Disability and Rehabilitation: Assistive Technology, 2011; Early Online, 1–10

informa healthcare

Distinct tilting behaviours with power tilt-in-space systems

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Accepted April 2011

Abstract

Purpose. To characterise the use of tilt-in-space systems and to form recommendations for tilt prescription and training based upon its use.

Method. Wheelchair occupancy and seat position of 45 full-time power wheelchair users were monitored for 1–2 weeks using an accelerometer, occupancy switch and data logger. Demographics, pressure ulcer history, functional and physical presentations of their disability, and sensation were also documented.

Results. Participants spent 12.1 h in their wheelchairs daily, with a median typical position of 8° (0°–47°). The median participant tilted every 27 min (0.1–16.6 tilts per occupancy hour). Pressure-relieving tilts (i.e. a tilt $\geq$30° for $\geq$1 min) were performed, on average, once every 10 h (0–2.2/h). Participants spent 19% of their seated time tilted past 15°. Seventeen participants utilised the tilt feature frequently and spent $>$20% of the time in multiple positions. The remaining participants sat in a single tilt range for $>$80% of the time.

Conclusions. Given the limited pressure relief compliance, alternative approaches to pressure relief and improved training may be needed for some clients. Wheelchair design and prescriptions may also need to reflect participants' preferences for sitting in small and medium tilts and changing position frequently.

Keywords: *Wheelchair, tilt-in-space, monitoring, pressure relief, seating, behaviour*

Introduction

Full-time power wheelchair users are considered to be at high risk of developing pressure ulcers. Some users experience increased durations of buttock loading from sitting up to 16 h each day [1] because of their limited mobility and inability to change position. In addition, full-time power wheelchair users may experience increased magnitudes of loading because muscle atrophy causes body weight to be supported by smaller surface areas [2]. Powered tilt-in-space systems are prescribed to full-time wheelchair users who are unable to independently reposition or perform pressure reliefs for the prevention of pressure ulcers. However, little is known about how tilt systems are used.

Tilt systems maintain constant hip and knee angles while tilting the whole system rearward. The clinical goal of tilt systems is to redistribute body weight from the seat to the backrest as the system tilts, thereby unweighting the ischial tuberosities. Most powered tilt systems rotate rearwards to achieve a tilt angle of 45°–60° from the horizontal. A number of studies have considered the interface pressure-relieving capabilities of tilt [3–6]. Despite varied methodologies and differences in results, they all reach the general conclusion that increasing the angle of tilt decreases the overall pressure at the buttock–cushion interface. This consensus result is important because the absolute angle of tilt needed for an acceptable weight shift is not known. Clinical recommendations suggest that users tilt 30°–65°, with an emphasis on tilting 'all the way back'.

Many other functional uses and benefits of tilt systems have been identified beyond decreasing interface pressure [7–10]. Tilting reduces the frictional forces at the seat interface as compared with upright sitting [6] and permits consistent positioning and switch access throughout the range of movements. Users have reported increased comfort and

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ISSN 1748-3107 print/ISSN 1748-3115 online © 2011 Informa UK, Ltd.
DOI: 10.3109/17483107.2011.580900

sitting tolerance, improved function and postural stability, improved sleep and rest, increased blood flow, easier feeding and improved respiratory function [1,7–11]. However, tilt systems may be problematic for some people, including those who have trouble tolerating static joint positions (hip/knee) throughout the day or those who have difficulty with bladder drainage while tilted.

To date, few studies have tried to determine how tilt systems are used. Lacoste et al. [11] asked 40 people who used tilt or recline wheelchairs about how and when they tilted. 97.5% of respondents reported using their systems daily. More than 70% of the respondents told that they used their tilt and recline systems for comfort, rest, relaxation and pain, while only about 50% reported using the chairs for physiological functions, a category that included prevention of pressure ulcers. This self-report methodology found that most people reported using tilt for reasons other than pressure relief. Given the limitations of self-report, there is a need for a quantitative study of the magnitude, frequency and duration of tilts.

Two studies have been published looking at tilt use quantitatively. A study by Ding et al. [12] included 11 participants, nine of whom had both tilt and recline systems available on their wheelchairs. They found that participants performed 19 ± 14 tilts per day (where a tilt required a change of 2.5°) and that subjects repositioned every 53.6 min. Tilts of less than 20° were found to be more frequent, but the role of recline in combination with the small tilts was not addressed, and some of the wheelchairs involved did not tilt past 20°, further skewing the results. Sonenblum et al. [1] reported tilt use of 16 subjects of varying diagnoses. The median subject performed 3.1 tilts every hour when seated in the wheelchair (mean (SD) = 4.3 (3.9)). A specific type of tilt, a pressure-relieving tilt (PRT), was defined as sitting with a tilt angle of $\geq 30^\circ$ for 1 min. While subjects used their tilt features to frequently change position, few performed PRTs. The median subject performed approximately one PRT every 7 h (median = 0.13/h, mean (SD) = 0.5 (0.7)).

The objective of this study was to characterise the use of tilt-in-space systems and to form recommendations for tilt prescription and training based upon its use. A descriptive analysis of tilt behaviours included participants' typical sitting positions, the magnitude and frequency of tilt manoeuvres performed throughout the day, and the time spent at different tilt angles. In addition, hypotheses concerning whether participants tilted to angles currently associated with pressure relief (i.e. large or extreme angles) were tested, secondary to the descriptive analysis.

Hypothesis (H) 1. Small and medium tilts were used more frequently than large and extreme tilts.

H2. PRTs were not used with the prescribed frequency.

This article represents an effort to improve the use of seated tilt to increase function, health and quality of life for people using power wheelchairs.

Methods

Participants

A convenience sample of 45 adults was recruited from a local hospital. Inclusion focused solely on the use of tilt-in-space systems without regard to diagnosis, gender or age. Only subjects who used a power tilt-in-space wheelchair as their primary mobility device were included. This study had institutional review board's (IRB's) approval, and subjects signed informed consent forms prior to beginning their participation in the study.

Instrumentation

This study utilised instrumentation previously developed to study wheelchairs' use and activity [13–16]. The instrumentation included three components: the accelerometer/data logger (MSR 145, MSR Electronics GmbH), an occupancy switch and external circuitry. The MSR is a microprocessor-controlled data logger in a compact package (18 mm × 14 mm × 62 mm). Also included in the package is a battery, flash memory suitable for collecting 1 week of data, and a triaxial accelerometer sensitive to $\pm 2g$. The MSR was mounted to the seat bottom. Accelerations were sampled at 1 Hz and converted to a tilt angle using the arcsine of the stationary acceleration parallel to the seat bottom (Figure 1). Wheelchair occupancy was ascertained by a mechanical switch (i.e. the occupancy switch) placed under the wheelchair cushion and logged through the MSR's external analogue input. Occupancy was sampled every 5s.

Protocol

After providing informed consent, subjects' wheelchairs were instrumented with the MSR data logger/accelerometer and occupancy switch. Subjects were asked a number of questions to ascertain demographic information (e.g. age, gender and race), functional and physical presentations of their disability (e.g. sensation and wheelchair history), pressure ulcer history and the purposes for which they tilt. Participants were categorised as having sensation at the buttocks if they reported the ability to feel deep

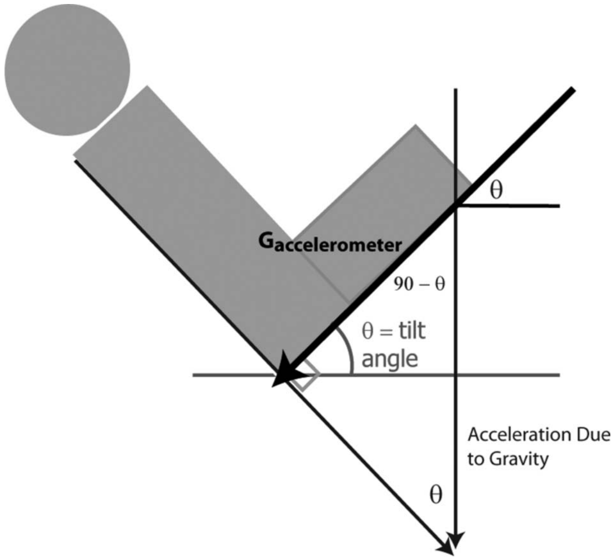

Figure 1. Schematic representation of the conversion of the accelerometer reading to a tilt angle. $G_{accelerometer}$ is the component of gravity parallel to the accelerometer, or the value measured by the accelerometer because the wheelchair was stationary during testing. Acceleration due to gravity is 1 g; therefore, $\theta = \text{arcsine}(G_{accelerometer})$.

pressure, light touch or pain on the buttocks. In addition, subjects' 'ability to reposition' (i.e. squirm) was defined to distinguish subjects able to independently change posture from those unable to reposition. The ability to reposition was operationally defined by the ability to unload 75% or more of the load at the greater trochanter, either by leaning in the opposite direction or pushing up to unweight the buttocks. Repositioning ability was defined to represent an ability to shift posture or squirm rather than the ability to perform a weight shift.

The instrumentation was left on the wheelchairs for 1 week, during which time the instrumentation operated without subjects' interaction. This resulted in six complete days of data to determine typical behaviour. This time frame was selected after analysing the data of the first 10 subjects enrolled with 12 days of data. Establishing a reliability of 0.95 (described by Cronbach's Alpha), 4.4 days of data would be needed to reliably measure the variable with the least day-to-day variability (i.e. typical position), and 7.5 days for the variable with the greatest day-to-day variability (i.e. number of tilts). Given the wide range in variables and the convenience of a 1-week instrumentation period (takedown 7 days following set up), 6 days was determined to be suitable.

Data analysis

Data processing was performed using MATLAB R2008a (Mathworks Inc., Natick, MA), and statistical analyses were done using Minitab 14 (Minitab Inc., State College, PA).

Accelerometer data were processed to filter noise and to identify tilt position changes according to a method described previously [1]. Briefly, position changes of less than 5° were ignored based upon the belief that smaller position differences may not be reliably differentiated by persons in wheelchairs. Furthermore, relevant position changes had to be maintained (within $\pm 2°$) for 20 s to eliminate transient events, such as wheeling or hitting a bump.

The variables considered in this study are described below. Unless otherwise described, variables are reported based on the median day for each subject. For a day to be included in the analysis, more than 23 h of data were required (i.e. the first and last days of instrumentation were not included), and participants needed to occupy the wheelchair for at least 15 min. Variables requiring $\geq$45° of tilt were calculated only for participants having more than 45° of tilt available on their wheelchairs.

Wheelchair occupancy time – The number of hours per day that subjects occupied their wheelchairs.

Typical position – The position at which the subjects spent the most time was defined by the mode of all the angles measured during the time the wheelchair was occupied. Angles were rounded to the nearest degree.

Time spent at small (0°–14°), medium (15°–29°), large (30°–44°) and extreme ($\geq$45°) tilt angles – Both absolute time and per cent of total occupancy time were calculated.

Number and percentage of small (0°–14°), medium (15°–29°), large (30°–44°), and extreme ($\geq$45°) magnitude tilts – These refer to the absolute value of the change in angle, regardless of the starting position. Percentage was computed based on all tilts performed by the participant.

Tilt frequency – 'Tilts' were defined as position changes of 5° or more in either direction (i.e. towards tilted or upright) that were maintained for at least 20 s. Tilt frequency was computed by dividing the daily total number of tilts by the number of hours of wheelchair occupancy on that day.

PRT frequency – PRT manoeuvres were defined as position changes from below 30° of tilt to greater than 30° of tilt lasting more than 1 min. The 30° tilt magnitude was based upon clinical recommendations suggesting 30°–65° of tilt. PRT frequency was computed by dividing the daily number of PRTs by the number of hours of wheelchair occupancy on that day.

Non-parametric statistics were used to test the hypotheses due to the skewed distributions in tilt behaviour. For H1, the number of small and medium tilts per day was compared with the number of large and extreme tilts per day using a Mann–Whitney test. H2 (PRTs are not used with prescribed frequency) was tested using a Wilcoxon signed rank test in which tilt frequency was compared with the conservative threshold of 1 tilt per hour.

Results

Description of sample population

Forty-five subjects were enrolled in this study. Participants' characteristics can be found in Table I. In terms of diagnosis, the majority of the participants had a spinal cord injury (SCI) ($n=30$, 68.2%). Other diagnoses included multiple sclerosis ($n=4$), cerebral palsy ($n=4$), brainstem stroke, spina bifida and muscular dystrophy. Of the 30 participants with SCI, half described their injury as incomplete, 14 as complete, and 1 was uncertain. Levels of SCI varied with 29 cervical injuries and 1 thoracic injury.

Wheelchair and cushion configurations were fairly limited, with most participants using an Invacare wheelchair in combination with a Roho ($n=20$, 44.4%) or Jay wheelchair cushion ($n=14$, 31.1%). Other cushion types included layered foam, honeycomb, and various combinations of air, foam and gel. Of 38 participants about whom complete wheelchair configuration information was known, 29 had chairs configured to tilt past 45° (range approximately 45°–60°). Finally, on average, wheelchairs were configured with approximately 100°of seat-to-back angle (mean (SD) = 101° (6°)).

Table I. Description of participants.

	Mean (SD)	Median (min–max)
Age (years) ($n=44$)	45 (14)	43 (22–69)
Height (m) ($n=43$)	1.74 (0.11)	1.75 (1.52–1.93)
Weight (kg) ($n=43$)	75 (19)	75 (39–114)
Years using a wheelchair ($n=44$)	14.4 (13.5)	10 (0.5–50)
Years using a tilt-in-space wheelchair ($n=44$)	6.1 (6.1)	3 (0.25–20)

	Number	Percentage
Gender ($n=45$)		
Female	12	27
Male	33	73
Race ($n=44$)		
African–American	18	40.9
Caucasian	25	56.8
Other (biracial)	1	2.3
Tilt-in-space is first wheelchair ($n=45$)	22	48.9
Able to reposition independently ($n=44$) (defined by the ability to unload greater trochanter)	25	56.8
Self-reported sensation ($n=42$) (any of: light touch, deep pressure or pain)	25	59.5
Pressure ulcer history ($n=42$)		
History of recurrent (more than one at same location)	14	33.3
Any history of pelvic pressure ulcer	28	63.6
Current pelvic pressure ulcer	9	20.9

Description of tilt-in-space behaviour

The majority of participants reported multiple reasons for using their tilt systems. Approximately three-fourth of participants reported using their tilt-in-space feature for comfort, discomfort or pain (77%) and/or pressure relief (73%). Two-thirds of participants reported using the feature for rest and/or relaxation, 48% for posture and 61% for function.

Participants spent a considerable amount of time in their wheelchairs, with half of the participants spending more than 12.1 h per day in their chairs (Table II). Seven of the 45 participants spent at least 1 day without getting into their wheelchairs at all. Each participant's typical position (median = 8°) was significantly larger than the minimum position allowed by their wheelchair (median = 2°, $p=0.000$), indicating that subjects utilised the tilt feature for their typical positions.

The median participant tilted every 27 min, meaning half of the participants performed tilts more frequently than twice per hour (Table II). Frequency of tilt use varied from barely once per day to every 3–4 min. As is typical with behavioural data in this

Table II. Use of tilt-in-space wheelchairs across median subject days.

Variable	Mean ± SD	Median (min–max)
Occupancy time (h)	11.7 ± 3.7	12.1 (4.1–24)
Typical position (°)	11 ± 9	8 (0–47)
Tilt frequency (tilts per occupancy hour)	3.0 ± 2.9	2.2 (0.1–16.6)
PRT frequency (PRTs per occupancy hour)	0.3 ± 0.5	0.1 (0.0–2.2)
% Time at position		
Small tilt (0°–14°)	65 ± 33	81 (0–100)
Medium tilt (15°–29°)	26 ± 28	15 (0–92)
Large tilt (30°–44°)	5 ± 8	1 (0–29)
Extreme tilt (≥45°) ($n=29$)	4 ± 13	0 (0–71)
% Tilts of magnitude		
Small magnitude (0°–14°)	65 ± 24	70 (5–100)
Medium magnitude (15°–29°)	23 ± 19	19 (0–83)
Large magnitude (30°–44°)	9 ± 13	4 (0–71)
Extreme magnitude (≥45°) ($n=29$)	3 ± 7	0 (0–28)

population [13], the distributions were skewed towards less use, making the median the appropriate descriptor despite the large sample size (Figure 2). PRTs were used with much less frequency than general tilts, with the median subject performing only one PRT every 10 h. Twenty-six participants failed to perform a PRT on at least 1 day, and 6 of these participants did not perform a PRT during the monitoring period. Seven of the 9 participants with current pressure ulcers performed PRTs more frequently than the median subject, but only two of these participants met the minimum recommendation for pressure relief of once per hour with a duration of at least 60 s.

Hypotheses

The data supported both hypotheses. With a median of 21.3 small and medium tilts per day compared with 0.7 large and extreme tilts per day, small and medium tilts were used more frequently than large and extreme tilts (95% CI for difference (12.3, 25.7), $p = 0.000$). The median PRT frequency of 0.1 PRTs per occupancy hour was significantly less than the minimal recommended one per hour ($p = 0.000$).

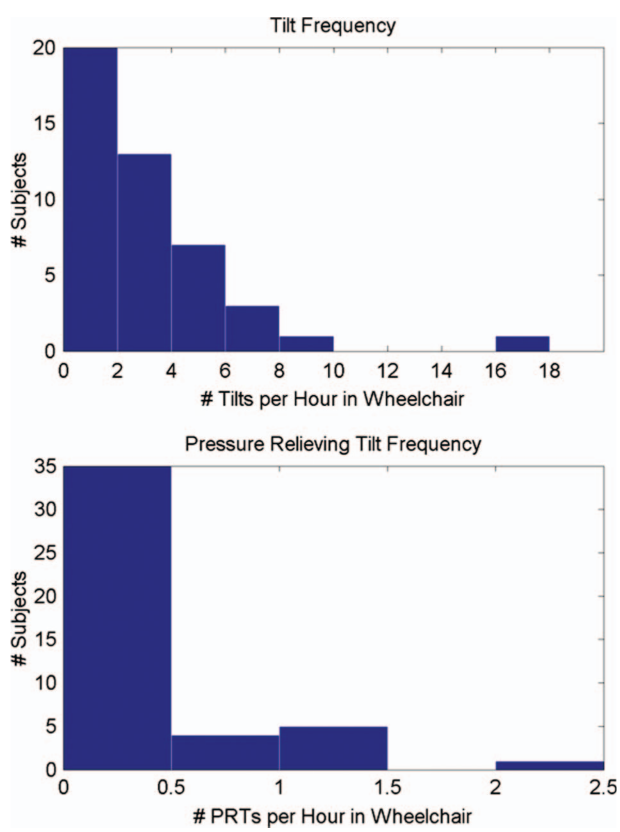

Figure 2. Distribution of frequency of tilt (top) and PRT (bottom) use across subjects.

Characteristics of tilt behaviour

Most participants spent their seated time in more than one tilt position (Table II, Figure 3). In fact, the median participant spent almost 2 h in a medium tilt. Figure 3 illustrates the median daily use by each participant.

Figure 3 is designed to illustrate two distinct behaviours or types of tilt use. One group of participants exhibited a habitual seat position defined by spending at least 80% of their time in a single tilt range (i.e. small, medium, large or extreme). Another group used their tilt systems regularly and spent more than 20% of their time at multiple positions (i.e. $<80\%$ of their time at any single position). The definitions of these categories resulted from post-hoc analysis to distinguish different behaviours. Across all subjects, the median per cent time spent in small tilts was 81%. This median value provided the basis for the threshold values used to distinguish the two behaviours.

The first 28 participants in Figure 3 habitually positioned their seat into a single tilt range for $>80\%$ of the time. Three of the subjects spent at least 80% of the time in the 15°–29° range, with the other 25 sitting predominately in the 0°–14° range. Only three of these participants performed PRTs more than once per hour. An example of a participant who chose to sit with a habitual seat position that was a fairly upright posture but still performed regular tilts is illustrated in Figure 4. This participant has a clear typical position of 5°.

The remaining participants, numbered 29–45 in Figure 3, changed positions regularly throughout the day, and each tilted more than once every 30 min. Participants who exhibited this behaviour performed significantly more frequent tilts and PRTs than participants who habitually sat in a single tilt range (Table III). Data from a participant who tilted regularly throughout the day are pictured in Figure 5. It is evident from the figure that this participant does not have a meaningful 'typical position'.

Exploratory analysis

Some analyses were done to explore relationships between tilt usage and user's characteristics. Metrics of tilt behaviour and wheelchair use (i.e. typical seat position, PRT frequency, tilt frequency and time at tilt positions) were compared with participants' characteristics (i.e. years using a wheelchair, presence of sensation at the buttocks, ability to reposition independently in wheelchair, pressure ulcer status and diagnosis of SCI). Of all the tilt behaviour metrics, only tilt frequency and time at tilt positions were related to any participant's characteristics.

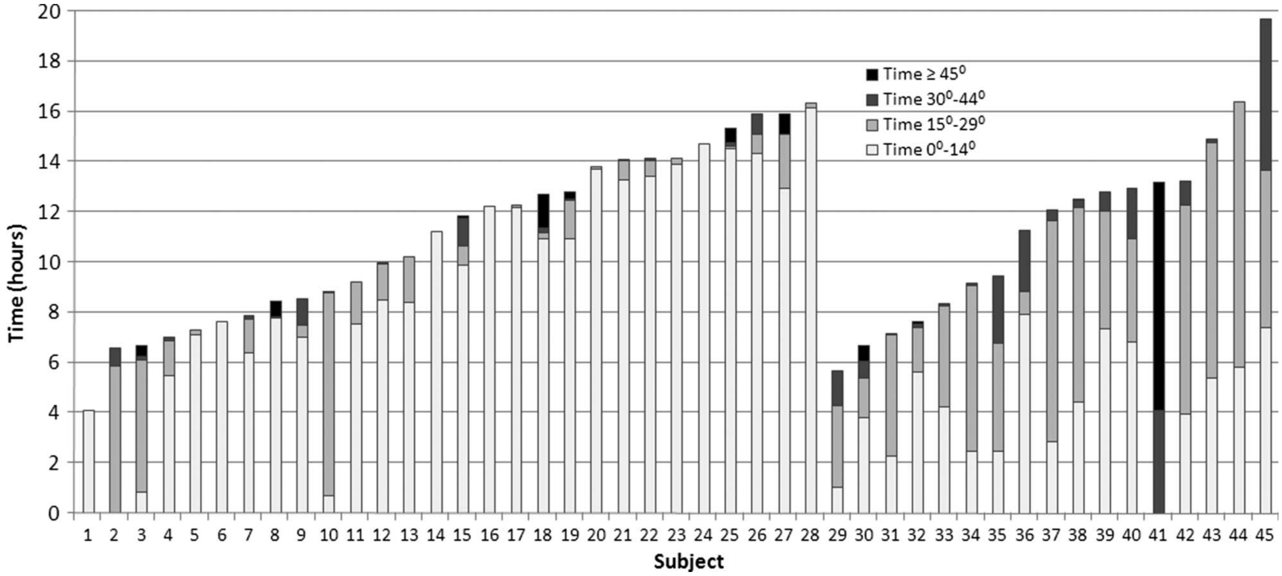

Figure 3. Breakdown of daily time in chair by wheelchair tilt position. Subjects 1–28 exhibited a habitual seat position, while subjects 29–45 tilted regularly and did not have a meaningful typical position.

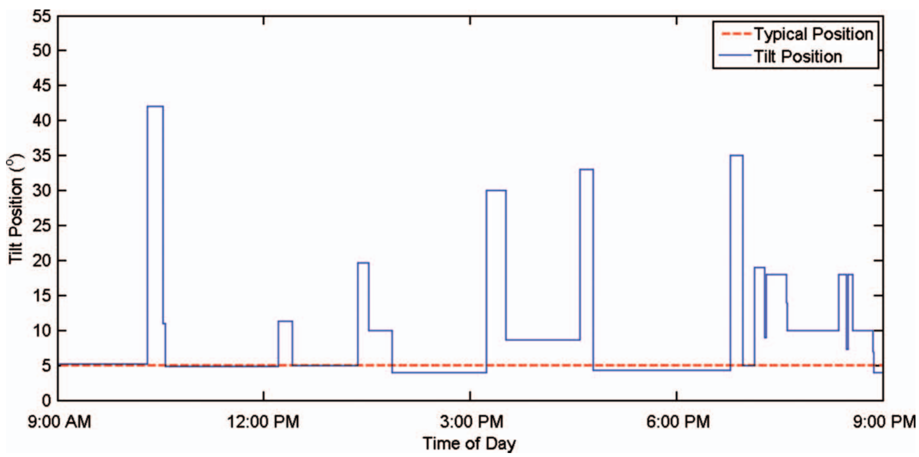

Figure 4. Example of a participant exhibiting a habitual seat position. This participant sits at a typical position of 5°, but performs small, medium and large tilts from that position (Subject 15).

Table III. Median tilt behaviour differed across categories of behaviour.

	Habitual	Non-habitual	*p*-Value
Occupancy (h)	12.0	13.1	0.725
Tilt frequency (tilts/h)	1.3	4.0	0.001
PRT frequency (PRTs/h)	0.1	0.2	0.035

'Habitual' refers to participants spending at least 80% of their time in a single tilt range, while 'non-habitual' participants spent <80% of their time at any single position. *p*-Value from Kruskal–Wallis.

Years in wheelchair was negatively associated with the tilt frequency (Pearson's $r = -0.301$, $p = 0.047$), while diagnosis of SCI was associated with greater tilt frequencies (2.7/h with SCI and 1.1/h without SCI, $p = 0.043$). Participants with the ability to reposition spent significantly more time in a small tilt than participants with no ability to reposition (85% vs. 50%, $p = 0.030$).

Discussion

The magnitude and frequency of tilt use varied widely across participants and may reflect the variability in function and activity among users as well as the diverse benefits of tilt systems. This disparity in the use of tilt is consistent with the belief that a combination of factors including living situation, availability of assistance, daily activity and functional ability will contribute to the use of a tilt-in-space system.

Average wheelchair occupancy of this study's participants was similar to findings of previous

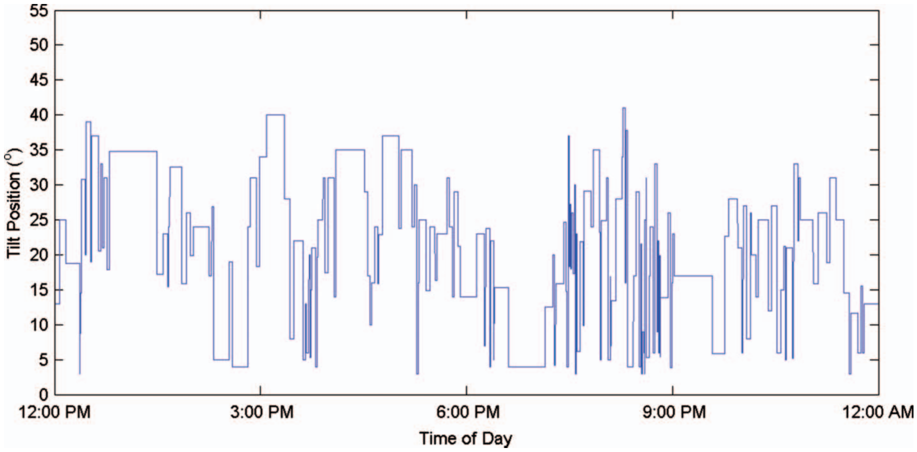

Figure 5. Example of a participant who sits at various positions throughout the day (Subject 35). Despite frequent position changes, this participant never reaches 45°.

studies of power wheelchair users [1,12,13], but was about 2 h greater than manual wheelchair users as reported by Yang et al. [17]. Most persons who use power tilt require assistance in transfers, so fewer transfers and therefore greater occupancy time would be expected as compared with manual wheelchair users who often transfer independently.

The frequency of tilt use measured in this study was slightly greater than that reported by Ding et al. [12] (2.2/h vs. 1.6/h) who recruited subjects using multifunction (i.e. tilt, recline and elevating) wheelchairs. Access to alternative positioning features may have reduced the use of the tilt feature.

The results of the hypotheses – that small and medium tilts are more common, and that PRTs are not done frequently – are also consistent with previous research [1,12]. While this is a consistent finding across tilt-in-space studies, the results of the present study highlight the need to look more closely at the tilt behaviour of individual participants, rather than just the central tendencies of the population. Addressing only the population as a whole neglects important behaviours, such as tilting regularly throughout the day (17 of 45 participants) and having a typical seat angle greater than 15° (14 of 45 participants).

Limited research has explored the biomechanical impacts of small tilts. A study of a subset of the population presented here demonstrated that small tilts from upright significantly increased the superficial blood flow in persons with SCI [18]. Alternatively, a separate study did not find an increase in blood flow at 15° of tilt [19]. Although these studies suggest limited biomechanical benefits to static, small magnitude tilts, further research is needed to determine the clinical benefits of dynamic use of tilt-in-space systems with commercial wheelchair cushions. In the meantime, it can generally be assumed that activity is good, and frequent, small tilts are certainly a better alternative to non-movement. Ideally, they would be used in between regular, large and extreme PRTs.

Insufficient PRTs

The finding that participants did not perform PRTs with their prescribed frequency is certainly one of the more important results of this study. The use of tilt for pressure reliefs was identified by 70% of participants, and about three-fourth of participants verbally described how far to tilt for pressure relief and demonstrated that position with reasonable accuracy. Therefore, the lack of performing PRTs does not appear to be due to poor understanding of the technique.

The posture associated with large and extreme tilts can be unsettling, and several participants readily proclaimed their unease with fully tilting their systems. Substantial angles of tilt are not conducive to functional activities and may impact adopting larger tilt magnitudes. However, most participants who used tilted positions simply switched to an upright posture when necessary. For example, participants sat upright for activities such as driving, eating, using the computer or sitting at a table.

Improved training and education may be helpful in increasing tilt use and frequency of PRTs. Tilting through the range of small, medium and large tilts with a clinician present might instill comfort and confidence in participants about performing such tilts. Follow-up training based on evaluation of tilt behaviour might allow for more appropriate training goals and approaches. For example, participants in the group who habitually sit in one position may need to learn and experience the variety of benefits of the tilt feature. It would help for the clinician to identify and address their client's reasons for disuse of the feature. In contrast, participants who tilt regularly but do not perform PRTs are well aware of their feature's capabilities but may need more targeted pressure relief training and education.

Tilting for comfort

The majority of participants in the current study (77%), as well as participants in studies by Ding et al. (100%) and Lacoste et al. (70%) reported using their tilt features for comfort, discomfort and/or pain [11,12]. Seated comfort and discomfort are complex constructs involving many objective and subjective factors, including those related to the person, seat and environment [20]. Decades of literature have shown that long-term static sitting is generally associated with discomfort and pain, e.g. [21], and increased body movements while sitting occur as a response to discomfort (as reviewed in Ref. [22]). Therefore, ergonomically designed seating, such as office chairs and truck seats, has long included dynamic components. Considering current knowledge about seat comfort in the able-bodied population, it is not surprising that some wheelchair users would use their tilt-in-space systems dynamically rather than solely as a device to perform scheduled pressure reliefs. Furthermore, it is interesting that of these participants who do not sit with a habitual position, the majority had sensation at their buttocks.

Providing wheelchair users a means to improve comfort is very important. Survey data have shown that seated comfort is a priority for many wheelchair users reviewed in: [23]. In addition, people have been found to be more productive when their discomfort is minimised [22]. If wheelchair users can spend more time out of bed and in their wheelchair, then their opportunities for participation are greatly increased. Although comfort is generally associated with persons with sensation [23], 11 of the 17 participants who reported having no sensation still reported using their tilt for comfort/discomfort/pain. Therefore, the issue of perceived comfort clearly extends beyond physiological sensation at the buttocks. Given the aforementioned benefit of increasing seated comfort for wheelchair users, comfort should be an important design criterion for powered tilt-in-space systems in addition to pressure relief. Future research should focus on evaluating if seated comfort has medical benefits – a requirement of reimbursing tilt-in-space systems.

Limitations

An observational study of this sort presents a number of limitations, including several factors that could have influenced the tilt behaviours of participants. Yet, we are confident that these factors did not have a significant impact on our conclusions. Participants may have increased their compliance with pressure relief guidelines because they were aware that their compliance was being recorded. However, compliance was sufficiently low as to make this unlikely. In addition, some participants who were originally prescribed a tilt-in-space wheelchair because they were unable to perform independent pressure reliefs may have experienced functional improvement in the time since prescription. These participants were able to perform independent pressure reliefs without using the tilt feature. However, this is an unlikely cause of the overall low compliance, as persons with the ability to perform pressure reliefs without the tilt feature actually performed more tilting pressure reliefs than other participants. Finally, our definition of a PRT has the potential to influence the results. The definition only required that participants tilt to 30°, smaller than the tilt angle often recommended. A definition requiring a greater tilt angle would only have served to further reduce the number of tilts for pressure relief. The definition also required that the tilt lasts at least 1 min, a factor that would exclude shorter pressure reliefs. From our observations, not many shorter pressure reliefs were observed.

In terms of the categorisation of behaviour type, it is important to remember that the behaviour categories were not defined a priori and instead they emerged empirically from our analysis. A better understanding of the behaviour categories could be gleaned from a future study that is designed to distinguish these two categories of behaviour.

Finally, this study did not consider recline, standing or multifunction wheelchairs. It is possible that the presence or additional positions might increase the pressure relief frequency. However, Ding et al. found that subjects with both tilt and recline features available to them still performed few large tilts and reclines [12].

Clinical, policy and design implications

The usage of tilt-in-space has implications for clinical practice, policy and design. In terms of clinical practice, the use and the potential for underuse of tilt-in-space may influence the prescription process, delivery of the wheelchair and follow-up care. When a tilt-in-space system seems appropriate for a client, it is worth addressing the client's concerns and factors that might limit its use (e.g. transportation, environment and comfort in a tilted position). When selecting a seating system for that client, the differences in maximum tilt position lauded by the manufacturers may not be an important selection criterion. Data suggest that few participants will regularly utilise the maximum range of the wheelchair, regardless of whether it can tilt to 45° or 55°.

The findings that participants' self-selected typical position is not perfectly upright (median = 8°) and that participants spent 19% of their seated time tilted $>15°$ are important when considering how to configure a wheelchair. It has been suggested that postures held longest in seating are the most stable postures [22]. This is consistent with the decreasing shear forces pulling a person out of the seat as tilt increases up to 25°, where Hobson [6] predicted the shear forces approach zero. Special attention should be paid during seating evaluations to the posture with the greatest stability.

The policy and design implications of the results are also significant and highly related. First, participants spent more than 12 h per day in their wheelchairs, more than most task seating. Across 12 h, the wheelchair serves many functions, both medical and non-medical, and ideally, the varied functions should be reflected in the design and funding. There are some potential medical benefits of improving posture and providing the ability for dynamic sitting, including reduced pressure ulcer incidence and decreased pain. Outcomes studies would help to evaluate the medical benefits and the cost effectiveness of providing a tilt system, but such studies are very difficult to perform. In addition to considering the duration of sitting in the design, designers should consider the main reasons for lack of use, such as the lack of stability and non-functional position in a full tilt, in future designs. Finally, there may be benefit to designing a simpler, less expensive system that tilts only to 15° or 20°, as it might provide improved function and quality of life for users who do not qualify for a full-featured tilt-in-space wheelchair.

Acknowledgements

The authors would also like to gratefully acknowledge Michelle Nemeth, PT, CCRP, and Chris Maurer, MPT, ATP, for their support and involvement with subject recruitment and data collection, as well as the subjects whose participation made the study possible.

Declaration of interest: This work was completed as part of the Mobility RERC, which is funded by the National Institute on Disability and Rehabilitation Research of the US Department of Education under grant number H133E080003. The opinions contained in this article are those of the grantee, and do not necessarily reflect those of the US Department of Education. The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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