Power seat function usage and wheelchair discomfort for power wheelchair users

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Objectives: To investigate correlations between power seat functions (PSFs) usage and wheelchair discomfort.

Design: Quasi-experimental design: Time series design.

Setting: In-home trial in participants' home/community.

Participants: Thirteen power wheelchair users who independently used power wheelchairs equipped with PSFs as their primary means of mobility.

Main Outcome Measures: PSF usage variables include the frequency of performing repositioning and using PSFs (tilt, recline, legrests and seat elevation), wheelchair occupancy, and driving distance. The Tool for Assessing Wheelchair disComfort (TAWC) were used to evaluate general discomfort and discomfort intensity.

Results: Spearman correlation coefficient showed that the frequency of using tilt, recline, and legrest is significantly correlated with discomfort intensity. Multiple regression analysis with backward stepwise indicated that these functions can explain 43.8% of the variance ($R^2 = .438$, $F(3,33) = 8.588$, $P < 0.01$) in the discomfort intensity score. The best-first decision tree shows that the frequency of using the legrest function was the top node, followed by recline and tilt functions. The overall accuracy of prediction with ten-fold cross validation for discomfort intensity was 79.4%.

Conclusions: For people who used power wheelchairs equipped with PSFs, correlation analysis and regression modeling provided evidence from the quantitative data that increasing the frequency of using PSFs may decrease wheelchair discomfort. Future studies should include interventions to encourage people to use their PSFs appropriately.

Keywords: Wheelchairs, Rehabilitation

Introduction

Historically, a dynamic sitting posture with frequent small postural changes has been viewed as a healthy sitting posture.¹ Previous studies have shown that there is not an optimal static sitting posture, because sitting postures increase the strain on active (muscle) and passive (tendon or ligament) spinal structures.^{2,3} People naturally change their postures frequently while sitting, including head, trunk and pelvis angles. Spontaneous postural change can potentially decrease sitting discomfort, since a prolonged stretched condition on contractile and non-contractile tissues and a long

duration of low muscular activity might be risk factors for pain or injury.⁴

Wheelchair seating discomfort is a very common problem for wheelchair users.⁵⁻⁸ This problem could be worse for power wheelchair users who spend most of their time in their wheelchair and may not be able to adjust their sitting posture as frequently as needed independently. In addition, other issues such as prolonged shear force on the back and buttock area or a slumping posture due to weak trunk control ability⁹ might cause wheelchair-sitting discomfort. For this reason, power seat functions (PSFs) become an important means for power wheelchair users to change their posture dynamically. PSFs include tilt-in-space, backrest recline, and legrests/leg support, all of which allow power wheelchair users to reposition themselves in

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their wheelchair, to redistribute pressure on areas that have a high probability of skin breakdown, and to stabilize their position while moving.⁹ Previous studies have mainly focused on the effect of using PSFs on preventing pressure ulcers and improving driving safety,^{10–14} and a few studies reported that wheelchair users tend to use tilt and recline functions to improve seating discomfort.^{8,15,16} The results from these studies are, however, based on users' reports or surveys, and no study has attempted to investigate if changing the frequency of adjusting posture in a wheelchair is able to alleviate wheelchair sitting discomfort. The aim of this study is to investigate correlations between PSF usage and wheelchair discomfort.

Methods

Participants

Thirteen individuals participated in an 8-week experiment in their home/community (Table 1). The inclusion criteria for selection of power wheelchair users was 18 years or older and with the ability to operate a power wheelchair equipped with PSFs as their primary means of mobility. All the participants had been approved for a new power wheelchair with PSFs when we recruited them for this study, and we used the window of the time while they were waiting for their new power wheelchair to conduct this study. In order to accommodate preferences for using different driving wheel configurations, we prepared front- (Permobil C500, seat width: 19"W × 18"D; Permobil AB, Timrå, Sweden), mid- (Pride Quantum 6400Z, seat width: 18"W × 18"D; Pride Mobility Products Corp., Exeter, PA, USA), and rear-wheel (Permobil Street, seat width: 19"W × 18"D) drive wheelchairs for this study. When a person agreed to participate in this

study, our power wheelchair was delivered to his/her home environment. A clinician who was also an Assistive Technology Professional (ATP) with more than 10 years of experience providing power wheelchairs with PSFs verified that the power wheelchair would be suitable in his/her environment. This study was approved by the Institutional Review Board at the University of Pittsburgh and the Department of Veterans Affairs Institutional Review Board.

Measurement of PSF usage

Each study power wheelchair was equipped with rotary encoders (A2K Absolute Optical Encoder, US Digital, Vancouver, WA, USA) to record angle changes for tilt, recline, legrests, and seat elevation. Two rotary encoders (E2 Optical Kit Encoder, US Digital) mounted on both wheels recorded the wheelchair driving distance. A customized seat switch was placed between the seat cushion and seat pan to detect wheelchair occupancy. All the sensors were mounted on the wheelchair securely with customized cases and were calibrated before each participant received the wheelchair (Fig. 1). A personal computer was attached behind the backrest of the wheelchair and the sensors were all interfaced to the computer.

Measurement of wheelchair discomfort

This study used the Tool for Assessing Wheelchair disComfort (TAWC) for measuring wheelchair discomfort.^{17,18} The TAWC consists of three sections. Section I is general information about factors that directly affect wheelchair-related discomfort. Section II contains eight statements related to discomfort and five statements related to comfort. These 13 statements are rated on a seven-point Likert scale where 1 is "strongly disagree" and 7 is "strongly agree" (score range: 13–91).

Table 1 Demographic data of participants

Subject	Sex	Age (year)	Height (Inch)	Weight (lb)	Diagnosis	Year of power wheelchair use	New PSFs Users
1	M	48	72	145	Muscular Dystrophy	11	No
2	M	59	71	192	Multiple Sclerosis	3	Yes
3	M	44	66	140	Cerebral Palsy	5	No
4	F	62	66	280	Poliomyelitis	0	Yes
5	M	47	68	153	Muscular Dystrophy	0	Yes
6	M	45	67	244	Spinal Cord Injury	10	Yes
7	F	67	64	174	Inclusion Body Myositis	4	Yes
8	F	44	65	140	Multiple Sclerosis	5	No
9	M	39	69	215	Spinal Cord Injury	0	Yes
10	M	57	70	248	Spinal Cord Injury	10	No
11	F	57	63	200	Degenerative Joint Disease	11	Yes
12	F	65	65	180	Multiple Sclerosis	0	Yes
13	F	43	66	158	Multiple Sclerosis	0	Yes
		52.07 ± 9.40	67.08 ± 5.51	189.92 ± 91.07	4.54 ± 9.11

Figure 1. The sensors to record PSFs for instruction group in tablet virtual seating coach study (colour online)

In Section III, seven body areas (back, neck, buttocks, legs, arms, feet, and hands) are rated for a degree of discomfort intensity on a scale of 0 (no discomfort) to 10 (severe discomfort). It also provides spaces which allow users to list any additional body areas, and the general discomfort intensity is also rated on the same 0–10 scale. This study only calculated the seven default body areas (score range: 0–70). Section II and III form two measures of discomfort—the 13 items in Section II are called the General Discomfort Score (GDS) and the seven items in Section III are the Discomfort Intensity Score (DIS). The TAWC has been reported as a reliable and stable tool for quantifying wheelchair seating discomfort.¹⁹ For the responsiveness measures, the average change on the GDS and DIS were 8.7 and 7.7.¹⁸

Procedure

The total length of the study was 8 weeks. The study period included 5 visits (4 phases: baseline and phases 1, 2 and 3), and the interval between each visit was 2 weeks. During the study, participants were instructed to go about their daily activities as they normally would. The study wheelchair tracked their usage of the wheelchair (e.g. driving distance and wheelchair occupancy) and seating habits (e.g. frequency of using PSFs and frequency of repositioning exercise). In addition, they were asked to fill out the TAWC each day.

Visit 1 was either performed on the same day of the participants' initial wheelchair assessment or scheduled at a time convenient for the participants within 2 weeks after their initial assessment. Our research

wheelchair was brought into the participant's home environment and was fitted and tuned to the subject's needs by the clinician. Once the participant transferred to our research wheelchair, the clinician instructed him/her to drive the wheelchair and access the PSFs to allow the participant to be familiar with our study wheelchairs. If our study wheelchairs were unable to fit participants' environment, the participants were withdrawn from the study.

In Visits 2–5, our research team collected the TAWC forms and downloaded the PSF usage data from the computer. In Visit 2, all participants reviewed a study pamphlet, pocket-size reminder cards, and compact disc containing educational materials on PSF usage. These educational materials included information on using PSFs for body position, posture realignment, transfers, and repositioning exercises. The materials included guidelines on driving in different environments, such as slopes. We expected to observe if the participants changed their behavior of using PSFs after reviewing the materials and if these changes in PSF usage were correlated with changes in wheelchair discomfort.

Data analysis

All the variables including the potential predictors and outcome variables (Table 2) within one phase were first averaged. Because the scores from TAWC are subjective to participants' personal feeling, the data of the other phases was normalized to the baseline. The reason for preprocessing the data with this method is that each participant had their own pattern of using PSFs and wheelchair discomfort is a subjective measurement, so only the changes of all variables from the baseline were analyzed. The total data points in the analysis were 39 (13 participants multiplied by three phases).

A test for normality was performed before other analyses. Correlation coefficients were calculated to determine predictor(s) for the linear regression model. Linear regression analysis using a backward stepwise method was performed to determine if TAWC wheelchair discomfort scores were predicted by the correlated variables. Correlation and linear regression analyses were performed using SPSS 22.0 (IBM Corp, Armonk, NY, USA).

In order to find the cut-off points that make the meaningful changes for GDS and DIS, the GDS and DIS results were classified as discomfort decreased (decreased), discomfort increased (increased), and discomfort not changed (neutral) based on the responsiveness (8.7 for GDS and 7.7 for DIS).¹⁸ Weka²⁰ was used to perform the best-first decision tree learning.²¹ The

Table 2 The definition of all variables

Name	Definition
<i>Potential Predictors</i>	
Freq_Tilt	The frequency of using tilt function within a day.
Freq_Recl	The frequency of using recline function within a day.
Freq_Legr	The frequency of using legrests function within a day.
Freq_Seat	The frequency of using seat elevation function within a day.
WOCO	Wheelchair occupancy (hour/day)
Freq_Repo	The frequency of performing repositioning exercise within a day (number/day). The repositioning exercise is defined if the users tilt backward to 30 degree and stay in that position for 30 seconds every hour in this study.
Distance	The driving distance of wheelchair (mile/day).
<i>Outcome Variables</i>	
GDS	General discomfort score in TAWC
DIS	Discomfort intensity score in TAWC

variables correlated with the GDS or DIS were used as the features to classify discomfort changes. The performance of predicting the GDS or DIS was evaluated using ten-fold cross validation.

Results

Table 3 shows median and interquartile range of all variables in each phase of the study. Most variables except wheelchair occupancy, general discomfort, and discomfort intensity were not normally distributed. Two outliers were removed, because data points were greater than 3 standard deviations beyond the mean. For this reason, Spearman correlation was performed to calculate the correlation matrix among all variables (Table 4). The results show that the frequency of using the tilt, recline, and legrests functions were significantly correlated with discomfort intensity, so these three variables served as the predictors in the linear regression analysis. The assumptions for linear regression were all met. The assumption of multicollinearity among three

predictors was not violated, since there was no significant correlation among the predictors (Table 4). The results of backward stepwise regression indicated that these predictors can explain 43.8% of the variance ($R^2 = 0.438$, $F(3,33) = 8.588$, $P < 0.01$) in discomfort intensity (Table 5 and Fig. 2). The value of Durbin-Watson test was 1.332, showing that the errors from each predictor were independent. Figure 3 shows the result of homoscedasticity. As can be seen, the residuals were randomly distributed at each level of the predictors and slope of linear curve fitting is close to 0, meaning that the residuals had the same variance at each level of the predictors. The Shapiro-Wilk (value = 0.983, $P = 0.825$) also indicated the errors of the linear regression model are normally distributed.

Best-first decision tree learning was performed to classify discomfort intensity. The frequency of using the tilt, recline, and legrests functions was the feature in the learning algorithm. The results of the decision tree are shown in Figure 4. The frequency of using

Table 3 The median and interquartile range (IQR) of all variables in each phase of the study

		Baseline	Phase 1	Phase 2	Phase 3
Freq_Tilt (numbers/day)	Median	3.94	4.33	4.00	4.78
	IQR	2.02	3.45	3.13	2.88
Freq_Recl (numbers/day)	Median	3.30	2.58	3.38	3.16
	IQR	1.67	4.25	2.02	3.03
Freq_Legr (numbers/day)	Median	4.76	3.31	3.38	3.31
	IQR	4.97	8.99	7.19	6.71
Freq_Seat (numbers/day)	Median	0.31	2.46	0.42	0.73
	IQR	1.32	1.33	2.15	2.26
WOCO (hours/day)	Median	5.30	6.08	6.32	5.31
	IQR	5.13	3.76	3.74	5.01
Freq_Repo (numbers/day)	Median	0.19	0.78	0.50	0.71
	IQR	0.54	1.58	0.46	1.22
Distance (miles/day)	Median	0.87	1.20	1.26	1.15
	IQR	1.18	1.39	1.13	1.70
GDS (score/day)	Median	40.11	39.21	40.95	42.15
	IQR	16.54	11.40	14.36	13.02
DIS (score/day)	Median	20	18.13	13.86	14.97
	IQR	12.33	14.69	16.57	15.28

Table 4 The correlation matrix of all variables

	Freq_Recl	Freq_Legr	Freq_Seat	Freq_Repo	WOCO	Distance	GDS	DIS
Freq_Tilt	0.281	0.280	0.104	0.661**	0.140	0.075	0.030	-0.353*
Freq_Recl		-0.277	0.095	0.094	-0.242	-0.093	-0.002	-0.543**
Freq_Legr			0.065	0.450**	0.203	-0.025	-0.186	0.353*
Freq_Seat				0.390*	0.104	0.272	-0.003	-0.081
Freq_Repo					-0.017	0.121	0.0027	-0.066
WOCO						-0.139	-0.287	0.114
Distance							-0.011	-0.149
GDS								0.139

*: $P < 0.05$ **: $P < 0.01$ **Table 5** The result of multiple regression using backward stepwise method to predict DIS

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig
Constant	-1.524	0.880		-1.732	0.093
Freq_Tilt	-0.252	0.105	-0.356	-2.414	0.022
Freq_Recl	-0.897	0.384	-0.344	-2.3363.360	0.026
Freq_Legr	0.734	0.303	-0.357	2.425	0.021

the legrests was the top node of the decision tree, followed by recline and tilt. The overall accuracy of prediction of discomfort intensity with ten-fold cross validation was 79.4%.

Discussion

This study investigated the correlation between PSF usage and wheelchair discomfort. The results from correlation analyses showed that wheelchair discomfort intensity is correlated with the frequency of using tilt, recline, and legrests functions. Correlation analysis also showed that the frequency of using the tilt, recline, and legrests functions were not correlated with

each other. This may indicate that all three PSFs contribute to changing wheelchair discomfort intensity. Multiple linear regression with backward stepwise modeling supported this result, since none of the functions were eliminated from the model. Also, the assumptions for the regression model were all met, so the model was able to show an unbiased result. The negative correlation indicates that increasing the frequency of using tilt and recline decreases wheelchair discomfort intensity. This result confirms previous studies showing that users tend to use the tilt and recline functions to improve seating discomfort.^{8,22,23} The tilt function is a gravity-assisted way to realign users in their

Figure 2. The result of multiple linear regression model shows that the score change of discomfort intensity can be 43.8% predicted by the frequency change of using tilt, recline and legrests functions

Figure 3. The assumption of homoscedasticity shows that the residuals had the same variance at each level of the predictors

Figure 4. The result of Best first decision tree

wheelchairs.^{9,24} It is also an important method for relieving seating pressure and restoring skin perfusion.¹⁶ In addition, the posture achieved using the recline function is believed to relax the lower back muscles.²⁵ Using the recline function can change the length and tension of contractile and non-contractile tissue in the lumbar and pelvic area, which is able to prevent prolonged low-level muscle activity which might impair muscle oxygenation and cause pain,²⁶ thus resulting in sitting discomfort.

One unexpected finding is the positive correlation between the frequency of using legrests and wheelchair discomfort intensity. Elevating legrests are a common way for power wheelchair users to deal with edema^{27,28} and contractures of knee joints.²⁴ When elevating the legrests, it is recommended that the backrest be reclined to prevent tight hamstring muscles from rotating the pelvis posteriorly leading to a slouching posture. This result indicates that caution is needed when using elevating legrests and emphasizes the importance of education.

Best-first decision tree analysis was performed to find cut-off points to understand levels of change in tilt, recline and legrests angles that results in significant differences in discomfort intensity. An advantage of decision tree algorithms is that they can describe a pathway and define thresholds for decision nodes to provide quantitative information on the degree of adjustment of PSF usage that can change wheelchair discomfort. The algorithm selected the frequency of legrests usage as the first decision node. Decreased discomfort intensity occurred when the frequency of using legrests was below 2.41 times per week. Increasing frequency of tilt and recline usage was

observed to mitigate discomfort due to increasing frequency of legrests elevation usage.

Study limitations

One limitation to this study is that even though this is a longitudinal observation of PSFs and wheelchair discomfort, the inherent disadvantage of correlation tests is that they do not prove causation. However, anecdotally, it is more likely that participants experienced less discomfort with increased use of PSFs. Another limitation is that there were only thirteen participants. The reasons that some participants dropped out of the study are (1) they received their new power wheelchair before the end of the study, and their living environment did not allow them to have two wheelchairs; (2) the participants could not fit into our research wheelchairs, since we only prepared the research wheelchairs with the size that most people can fit in according to the statistics from the clinics; (3) our study wheelchairs did not fit into users' environments and the users could not accommodate them; and (4) the participants could not answer the TAWC questionnaire each day. In addition, we provided the educational materials to the participants in visit 2 and expected that they would lead to increased PSF usage, so we would be able to observe the decrease of wheelchair discomfort. However, some of our participants did not increase or decrease PSF usage. Nonetheless, the multiple linear regression model can reflect the increasing and decreasing change of discomfort intensity explained by the changes of tilt, recline and legrests functions usage. The limitation of the decision tree model is that most of the changes were below the responsiveness score (7.7 for discomfort intensity score) and we only observed a few data points with meaningful discomfort intensity decrease (only 7 discomfort intensity decrease from 37 data points). The imbalance of the data points could weaken the generalization of the decision tree model. Future studies should utilize an intervention which could significantly and continuously facilitate users in utilizing their PSFs, so it can further consolidate the relationship between using PSFs and wheelchair discomfort and verify the effect of any intervention. Furthermore, this study reports that power wheelchair users should utilize a dynamic sitting posture (changing their posture periodically by PSFs) in order to have better wheelchair comfort, rather than staying in a posture for a relatively long time. However, the wheelchair discomfort might result from other medical or physiological factors and the maximal improvement of wheelchair comfort that the PSFs can achieve should be further investigated.

Conclusion

This study investigated the relationship between PSF usage and wheelchair discomfort for power wheelchair users. The evidence from the quantitative data indicates that increasing the frequency of using PSFs - especially the tilt and recline functions - can potentially decrease wheelchair discomfort. Future studies should develop an intervention which can significantly change the PSF usage and observe the improvement of the wheelchair discomfort.

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