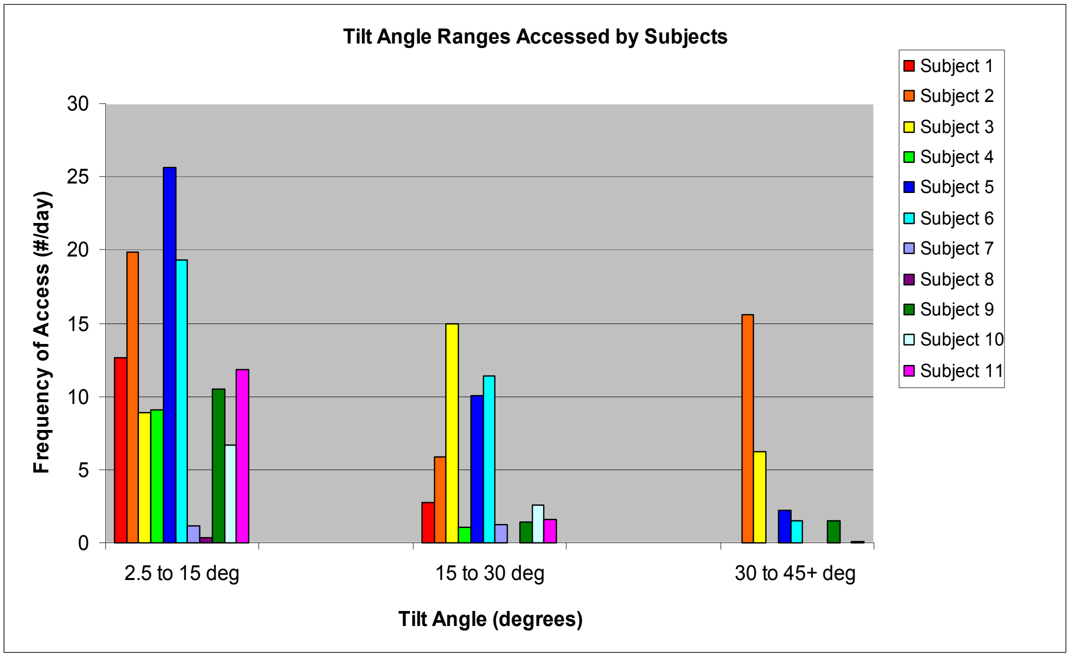

Figure 6: Tilt angle ranges accessed by subjects during the study.

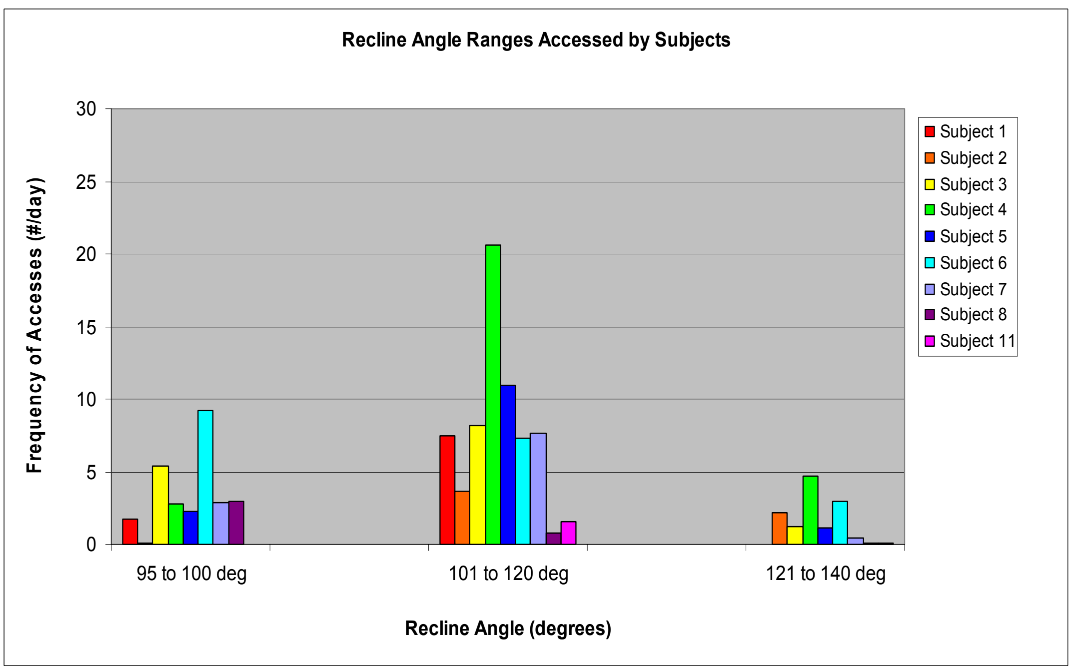

Figure 7: Recline angle ranges accessed by subjects during the study.

4.3 EFFECTIVENESS OF SEAT FEATURE USAGE

To examine the effectiveness of seat feature usage, we compared the seat tilt and backrest recline data obtained from the SFDL with peak seat pressure readings at different tilt and recline positions obtained during the pressure-mapping procedure. Based on clinical practice, peak seat interface pressures can be classified as low, intermediate, or high if they were below 80 mmHg, between 80 and 120 mmHg, and above 120 mmHg, respectively (Shapcott & Levy, 1999). Table 10 shows the peak pressure ranges observed during the pressure-mapping procedure, and the access frequency of positions known to achieve low, intermediate, and high peak pressure levels. Table 11 shows the duration of positions accessed by subjects which were known to achieve low, intermediate, and high peak pressure levels. Subjects accessed low peak pressure positions 9.6 ± 8.4 times per day for 4.4 ± 3.9 hours per day. Intermediate peak pressure positions were accessed an average of 3.4 ± 5.2 times per day for 1.5 ± 2.5 hours, and high peak pressure positions were accessed 3.2 ± 5.1 times per day for 2.2 ± 3.9 hours.

Table 10: Access frequency of positions known to achieve low, intermediate and high pressures.

Subject	Peak Pressure Range (mmHg)	LOW Pressure Position Accesses (#/day)	INTERMEDIATE Pressure Position Accesses (#/day)	HIGH Pressure Position Accesses (#/day)
1	78 – 200	1.9 ± 1.5	6.9 ± 5.6	4.7 ± 4.8
2	24 – 143	17.9 ± 4.7	16.9 ± 5.2	0.0 ± 0.0
3	20 – 200	13.7 ± 6.5	6.5 ± 3.4	13.5 ± 7.6
4	38 – 200	3.8 ± 2.8	1.8 ± 1.4	5.2 ± 3.0
5	6.3 – 67	23.3 ± 5.9	0.0 ± 0.0	0.0 ± 0.0
6	39 – 64	21.4 ± 3.4	0.0 ± 0.0	0.0 ± 0.0
7	21 – 75	4.0 ± 3.2	0.0 ± 0.0	0.0 ± 0.0
8	5.5 – 65	1.2 ± 0.6	0.0 ± 0.0	0.0 ± 0.0
9	44 – 174	0.2 ± 0.4	1.4 ± 0.9	11.8 ± 3.1
10	45 – 78	9.4 ± 4.9	0.0 ± 0.0	0.0 ± 0.0
11	35 – 104	8.9 ± 5.5	3.6 ± 3.8	0.0 ± 0.0

Table 11: Duration of accessing positions known to achieve low, intermediate and high pressures.

Subject	LOW Pressure Positions (hours/day)	INTERMEDIATE Pressure Positions (hours/day)	HIGH Pressure Positions (hours/day)
1	0.6 ± 0.6	6.9 ± 5.3	2.6 ± 2.8
2	2.3 ± 1.1	5.8 ± 1.4	0.0 ± 0.0
3	3.1 ± 1.9	1.3 ± 1.2	4.0 ± 2.5
4	1.3 ± 1.4	1.3 ± 1.1	5.3 ± 3.1
5	7.7 ± 1.8	0.0 ± 0.0	0.0 ± 0.0
6	6.7 ± 3.0	0.0 ± 0.0	0.0 ± 0.0
7	4.8 ± 2.3	0.0 ± 0.0	0.0 ± 0.0
8	2.5 ± 3.5	0.0 ± 0.0	0.0 ± 0.0
9	0.1 ± 0.2	0.4 ± 1.0	12.4 ± 1.6
10	13.4 ± 1.9	0.0 ± 0.0	0.0 ± 0.0
11	6.0 ± 2.8	0.5 ± 0.6	0.0 ± 0.0

Figures 8 and 9 are plots of two subject's SFDL data overlapping with pressure-mapping data. The SFDL data are the tilt and recline angle combinations used over the entire length of the study, and are represented by blue open circles. The pressure-mapping data are the tilt and recline angle combinations achieved during the pressure-mapping procedure, and were assigned a colored dot (green, yellow, or red) based on the peak seat pressure reading observed at that position. The figures show the approximate pressures achieved in positions used during the study. These two figures also illustrate the variability of usage patterns observed among the subjects in this study. The subject whose data are shown in Figure 8 used many different angles and therefore achieved positions resulting in low, intermediate, and high pressures; the subject whose data are shown in Figure 9 consistently used the same range of angles and only accessed positions resulting in low and intermediate pressures.

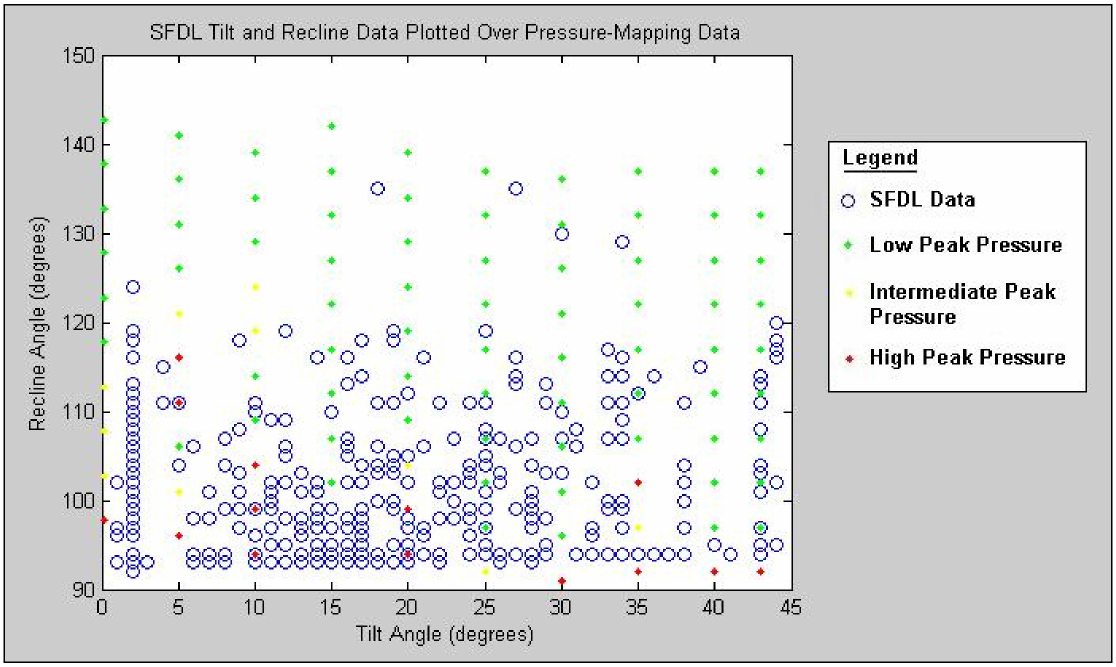

Figure 8: Tilt and recline angle combinations obtained from SFDL data and pressure-mapping data, showing the approximate pressures achieved in positions used during the study period. This is an example of a subject who accessed a wide range of tilt and recline angle combinations.

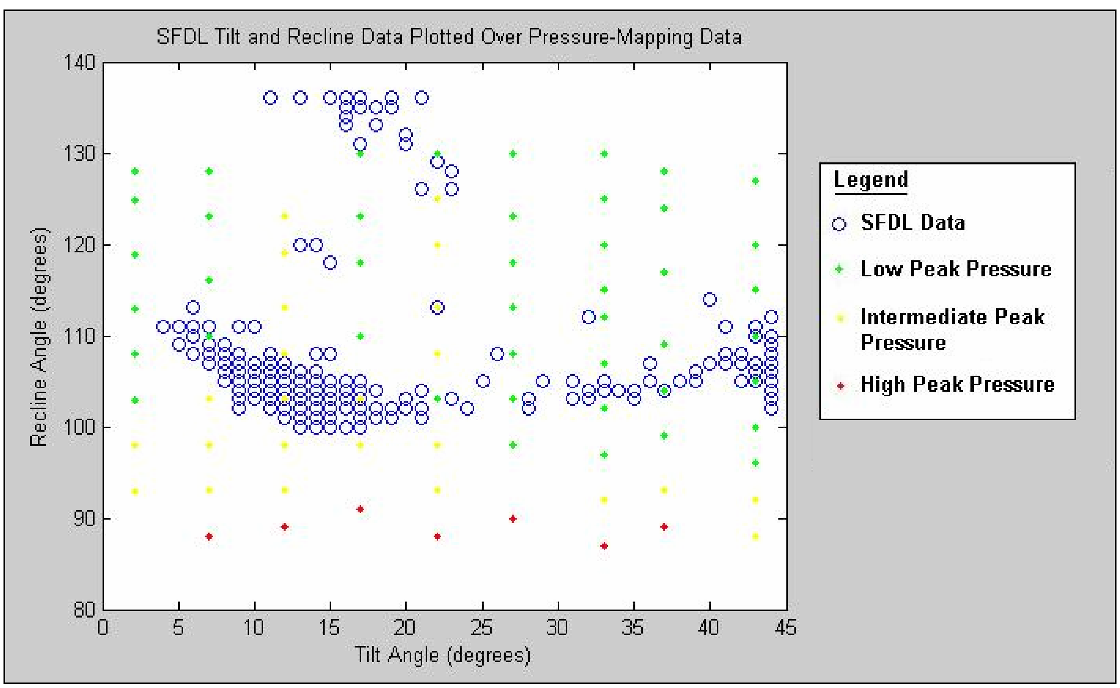

Figure 9: Tilt and recline angle combinations obtained from SFDL data and pressure-mapping data, showing the approximate pressures achieved in positions used during the study period. This is an example of a subject who used a consistent set of tilt and recline angle combinations.

4.4 QUESTIONNAIRE

Data from the questionnaire administered at the completion of the study are in Table 12. The estimated and actual (obtained from the SFDL) frequencies of tilt, recline, and seat elevation use are listed, and these values are plotted in comparison to each other (Figures 10, 11, 12). A Wilcoxon signed ranks test was applied to determine if estimated and actual frequency values differed significantly. It was found that subjects significantly underestimated frequency of tilt accesses ($p=0.041$), however no significant difference was found between estimated and actual frequency of recline accesses ($p=0.441$) or seat elevator accesses ($p=0.753$).

Table 12: Estimated and actual frequencies of seat feature accesses.

Subject	EST. Freq. of Tilt Accesses (#/day)	ACTUAL Freq. of Tilt Accesses (#/day)	EST. Freq. of Recline Accesses (#/day)	ACTUAL Freq. of Recline Accesses (#/day)	EST. Freq. of Seat Elev. Accesses (#/day)	ACTUAL Freq. of Seat Elev. Accesses (#/day)
1	10	15.4	10	9.0	C/A	C/A
2	24	41.3	3	5.9	7	8.8
3	20	30.1	10	12.1	4	9.3
4	20	10.2	30	28.2	C/A	C/A
5	28	38.0	5	14.4	2	2.3
6	10	32.2	10	19.5	0	0.1
7	4	2.4	8	10.2	12	4.8
8	2	0.4	6	2.9	C/A	C/A
9	2.5	13.4	N/A	N/A	N/A	N/A
10	5	9.3	N/A	N/A	1	0.2
11	5	13.6	8	1.7	N/A	N/A

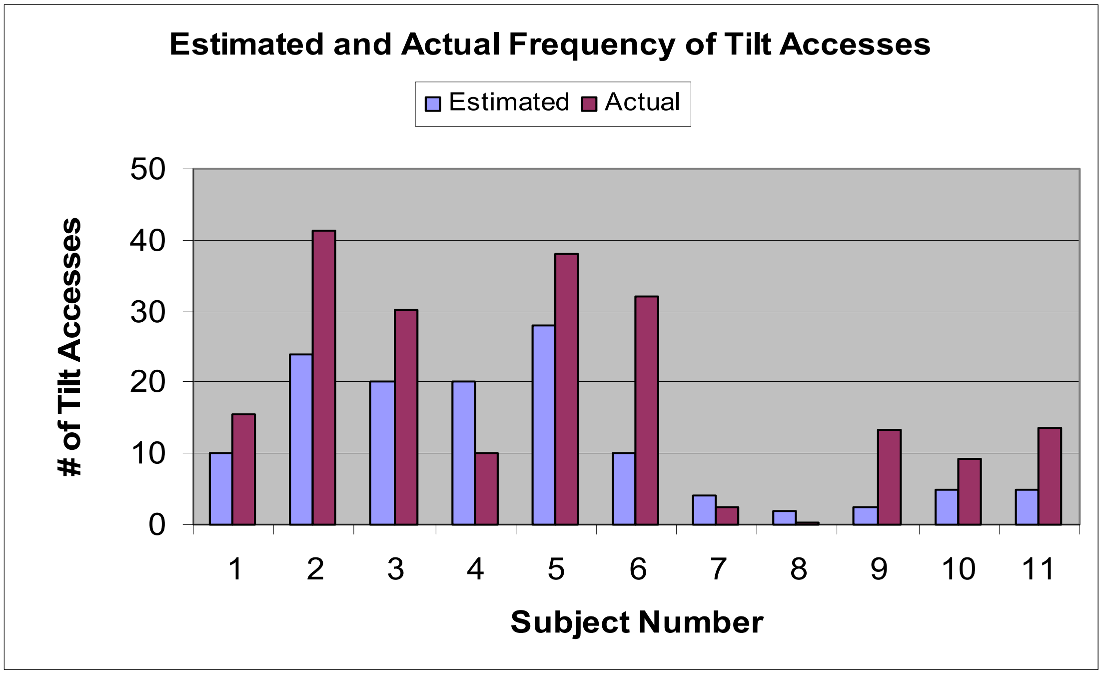

Figure 10: Estimated and actual frequency of tilt accesses per day.

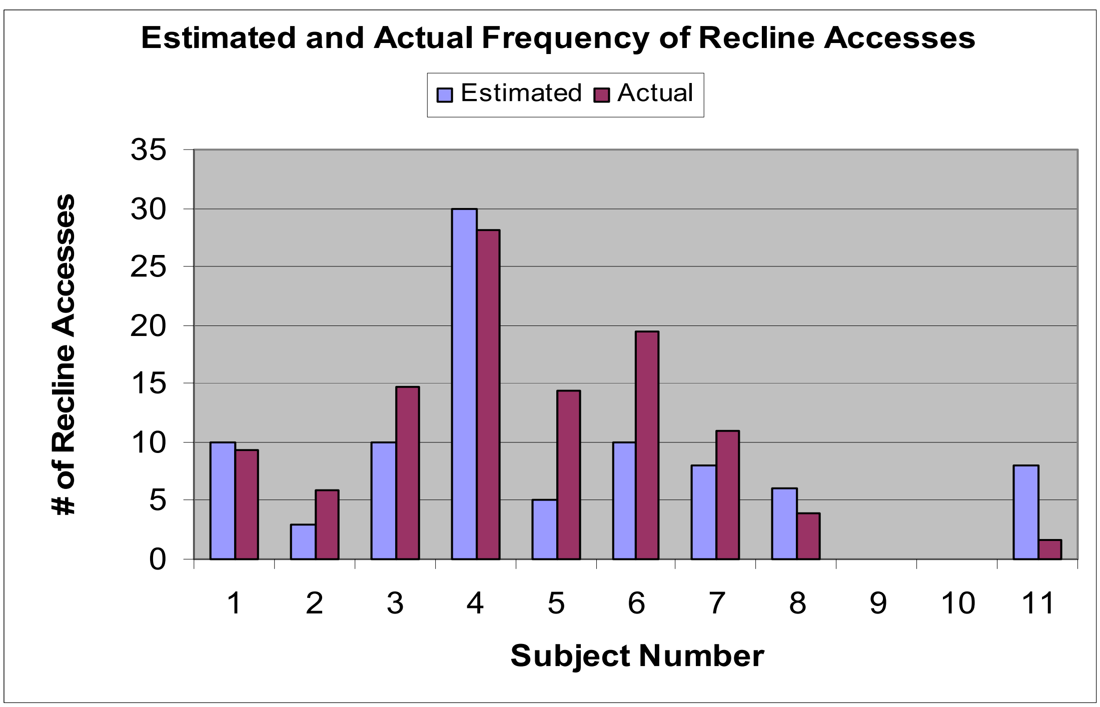

Figure 11: Estimated and actual frequency of recline accesses per day.

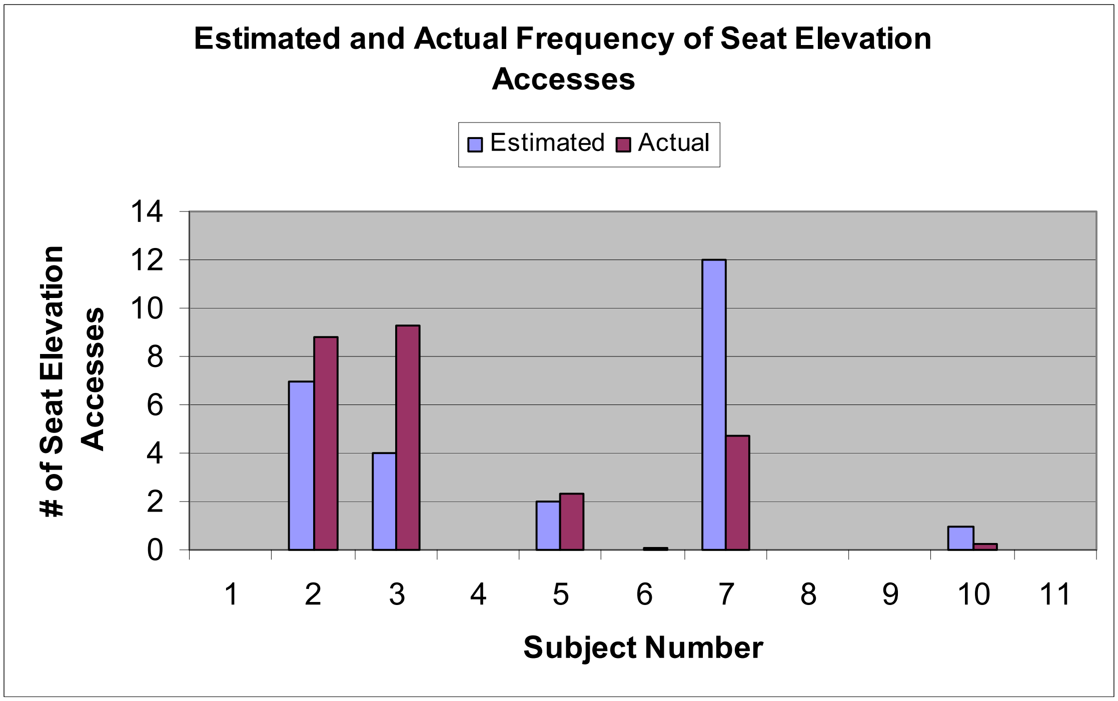

Figure 12: Estimated and actual frequency of seat elevation accesses per day.

The questionnaire also asked subjects to indicate their reasons for using power seat features. There were 5 identical reasons for each seat feature: 1) to relieve buttock pressure, 2) to adjust posture for comfort, 3) to relax, 4) for fun, and 5) other. Subjects were instructed to select all reasons that applied to their use of power seat features. Figure 13 shows the percentage of subjects who chose each reason for each seat feature. Note that the percentage of subjects is based on the total number of subjects whose wheelchairs were equipped with a particular feature (11 subjects had chairs equipped with tilt, 9 with recline, and 9 with seat elevation). 100 percent of tilt users indicated that they use this feature to adjust posture for comfort. In addition, over 50 percent of tilt and recline users indicated that they use these features to relieve pressure on the buttocks, to adjust posture for comfort, and to relax. Finally, most subjects with seat elevation did not use this feature for any of the reasons listed on the questionnaire, and indicated "other" in their responses. Therefore these responses were grouped into three categories that were consistently cited by subjects as reasons for using seat elevation. These reasons were to reach things, to socialize, and to transfer in or out of their wheelchair. One subject indicated that she used the feature "for fun" (while out shopping), and this was grouped into the "other" category in Figure 13.

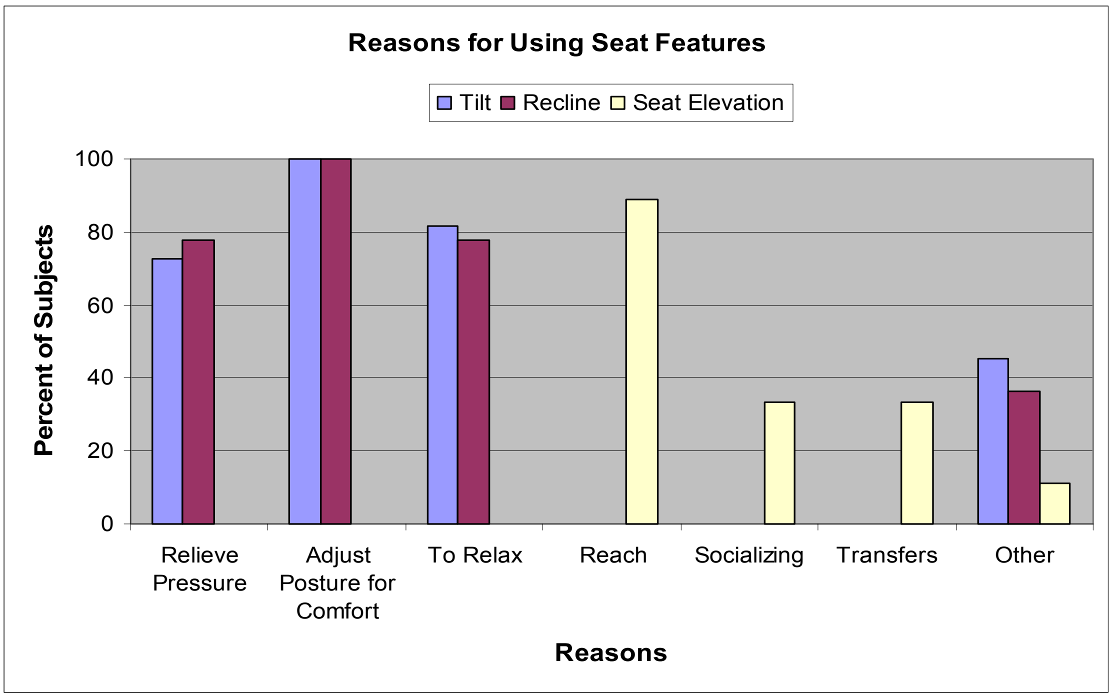

Figure 13: Reasons for using seat features.

5.0 DISCUSSION

5.1 CHAIR OCCUPANCY

This study investigated daily use of powered seat tilt, backrest recline, and seat elevation features on EPWs. Usage data of these seat features were recorded from 11 EPW users using a custom data logger. On average subjects spent a total of 12.0 ± 3.0 hours in their powered wheelchairs everyday, with a longest single continuous occupancy of 10.6 ± 3.6 hours. This is similar to results obtained by Sonenblum, Sprigle, and Maurer (2006) who found that power wheelchair users occupied their wheelchairs for 10 hours per day on average. Tolerico (2005) also found that a group of manual wheelchair users were active for 12 ± 3.56 hours per day at the National Veterans Wheelchair Games and for 7.13 ± 4.85 hours per day in their home environments. Given the considerable amount of time wheelchair users spend in their wheelchairs, seat features that allow for posture changes and pressure relief are important for those who cannot independently adjust their position, or who are at risk for pressure ulcers. Kosiak (1959) showed in experiments with dogs that tissues are able to tolerate low pressures over longer durations and high pressures over shorter durations. Indeed, prolonged static sitting at a continuous pressure has been shown to lead to the development of pressure sores (Reswick & Rogers, 1976). These investigators studied pressure sore formation in a group of individuals with spinal cord injury and found the same inverse relationship between pressure and time that Kosiak (1959) found (see Figure 14). Figure 14 suggests that 11 hours of continuous pressure at 50 mmHg is unacceptable, therefore repositioning throughout the day is essential to prevent pressure sores from developing. Clinical guidelines recommend that persons sitting for extended periods of time reposition themselves every 15 minutes (WOCN, 2003).

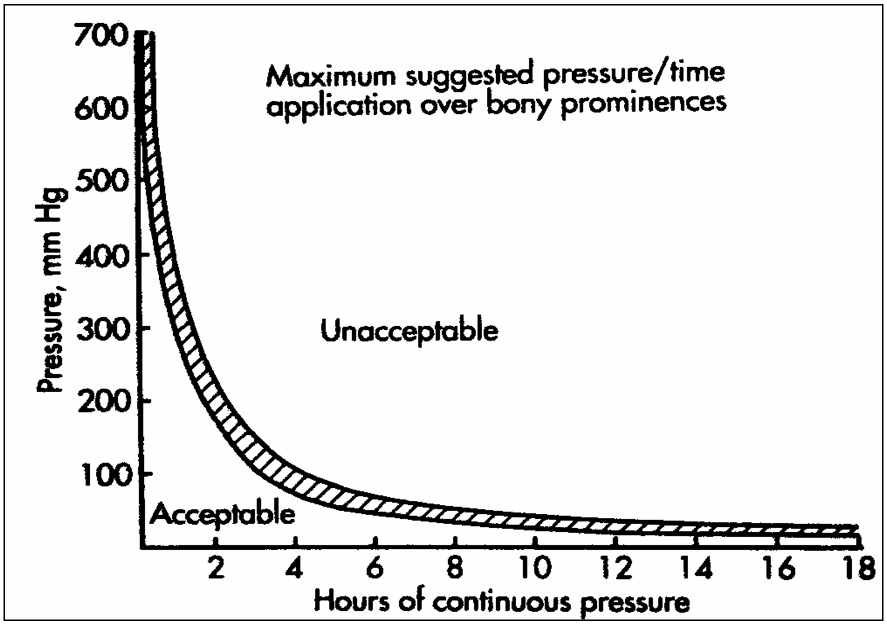

Figure 14: Reswick and Rogers' pressure versus time curve (1976).

It was also found that subjects transferred in and out of their wheelchairs for an average of 5.0 ± 5.3 times per day. For subjects who need assistance with transfers, it appeared from the data that transfers were from the subject's bed to their wheelchair, and vice versa. Subjects who were able to independently transfer likely transferred in and out of their wheelchair to perform activities of daily living, such as transferring to the toilet. For many subjects it was found that transfers correlated with use of the seat elevation feature, however no statistically significant correlation was found.

5.2 SEAT TILT USAGE

It was found that subjects in this study spent very little time in a fully upright position (0.7 ± 1.5 hours per day). Comfort and postural factors may play a role in this study population's near-constant use of tilt and/or recline. Maintaining a fully upright position is difficult for individuals with disabilities, as the trunk has a tendency to fall forward when resting against a vertical surface (Engström, 2002). Five subjects had high level spinal cord injuries and therefore reduced trunk control, and 3 subjects had multiple sclerosis and were therefore susceptible to fatigue. Using tilt and/or recline helps stabilize the upper body (Engström, 2002), preventing the individual from sliding out of their wheelchair. In addition, reclining the backrest has been found to reduce pressure in the vertebrae of the lower back (Nachemson, 1975). Given the natural tendency of individuals to avoid uncomfortable positions, it is not surprising that subjects in this study spent more time in a tilted versus an upright position ($p=0.003$).

Subjects accessed tilt for an average of 18.4 ± 14.4 times per day, with a total duration of 8.5 ± 5.2 hours. Similarly, Sonenblum *et al*. (2006) found that subjects used tilt for an average of 16 ± 10 times per day, where a tilt access was defined as a position change in either direction of greater than 15º. It was also determined in our study that subjects used small amplitude tilt angles (2.5º to 15º) more than they used intermediate tilt angles (15º to 30º), and they used intermediate angles more than they used large angles (30º and above). Moreover, the most common tilt angle based on duration used by subjects in our study ranged from 2.5º to 15º. The most common tilt angle based on frequency of accesses (MCTB) ranged from 2.5º to 45º, but only one subject regularly used a tilt angle of 45º (the MCTB range for the rest of the subjects was 2.5º to 20º). Lacoste *et al*. (2003) obtained similar findings in their questionnaire study – individuals with powered tilt said they used small and middle amplitude angles more than large angles. Further, Sonenblum *et al*. (2006) found that subjects spent the greatest amount of time in tilt angles below 20º. The fact that smaller angles of seat tilt were used in our study possibly implies that this feature is being used more for improving posture and comfort than shifting weight or relieving pressure. Subjects have indicated in studies that comfort is a primary concern with regard to their seating system (Weiss-Lambrou, Tremblay, LeBlanc, Lacoste, and Dansereau, 1999; Lacoste *et al*., 2003) and that they used smaller tilt angles to increase comfort (Lacoste *et al*., 2003). All of the subjects in our study indicated that they use tilt to adjust posture for comfort, in addition to other reasons for using this seat feature.

Perhaps seat tilt usage is related to the back pressure distribution. One study showed that a tilt of 15º or less can be used to change back pressure distribution, but that a tilt angle above 15º is necessary to achieve an effective weight shift (Aissaoui *et al*., 2001). In addition, research has shown that maximum reductions in peak seat pressures occur when tilt angles equal or exceed 45º (Henderson *et al*., 1994; Aissaoui *et al*., 2001). In our study some subjects' wheelchairs were not capable of achieving a tilt angle of 45º or above, and for those subjects whose wheelchairs were capable, many did not commonly use tilt angles of 45º or higher. However, it is unrealistic to expect individuals to utilize such a non-functional position for long periods of time, especially if that individual is employed or attends school or an organized day program (which was the case for 8 out of 11 subjects in this study). Furthermore, any position is unacceptable if held for too long, as evidenced by the pressure versus time curve of Reswick & Rogers (1976). Subjects in our study changed their seat tilt angle every 38 minutes on average (the average of the chair occupancy time divided by the frequency of tilt accesses). According to the pressures observed during the pressure-mapping procedure, staying in a particular tilt angle for 38 minutes would fall into the "acceptable" area of the pressure versus time curve.

5.3 BACKREST RECLINE USAGE

The recline features was accessed 11.5 ± 8.4 times per day with a total duration of 8.6 ± 4.6 hours. Subjects also tended to access small (95º to 100º) and intermediate (101º to 120º) amplitude recline angles more than large (121º and above) amplitude angles. The most common recline angle based on duration of accesses in our study ranged from 95º to 122.5º. The most common recline angle based on frequency of accesses (MCRB) ranged from 95º to 137.5º, but only one subject commonly used a recline angle of 137.5º (the MCRB range for the rest of the subjects was 92.5º to 110º). This is similar to the results for tilt in our study and the findings of Lacoste *et al*. (2003).

The use of recline alone has been associated with shearing on the back (Pope, 1985; Gilsdorf *et al*., 1990; Hobson, 1992), which is a risk factor for pressure ulcer development. A reclined position can also be undesirable in cases where instability is a problem (Pope, 1985). Although it was not found that recline was used significantly less than tilt, they accessed recline about 6 times per day fewer than they accessed tilt. It is possible that subjects accessed recline less frequently than tilt to avoid such shearing. Studies have also found that using recline alone can help relieve peak pressures on the buttocks (Gilsdorf *et al*., 1990; Hobson, 1992) but other studies have shown that these reductions were not significant (Shields & Cook, 1988; Stinson *et al*., 2003b). In particular, Stinson *et al*. (2003b) found no significant reduction in peak seat interface pressures between 10º, 20º, and 30º of recline (100º, 110º, and 120º in our study) but did find a significant reduction in average pressure between 0º and 30º of recline. Aissaoui *et al*. (2001) found that reductions in peak pressure depend more on seat tilt than backrest recline.

In the Lacoste *et al*. (2003) questionnaire study, wheelchair users indicated that they used recline to increase comfort, reduce discomfort, and rest, and furthermore indicated that they avoided large recline angles to prevent redness from developing on their lower backs. In our study, 7 subjects out of 9 with a recline feature said they used recline to relieve pressure on the buttocks, and all 9 said they used this feature to adjust their posture for comfort. Other reasons for using recline included napping, safety (while driving down hills and in vehicles), self-catheterization, and leg stretches/exercises.

5.4 SIMULTANEOUS SEAT TILT AND BACKREST RECLINE USAGE

Subjects accessed tilt and recline together for an average of 4.8 ± 4.6 hours – slightly more than half the time that subjects occupied their wheelchairs. It has been shown that combining tilt and recline leads to maximum reductions in peak pressure than when these features are used alone (Aissaoui *et al.*, 2001). The same authors found that different combinations of tilt and recline can lead to similar reductions in peak pressure. In addition to the pressure benefits that a combined tilt and recline system can afford, these systems provide a larger variety of positions from which the user can choose to maintain comfort, improve stability, and reduce pressure. Also, people tend to slide forward out of their wheelchairs when recline is used alone (Pope, 1985), and using tilt in parallel with recline can prevent such sliding.

5.5 SEAT ELEVATION USAGE

The seat elevation feature was accessed 4.3 ± 4.1 times for a total duration of 2.8 ± 4.6 hours. Arva *et al*. (2005) put forth that seat elevators are just as necessary as seat tilt and backrest recline systems. They cite numerous examples of how seat elevators not only facilitate the completion of activities of daily living, but can also offer psychosocial benefits to the user. In particular they list transfers, reach, and eye-to-eye contact as essential uses of the seat elevation feature. Subjects in this study indicated similar reasons for using their seat elevators. Because seat elevators are used more for the completion of activities of daily living, it is not surprising that this feature was used less frequently and for shorter durations than tilt. And although it was not found that tilt was used significantly more than seat elevation, the relationship approached significance ($p=0.046$). Nine individuals in this study had seat elevators and although SFDL data were collected for only 6 of these, questionnaire data were collected for all 9. Five of the nine subjects said they used seat elevation to reach things (either at home, work, or out in public); 4 out of 9 said they used the seat elevator to be at a different level (to work at levels, to socialize at the bar, etc.); and 3 out of 9 said they used the seat elevator to facilitate transfers (see Figure 13).

5.6 EFFECTIVENESS OF SEAT FEATURE USAGE

Subjects accessed low peak pressure positions more frequently and for longer durations than intermediate and high peak pressure positions. Low peak pressure positions were accessed 9.6 ± 8.4 times per day for 4.4 ± 3.9 hours, intermediate pressure positions were accessed 3.4 ± 5.2 times per day for 1.5 ± 2.5 hours, and high pressure positions were accessed 3.2 ± 5.1 times per day for 2.2 ± 3.9 hours. This is encouraging because it indicates that users are using their systems effectively. Even though intermediate and high peak pressures are not avoided entirely, positions resulting in these pressure levels are used less frequently and for shorter durations. For subjects with intact sensation, using low pressure positions may come naturally since high pressure positions are presumably less comfortable. Other subjects may have been well-educated in pressure relief practices and know when they need to perform weight shifts to prevent the formation of pressure sores. Cushion type (Table 1) can also have a strong impact on seat interface pressures (Koo *et al*., 1996) and this could have been a factor in the pressure-mapping results. In addition to cushion type, body build is also an important factor in the determination of peak seat pressures. Stinson *et al*. (2003b) showed that body mass index (BMI) was significantly correlated with average pressure. Furthermore, pressure on bony prominences is one cause of pressure sores in wheelchair users (Rosenthal *et al*., 1996) and people with a higher percentage of body fat tend to have more padding on these prominences. Cushions can help reduce pressure on bony areas, but a good cushion alone is insufficient for adequate pressure relief (Henderson *et al*., 1994), making tilt and recline systems necessary for wheelchair users who cannot independently shift weight prevent pressure sores from developing. As an example, in our study subjects 2 and 5 used the same seat cushion (Roho), but because subject 2 was thinner and bonier than subject 5, he had higher peak pressures than subject 5.

Pressure-mapping results should be interpreted with some caution, as studies have indicated that peak pressures are not reliable or stable (Sprigle *et al*., 2003; Stinson, Porter, & Eakin, 2002). But Sprigle *et al*. (2003) also found that average pressure is a less volatile measure (i.e. differences in pressure between positions or cushions are not easily detected when using average pressure for comparison). This is why peak pressures are frequently used by clinicians when choosing seat cushions for a client. Peak pressure was used in this study because it gave a better indication of relative pressure differences between tilt and recline positions. Also, peak pressures can help indicate problem areas where pressure sores are likely to occur. The pressure-mapping procedure of this study revealed that pressure reductions based on tilt and recline position differed greatly between subjects. For instance, peak pressures for some subjects did not change much for any combination of tilt and recline, while for other subjects certain positions offered vast reductions in pressure. Variability in sitting postures among subjects could contribute to this.

5.7 LIMITATIONS

There were a few limitations associated with this study. Due to the small sample size, the data cannot be generalized to the entire population of power wheelchair users with tilt, recline, or seat elevation. In addition, all subjects were taken from the Pittsburgh area and this could have biased results. Many subjects in this study were also affiliated or familiar with the University of Pittsburgh's Center for Assistive Technology and the Human Engineering Research Laboratories – institutions known for their work in wheeled mobility – so subjects might have been better educated in the use of seat features than the typical powered wheelchair user. Furthermore, data were only collected for a period of two weeks. It is possible that weather or other circumstances during that period could have significantly affected subjects' use of power seat features. There were also limitations related to the equipment used in this study. The pressure sensors used to detect chair occupancy did not always function as intended, which made data analysis difficult for some subjects. More accurate and reliable pressure sensors would allow for the development of a more robust data reduction algorithm. Also, the seat elevation sensor could not be mounted on 3 subject's wheelchairs due to space constraints, resulting in a loss of important data. Finally, the questionnaire we used was very simple. Subjects should have been asked in greater detail the reasons why they use seat features.

5.8 FUTURE STUDIES

Future studies should collect data on more subjects from different locations and with a wider variety of disabling conditions. It might be helpful to improve the current pressure-mapping procedure by measuring back pressure distribution in addition to seat pressure distribution. Possible improvements to the existing Seat Feature Data Logger (SFDL) should be explored – for instance, a different seat elevation sensor which can accommodate more wheelchairs without sacrificing accuracy. The addition of sensors which can monitor the use of elevating leg rests and standing or lateral tilt systems might be beneficial. Further, adding a camera to the SFDL would allow for the collection of context-specific usage data which could be used for interventional purposes (i.e. reminders in the form of audio and/or video that prompt subjects/patients to utilize particular features). In addition, the SFDL should be developed into a more robust technology for possible commercialization and/or clinical use. Clinicians could loan instrumented chairs as a teaching tool to first-time power seat feature users before they receive their own wheelchair. Future studies with the SFDL would also benefit from a revised questionnaire which asks for more information about the individuals and the environments and circumstances in which they use their power seat features. A personal digital assistant (PDA) could be used to administer the survey, prompting subjects throughout the study period to answer questions regarding seat feature usage. Many previous studies involved healthy subjects in a laboratory setting. This is the first study that we know of which quantifies real-life usage of power wheelchair seat features.

APPENDIX A

RECRUITMENT FLYER

"Effectiveness and Use of Tilt in Space and Recline Wheelchairs"

We will record your usage of tilt-in-space, recline and elevation functions during the course of the study as you go about your usual daily activities.

You may be eligible to participate if…

You are between the ages of 18 and 70

and

You use a powered wheelchair with tilt-in-space, recline or seat elevation functions as your primary source of mobility

During participation in this research study we will…

- Complete a pressure mapping procedure
- Attach a datalogger (small computer device) to your wheelchair for 2 weeks
- Complete a brief questionnaire
- You will be compensated $25 for your participation

Please contact Annmarie Kelleher, Emily Teodorski or Liz Leister at 412-365-4850

Principal Investigator: Michael Boninger, MD
Human Engineering Research Laboratories, VA Pittsburgh Healthcare System
Building 4, 2nd Floor, East Wing 151R1-H
7180 Highland Drive
Pittsburgh, PA 15206
412-365-4850

APPENDIX B

DEMOGRAPHIC INFORMATION

Effectiveness and Use of Tilt-in-Space and Recline Wheelchairs

Questionnaire

Subject ID #: ______________

Date of Birth: ___/___/___

Gender: ______**male**
______**female**

Ethnic Origin: ______ **African -American**
______ **American Indian**
______ **Asian- American**
______ **Caucasian**
______ **Hispanic**
______ **Other** ____________________

Diagnosis: _____________________

Wheelchair Make: ____________________________ **Model:** __________________

Age of Current Wheelchair: ____________

Tilt-in-space function: ___________ **Tilt range:** ___________

Recline function: ___________ **Recline range:** ___________

Elevation function: ___________ **Elevation range:** ___________

APPENDIX C

QUESTIONNAIRE

1a) On average, how often do you access the **tilt-in-space** feature per day?

________ # of times

1b) On average, how long do you spend in a **tilted** position per day?

_________ minutes/hours (circle one)

2a) On average, how often do you access the **recline** feature per day?

________ # of times

2b) On average, how long do you spend in a **reclined** position per day?

_________ minutes/hours (circle one)

3a) On average, how often do you access the **seat elevation** feature per day?

________ # of times

3b) On average, how long do you spend in an **elevated** position per day?

_________ minutes/hours (circle one)

4) The **tilt-in-space** feature of your wheelchair is effective in providing postural stability and comfort.

1 __________ Strongly Agree
2 __________ Agree
3 __________ Neutral
4 __________ Disagree
5 __________ Strongly Disagree

5) The **recline** feature of your wheelchair is effective in reducing pressure in the buttocks.

1 __________ Strongly Agree
2 __________ Agree
3 __________ Neutral
4 __________ Disagree
5 __________ Strongly Disagree

6) The **seat elevation** feature of your wheelchair is useful in your daily activities.

1 __________ Strongly Agree
2 __________ Agree
3 __________ Neutral
4 __________ Disagree
5 __________ Strongly Disagree

7) In what circumstances do you usually access the **tilt-in-space** feature of your wheelchair (check all that apply)?

- ❑ To relieve buttock pressure
- ❑ To adjust posture for comfort
- ❑ To relax
- ❑ For fun
- ❑ Other (please specify) ______________________

8) In what circumstances do you usually access the **recline** feature of your wheelchair (check all that apply)?

- ❑ To relieve buttock pressure
- ❑ To adjust posture for comfort
- ❑ To relax
- ❑ For fun
- ❑ Other (please specify) ______________________

9) In what circumstances do you usually access the **seat elevation** feature of your wheelchair (check all that apply)?

- ❑ To relieve buttock pressure
- ❑ To adjust posture for comfort
- ❑ To relax
- ❑ For fun
- ❑ Other (please specify) ______________________

APPENDIX D

MATLAB CODE

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% TILT, RECLINE, and SEAT ELEVATION ANALYSIS PROGRAM
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This program is for use with the tilt/recline/seat elevator
% datalogger study, entitled "The Effectiveness and Use of
% Tilt-in-Space and Recline Wheelchairs".
%%%%
%

%% Select a datafile to run through the program
clear all;
% Select and open first data file
[filename, pathname]=uigetfile('*.dat','Select file')
fid=fopen([pathname filename], 'r');
suggest=strtok(filename,'.');

% Select and open second data file
[filename2, pathname2]=uigetfile('*.dat','Select file')
fid2=fopen([pathname2 filename2], 'r');
suggest2=strtok(filename,'.');

% This reads what is in the file and reshapes the array
% into a matrix of data. The format of the data is:
% 18 columns by ___# of data rows

% [              Data                  ][   Time Stamp   ]
% [P1 0 P2 0 P3 0 T1 0 T2 0 T3 0 H 0][Day Hour Min Sec]

% Where P1, P2, P3, T1, T2, T3, and H are the 3 pressure sensors,
% the 3 tilt sensors, and the height sensor, respectively
%
% Abbreviations:
% P1=pressure sensor #1 (ischial tuberosity)
% P2=pressure sensor #2 (thigh)
% P3=pressure sensor #3 (thigh)
% T1=tilt sensor #1 (base angle)
% T2=tilt sensor #2 (seat tilt angle)
% T3=tilt sensor #3 (backrest recline angle)
% H=seat elevation sensor

% The data above is separated by zeros because of the way the STORE
% function works in the TFBasic programming language (it is a 16-bit
% function, but we are only storing in the first 8 bits).

[A,count] = fread(fid,inf,'uint8'); % when the file is in binary mode
```

```
Time_startA=A(1:6);                          % month/day/hour/minute/second/year
A=A(7:length(A));                            % A without start-date

% Note for DD:
%%%%%%%%%
% The below loop doesn't work for these datafiles: - fixed
% DS3665 8-29-2005
% TO4377 4-4-2006
% checking errors in the datafile

% Check A for errors
i=2;
while (1)
    index=find(A==Time_startA(2));
    tempi=index(i);
    for j=1:3
        if (A(tempi)==Time_startA(2) && abs(A(tempi+1)-Time_startA(3))<=1)
            tempi=tempi+18;
        else
            break;
        end
    end
    if (j==3)
        A(1:index(i)-15)=[];
        break;
    else
        i=i+1;
    end
end
clear i j index
Amod1=A;
numsets=fix(length(Amod1)/18);  % # of sets of volt-data-followed-by-time-
data pairs
Amod1=reshape(Amod1(1:18*numsets),18,numsets);
Amod1=Amod1';
Amod1(find(Amod1(:,15)>31),:)=[];          %Delete bad data
Amod1(find(Amod1(:,15)==0 | Amod1(:,16)>23 | Amod1(:,17)>59 |
Amod1(:,18)>59),:)=[];  %Delete bad data

first=find(Amod1(:,15)==Time_startA(2));
Amod1(first,:)=[];
last=find(Amod1(:,15)==Amod1(end,15));
Amod1(last,:)=[];
clear first last

% Second datafile
[A2,count2] = fread(fid2,inf,'uint8'); % when the file is in binary mode
Time_startA2=A2(1:6);                  % month/day/hour/minute/second/year
A2=A2(7:length(A2));                    % A without start-date

% Check A2 for errors
i=2;
while (1)
    index=find(A2==Time_startA2(2));
    tempi=index(i);
    for j=1:3
```

```
        if (A2(tempi)==Time_startA2(2) && abs(A2(tempi+1)-
Time_startA2(3))<=1)
            tempi=tempi+18;
        else
            break;
        end
    end
    if (j==3)
        A2(1:index(i)-15)=[];
        break;
    else
        i=i+1;
    end
end
clear i j index
Amod2=A2;
numsets=fix(length(Amod2)/18);   % # of sets of volt-data-followed-by-time-
data pairs
Amod2=reshape(Amod2(1:18*numsets),18,numsets);
Amod2=Amod2';
Amod2(find(Amod2(:,15)>31),:)=[];          %Delete bad data
Amod2(find(Amod2(:,15)==0 | Amod2(:,16)>23 | Amod2(:,17)>59 |
Amod2(:,18)>59),:)=[];  %Delete bad data %

first=find(Amod2(:,15)==Time_startA2(2));
Amod2(first,:)=[];
last=find(Amod2(:,15)==Amod2(end,15));
Amod2(last,:)=[];
clear first last

Amod=cat(1,Amod1,Amod2);
%Amod(1:2,:)=[]; % for subject DS3665


%% Calculation of the Hour Vector
% Calculate the Sec_Vector for the first datafile, then calculate it for
% the second datafile and put them together

% FIRST DATAFILE
Time_startB=Amod1(1,15:18);

MCindex1=find(diff(Amod1(:,15))<0);     % Month change index (if acquisition
occurred at end of one month and beginning of next)
if (isempty(MCindex1)==1)
    month1=1;     % if MCindex is empty acquisition occurred w/in same month
else
    month1=2;
end
Time_start_sec1=(Time_startB(1)*24*60*60)+(Time_startB(2)*60*60)+(Time_startB
(3)*60)+(Time_startB(4));
if month1==1
    m1 = 2:length(Amod1);

Sec_Vector_file1(m1)=(Amod1(m1,15)*24*60*60)+(Amod1(m1,16)*60*60)+(Amod1(m1,1
7)*60)+(Amod1(m1,18))-(Time_start_sec1);
elseif month1==2
    i = 1:MCindex1;
```

```
Sec_Vector1(i)=(Amod1(i,15)*24*60*60)+(Amod1(i,16)*60*60)+(Amod1(i,17)*60)+(A
mod1(i,18))-(Time_start_sec1);
    j = MCindex1+1:length(Amod1);
    k = 1:(length(j));
    days1 = Amod1(MCindex1,15);

Sec_Vector1b(k)=((Amod1(j,15)+days1)*24*60*60)+(Amod1(j,16)*60*60)+(Amod1(j,1
7)*60)+(Amod1(j,18))-(Time_start_sec1);
    Sec_Vector_file1=[Sec_Vector1, Sec_Vector1b];
end
clear i j k m

Sec_Vector_file1=Sec_Vector_file1';                   % Time_set in seconds
Hour_Vector_file1 = ((Sec_Vector_file1)/60/60);       % Time_set in hours


% SECOND DATAFILE
Time_startB2=Amod2(1,15:18);

MCindex2=find(diff(Amod2(:,15))<0);  % Month change index (if acquisition
occurred at end of one month and beginning of the next)
if (isempty(MCindex2)==1)
    month2=1;     % if MCindex is empty acquisition occurred w/in same month
else
    month2=2;
end
Time_start_sec2=(Time_startB2(1)*24*60*60)+(Time_startB2(2)*60*60)+(Time_star
tB2(3)*60)+(Time_startB2(4));
if month2==1
    m2 = 2:length(Amod2);

Sec_Vector_file2(m2)=(Amod2(m2,15)*24*60*60)+(Amod2(m2,16)*60*60)+(Amod2(m2,1
7)*60)+(Amod2(m2,18))-(Time_start_sec2);
elseif month2==2
    i = 1:MCindex2;

Sec_Vector2(i)=(Amod2(i,15)*24*60*60)+(Amod2(i,16)*60*60)+(Amod2(i,17)*60)+(A
mod2(i,18))-(Time_start_sec2);
    j = MCindex2+1:length(Amod2);
    k = 1:(length(j));
    days2 = Amod2(MCindex2,15);

Sec_Vector2b(k)=((Amod2(j,15)+days2)*24*60*60)+(Amod2(j,16)*60*60)+(Amod2(j,1
7)*60)+(Amod2(j,18))-(Time_start_sec2);
    Sec_Vector_file2=[Sec_Vector2, Sec_Vector2b];
end
clear i j k m

Sec_Vector_file2=Sec_Vector_file2';                   % Time_set in seconds
Hour_Vector_file2 = ((Sec_Vector_file2)/60/60);       % Time_set in hours
Hour_Vector_file2 = Hour_Vector_file2+Hour_Vector_file1(end);

% Combine Hour_Vector_file1 and Hour_Vector_file2
Hour_Vector=cat(1,Hour_Vector_file1,Hour_Vector_file2);

%Hour_Vector(1:2)=[]; % for subject DS3665
```

```
%% Program variables
%%%%%%%%%%%%

% Calculating values for each sensor
Digital=Amod(:,1:14);    % Get rid of columns of zeros
Digital(:,2:2:14)=[];
Volt=(5/256)*Digital;    % Converts Digital from digital to analog
Press_volt=Volt(1:length(Volt),1:3);     % Pressure sensor voltages
Ang_volt=Volt(1:length(Volt),4:6);       % Tilt sensor voltages
Height_volt=Volt(1:length(Volt),7);      % Height sensor voltage

% erroneous data may exist for first pressure data. The second and third
% pressure sensors seem never triggered. sensor placement?

% Each set of sensors has different calibration constants. Here I calculate
% the correct values for the sensors I used on a particular subject's chair.
% Subject ID numbers have to be added to the program as people are entered
% into the study

IDnum=char(filename(1:6));
switch(IDnum)
    case{'JC2955','DS3665','JK5957','TO4377'}
        vZero1 = 2.490;         % Serial #: 03008831
        vZero2 = 2.487;         % Serial #: 03008829
        vZero3 = 2.473;         % Serial #: 03008840
        Sens1 = 2.006943863;    % Sens = (Sens(mV/deg)/1000)/sin(1)
        Sens2 = 2.008720123;
        Sens3 = 2.018117108;

case{'GT0009','MF3833','RM3193','R3193B','JM1666','ML3940','JS1382','DS7200'}
        vZero1 = 2.495;         % Serial #: 03I05481
        vZero2 = 2.510;         % Serial #: 03I05483
        vZero3 = 2.426;         % Serial #: 03I05524
        Sens1 = 2.004422721;    % Sens = (Sens(mV/deg)/1000)/sin(1)
        Sens2 = 2.001958877;
        Sens3 = 2.014908381;
    case{'NM8630'}
        vZero1 = 2.463;         % Serial #: 03I05517
        vZero2 = 2.528;         % Serial #: 03I05561
        vZero3 = 2.489;         % Serial #: 03I05486
        Sens1 = 2.003907033;    % Sens = (Sens(mV/deg)/1000)/sin(1)
        Sens2 = 2.000010722;
        Sens3 = 2.015137576;
end

% Variables used to calculate tilt and recline angles
arg1 = (Ang_volt(:,1)-vZero1)/Sens1;
arg2 = (Ang_volt(:,2)-vZero2)/Sens2;
arg3 = (Ang_volt(:,3)-vZero3)/Sens3;

% Subject JC2955 has odd tilt sensor readings. Multiplying the tilt and
% recline sensor arguments seems to yield data which makes more sense, but
% it is still questionnable - maybe the sensors were not attached properly?
if (IDnum == 'JC2955')
    arg2=arg2*(-1);
    arg3=arg3*(-1);
end
```

```
base_angle = (atan(arg1./sqrt(1-arg1.*arg1)))*(180/pi);
seat_angle = (atan(arg2./sqrt(1-arg2.*arg2)))*(180/pi);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Which features does the wheelchair have?
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tiltQ = input('Does the chair have a tilt feature? (y/n): ', 's');
if tiltQ == 'y';
    tilt_angle = seat_angle-base_angle;
end
reclineQ = input('Does the chair have a recline feature? (y/n): ', 's');
if reclineQ == 'y';
    back_angle = (atan(arg3./sqrt(1-arg3.*arg3)))*(180/pi);
    recline_angle = 180-(seat_angle+(180-(90+back_angle)));
end
heightQ = input('Does the chair have a seat elevation feature? (y/n): ',
's');
if heightQ == 'y';
    height = 9.9916*Height_volt;  %Height in cm (Serial#: 35010289),
intercept set to zero
    height_init=min(height);
    height=height-height_init;
end

% Tilt and recline together
if tiltQ=='y' && reclineQ=='y';
    tiltrec=cat(2,tilt_angle,recline_angle);
end


%% ENTER LOOP TO CALCULATE EVERYTHING PER DAY
day = find(diff(Amod(:,15))~=0);
i=[0;day;length(Amod)];
count=1; Tcount=1; Rcount=1; Hcount=1; TRcount=1;

in_time=[];
max_single_time=[];
transfer_freq=[];

%OutIndex=[];

% Start looping
for j=1:length(i)-1                % Go through this loop for each day
%j=1
    flag=0;
    start_index=i(j)+1;
    last_index=i(j+1);
    Hour_Vector_loop=Hour_Vector(start_index:last_index);   %Hours for a
specific day
    Hour_diff_loop = diff(Hour_Vector_loop);
    Press_volt1_loop=Press_volt(start_index:last_index,1);
    Press_volt2_loop=Press_volt(start_index:last_index,2);
    Press_volt3_loop=Press_volt(start_index:last_index,3);

    if tiltQ == 'y';
        tilt_angle_loop=tilt_angle(start_index:last_index);
```

```
    end
    if reclineQ == 'y';
        recline_angle_loop=recline_angle(start_index:last_index);
    end
    if heightQ == 'y';
        height_loop=height(start_index:last_index);
    end
    if tiltQ=='y' && reclineQ=='y';
        tiltrec_loop=tiltrec(start_index:last_index,:);
    end

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Time in chair and Time out of chair
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % NOTE: May not be able to calculate in-chair and out-of chair time
    % for JS1382 (data is too inconclusive). Leg pressure sensors were not
    % triggered (maybe because of the subject's cushion? Custom contoured
    % cushion...) The IT sensor was always triggered (at the end of the study
    % when I removed it, it had shifted a little, maybe that is why...)

    switch(IDnum)
        % Method #1: Find large gaps in time

case{'DS3665','DS7200','TO4377','RM3193','MF3833','GT0009','NM8630','JC2955'}
            %DS3665 seems OK
            %DS7200 seems OK
            %TO4377 seems OK
            %RM3193 one day really short stay, could elimiate
            %MF3833 seems OK
            %GT0009 never leave the chair
            %NM8630 seems OK
            %JC2955 not sure if it's right, as the data is collected with
            %different program
           out=find(diff(Hour_Vector_loop)>(0.166));
           inchair=find(diff(Hour_Vector_loop)>(0.166));
           total_time=Hour_Vector_loop(end)-Hour_Vector_loop(1);
           if(isempty(inchair))
               in_time=[in_time total_time];
               max_single_time=[max_single_time total_time];
               transfer_freq=[transfer_freq 0];
               flag=1;
           end
           if (~flag)
               out_time=Hour_Vector_loop(inchair+1)-
Hour_Vector_loop(inchair);
               in_time=[in_time total_time-sum(out_time)];  % total time in
the chair

               inchair_1=inchair+1;
               if(inchair(end)~= length(Hour_Vector_loop))
                    inchair=[inchair; length(Hour_Vector_loop)];
               end
               if(inchair(1)~=1)
                    inchair_1=[1; inchair_1];
               end
               in_time_single=(Hour_Vector_loop(inchair)-
Hour_Vector_loop(inchair_1))*60;   %single occupancy time
```

```
                max_single_time=[max_single_time max(in_time_single)/60];
%max of
                transfer_freq=[transfer_freq length(inchair)*2-
length(find(in_time_single<=2))*2];  %transfer out and in the chair
           end
% excluding sitting time shorter than 2 minutes

        % Method #2: Voltage threshold for pressure sensors
        case{'JK5957','ML3940'}
            inchair = find(Press_volt1_loop>4.2);
            inmax=find(inchair==length(Hour_Vector_loop));
            inchair(inmax)=[];
            in_time(count)=sum(Hour_Vector_loop(inchair+1)-
Hour_Vector_loop(inchair));
            %max_single_time=[max_single_time max(in_time(count))/60];

            out = find(Press_volt1_loop<4.2);
            outmax=find(out==length(Hour_Vector_loop));
            out(outmax)=[];

        case{'JM1666'}
            inchair = find(Press_volt2_loop>0.25 & Press_volt3_loop>0.25);
            inmax=find(inchair==length(Hour_Vector_loop));
            inchair(inmax)=[];
            in_time(count)=sum(Hour_Vector_loop(inchair+1)-
Hour_Vector_loop(inchair));

            out = find(Press_volt2_loop<0.25 & Press_volt3_loop<0.25);
            outmax=find(out==length(Hour_Vector_loop));
            out(outmax)=[];

        % Method #3: Change in days? Low activity?
        case{'JS1382'}
            out=[];
            time_in='Cannot Calculate';
    end
    count=count+1;


    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Access Calculations (per day)
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    OutIndex=out;       %find(diff(Hour_Vector_loop)>=0.3);
    OutIndex=sort([OutIndex; OutIndex+1]);
    OutIndex=[1;OutIndex;length(Hour_Vector_loop)];
    if (isempty(OutIndex)==1)
        OutIndex=[start_index; last_index];
    end

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %% Find positive and negative peaks
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % For TILT
    if tiltQ == 'y';
        [Tpospeakind,Tnegpeakind]=peakdetect(tilt_angle_loop);
        tcat=cat(1,Tpospeakind,Tnegpeakind);
        tcat=sort(tcat,1);
```

```
        tcat(find(diff(tcat)==0))=[];
        Vtilt_angle=tilt_angle_loop(tcat);
        VThour=Hour_Vector_loop(tcat);

        % Reduce the data for TILT
        L(1)=0;
        Tcount2=0;
        for m=1:length(OutIndex)-1
            if (OutIndex(m+1)-OutIndex(m)<5)
                L(m+1)=L(m);
                continue;
            else
                Tindex=(tcat>=OutIndex(m)& tcat<=OutIndex(m+1));
                Tindex=find(Tindex==1);
                if isempty(Tindex)==1
                    TIB=1;
                    TIE=1;
                else
                    TIB=Tindex(1);
                    TIE=Tindex(end);
                end
                if isempty(TIB)==0
                    Tcount2=Tcount2+1;
                end
                IndexHist(Tcount2,:)=[TIB,TIE];    % A record of values for
            TIB and TIE

                DTiltAng=diff(Vtilt_angle(TIB:TIE));
                DIndex=find(abs(DTiltAng)>=2.5);       % Threshold of 2.5 deg
                DIndex=[0; DIndex; TIE-TIB+1];
                L(m+1)=L(m)+length(DIndex);
                for k=1:length(DIndex)-1
                    % Filter tilt angle by averaging pieces of data that
don't change much
                    NVtilt{1,Tcount}(TIB+DIndex(k):TIB+DIndex(k+1)-
1)=mean(Vtilt_angle(TIB+DIndex(k):TIB+DIndex(k+1)-1));

HisDataT{1,Tcount}(k+L(m),1)=mean(Vtilt_angle(TIB+DIndex(k):TIB+DIndex(k+1)-
1));
                    HisDataT{1,Tcount}(k+L(m),2)=(VThour(TIB+DIndex(k+1)-1)-
VThour(TIB+DIndex(k)))*60;  %minutes
                end
            end
        end
        Tcount=Tcount+1;      % Increase count and restart data reduction
loop
    end
    clear DIndex

    % For RECLINE
    if reclineQ == 'y';
        [Rpospeakind,Rnegpeakind]=peakdetect(recline_angle_loop);
        rcat=cat(1,Rpospeakind,Rnegpeakind);
        rcat=sort(rcat,1);
        rcat(find(diff(rcat)==0))=[];
        Vrecline_angle=recline_angle_loop(rcat);
        VRhour=Hour_Vector_loop(rcat);
```

```
        % Reduce the data for RECLINE
        L(1)=0;
        Rcount2=0;
        for m=1:length(OutIndex)-1
            if (OutIndex(m+1)-OutIndex(m)<5)
                L(m+1)=L(m);
                continue;
            else
                Rindex=(rcat>=OutIndex(m)& rcat<=OutIndex(m+1));
                Rindex=find(Rindex==1);
                RIB=Rindex(1);
                RIE=Rindex(end);
                if isempty(RIB)==0
                    Rcount2=Rcount2+1;
                end
                IndexHist(Rcount2,:)=[RIB,RIE];    % A record of values for
RIB and RIE

                DReclineAng=diff(Vrecline_angle(RIB:RIE));
                DIndex=find(abs(DReclineAng)>=2.5);    % Threshold of 2.5 deg
                DIndex=[0; DIndex; RIE-RIB+1];
                L(m+1)=L(m)+length(DIndex);
                for k=1:length(DIndex)-1
                    % Filter recline angle by averaging pieces of data that
don't change much
                    NVrecline{1,Rcount}(RIB+DIndex(k):RIB+DIndex(k+1)-
1)=mean(Vrecline_angle(RIB+DIndex(k):RIB+DIndex(k+1)-1));

HisDataR{1,Rcount}(k+L(m),1)=mean(Vrecline_angle(RIB+DIndex(k):RIB+DIndex(k+1
)-1));
                    HisDataR{1,Rcount}(k+L(m),2)=(VRhour(RIB+DIndex(k+1)-1)-
VRhour(RIB+DIndex(k)))*60;  %minutes
                end
            end
        end
        Rcount=Rcount+1;    % Increase count and restart data reduction loop
    end
    clear DIndex


    % For TILT and RECLINE TOGETHER
    if tiltQ=='y' && reclineQ=='y';
        [TRpospeakind,TRnegpeakind]=peakdetect(tiltrec_loop(:,1));   % reduce
data using tilt
        %[TRpospeakind,TRnegpeakind]=peakdetect(tiltrec_loop(:,2)); % reduce
data using recline
        trcat=cat(1,TRpospeakind,TRnegpeakind);
        trcat=sort(trcat,1);
        trcat(find(diff(trcat)==0))=[];
        Vtiltrec_angle=tiltrec_loop(trcat,:);
        VTRhour=Hour_Vector_loop(trcat);
        VTRcombo=[Vtiltrec_angle,VTRhour];

        % Reduce the data for TILT + RECLINE
        L(1)=0;
        TRcount2=0;
```

```
        for m=1:length(OutIndex)-1
            if (OutIndex(m+1)-OutIndex(m)<5)
                L(m+1)=L(m);
                continue;
            else
                TRindex=(trcat>=OutIndex(m)& trcat<=OutIndex(m+1));
                TRindex=find(TRindex==1);
                TRIB=TRindex(1);
                TRIE=TRindex(end);
                if isempty(TRIB)==0
                    TRcount2=TRcount2+1;
                end
                IndexHist(TRcount2,:)=[TRIB,TRIE];    % A record of values for
TRIB and TRIE

                DTRAng=diff(Vtiltrec_angle(TRIB:TRIE,1));
                DIndex=find(abs(DTRAng)>=2.5);         % Threshold of 2.5 deg
                DIndex=[0; DIndex; TRIE-TRIB+1];
                L(m+1)=L(m)+length(DIndex);
                for k=1:length(DIndex)-1
                    % Filter tilt angle by averaging pieces of data that
don't change much
                    NVtiltrec{1,TRcount}(TRIB+DIndex(k):TRIB+DIndex(k+1)-
1,1)=mean(Vtiltrec_angle(TRIB+DIndex(k):TRIB+DIndex(k+1)-1,1));
                    NVtiltrec{1,TRcount}(TRIB+DIndex(k):TRIB+DIndex(k+1)-
1,2)=mean(Vtiltrec_angle(TRIB+DIndex(k):TRIB+DIndex(k+1)-1,2));

HisDataTR{1,TRcount}(k+L(m),1)=mean(Vtiltrec_angle((TRIB+DIndex(k):TRIB+DInde
x(k+1)-1),1));

HisDataTR{1,TRcount}(k+L(m),2)=mean(Vtiltrec_angle((TRIB+DIndex(k):TRIB+DInde
x(k+1)-1),2));
                    HisDataTR{1,TRcount}(k+L(m),3)=(VTRhour(TRIB+DIndex(k+1)-
1)-VTRhour(TRIB+DIndex(k)))*60;  %minutes
                end
            end
        end
        TRcount=TRcount+1;      % Increase count and restart data reduction
loop
    end
    clear DIndex

    % For SEAT ELEVATION
    if heightQ == 'y';
        [Hpospeakind,Hnegpeakind]=peakdetect(height_loop);
        hcat=cat(1,Hpospeakind,Hnegpeakind);
        hcat=sort(hcat,1);
        hcat(find(diff(hcat)==0))=[];
        Vheight=height_loop(hcat);
        VHhour=Hour_Vector_loop(hcat);

        % Reduce the data for SEAT ELEVATION
        L(1)=0;
        Hcount2=0;
        for m=1:length(OutIndex)-1
            if (OutIndex(m+1)-OutIndex(m)<5)
                L(m+1)=L(m);
```

```
                continue;
            else
                Hindex=(hcat>=OutIndex(m)& hcat<=OutIndex(m+1));
                Hindex=find(Hindex==1);
                if isempty(Hindex)==1
                    HIB=[];
                    HIE=[];
                else
                    HIB=Hindex(1);
                    HIE=Hindex(end);
                end
                if isempty(HIB)==0
                    Hcount2=Hcount2+1;
                end
                IndexHist(Hcount2,:)=[HIB,HIE];    % A record of values for
HIB and HIE

                DHeight=diff(Vheight(HIB:HIE));
                DIndex=find(abs(DHeight)>=1);        % Threshold of 1 cm
                DIndex=[0; DIndex; HIE-HIB+1];
                L(m+1)=L(m)+length(DIndex);
                for k=1:length(DIndex)-1
                    % Filter heights by averaging pieces of data that don't
change much
                    NVheight{1,Hcount}(HIB+DIndex(k):HIB+DIndex(k+1)-
1)=mean(Vheight(HIB+DIndex(k):HIB+DIndex(k+1)-1));

HisDataH{1,Hcount}(k+L(m),1)=mean(Vheight(HIB+DIndex(k):HIB+DIndex(k+1)-1));
                    HisDataH{1,Hcount}(k+L(m),2)=(VHhour(HIB+DIndex(k+1)-1)-
VHhour(HIB+DIndex(k)))*60;  %minutes
                end
            end
        end
        Hcount=Hcount+1;      % Increase count and restart data reduction
loop
    end
    clear DIndex
end
clear i j k m count index


%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Edit HisData array
%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Get rid of angles that were accessed for ZERO minutes
% Q: Should we get rid of angles accessed for less than 2 minutes??

% Tilt time
if tiltQ == 'y'
    tilttime=[];
    for i=1:length(HisDataT)
        if isempty(HisDataT{:,i}), continue, end
        index = find(HisDataT{1,i}(:,1)>=2.5);
        THour=HisDataT{1,i}(index,2);
        tilttime=[tilttime sum(THour)];
    end
end
```

```
% Recline time
if reclineQ == 'y'
    reclinetime=[];
    for i=1:length(HisDataR)
        if isempty(HisDataR{:,i}), continue, end
        index = find(HisDataR{1,i}(:,1)>=92.5);
        RHour=HisDataR{1,i}(index,2);
        reclinetime=[reclinetime sum(RHour)];
    end
end

% Height time
if heightQ == 'y'
    heighttime=[];
    for i=1:length(HisDataH)
        if isempty(HisDataH{:,i}), continue, end
        index = find(HisDataH{1,i}(:,1)>=1);
        HHour=HisDataH{1,i}(index,2);
        heighttime=[heighttime sum(HHour)];
    end
end

% Upright time
if tiltQ == 'y' && reclineQ == 'y'
    uprighttime=[];
    tiltrectime=[];
    for i=1:length(HisDataTR)
        if isempty(HisDataTR{:,i}), continue, end
        index = find(HisDataTR{1,i}(:,1)<2.5 & HisDataTR{1,i}(:,2)<92.5);
        TRHour=HisDataTR{1,i}(index,3);
        uprighttime=[uprighttime sum(TRHour)];

        index2 = find(HisDataTR{1,i}(:,1)>=2.5 & HisDataTR{1,i}(:,2)>=92.5);
        TRHour2=HisDataTR{1,i}(index2,3);
        tiltrectime=[tiltrectime sum(TRHour2)];
    end
end

if tiltQ == 'y' && reclineQ == 'n'
    uprighttime=[];
    for i=1:length(HisDataT)
        if isempty(HisDataT{:,i}), continue, end
        index = find(HisDataT{1,i}(:,1)<2.5);
        THour=HisDataT{1,i}(index,2);
        uprighttime=[uprighttime sum(THour)];
    end
end


for i=1:length(HisDataT)
    if tiltQ == 'y'
    if isempty(HisDataT{:,i}), continue, end
        HDTdelete=find(HisDataT{:,i}(:,2)<1);     % Ignore peaks lasting less
than 1 min
        HisDataT{:,i}(HDTdelete,:)=[];
        HisDataT{:,i}(:,1)=round(HisDataT{:,i}(:,1));
```

```
    end
    if reclineQ == 'y'
        if isempty(HisDataR{:,i}), continue, end
        HDRdelete=find(HisDataR{:,i}(:,2)<1);       % Ignore peaks lasting
less than 1 min
        HisDataR{:,i}(HDRdelete,:)=[];
        HisDataR{:,i}(:,1)=round(HisDataR{:,i}(:,1));
    end
    if tiltQ == 'y' && reclineQ == 'y'
        if isempty(HisDataTR{:,i}), continue, end
        HDTRdelete=find(HisDataTR{:,i}(:,3)<1);       % Ignore peaks lasting
less than 1 min
        HisDataTR{:,i}(HDTRdelete,:)=[];
        HisDataTR{:,i}(:,1:2)=round(HisDataTR{:,i}(:,1:2));
        HisDataTR{:,i}(:,1:2)=(HisDataTR{:,i}(:,1:2));
    end
    if heightQ == 'y'
        if isempty(HisDataH{:,i}), continue, end
        HDHdelete=find(HisDataH{:,i}(:,2)==0);      % Ignore peaks lasting 0
min
        HisDataH{:,i}(HDHdelete,:)=[];
        HisDataH{:,i}(:,1)=round(HisDataH{:,i}(:,1));
    end
end
clear i

% If angles/heights are similar, average them and add up the corresponding
% time durations. For example:
% Tilt Angle        Time spent in tilt angle         New tilt     New min
% ----------        ------------------------         --------     -------
%  9.8877 (degrees)      7.25 (minutes)  -------->>    9.8877       7.25
%  4.0219                6.75                          4.0219       6.75
%  25.1831_              4.5    _                      25.1831      4.5
%  3.8965  |             45.25   |       -------->>    4.399        64.5
%  4.2621  | Average     8.75    | Sum
%  4.9279  | these       5.75    | these
%  4.5096 _|             4.75   _|

%%%%%%%%%%%%%%%%%%%%%%%%%
% Let's do this for TILT
%%%%%%%%%%%%%%%%%%%%%%%%%
if tiltQ == 'y'
    for k=1:length(HisDataT);
        if isempty(HisDataT{:,k}), continue, end
        HD1=HisDataT{1,k}(:,1);
        HD2=HisDataT{1,k}(:,2);
        B=diff(HD1);
        C=find(abs(B)<2.5);              % Threshold of 2.5 deg
        j=1;count=1;i=1;
        while(1)
            if(i>length(HD1)) break;
            end
            if(isempty(find((C-i)==0))==1)
                Tiltsum{1,k}(j,:)=HisDataT{1,k}(i,:);
                j=j+1;
                i=i+1;
            else
```

```
                index=i;
                i=i+1;
                while(1)
                    if(isempty(find((C-i)==0))==1)

Tiltsum{1,k}(j,1)=(mean(HisDataT{1,k}(index:index+count,1)));

%Tiltsum{1,k}(j,1)=round(mean(HisDataT{1,k}(index:index+count,1)));
%(A(index:index+count));

Tiltsum{1,k}(j,2)=sum(HisDataT{1,k}(index:index+count,2));
                        j=j+1;
                        count=1;
                        i=i+1;
                        break;
                    else
                        i=i+1;
                        count=count+1;
                    end
                end
            end
        end
    end
    clear i j k count index HD1 HD2 newlength B C D

    tilttime2=[];
    for i=1:length(Tiltsum)
        if isempty(Tiltsum{:,i}), continue, end
        index = find(Tiltsum{1,i}(:,1)>=2.5);
        THour=Tiltsum{1,i}(index,2);
        tilttime2=[tilttime2 sum(THour)];
    end
    clear i index THour

    % Number of times tilt was accessed and for how long
    Tiltsum2=Tiltsum;
    for s=1:length(Tiltsum2)
        if isempty(Tiltsum2{1,s})
            x=[];
        else
            x=find(Tiltsum2{1,s}(:,1)<2.5);
        end
        Tiltsum2{1,s}(x,:)=[];
        tiltaccess(s)=size(Tiltsum2{1,s},1);
    end

    % Most common tilt angle (by duration of accesses).
    TScat=vertcat(Tiltsum2{1:length(Tiltsum2)});
    TSsort=sortrows(TScat,1);
    TSdiff=diff(TSsort(:,1));
    TSindex=find(diff(TSsort(:,1))~=0);

    TS1=TScat(:,1);
    TS2=TScat(:,2);
    B=diff(TS1);
    C=find(abs(B)<2.5);
    j=1;count=1;i=1;
```

```
    while(1)
        if(i>length(TS1)) break;
        end
        if(isempty(find((C-i)==0))==1)
            newTSsort(j,1)=TS1(i);
            newTSsort(j,2)=TS2(i);
            j=j+1;
            i=i+1;
        else
            index=i;
            i=i+1;
            while(1)
                if(isempty(find((C-i)==0))==1)
                    newTSsort(j,1)=mean(TS1(index:index+count));
                    newTSsort(j,2)=sum(TS2(index:index+count));
                    j=j+1;
                    count=1;
                    i=i+1;
                    break;
                else
                    i=i+1;
                    count=count+1;
                end
            end
        end
    end
    newTSsort=[round(newTSsort(:,1)) newTSsort(:,2)];

    maxnewTSsort=max(newTSsort(:,1));
    if isinteger((maxnewTSsort/1.25))==0
        bins=[3.75:2.5:max(newTSsort(:,1))+1.25];
    else
        bins=[3.75:2.5:max(newTSsort(:,1))];
    end
    hist(newTSsort(:,1),bins)
    [x y]=hist(newTSsort(:,1),bins);
    for i=1:length(bins)
        tiltmode1index=find(newTSsort(:,1)>bins(i)-1.25 &
newTSsort(:,1)<=bins(i)+1.25);
        timetiltmode1(i)=sum(newTSsort(tiltmode1index,2));
    end
    [timetiltmode1, index]=max(timetiltmode1);
    tiltmode1=[bins(index)-1.25 bins(index)+1.25];
    tiltmodepercent1=((timetiltmode1/60)/(sum(in_time)))*100;

    % Most common tilt angle (by frequency of accesses).
    [TSmax, TSindex]=max(x);
    tiltmode2=[y(TSindex)-1.25 y(TSindex)+1.25];
    time2index=find(newTSsort(:,1)>tiltmode2(1) &
newTSsort(:,1)<=tiltmode2(2));
    timetiltmode2=sum(newTSsort(time2index,2));    % time spent in most common
tilt angle (in minutes)
    tiltmodepercent2=((timetiltmode2/60)/(sum(in_time)))*100;
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Let's do this for RECLINE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if reclineQ == 'y'
    for k=1:length(HisDataR);
        if isempty(HisDataR{:,k}), continue, end
        HD1=HisDataR{1,k}(:,1);
        HD2=HisDataR{1,k}(:,2);
        B=diff(HD1);
        C=find(abs(B)<2.5);          % Threshold of 2.5 deg
        D=find(diff(C)==1);
        j=1;count=1;i=1;
        while(1)
            if(i>length(HD1)) break;
            end
            if(isempty(find((C-i)==0))==1)
                Reclinesum{1,k}(j,:)=HisDataR{1,k}(i,:);
                j=j+1;
                i=i+1;
            else
                index=i;
                i=i+1;
                while(1)
                    if(isempty(find((C-i)==0))==1)

Reclinesum{1,k}(j,1)=round(mean(HisDataR{1,k}(index:index+count,1)));

Reclinesum{1,k}(j,2)=sum(HisDataR{1,k}(index:index+count,2));
                        j=j+1;
                        count=1;
                        i=i+1;
                        break;
                    else
                        i=i+1;
                        count=count+1;
                    end
                end
            end
        end
    end
    clear i j k count index HD1 HD2 newlength B C D

    reclinetime2=[];
    for i=1:length(Reclinesum)
        if isempty(Reclinesum{:,i}), continue, end
        index = find(Reclinesum{1,i}(:,1)>=92.5);
        RHour=Reclinesum{1,i}(index,2);
        reclinetime2=[reclinetime2 sum(RHour)];
    end
    clear i index RHour

    % Number of times recline was accessed and for how long
    Reclinesum2=Reclinesum;
    for s=1:length(Reclinesum2)
        if isempty(Reclinesum2{1,s})
            x=[];
        else
```

```
            x=find(Reclinesum2{:,s}(:,1)<92.5);
        end
        Reclinesum2{:,s}(x,:)=[];
        reclineaccess(s)=size(Reclinesum2{1,s},1);
    end

    % Most common recline angle (by duration of accesses).
    RScat=vertcat(Reclinesum2{1:length(Reclinesum2)});
    RSsort=sortrows(RScat,1);
    RSdiff=diff(RSsort(:,1));
    RSindex=find(diff(RSsort(:,1))~=0);

    RS1=RScat(:,1);
    RS2=RScat(:,2);
    B=diff(RS1);
    C=find(abs(B)<2.5);
    j=1;count=1;i=1;
    while(1)
        if(i>length(RS1)) break;
        end
        if(isempty(find((C-i)==0))==1)
            newRSsort(j,1)=RS1(i);
            newRSsort(j,2)=RS2(i);
            j=j+1;
            i=i+1;
        else
            index=i;
            i=i+1;
            while(1)
                if(isempty(find((C-i)==0))==1)
                    newRSsort(j,1)=mean(RS1(index:index+count));
                    newRSsort(j,2)=sum(RS2(index:index+count));
                    j=j+1;
                    count=1;
                    i=i+1;
                    break;
                else
                    i=i+1;
                    count=count+1;
                end
            end
        end
    end
    newRSsort=[round(newRSsort(:,1)) newRSsort(:,2)];

    maxnewRSsort=max(newRSsort(:,1));
    if isinteger((maxnewRSsort/1.25))==0
        bins=[93.75:2.5:max(newRSsort(:,1))+1.25];
    else
        bins=[93.75:2.5:max(newRSsort(:,1))];
    end
    hist(newRSsort(:,1),bins)
    [x y]=hist(newRSsort(:,1),bins);
    for i=1:length(bins)
        reclinemode1index=find(newRSsort(:,1)>bins(i)-1.25 &
newRSsort(:,1)<=bins(i)+1.25);
        timereclinemode1(i)=sum(newRSsort(reclinemode1index,2));
```

```
    end
    [timereclinemode1, index]=max(timereclinemode1);
    reclinemode1=[bins(index)-1.25 bins(index)+1.25];
    reclinemodepercent1=((timereclinemode1/60)/(sum(in_time)))*100;

    % Most common recline angle (by frequency of accesses).
    [RSmax, RSindex]=max(x);
    reclinemode2=[y(RSindex)-1.25 y(RSindex)+1.25];
    time2index=find(newRSsort(:,1)>reclinemode2(1) &
newRSsort(:,1)<=reclinemode2(2));
    timereclinemode2=sum(newRSsort(time2index,2));  % time spent in most
common recline angle (in minutes)
    reclinemodepercent2=((timereclinemode2/60)/(sum(in_time)))*100;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Let's do this for TILT + RECLINE
% The logic here is a little different - we just want to calucate duration
% of simultaneous tilt/recline use, so we don't need frequency of accesses
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

if tiltQ == 'y' && reclineQ == 'y'
    for k=1:length(HisDataTR);
        if isempty(HisDataTR{:,k}), continue, end
        HD1=HisDataTR{1,k}(:,1);
        HD2=HisDataTR{1,k}(:,2);
        HD3=HisDataTR{1,k}(:,3);
        B=diff(HD1);
        C=find(abs(B)<2.5);
        j=1;count=1;i=1;

        while(1)
            if(i>length(HD1)) break;
            end
            if(isempty(find((C-i)==0))==1)
                Tiltrecsum{1,k}(j,:)=HisDataTR{1,k}(i,:);
                j=j+1;
                i=i+1;
            else
                index=i;
                i=i+1;
                while(1)
                    if(isempty(find((C-i)==0))==1)

Tiltrecsum{1,k}(j,1)=round(mean(HisDataTR{1,k}(index:index+count,1)));
%(A(index:index+count));

Tiltrecsum{1,k}(j,2)=round(mean(HisDataTR{1,k}(index:index+count,2)));

Tiltrecsum{1,k}(j,3)=sum(HisDataTR{1,k}(index:index+count,3));
                        j=j+1;
                        count=1;
                        i=i+1;
                        break;
                    else
                        i=i+1;
                        count=count+1;
```

```
                    end
                end
            end
        end
    end
    clear i j k count index HD1 HD2 newlength B C D x y
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Let's do this for SEAT ELEVATION
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if heightQ == 'y'
    for k=1:length(HisDataH);
        if isempty(HisDataH{:,k}), continue, end
        HD1=HisDataH{1,k}(:,1);
        HD2=HisDataH{1,k}(:,2);
        B=diff(HD1);
        C=find(abs(B)<=1);               % Threshold of 1 cm
        D=find(diff(C)==1);
        j=1;count=1;i=1;
        while(1)
            if(i>length(HD1)) break;
            end
            if(isempty(find((C-i)==0))==1)
                Heightsum{1,k}(j,:)=HisDataH{1,k}(i,:);
                j=j+1;
                i=i+1;
            else
                index=i;
                i=i+1;
                while(1)
                    if(isempty(find((C-i)==0))==1)

Heightsum{1,k}(j,1)=round(mean(HisDataH{1,k}(index:index+count,1)));

Heightsum{1,k}(j,2)=sum(HisDataH{1,k}(index:index+count,2));
                        j=j+1;
                        count=1;
                        i=i+1;
                        break;
                    else
                        i=i+1;
                        count=count+1;
                    end
                end
            end
        end
    end
    clear i j k count index HD1 HD2 newlength B C D

    heighttime2=[];
    for i=1:length(Heightsum)
        if isempty(Heightsum{:,i}), continue, end
        index = find(Heightsum{1,i}(:,1)>=1);
        HHour=Heightsum{1,i}(index,2);
        heighttime2=[heighttime2 sum(HHour)];
```

```
    end
    clear i index HHour


    % Number of times seat elevator was accessed and for how long
    % (Exlucing heights below 1 cm)
    Heightsum2=Heightsum;
    for s=1:length(Heightsum2)
        x=find(Heightsum2{:,s}(:,1)<1);
        Heightsum2{:,s}(x,:)=[];
        heightaccess(s)=size(Heightsum2{1,s},1);
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% PRESSURE RELIEF CALCULATIONS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Pressure-Relief Results
Pressfile=char('Position vs Max Pressure DS7200.xls');
PM=xlsread(Pressfile);
%PM(1,:)=[];
PM(:,2)=[];
%PM(:,4)=[];
Pressarray=cell(1,length(Tiltsum2));

if tiltQ=='y' && reclineQ=='y'
    count=1; k=1;
    TRsize=size(Tiltrecsum);
    for m=1:TRsize(:,2)
        TRPress=Tiltrecsum{:,m};
        TRsize=size(TRPress);
        PP=zeros(1,3);
        PP2=zeros(1,3);
        for i=1:TRsize(:,1)
            for j=1:length(PM)
                xdiff=TRPress(i,1)-PM(j,1);
                ydiff=TRPress(i,2)-PM(j,2);
                dist(count)=sqrt((xdiff^2)+(ydiff^2));
                if (dist(count)<2.5)
                    PP(k,:)=PM(j,:);
                    PP2(k,:)=TRPress(i,:);
                    k=k+1;
                end
                count=count+1;
            end
        end
        Pressarray{:,m}=cat(2,PP(:,3),PP2(:,3));
        count=1; k=1;
    end
    clear i j dist xdiff ydiff PP PP2 TRpress
    Presssize=size(Pressarray);
    for i=1:Presssize(:,2);
        Lowindex=find(Pressarray{:,i}(:,1)<80);
        Lowpresstime{:,i}=Pressarray{:,i}(Lowindex,2);

        Medindex=find(Pressarray{:,i}(:,1)>80 & Pressarray{:,i}(:,1)<120);
```

```
        Medpresstime{:,i}=Pressarray{:,i}(Medindex,2);

        Highindex=find(Pressarray{:,i}(:,1)>120);
        Highpresstime{:,i}=Pressarray{:,i}(Highindex,2);
    end
end
clear i j

if tiltQ=='y' && reclineQ=='n'
    PM(:,4)=[];
    count=1; k=1;
    TRsize=size(Tiltsum2);
    for m=1:TRsize(:,2)
        TRPress=Tiltsum2{:,m};
        TRsize=size(TRPress);
        PP=zeros(1,3);
        PP2=zeros(1,2);
        for i=1:TRsize(:,1)
            for j=1:length(PM)
                xdiff=TRPress(i,1)-PM(j,1);
                ydiff=0;
                dist(count)=sqrt((xdiff^2)+(ydiff^2));
                if (dist(count)<2.5)
                    PP(k,:)=PM(j,:);
                    PP2(k,:)=TRPress(i,:);
                    k=k+1;
                end
                count=count+1;
            end
        end
        Pressarray{:,m}=cat(2,PP(:,3),PP2(:,2));
        count=1; k=1;
    end
    clear i j dist xdiff ydiff PP PP2 TRpress
    Presssize=size(Pressarray);
    for i=1:Presssize(:,2);
        Lowindex=find(Pressarray{:,i}(:,1)<80);
        Lowpresstime{:,i}=Pressarray{:,i}(Lowindex,2);

        Medindex=find(Pressarray{:,i}(:,1)>80 & Pressarray{:,i}(:,1)<120);
        Medpresstime{:,i}=Pressarray{:,i}(Medindex,2);

        Highindex=find(Pressarray{:,i}(:,1)>120);
        Highpresstime{:,i}=Pressarray{:,i}(Highindex,2);
    end
end
clear i j

% Frequency and duration (LOW pressure)
Lowsize=size(Lowpresstime);
for i=1:Lowsize(:,2)
    Lowpressfreq(i)=length(Lowpresstime{:,i});
end

for i=1:Lowsize(:,2)
    Lowduration(i)=sum(Lowpresstime{1,i}(:,1));
end
```

```
clear i

% Frequency and duration (MED pressure)
Medsize=size(Medpresstime);
for i=1:Medsize(:,2)
    Medpressfreq(i)=length(Medpresstime{:,i});
end

for i=1:Medsize(:,2)
    Medduration(i)=sum(Medpresstime{1,i}(:,1));
end
clear i

% Frequency and duration (HIGH pressure)
Highsize=size(Highpresstime);
for i=1:Highsize(:,2)
    Highpressfreq(i)=length(Highpresstime{:,i});
end

for i=1:Highsize(:,2)
    Highduration(i)=sum(Highpresstime{1,i}(:,1));
end
clear i

% Plot the Pressure-mapping data and study data
figure
for i=1:length(Tiltrecsum)
    plot(Tiltrecsum{1,i}(:,1),Tiltrecsum{1,i}(:,2),'o')
    hold on
end
hold on
for i=1:length(PM)
    if PM(i,3)>120
        plot(PM(i,1),PM(i,2),'r.')
    elseif PM(i,3)<120 && PM(i,3)>80
        plot(PM(i,1),PM(i,2),'y.')
    elseif PM(i,3)<80
        plot(PM(i,1),PM(i,2),'g.')
    end
end


%% Data summary
disp('Total chair occupancy time (hours/day)')
in_time'
disp('Maximum occupancy time (hours/day)')
max_single_time'
disp('Transfer Frequency')
transfer_freq'
disp('Upright Time (hours/day)')
uprighttime'/60

% Access Results
if tiltQ=='y'
    disp('Tilt accesses per day')
    tiltaccess'
    disp('Average time tilt accessed')
```

```
    tilttime'/60
end
if reclineQ=='y'
    disp('Recline accesses per day')
    reclineaccess'
    disp('Average time recline accessed')
    reclinetime'/60
end
if tiltQ=='y' & reclineQ=='y'
   disp('Simultaneous Use of Tilt and Recline')
   tiltrectime'/60
end
if heightQ=='y'
    disp('Seat Elevator accesses per day')
    heightaccess'
    disp('Average time seat elevation accessed')
    heighttime'/60
end

% "Most Common..." Results
if tiltQ=='y'
    disp('Tilt Modes')
    tiltmode1
    tiltmodepercent1
    tiltmode2
    tiltmodepercent2
end

if reclineQ=='y'
    disp('Recline Modes')
    reclinemode1
    reclinemodepercent1
    reclinemode2
    reclinemodepercent2
end

% Pressure Results
disp('Low Pressure Position Frequency (#/day)')
Lowpressfreq'

disp('Low Pressure Position Duration (hrs/day)')
Lowduration'/60

disp('Med Pressure Position Frequency (#/day)')
Medpressfreq'

disp('Med Pressure Position Duration (hrs/day)')
Medduration'/60

disp('High Pressure Position Frequency (#/day)')
Highpressfreq'

disp('High Pressure Position Duration (hrs/day)')
Highduration'/60
```

BIBLIOGRAPHY

Aissaoui, R., Lacoste, M., & Dansereau, J. (2001). Analysis of sliding and pressure distribution during a repositioning of persons in a simulator chair. *IEEE Transactions in Rehabilitation Engineering*, 9(2), 215-224.

Andrews, R.D. (1998). Instrumentation for the remote monitoring of physiological and behavioral variables. *Journal of Applied Physiology*, 85, 1974-1981.

Arva, J., Schmeler, M., Lange, M., & Lipka, D. (2005). RESNA position on the application of seat-elevating devices for wheelchair users. Arlington, VA: Rehabilitation Engineering & Assistive Technology Society of North America.

Brienza, D.M., Geyer, M.J., & Karg, P. (2001). White Paper on Pressure Management, in Wheelchair Seating: *A State of the Science Conference on Seating Issues for Persons with Disabilities*. Pittsburgh, PA: University of Pittsburgh.

Ceelen, K.K. (2003). Aetiology of pressure ulcers: a literature review (MS thesis). Eindhoven: Dept. of Biomedical Engineering, Faculty of Biomedical Engineering, Eindhoven University of Technology.

Coggrave, M.J., & Rose, L.S. (2003). A specialist seating assessment clinic: changing pressure relief practice. *Spinal Cord*, 41, 692-695.

Cooper, R.A., Boninger, M.L., Cooper, R., Fitzgerald, S.G., Kelleher, A. (2004). Preliminary assessment of a prototype advanced mobility device in the work environment of veterans with spinal cord injury. *NeuroRehabilitation*, 19, 161-170.

Cooper, R.A., Thorman, T., Cooper, R., Dvorznak, M.J., Fitzgerald, S.G., Ammer, W., Song-Feng, G., Boninger, M.L. (2002). Driving characteristics of electric-powered wheelchair users: how far, fast, and often do people drive? *Archives of Physical Medicine and Rehabilitation*, 83(2), 250-255.

Crane, B., Hobson, D. (2003). No room for discomfort: what difference does comfortable seating make? For many wheelchair users, quite a lot. *RehabManagement*, Jan/Feb, 30-35.

Crane, B.A., Holm, M.B., Hobson, D.A., Cooper, R.A., Reed, M.P., & Stadelmeier, S. (2004). Development of a consumer-driven Wheelchair Seating Discomfort Assessment Tool (WcS-DAT). *International Journal of Rehabilitation Research*, 27, 85-90.

Crane, B.A., Holm, M.B., Hobson, D.A., Cooper, R.A., Reed, M.P., & Stadelmeier, S. (2005). Test-retest reliability, internal item consistency, and concurrent validity of the Wheelchair Seating Discomfort Assessment Tool. *Assistive Technology*, 17, 98-107.

de Looze, M.P., Kuijt-Evers, L.F., van Dieen, J. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, 46(10), 985-997.

Edlich, R.F., Heather, C.L., & Galumbeck, M.H. (2003). Revolutionary advances in adaptive seating systems for the elderly and persons with disabilities that assist sit-to-stand transfers. *Journal of Long-Term Effects of Medical Implants*, 13(1), 31-39.

Engström, B. (2002). Ergonomic seating; a true challenge when using wheelchairs. Posturalis Books (pp.40-43).

Gibbs, C.H., Keeling, S., Dean, G.S., Bar-Zion, Y. Plumley, Jr., H.H. (2000). *U.S. Patent No.* 6,099,303. Washington DC: U.S. Patent and Trademark Office.

Gilsdorf, P., Patterson, R., Fisher, S., & Appel, N. (1990). Sitting forces and wheelchair mechanics. *Journal of Rehabilitation Research and Development*, 27(3), 239-246.

Goossens, R.H., Teeuw, R., Snijders, C.J. (2005). Sensitivity for pressure difference on the ischial tuberosity. *Ergonomics*, 48(7), 895-902.

Helfenstein, A., Lankes, M., Ohlert, K., Varoga, D., Hahne, H.J., Ulrich, H.W., Hassenpflug, J. (2006). The objective determination of compliance in treatment of adolescent idiopathic scoliosis with spinal orthoses. *Spine*, 31(3), 339-344.

Henderson, J.L., Price, S.H., Brandstater, M.E., & Mandac, B.R. (1994). Efficacy of three measures to relieve pressure in seated persons with spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, 75, 535-539.

Hobson, D.A. (1992). Comparative effects of posture on pressure and shear at the body-seat interface. *Journal of Rehabilitation Research and Development*, 29(4), 21-31.

Janssen, W.G.M., Bussmann, H.B.J., & Stam, H.J. (2002). Determinants of the sit-to-stand movement: a review. *Physical Therapy*, 82(9), 866-879.

Kaminski, B. (2004). *Application of a commercial datalogger to electric powered and manual wheelchairs of children*. Master's Thesis. University of Pittsburgh, Pittsburgh, PA.

Kemper, K. (1993). Gravitating toward tilt-in-space: As demand increases, options on tilt-in-space systems are expanding to meet the active user's needs. *TeamRehab Report*, Mar/Apr, 31-32, & 34-35.

Koo, T.K., Mak, A.T., & Lee, Y.L. (1996). Posture effects on seating interface biomechanics: comparison between two seating cushions. *Archives of Physical Medicine and Rehabilitation*, 77, 40-47.

Kosiak, M. (1959). Etiology and pathology of ischemic ulcers. *Archives of Physical Medicine and Rehabilitation*, 40(2), 62-69.

Lacoste, M., Weiss-Lambrou, R., Allard, M., & Dansereau, J. (2003). Powered tilt/recline systems: why and how are they used? *Assistive Technology*, 15, 58-68.

Lankton, S., Sonenblum, S., Sprigle, S., Wolf, J., & Oliveira, M. (2005). Use of GPS and Sensor-based Instrumentation as a Supplement to Self-Report in Studies of Activity and Participation. *Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Conference Proceedings*. Atlanta, GA.

Leister, E., Ding, D., Cooper, R., Kelleher, A., Cooper, R.A., Fitzgerald, S., & Boninger, M.L. (2005). Effectiveness and use of tilt-in-space and recline wheelchairs. *Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Conference Proceedings*. Atlanta, GA.

McCracken, G.I., Janssen, J., Steen, N., DeJager, M., Heasman, P.A. (2002). A clinical evaluation of a novel data logger to determine compliance with the use of powered toothbrushes. *Journal of Clinical Periodontology*, 29(9), 838-843.

Nachemson, A. (1975). Towards a better understanding of low-back pain: a review of the mechanics of the lumbar disc. *Rheumatology and Rehabilitation*, 14(3), 129-43.

Onset Computer Corporation. (Copyright 1996-2003). *What is a datalogger?* Available at http://www.onsetcomp.com/MiscInfo/3564_whatlogger.html, Accessed May 1 2006.

Pope, P.M. (1985). A study of instability in relation to posture in the wheelchair. *Physiotherapy*, 71(3), 124-129.

Portney, L.G., & Watkins, M.P. (2000). Foundations of clinical research: applications to practice. 2nd ed. Upper Saddle Rive, NJ: Prentice-Hall, Inc. (pp.171).

Reswick, J., & Rogers, J. (1976). Experience at Rancho Los Amigos Hospital with devices and techniques to prevent pressure sores. In R.M. Kennedy, J.M. Cowden, and J.T. Scales (Eds.), *Bedsore biomechanics*. Baltimore: University Park Press. (pp. 301-310)

Rosenthal, M.J., Felton, R.M., Hileman, D.L., Lee, M., Friedman, M., Navach, J.H. (1996). A wheelchair cushion designed to redistribute sites of sitting pressure. *Archives of Physical Medicine and Rehabilitation*, 77(3), 278-282.

Shields, R.K., & Cook, T.M. (1988). Effect of seat angle and lumbar support on seated buttock pressure. *Physical Therapy*, 68(11), 1682-1686.

Shapcott, N., & Levy, B. (1999). By the numbers: Making the case for clinical use of pressure measurement mat technology to prevent the development of pressure ulcers. *TeamRehab Report*, Jan, 16-18, & 20.

Sonenblum, S.E., Sprigle, S., Maurer, C. (2006). Monitoring power upright and tilt-in-space wheelchair use. *Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Conference Proceedings*. Atlanta, GA.

Speath, D.M., Arva, J., & Cooper, R.A. (2000). Application of a commercial datalogger for rehabilitation research. *Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Conference Proceedings*. Orlando, FL.

Sprigle, S., & Sposato, B. (1997). Physiologic effects and design considerations of tilt and recline wheelchairs. *Orthopedic Physical Therapy Clinics of North America,* 6(1), 99-122.

Sprigle, S., Dunlop, W., & Press, L. (2003). Reliability of bench tests of interface pressure. *Assistive Technology*, 15, 49-57.

Stinson, M.D., Porter, A.P., & Eakin, P.A. (2002). Measuring interface pressure: a laboratory-based investigation into the effects of repositioning and sitting. *American Journal of Occupational Therapy*, 56, 185-190.

Stinson, M.D., Porter-Armstrong, A.P., & Eakin, P.A. (2003a). Pressure mapping systems: reliability of pressure map interpretation. *Clinical Rehabilitation*, 17, 504-511.

Stinson, M.D., Porter-Armstrong, A.P., & Eakin, P.A. (2003b). Seat-interface pressure: a pilot study of the relationship to gender, body mass index, and seating position. *Archives of Physical Medicine and Rehabilitation*, 84, 405-409.

Tolerico, M. (2005). *Investigation of the mobility characteristics and activity levels of manual wheelchair users in two real world environments*. Master's Thesis. University of Pittsburgh, Pittsburgh, PA.

Vyssotski, A.L., Serkov, A.N., Itskov, P.M., Dell'Omo, G., Latanov, A.V., Wolfer, D.P., & Lipp, H-P. (2006). Miniature neurologgers for flying pigeons: multichannel EEG and action and field potentials in combination with GPS recording. *Journal of Neurophysiology*, 95, 1263-1273.

Weiss-Lambrou, R., Tremblay, C., LeBlanc, R., Lacoste, M., and Dansereau, J. (1999). Wheelchair seating aids: how satisfied are consumers? *Assistive Technology*, 11: 43-53.

Wound, Ostomy, and Continence Nurses Society (WOCN). (2003). Guideline for prevention and management of pressure ulcers. Glenview (IL): Wound, Ostomy, and Continence Nurses Society (WOCN). (pp. 52). (WOCN clinical practice guideline; no. 2).

Xakellis, G.C., & Frantz, R. (1996). The cost of healing pressure ulcers across multiple health care settings. *Advances in Wound Care*, 9, 18–22.

LIST OF SUPPLIERS

a) Onset Computer Corporation. 470 MacArthur Blvd., Bourne, MA 02532.
b) Crossbow Technology. 4145 N. First St., San Jose, CA 95134.
c) Interlink Electronics, Inc. 546 Flynn Rd., Camarillo, CA 93012.
d) UniMeasure, Inc. 4175 SW Research Way. Corvallis, OR 97333.
e) Vista Medical. Unit 3 – 55 Henlow Bay. Winnipeg, Manitoba, Canada R3Y 1G4.
f) The MathWorks, Inc. 3 Apple Hill Drive. Natick, MA 01760.
g) SPSS, Inc. 233 S. Wacker Drive, 11^{th} Floor. Chicago, IL 60606.