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Caregiver Trunk and Upper Limb Kinematics When Using Three Different Patient Transport Chairs

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Clinical settings such as hospitals and patient care facilities rely on patient transport wheelchairs for mobilization of patients. Individuals who are unable to mobilize independently are completely dependent on caregivers for transportation in and around the facility. Transport wheelchairs are generally designed for patient comfort for short-term transport and to minimize costs for the hospital. Unfortunately, little attention is given to reducing caregiver burden during transport tasks (Lee, 2013)

Studies have shown that the prevalence of musculoskeletal injuries is particularly high in the healthcare profession, especially among caregivers who manually handle patients (Oranye, 2016; Kothiyal 2004). Occupational factors that increase the risk of developing musculoskeletal overuse injuries include repetitive flexion and extension of the elbow, trunk, and knee, repetitive rotation of the shoulder, prolonged or excessive handling activities, and extended or nonstandard work schedules—occupational features commonplace to healthcare professionals (Oranye, 2016). The most frequently documented work-related complaint for caregivers is lower back pain, although upper extremity pain is also extremely prevalent (Daikoku, 2008).

Currently, the most common wheelchair used in patient care facilities is the depot style wheelchair because it is low cost. These chairs, while affordable, offer little adjustment for patients and caregivers thereby making them unsuitable for long-term use (Karmarkar, 2011). The need for adjustability would greatly aid caregivers in their day-to-day tasks by accommodating for individuals of varying physical dimensions. Such flexibility in chairs will reduce caregiver burden and chance of injury.

A proposed mechanism of reducing caregiver injuries is by optimizing wheelchair design for patient and caregiver comfort. Two wheelchairs have been ergonomically designed to reduce caregiver strain and musculoskeletal burden: 1) the Stryker® Prime TC (PTC) and 2) the Staxi® Medical Chair (SXM). The details of the adjustable features of each chair are detailed in Table 1. Some highlights of the Prime TC include vertically orientated push handles, maneuverable frames, and adjustable armrests and footrests that do not require the caregiver to bend to adjust thus allowing for more neutral postures to reduce caregiver injury. The Staxi medical chair also incorporates ergonomic features, including a horizontal handle bar, hand-operated brakes that do not require bending to operate, and a lightweight design to reduce the amount of effort needed to push an individual in the transport chair. While both chairs have incorporated ergonomic features into their designs, few studies have examined how ergonomic design impacts caregiver posture during transport tasks.

The purpose of this study is to determine if ergonomically designed transport chairs promote more favorable joint angles compared to a standard depot-style transport chair. More neutral angles are expected with the Stryker and Staxi chairs due to their ergonomic design. Having chairs that promote more neutral joint angles will reduce the risk of common workplace problems such as carpal tunnel syndrome, rotator cuff tears, and lower back injuries among caregivers.

Table 1. Design specifications of the patient transport chairs used in this study

Specifications	**Stryker® Prime TC** 	**Staxi® Medical** 	**Breezy® Ultra 4** 
Overall length (cm)	101.6	104.1	80
Overall width (cm)	71.9	68.6	63.5
Seat height from floor (cm)	53.3	53.3	50.8
Handle bar height from floor (cm)	88.9-114.3	102.9	96.5
Handle grip diameter (cm)	~3.8-5.1	6.35	2.5
Weight (kgs)	63.5	25.9	16.8
Weight capacity (kgs)	226.8	226.8	113.4
Foot rest type	Flip up and swing away	Flip up	Swing away or removable
Operation method	push	grip handles and push	push
Brake operation	Press footplate	Release push handles	Wheel locks
Preferred patient entry/exit direction	Front	Side	Front

2. Methods

Twenty-three subjects were recruited and signed informed consent forms prior to study procedures. All participants had at least 2 years of patient transport experience and were over 18 years of age. Subjects were excluded from the study if they had a recent history of back pain or injury that may be aggravated by bending or pushing a wheelchair. The study was approved by the VA Pittsburgh Healthcare System's Institutional Review Board.

2.1 Experimental Protocol

Prior to implementation of study procedures, subjects completed a demographics questionnaire that allowed the procurement of information such as age, height, weight, gender, occupation, and years of experience with various groups of patients.

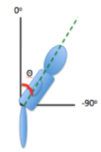
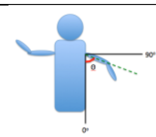
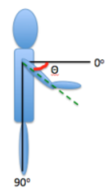
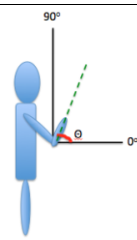
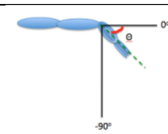
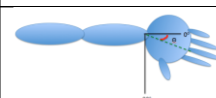
Subjects were asked to maneuver three different patient transport wheelchairs through a simulated hospital setting including elements that a caretaker would commonly traverse including straight level ground (LT), a five-degree incline (RI), and a five-degree decline (RD). The three chairs tested were 1). Stryker® Prime TC, 2). Staxi® Medical Chair, and 3). Breezy® Ultra 4 Wheelchair (see Table #). The wheelchairs were weighted with a 50th percentile, 84 kg test dummy for all tasks.

Kinematic data were collected using a twenty-camera Vicon motion capture system (Version 1.8). Subjects had 63 reflective Vicon markers placed on boney landmarks on the arms, trunk, and legs.

Before beginning testing, the subjects were provided with a short overview of the functionality of each chair and were permitted to familiarize themselves with the chairs by pushing each chair around the lab area until they felt comfortable using them. The order of the chairs was randomized for each subject.

The level ground trial was a 30-meter-long walkway, and subjects walked at a controlled pace of 60 steps per minute. The two ramped trials were 4.2 meters long, and subjects were permitted to walk at a self-selected pace. Motion capture data were collected at a frequency of 100 Hz.

Table 2. Definition of joint angles analyzed in this study.

Angle Name	***Angle Abbreviation***	***Angle Diagram***
Trunk Flexion	*Tr_Flex*	
Shoulder Elevation R	R_Shou_Elev	
Shoulder Elevation L	L_Shou_Elev	
Shoulder Internal Rotation R	R_Shou_Int_Rot	
Shoulder Internal Rotation L	L_Shou_Int_Rot	
Elbow Flexion R	R_Elb_Flex	
Elbow Flexion L	L_Elb_Flex	
Wrist Flexion R	R_Wr_Flex	
Wrist Flexion L	L_Wr_Flex	
Ulnar Deviation R	R_Wr_Uln_Dev	
Ulnar Deviation L	L_Wr_Uln_Dev	

2.2 Data Analysis

Joint kinematic data for the trials were calculated using the Joint Coordinate System (JCS) defined by the standard set by the International Society of Biomechanics (Wu, 2002). The joint angles analyzed are outlined and described in Table 2. Trunk flexion was defined by the angle at which the trunk and pelvic vectors intersected using the modified JCS guidelines. Maximum and minimum joint angles were identified from each gait cycle and were averaged across the cycles. Gait cycles were determined using a marker on the heel and estimating when heel strike occurred. A custom Matlab (R2012b) code was used to calculate and analyze joint angles. Occlusions of the body markers with the devices and 'missing' markers occurred during the some of the trials on the uphill and downhill walking trials. As a result, subjects who were missing too many markers for four or more out of the nine trials analyzed were removed from the analysis. A group mean imputation was used for subjects that were remaining and were missing three or fewer angles across the nine conditions.

A two-way repeated measures ANOVA was performed to determine statistical significance (SPSS Version 25, IBM). Interaction and main effects were analyzed. Significant differences were further analyzed with post-hoc Bonferroni correction factors for paired comparisons to control for type 1 error. The level of significance was set to a p-value of 0.05.

Table 3. Averages of maximum joint angle values shown in degrees. L indicates level trials, D indicates downhill, U indicates uphill. B is the Breezy chair, S is the Stryker chair, and X is the Staxi chair.

		Breezy		Staxi		Stryker		P-Value
Angle Name	(Degrees)	Mean	STD	Mean	STD	Mean	STD	
Tr_Flex	*Level*	-20.03	11.34	-10.90	9.14	-8.22	7.97	Chair: B<S p=0.004 Condition: L<U p=0.008 L<D p<0.0001
	Uphill	-7.64	19.01	-4.59	18.97	-2.33	9.50	
	Downhill	-10.73	22.26	-0.29	9.77	2.38	9.94	
R_Shou_Elev_Ang	*Level*	29.68	10.71	30.95	10.39	32.80	7.41	
	Uphill	34.33	11.03	42.97	21.40	37.67	11.33	
	Downhill	29.07	12.87	29.35	5.91	35.41	7.80	
L_Shou_Elev_Ang	*Level*	26.64	8.85	29.84	8.85	30.14	7.02	
	Uphill	33.49	12.44	35.77	14.99	36.70	9.28	
	Downhill	24.51	11.53	28.12	5.49	33.13	8.72	
R_Shou_Int_Rot	*Level*	29.81	18.08	14.06	26.68	43.98	18.78	
	Uphill	35.65	20.88	28.84	22.87	28.29	43.84	
	Downhill	19.84	41.78	16.86	20.12	39.47	36.45	
L_Shou_Int_Rot	*Level*	39.50	10.24	24.18	27.89	48.68	20.85	Interaction effect P=0.02
	Uphill	38.27	22.78	33.99	20.71	30.26	27.22	
	Downhill	43.93	22.19	24.40	19.68	49.44	22.88	
R_Elb_Flex	*Level*	44.70	10.01	75.89	13.69	66.51	11.69	Chair: B<X p<0.001 B<S p<0.001 Condition: L<U p<0.001 L>D p<0.001 U>D p<0.001
	Uphill	58.81	18.83	87.53	14.15	85.23	23.26	
	Downhill	32.21	15.96	62.83	14.24	54.62	16.20	
L_Elb_Flex	*Level*	38.20	18.86	74.67	14.22	65.31	11.64	Chair: B<X p<0.001 B<S p=0.001 Condition: U>L p=0.014 U>D p<0.001
	Uphill	58.49	24.38	83.83	26.09	69.39	40.98	
	Downhill	36.54	9.10	63.59	17.74	59.76	24.01	
R_Wr_Flex	*Level*	-37.92	10.01	-46.82	12.96	-32.01	24.47	Chair: B>X p=0.004 X<S p<0.001 Condition: L<U p=0.001 L<D p<0.001
	Uphill	-18.50	19.64	-33.27	24.69	-8.36	35.23	
	Downhill	-12.22	25.80	-21.43	25.05	-16.65	20.20	
L_Wr_Flex	*Level*	-31.38	24.12	-43.71	24.64	-36.26	20.81	Condition: L<U p=0.043 L<D p=0.002
	Uphill	-16.09	19.85	-33.97	28.86	-30.91	12.17	
	Downhill	-23.80	10.65	-18.18	27.59	-15.79	20.99	
R_Wr_Uln_Dev	*Level*	10.07	9.41	-2.99	9.30	2.53	9.73	Chair: B>X p=0.003 B>S p<0.001
	Uphill	9.23	9.42	-1.68	10.92	2.04	10.33	
	Downhill	5.17	13.04	0.20	13.03	-3.54	11.25	
L_Wr_Uln_Dev	*Level*	9.62	11.97	-6.27	12.31	-0.82	9.48	Chair: B>X p<0.001 B>S p<0.001 X<S p=0.04
	Uphill	12.03	12.17	-6.47	8.42	-2.84	10.58	
	Downhill	7.51	8.97	-1.15	15.58	2.83	15.72	

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Table 4. Averages of minimum joint angle values shown in degrees. L indicates level trials, D indicates downhill, U indicates uphill. B is the Breezy chair, S is the Stryker chair, and X is the Staxi chair.

		Breezy		Staxi		Stryker		
Angle Name	(Degrees)	Mean	STD	Mean	STD	Mean	STD	P-Value
Tr_Flex	*Level*	-23.96	10.02	-15.14	9.35	-12.44	7.92	Chair: B<S p=0.02 Condition: L<D p=0.001
	Uphill	-14.84	20.27	-12.54	21.41	-11.50	10.49	
	Downhill	-15.40	21.97	-6.64	9.37	-3.81	8.94	
R_Shou_Elev_Ang	*Level*	22.71	10.23	24.55	8.83	25.61	5.64	
	Uphill	21.74	7.52	29.71	19.54	27.24	14.66	
	Downhill	22.40	10.67	23.70	5.49	25.84	5.70	
L_Shou_Elev_Ang	*Level*	20.18	8.67	23.32	8.26	23.52	6.57	
	Uphill	20.00	8.35	24.33	10.32	27.39	10.19	
	Downhill	19.05	11.38	22.26	5.73	23.06	7.01	
R_Shou_Int_Rot	*Level*	6.71	21.01	-4.41	27.28	30.02	19.96	
	Uphill	4.10	34.97	0.70	27.27	0.60	34.59	
	Downhill	1.14	43.41	-4.26	24.02	14.57	48.20	
L_Shou_Int_Rot	*Level*	20.05	12.72	4.61	32.28	32.19	26.16	Interaction effects P=0.048
	Uphill	11.94	32.15	4.86	26.15	-0.07	36.48	
	Downhill	17.45	28.64	-0.84	23.21	22.87	33.23	
R_Elb_Flex	*Level*	27.44	8.56	58.99	15.28	49.08	13.05	Interactions effects P=0.006
	Uphill	36.00	11.04	60.90	16.28	66.91	22.53	
	Downhill	24.09	9.02	49.82	13.16	39.33	13.86	
L_Elb_Flex	*Level*	28.78	7.62	58.58	15.31	49.50	12.04	Chair: B<X p<0.001 B<S p<0.001 Condition: L<U p=0.004 U>D p<0.001
	Uphill	40.49	14.69	64.82	21.53	63.28	22.09	
	Downhill	25.73	9.30	49.49	16.02	47.73	18.61	
R_Wr_Flex	*Level*	-46.31	9.49	-59.29	12.08	-47.05	13.41	Chair: B>X p=0.001 X<S p=0.002 Condition: L<U p<0.001 L<D p=0.001
	Uphill	-30.04	21.86	-52.17	24.66	-16.83	33.89	
	Downhill	-28.11	26.44	-34.93	23.89	-26.40	21.02	
L_Wr_Flex	*Level*	-39.54	18.75	-57.06	19.12	-47.23	18.84	Chair: B>X p<0.001 Condition: L<D p=0.005 U<D p=0.021
	Uphill	-29.93	20.35	-52.71	26.96	-44.38	12.69	
	Downhill	-34.77	14.10	-32.22	25.41	-31.76	24.88	
R_Wr_Uln_Dev	*Level*	0.39	9.99	-12.38	11.92	-7.55	11.38	Interaction effects P=0.008
	Uphill	1.31	7.76	-15.79	7.85	-4.20	10.70	
	Downhill	-3.62	10.86	-10.89	10.11	-10.92	10.08	
L_Wr_Uln_Dev	*Level*	1.83	13.95	-16.06	13.05	-8.21	10.41	Chair: B>X p<0.001 X<S p=0.033
	Uphill	1.83	17.56	-17.65	10.50	-13.62	9.66	
	Downhill	1.67	10.34	-12.34	12.87	-7.04	19.74	

3. Results

Gait cycle averaged maximum and minimum upper extremity joint angles can be seen in Tables 3 and 4 respectively. On average, subjects had increased trunk flexion when using the Breezy chair compared to the Stryker chair with both the minimum and maximum values showing more flexion. Individuals had increased wrist extension when using the Staxi chair compared to both Stryker and Breezy chair. In contrast, the Breezy chair showed the least elbow flexion in comparison to the other two. The Stryker chair shows a different trend than the other two chairs when walking between the

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surfaces with a decrease in shoulder internal rotation when subjects were asked to push the chair up the hill compared to an increase in the other two chairs. Moreover, the Staxi chair showed increased ulnar deviation for the downhill trials compared to decreased values in the other two chairs.

Subjects showed increased trunk flexion when walking on level ground compared to walking downhill. Additionally, wrist flexion was greater on level ground compared to walking downhill. When subjects pushed the chairs uphill, they had increased elbow flexion, with the smallest amount of elbow flexion being seen in level ground trials.

4. Discussion

This study revealed that both the Stryker and Staxi chairs, both of which were ergonomically designed, promoted more favorable joint angles in the shoulder, back, and wrist. The increased trunk flexion in the Breezy chair can be explained by the discrepancy in the heights of the chairs. Because the Breezy chair push handles are closer to the ground, subjects had to bend down further to establish a comfortable grip. Repeated and prolonged bending from the pelvis can increase the risk of developing chronic back pain, a common workplace complaint from caregivers. This height difference also explains the trend in the elbow flexion. The lower height of the chair meant that subjects had to extend their arms more in order to reach the push bars of the Breezy wheelchair. In contrast, the Staxi chair has a similar horizontal bar, however it is high up off of the ground promoting positions closer to the ideal 90 degrees. The Stryker chair has push bars that are vertical and are closer to the subject’s chest also resulting in positions closer to 90 degrees. . The design of the braking mechanism in the Staxi chair explains the increase in wrist extension during use. Because one must keep the handlebar pressed down to move the chair, subjects were in a constantly flexed position in order to maintain control of the chair. This design may increase the risk of developing carpal tunnel with repeated use. The vertical push bars can explain the difference in the trend of shoulder internal rotation with the Stryker chair, with it showing less internal rotation compared to the other conditions as opposed to an increase with the other chairs. When pushing the wheelchairs up the hill, the subjects had to compensate for the lower handles as well as the ramped surface. The Stryker chair’s raised handles allowed subjects to establish a comfortable and powerful grip. Reducing the strain on the shoulder will consequently reduce the risk of caregivers developing rotator cuff injuries, which can often cause workers to be unable to work for extended periods of time.

When subjects were travelling down the ramp, they had to compensate for the downward pull of the wheelchair and the dummy by leaning backwards to keep control of the chair. This backward lean can be seen by the fact that the level ground trial showed more trunk flexion than the downhill trial. The increased elbow flexion when travelling uphill occurs because the subjects need to keep the chair closer to their center of mass in order to generate enough force to push the chair up the ramp with control.

4.1 Limitations and Future Directions

While subject walking tasks were consistent in length, walking speeds and cadences could have differed on the uphill and downhill surfaces. Differences in step size and walking speed may affect positioning for certain tasks, and should be taken into consideration. Additionally, the level walkway had a longer distance than both ramped conditions. Because the ramped conditions were limited by ramp length, less gait cycles were found for those conditions, sometimes limiting the amount of usable gait cycles in data analysis. Finally, reduced motion capture sensitivity resulted in missing data for some of the ramped walking conditions, requiring imputation of data of approximately 15%. Future studies may want to examine positioning changes over longer distances.

5. Conclusion

The ergonomically designed Strkyer and Staxi chairs improved many of the upper body joint angles by promoting a more neutral stance. Areas of improvement in these wheelchairs lie within the grip of the handlebar to make it more versatile for various body types. Smalldeviations in wrist angles can cause harmful effects to the wrist and thus must be addressed in the design of wheelchairs. By considering ergonomic design in patient transport chairs, caregivers will be able to operate devices in more biomechanically favorable positions, reducing their risk for pain and injury as a result of work-related transport tasks.

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