Research Article

Wheelchair backs that support the spinal curves: Assessing postural and functional changes

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Objective: To compare outcomes using a wheelchair back designed to support the natural seated spinal curves versus an upholstered back that promotes posterior pelvic tilt and thoracolumbar kyphosis.
Design: Cross-over intervention.
Setting: Two free-standing spinal cord injury (SCI) model system hospitals.
Participants: Fifty adults with motor complete SCI C6-T4, between the ages of 18–60 years who use a manual wheelchair for mobility were recruited from a convenience sample.
Intervention: Each participant's wheelchair back support was removed and replaced by an upholstered back and a solid back in randomized order. Postural and functional outcomes, pain, and satisfaction were evaluated using each back.
Outcome measures: Seated postural measurements included pelvic angle, spinal angle of kyphosis and linear measurement of spine. Functional outcomes included vertical forward reach, one stroke push, timed forward wheeling, ramp ascent and descent. Numerical pain rating and a satisfaction survey provided input pertaining to both backs.
Results: The solid back demonstrated significance in seated postural measurements. Participants using the solid back trended to higher scores in functional outcome measures including vertical forward reach, one stroke push and timed ramp ascent. Participants reported increased satisfaction with comfort and stability with the solid back.
Conclusions: This pilot study demonstrated that a wheelchair back, which supports the seated spinal curves improves upright posture, functional reach, and wheelchair propulsion skills. Further research is necessary to demonstrate statistical findings as well as to assess back height and lateral support.

Keywords: Manual wheelchair, Wheelchair back supports, Functional outcomes manual wheelchair

Introduction

The interaction between a person's individual body structure, physical impairments, and their environment helps to determine their functional capabilities. A properly fit wheelchair and seating system can have a profound impact on the daily life of people with spinal cord injury (SCI) including independence, participation and quality of life.[1]

A seating system, comprised of a cushion and back dictates the pelvis and trunk positions. The integration of the seating system provides mobility in addition to postural support. An appropriate back support can also restore pelvic alignment.[2] Positioning in a wheelchair through a seating system including the backrest impacts stability, management of tone, optimization of skin protection, prevention of further postural asymmetry, participation in functional skills, as well as comfort.[2]

The pelvis provides a foundation for stability and affects spinal positioning, which in turn supports the upper limbs through interaction of the axial and appendicular skeleton.[3] Specific support for function is

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essential in cases where muscles of the trunk are denervated as in SCI.[4] In comparison to healthy, able-bodied individuals, persons with SCI demonstrate decreased multi-directional stability.[5] Postural changes can affect proprioception through effects on joint position. This occurs through alterations in muscle length/tension, fatigue, and pain and may be particularly relevant though the neck and shoulder girdle region.[6] Postural alignment, including pelvic position, affect shoulder range of motion in persons with SCI.[7] A more neutral upright trunk posture in comparison to a flexed trunk has been shown to improve upper extremity performance during both gross and fine motor functional tasks in healthy adults.[3] Provision of effective pelvic and trunk support with the balance of adequate mobility is integral to an individual's function.[8]

Stability as provided by a seating system and mobility performance are inter-related.[1] A backrest configured to enhance pelvic and spinal alignment influences trunk posture, upper extremity active range of motion and functional performance of push angle, push time and push frequency.[1] There is a high incidence of upper extremity pain in manual wheelchair (MWC) users related to repetitive stresses.[9] Positioning the trunk in order to affect minimization of overuse and joint forces is imperative to maintenance of mobility performance in MWC users.

Limited objective data exists comparing posture and function between these components and the standard elements on the wheelchair. Manual wheelchairs come standard with an upholstery back, which is flexible and can conform to the users back, allowing for the typical posture of a posterior pelvic tilt and rounded spine. The fabric can become further stretched over time. A rigid back support forms a close fit to the user's back in order to provide a stable base for the spinal column and pelvis.[4] Clinicians must make informed choices, and objective measurements related to seating posture and mobility are important.[10] The aim of this pilot study was to determine if using a solid back, designed to support the natural seated spinal curves, would improve postural alignment, increase forward upward reach, promote respiratory function, and facilitate wheelchair mobility as compared with an upholstery back.

Methods

Ethics approval

Approval for this study was obtained by each of the sites' local institutional review boards, to confirm the design to ethical standards. Written informed consent forms were provided to each subject for review prior to consenting. If the subject was still interested, consent was obtained from each participant before the initiation of the study's interventions.

Participants

Fifty full-time MWC users with motor complete SCI from C6-T4, between the ages of 18–60 were recruited through therapist or physician referral, flyers posted in each facility, and the websites of Shirley Ryan AbilityLab, Craig Rehabilitation Hospital, local Spinal Cord Injury Association, Veterans Administration Hospitals, the Shirley Ryan AbilityLab SCI Research Registry, and clinicaltrials.gov. Once the participant consented, s/he provided a brief, pertinent medical history including: weight, age, details of their spinal cord injury (level and onset), and past surgeries. Participants were excluded if they weighed over 250 pounds (maximum weight capacity of wheelchair), had a pressure ulcer, could not grip the wheelchair push rim or had significant shoulder pain that precluded independent MWC mobility. They were also excluded if they did not have spinal flexibility to bring the pelvis and spine to neutral sitting angles and had shoulder flexion range of motion limitations of less than 120 degrees.

Study design

A cross-over intervention study was conducted at two Model Systems Rehabilitation centers. Participants used their personal wheelchair and seat cushion to minimize seating system variation, with the exception of the backrest intervention. Subjects first performed each outcome measure using their personal backrest to familiarize themselves with the tasks. Their personal backrest was then removed and outcome measures were repeated using the upholstery backrest (Invacare Versair) and the solid (Matrx Elite) backrest (Fig. 1). The order in which these were trialed was randomized across participants by a random number generator. The solid back was adjusted to the individual's pelvis and spine to encourage the pelvis in a more upright position with spinal extension. The upholstery back was purposely placed to allow a posterior pelvic tilt and slight kyphosis of the spine, typical of a standard MWC upholstery back and mirroring postures of someone seated in a back support that does not support the seated spinal curves. Eight physical and occupational therapists were involved in the data collection. For each participant, there was a therapist to measure and another to assist as a spotter, note taker, and picture taker. Inter-rater reliability was ensured during study development and tester protocol education.

Figure 1 Upholstered and Solid Back – The upholstered back was placed on the participant's wheelchair in standard configuration which allowed a slight posterior pelvic tilt. The solid back was configured to support the spinal curves in a neutral sitting position. (Photo courtesy Cynthia Smith – used with permission.)

Figure 2 Pelvic Angle – Femur to pelvis angle was measured by placing the goniometer over the hip and the arms aligned with pelvis and femur. This denotes pelvic tilt. (Photo courtesy Jessica Presperin Pedersen-used with permission.)

Outcome measures

Each of the outcome measures was performed once for each subject by a single study team member with the solid back, and once by a the same study team member with the upholstered back purposely positioned to allow posterior pelvic tilt and slight kyphosis.

Seated postural measurements:

Pelvic Angle: Femur to Pelvis angle is measured by placing the goniometer pivot center over the lateral hip center point. The stationary arm was aligned perpendicular to the sagittal pelvic line, pointing towards the iliac crest. The moveable arm was aligned along the sagittal thigh line, pointing towards the lateral condyle of the knee (Fig. 2).[11]

Spinal angle of kyphosis: Femur to acromion is the angle of orientation of the upper trunk in the sagittal plane with respect to vertical. This measure captures the orientation of the upper back and reflects spinal flexion or extension. The goniometer pivot center was placed over the iliac crest, with the stationary arm aligned with the vertical reference line and the moveable arm aligned with the sagittal upper trunk line (Fig. 3).[11]

Linear measurement of spine: A linear measurement from the wheelchair seat to the acromion and from the

Figure 3 Spinal Angle of Kyphosis – Femur to acromion was measured by placing the goniometer over the hip and the arms aligned with acromion and femur. This denotes the orientation of the upper back and reflects spinal flexion or extension. (Photo courtesy Cindy Smith. Used with permission)

Figure 4 Linear Measurement of Spine (Floor to Acromion) – The distance of the floor to acromion was measured. This denotes whether there were differences in participant height with alternate back supports. (Photo courtesy Cindy Smith. Used with permission)

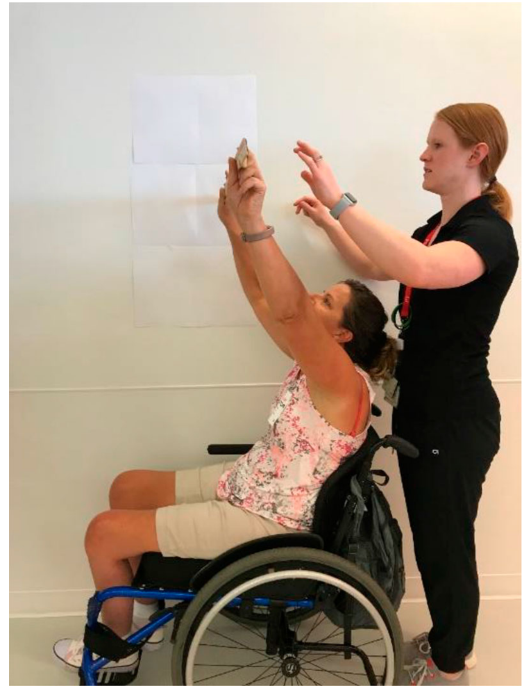

Figure 5 Vertical Forward Reach – The highest point reached parallel to the floor was measured. This evaluates participant stability and is a measure of functional mobility. (Photo courtesy Jessica Presperin Pedersen-used with permission.)

floor to the acromion were taken to note if there were differences in participant height with alternate back supports (Fig. 4).

Functional outcome measures:

Vertical forward reach: The participant's wheelchair was positioned parallel to a marking board. Participants held a yardstick with bilateral upper extremities, palms facing down, using cuff supports if necessary. The measuring stick had a pen attached to one end and a level secured to the center. Participants started with forearms parallel to their thighs and raised the stick upward while instructed to keep the stick level. The highest point reached was measured in centimeters as the distance from the floor (Fig. 5).[2,10]

One stroke push: Participant begins with all four wheels of the wheelchair positioned on a carpeted surface. The participant is instructed to propel the wheelchair forward by pushing once with maximal effort. Hand placement on the wheel rims was determined by each participant. The distance pushed is measured from the starting position of an easily identifiable MWC landmark to the same landmark once the wheelchair rolled to a stop after the single push. If the rear wheels were asymmetrical after the push, the shortest distance was recorded (Fig. 6).[2,10]

Figure 6 One Stroke Push – The forward distance propelled when pushing once with maximal effort on carpet was measured. This evaluates single stroke propulsion efficiency and is a functional mobility measure.

Timed forward wheeling: The participant wheeled 23 m on a smooth, level surface and the time it took to cover the distance was recorded. For safety, the tester served as a spotter especially during the initial push cycle.[2,10]

Ramp Ascent and Ramp Descent: Ramp ascent/descent is a timed test on a 10.3 m ramp with a 1:13 grade slope.[2,10] Timing began when the front casters crossed the start line and continued until the rear wheel crossed the finish line at the top or bottom of the ramp. For safety, one tester served as a spotter throughout the test. If the participant could not complete ramp ascension safely or without assistance, the test was terminated.

Pain scale

Following each back-support intervention, participants rated their pain on a scale of 0–10, with 0 being no pain and 10 being worst possible pain.

Satisfaction survey

Throughout the study, subjective comments were collected in order to capture information regarding subject preference for back supports and a formal survey was completed at the end of each back-support intervention.

Statistical analysis

All statistical analyses were performed using R statistical software assuming a significance level of 0.05 unless otherwise specified. Participant's demographic and injury characteristics were summarized using means and standard deviations (SDs) for the continuous variables and frequency counts and percentages for the categorical variables. Each outcome was also summarized for the sample using means and SDs for when the participants used the upholstery backrest and the solid backrest respectively.

Differences in the outcome measures between the upholstery backrest and the solid backrest were assessed using *t*-tests. The *t*-test results were summarized using the mean difference, effect size, and Ƥ value. Effect size was calculated using the mean difference between upholstery and solid backrests divided by the pooled SD. An effect size of 0.2, 0.5, and 0.8 are typically interpreted to be small, medium, and large, respectively.[12]

Results

Participant demographics

The participant's demographic and injury characteristics are displayed in Table 1. The sample was 35 years old and weighed 162 pounds on average. The majority of the sample was male and sustained a C6-C8 injury.

Table 1 Participant's demographic and injury-related characteristics.

	Mean	SD
Age (years)	34.48	11.63
Weight (lbs.)	161.84	31.35
Gender	*N*	%
Male	39	78.0%
Female	11	22.0%
Past Surgery		
Yes	24	48.0%
No	26	52.0%
Level of Injury		
C6-C8	26	52%
T1-T4	24	28%

SD: Standard Deviation.

Seated postural measurements

The pelvic angle was significantly reduced by 9.16 degrees on average when participants used the solid backrest compared to the upholstery backrest (Ƥ value <0.0001). This indicates reduced posterior pelvic tilt. Participants using the solid backrest also had a 1.82 degree reduction in the spinal angle of kyphosis (Ƥ value = 0.3555), a 0.70 inch increase in the linear spine measurement from the seat to acromion (Ƥ value = 0.0720), and a 0.71 inch increase from the floor to acromion (Ƥ value = 0.0655). However, these differences were not found to be statistically or clinically significant. Table 2 contains all posture results.

Functional outcome measures

All functional outcome measures were improved when using the solid backrest, however, statistical significance was not achieved. Vertical forward reach increased by an average of 2.04 in. (Ƥ = 0.0642) which is a clinically significant difference as it is double the minimal detectable change for this outcome measure.[10] Eighty-eight percent of the participants increased their vertical forward reach height when using the solid backrest (Fig. 7). The one stroke push test distance increased by an average of 9.69 in. (Ƥ = 0.2762) which is twice the minimal detectable change and demonstrates clinical significance (Fig. 8).[10] Ramp Ascent was faster by an average of 6.82 s (Fig. 9). Timed forward wheeling and ramp decent were faster for the solid backrest. These outcomes results were neither statistically or clinically significant. All functional outcome results are displayed in Table 2.

Table 2 Participant's outcome results between the upholstery backrest and the solid backrest.

	Upholstery		Solid				
	N	Mean (SD)	*N*	Mean (SD)	Mean Difference*	Effect Size	P value
Seated Postural Measurements							
Pelvis Angle (degree)	50	106.1 (10.6)	50	96.9 (9.5)	−9.16	0.91	<0.0001
Spinal Angle of Kyphosis (degree)	50	100.0 (11.8)	50	98.2 (7.3)	−1.82	0.19	0.3555
Seat to Acromion (in)	46	23.7 (1.8)	46	24.4 (1.9)	0.70	0.38	0.0720
Floor to Acromion (in)	46	40.6 (1.8)	46	41.3 (1.9)	0.71	0.39	0.0655
Functional Outcomes							
Vertical Forward Reach (in)	50	60.0 (5.6)	50	62.0 (5.2)	2.04	0.37	0.0642
One Stroke Push (in)	45	57.6 (39.6)	44	67.8 (47.7)	9.69	0.22	0.2762
Timed Forward Wheeling (sec)	50	17.0 (9.9)	50	15.2 (8.2)	−1.75	0.19	0.3395
Ramp Ascent (sec)	45	22.3 (24.8)	47	15.5 (12.9)	−7.07	0.36	0.1055
Ramp Decent (sec)	45	7.1 (4.8)	46	6.0 (3.8)	−1.30	0.30	0.2395
Pain Outcomes							
Pain Scale	50	2.2 (2.5)	47	1.4 (2.1)	−0.79	0.34	0.1026

SD: Standard Deviation, *: Solid – Upholstery.

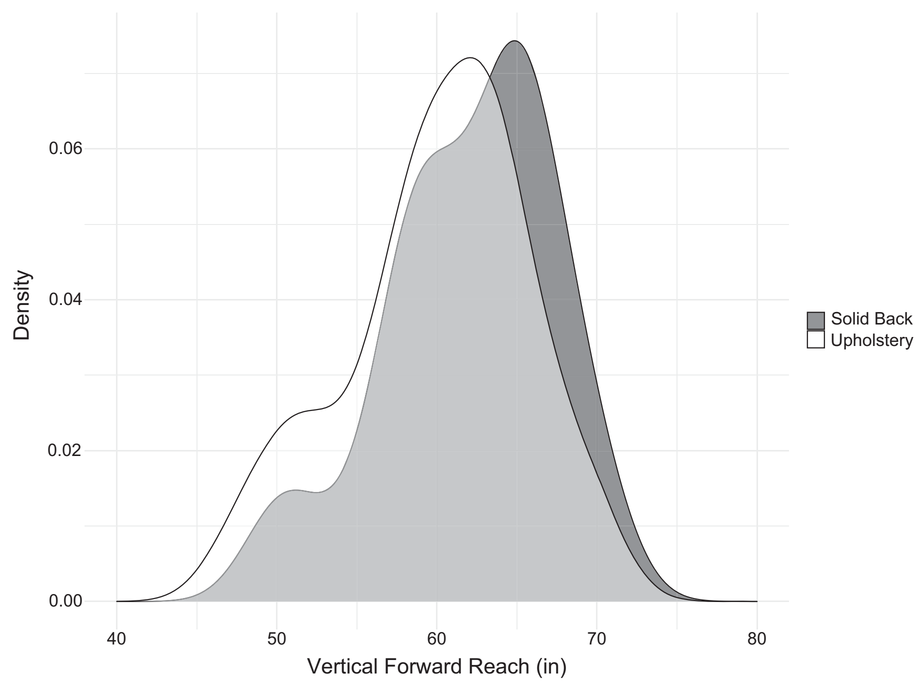

Figure 7 Vertical Forward Reach density plot.

Pain scale

Participant's pain was found to be lower on average when using the solid backrest. The pain scale was 1.4 for the solid backrest compared to 2.2 for the upholstery backrest. This difference of 0.79 units was not found to be statistically significant ($P = 0.1026$). Full pain results are provided in Table 2.

Satisfaction survey

Overall satisfaction was favorable for participants when using the solid backrest with 85% reporting they would use it on a daily basis compared to only 4% that would use the upholstery backrest. Seventeen participants felt extremely comfortable when using the solid backrest versus zero participants when using the upholstery backrest. Conversely, 25 people reported the upholstery backrest to be uncomfortable compared to just 3 when using the solid backrest. Eighty-nine percent felt stable when using the solid backrest, while 88% felt unstable using the upholstery backrest. Additionally, 57% of participants reported that using the solid backrest would make life easier for them, while 92% reported that using the upholstery backrest would make life harder for them. Table 3 contains the full survey responses.

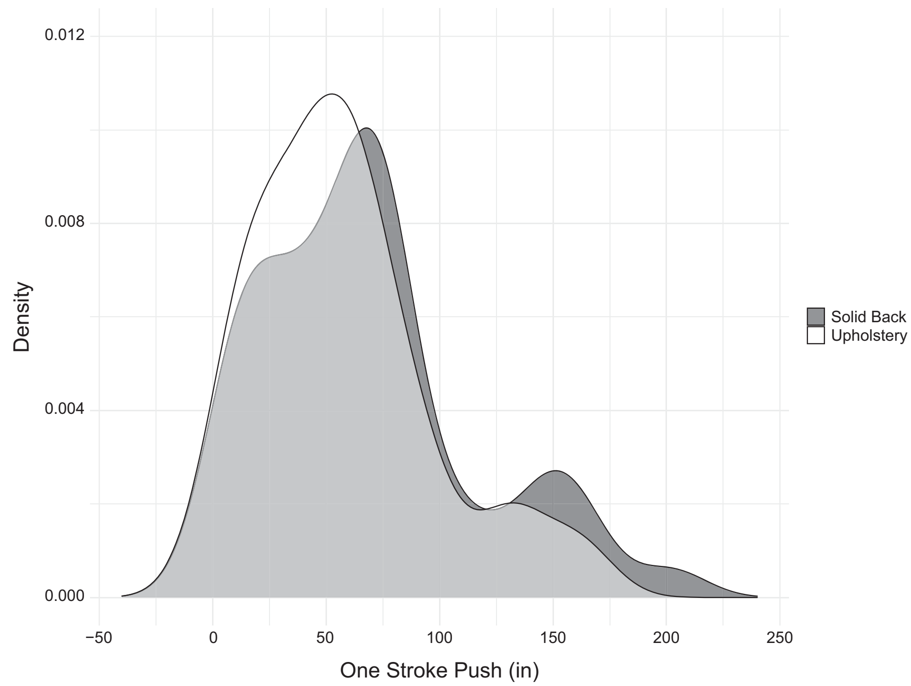

Figure 8 One Stroke Push density plot.

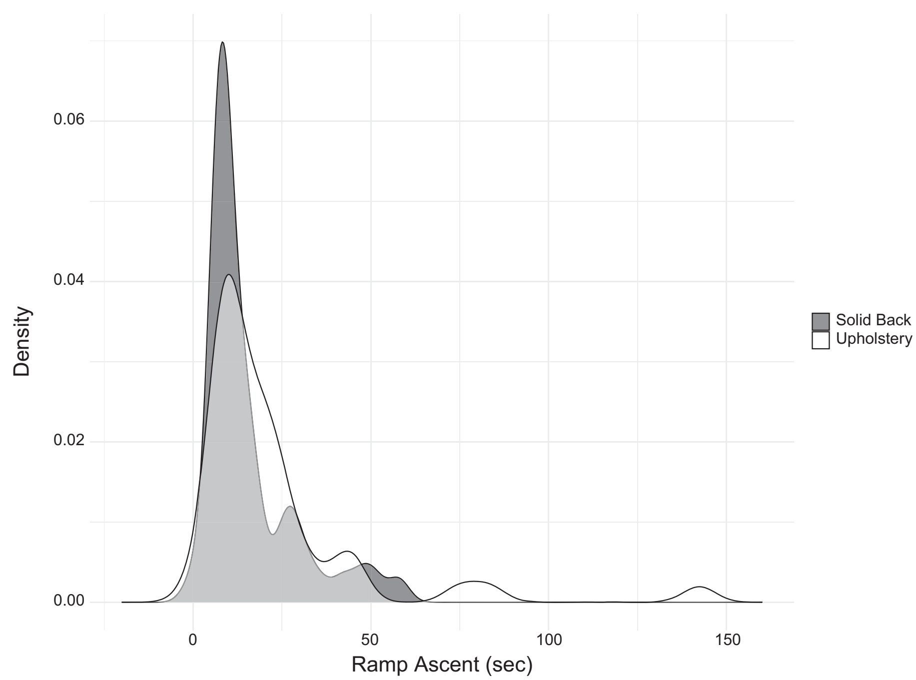

Figure 9 Ramp Ascent density plot.

Discussion

This study investigated whether using a solid back, designed to support the natural spinal curves, would improve postural alignment, increase forward upward reach, promote respiratory function, and facilitate wheelchair mobility as compared with an upholstery back. These results suggest that using a solid back promotes a more neutral pelvis/base of support, improves functional mobility, and increases comfort and overall satisfaction as compared with a standard upholstery back. Data trended toward higher vertical forward reach, further one stroke push, and faster timed 23 m push and ramp ascent. However, statistical significance was not reached, likely due to the relatively

Table 3 Satisfaction survey results for the upholstery and the solid backrest.

	Upholstery		Solid	
	N	%	*N*	%
Do you feel that the backrest helps to keep your pelvis from sliding forward?				
Yes, I feel that my pelvis will not move much	4	8.33%	38	80.85%
Yes, but I will probably feel the need to slide my pelvis forward after a short while	7	14.58%	8	17.02%
No, I feel that I am sitting in a slumped position	37	77.08%	1	2.13%
(Missing)	(2)		(3)	
Is this back support comfortable?				
Extremely Comfortable	0	0.00%	17	36.17%
Moderately Comfortable	9	18.75%	26	55.32%
Mildly Comfortable	14	29.17%	1	2.13%
Not Comfortable at all / Uncomfortable	25	52.08%	3	6.38%
(Missing)	(2)		(3)	
Would you use this back support on a daily basis?				
Yes	2	4.17%	40	85.11%
No	46	95.83%	7	14.89%
(Missing)	(2)		(3)	
Think about the things you do every day. How would using this back support affect these things? Would your daily life be easier or harder if you used the back support?				
It would make my daily life much easier	0	0.00%	18	38.30%
It would make my daily life a little bit easier	2	4.17%	9	19.15%
It would not really affect how easy or hard it is for me to do the things I do every day	2	4.17%	10	21.28%
It would make my daily life a little bit harder	11	22.92%	7	14.89%
It would make my daily life much harder	33	68.75%	3	6.38%
(Missing)	(2)		(3)	
How stable do you feel while using this back support?				
Very Stable	2	4.17%	27	57.45%
Somewhat Stable	4	8.33%	15	31.91%
Somewhat Unstable	17	35.42%	3	6.38%
Very Unstable	25	52.08%	2	4.26%
(Missing)	(2)		(3)	

Figure 10 Upholstery Back, slouch. (Photo courtesy Cindy Smith. Used with permission.)

Figure 11 Solid Back, upright. (Photo courtesy Cindy Smith. Used with permission.)

low number of participants and high variability in this pilot study.

Seated postural measures

Participants achieved an overall more upright and midline posture when utilizing the solid back as compared with the upholstery back. Subjects tended to sit with more posterior pelvic tilt and resulting thoracolumbar kyphosis when using the upholstery back (Fig. 10). The upholstery back does not allow for dissociation of the trunk and pelvis, but rather forces the person to slump into the back in an effort to be supported through the spine, putting the pelvis into posterior pelvic tilt and resulting in a relatively open (>90°) thigh-pelvis angle. By allowing adjustability in height, depth, and angle, the solid back position can be customized to each person's distinct anthropometrics by changing the height, depth, and angle of the back support, promoting both the pelvis and the spine in more neutral alignment (Fig. 11). In fact, thigh-pelvis angle decreased on average by approximately 9 degrees towards neutral when using the solid back.

Functional outcome measures

Participant's demonstrated overall greater functional mobility when using the solid back versus the upholstery back. Although statistical significance was not reached, minimal detectable change was achieved and exceeded in comparing the difference in mean values during the vertical forward reach and one stroke push tests. Participants were also able to traverse 23 m faster and propel up and down a 12:1 ramp faster when using the solid versus the upholstery back, although statistical significance was not reached. Several factors may contribute to the functional mobility improvements, including increased stability and more optimal joint mechanics.

Vertical Forward Reach: Participants were able to achieve a 2.03 inch higher vertical forward reach on average when using the solid back as compared with the upholstery back. Although the minimal clinically important difference has not been established for people with spinal cord injury, subjects attained a mean difference of double the minimal detectable change for this outcome measure.[10] The solid back helped participants attain a more upright posture, with overall functional height increasing by an average of approximately 0.7 in.. The mean vertical forward reach increased 2.03 in.. The variance of increased functional sitting height at .7 in. to a mean vertical forward reach of 2.03 in. (1.33 in.) may be an increase in confidence when using the solid back as compared with the upholstery back. This is evidenced by the following comment given by a research participant when using the upholstery back: "The chest strap seems more necessary – I have more of a chance of randomly falling over". It may also be that supporting the natural spinal curves better aligns the scapulothoracic and glenohumeral joints to optimize joint biomechanics and muscle length-tension relationships across those joints so that patients with limited motor control can maximize their functional abilities.[3]

One Stroke Push: Participants were able to achieve a more effective push, increasing the distance pushed in one stroke by 10.2 in. on average, when using the solid back as compared with the upholstery back. Although the minimal clinically important difference has not been established for people with spinal cord injury, this is 2.4 times the minimal detectable change reported for this outcome measure.[10] Persons with spinal cord injury, who are MWC users, are at increased risk for repetitive use and overuse syndromes, which can cause shoulder and other upper extremity injury, require surgery, increase burden of care and increase healthcare costs[1,9,13,14] Minimizing the number of push-strokes per task or per day becomes an important consideration in an effort to reduce these co-morbidities. Statistical significance was not reached, however the large increase in push-stroke distance may be clinically significant. Similar factors in stability and biomechanics are likely contributing to the improved functional push as they were to improvements in vertical forward reach.

Timed forward wheeling, ramp ascent, and ramp descent: Minor improvements in time to propel 23 m over level firm surface were noted (1.75 s mean difference), however, participants were able to push up a 12 foot 12:1 ramp an average of 6.82 s faster when using the solid back as compared with the upholstery back. Increasing the efficiency of pushing uphill is clinically important to decrease the strain on upper extremity muscles due to increased forces and on energy expenditure.[9] In addition to the aforementioned contributing factors of stability and biomechanics, the rigidity of the solid back may also be an important factor when comparing to the upholstery back. Under normal circumstances in the healthy uninjured adult, anticipatory postural reactions engage abdominal and back muscles to stabilize the trunk when moving extremities or exerting a force on the outside world.[3] The inability to activate core muscles, as occurs with paraplegia and tetraplegia, results in the reliance of external support surfaces such as the interaction of the back support with the seat cushion. Some force is likely lost/absorbed by the compliance of upholstery back, which may be returned by the solid back. As one participant commented when using the upholstery back, "it feels like gelatin".

Pain

Participants did report a 20% reduction in pain when using the solid backrest. It is noted that this measure was taken after spending approximately one hour in each back support. This may not provide adequate time for physiologic pain responses to manifest. Future studies may consider long term trial of back supports.

Satisfaction survey

Participant satisfaction is arguably one of the most important outcomes evaluated as client choice plays a role in selecting seating options. Patient comfort was evaluated and 91% of participants reported the solid backrest to be either extremely or moderately comfortable while 52% of participants reported the upholstery backrest being not comfortable at all/uncomfortable. Perception of stability may impact participant performance in functional tasks and 57.45% of participants reported feeling very stable in the solid back compared to only 4% of participants in the upholstered backrest and 52% of participants reported feeling very unstable in the upholstered back.

Limitations and future studies

Within this pilot study, the sample size did not provide adequate power in order to determine statistical significance although trends are noted. A power analysis determined that the larger study should be performed on a minimum of 120 participants. This may also be impacted by the variability of performance, level and chronicity of injury. The results from the various levels of spinal cord injury were not stratified. Analysis of joint kinetics during propulsion has previously shown significant differences between tetraplegic and paraplegic population which may lead to variability in pushing tasks.[15] In the current study we did not evaluate the effect of lateral stability in participants. A neutral trunk in comparison to laterally flexed trunk has been shown to improve upper extremity function[3] and a range of back asymmetries have been found in individuals with neurologic disorders in a seated position.[4] Future studies may consider stratifying by level of injury, chronicity, as well as evaluation of backrest depth and contour. Utilization of body sensors could also provide objective measurements comparing trunk stability provided by the two back supports.

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Disclaimer statements

Contributors None.

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Conflicts of interest None of the authors has any conflict of interest to report in regards to the research performed.

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