Research Article

User-centered design and development of a trunk control device for persons with spinal cord injury: A pilot study

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Context/Objective: There are no wheelchair products designed to allow users to dynamically control trunk posture to both significantly improve functional reach and provide pressure relief during forward lean. This pilot study sought to (1) gather stakeholder desires regarding necessary features for a trunk control system and (2) subsequently develop and pilot test a first-generation trunk control prototype.
Design: Multi-staged mixed methods study design.
Setting: Minneapolis VA Health Care System, Minneapolis, MN.
Participants: Eight people with spinal cord injuries were recruited to participate in a focus group. Five participants returned to discuss, rate, and select a design concepts for prototype development. Two participants returned to test the first-generation trunk control prototype.
Interventions: The focus group members selected a trunk control device design that uses backpack straps with a single cable as the most desired option. Our design team then manufactured the first-generation prototype at the Minneapolis VA.
Outcome Measures: Bimanual workspace capabilities ($n = 1$) and pressure map relief changes ($n = 2$) during supported forward lean were measured. Both participants also provided feedback on the trunk control devices usability.
Results: Bimanual workspace (for Participant 1) was increased by 311% in the sagittal plane with use of the trunk control device as compared to without. Pressure relief during a forward lean was increased with an overall dispersion index reduction of 87.6% and 27.7% for Participant 1 and Participant 2 respectfully.
Conclusion: This pilot study successfully elicited desired features for a trunk control device from stakeholders and successfully developed and tested a first-generation trunk control prototype.

KEYWORDS: Spinal cord injury, Pressure relief, Wheelchairs, Focus groups, Assistive device

Introduction

Impaired trunk control afflicts people with spinal cord injury (SCI), as well as people with many other pathologies including multiple sclerosis, strokes, cerebral palsy, primary muscle disorders and motor neuron diseases.[1–3] The rehabilitation literature has focused relatively little attention on trunk stability, even though people with SCI rank it as a high priority related to quality of life.[4] Importantly, a deficit in trunk control is correlated with an inability to complete critical activities of daily living (ADLs)[5] and limits options for relieving skin pressure.[6]

Limited pressure relief can be catastrophic for persons with SCI as pressure injuries are a common

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secondary complication[7] and often cause both physical and financial disability.[8,9] Persons with SCI are educated during rehabilitation on the importance of using a variety of strategies to facilitate pressure relief including vertical push-ups, lateral and forward leans. Forward leaning is one of the most effective pressure relief strategies for redistributing pressure from the ischial tuberosities to the thighs.[10] Redistributing pressure away from the ischial tuberosities is important for reducing the risk of developing pressure injuries during sitting.[6] Thus, compensatory strategies are also taught to facilitate pressure relief from the ischial tuberosities as persons with impaired trunk stability perform ADLs.[11]

One common trunk stability compensatory strategy uses the upper extremities to support the upper body on part of the wheelchair (i.e. frame or armrest), on the thighs or on a table. As confidence grows, one upper extremity can be freed to begin reaching activities while the other hand maintains the trunk posture. However, having only one available hand can be problematic, especially for people with reduced hand function (i.e. tetraplegia) who need to grasp objects with both hands to pick them up (e.g. a glass of water). Furthermore, bilateral reach has a stronger relationship to ADL performance compared to unilateral reach.[12]

Another consideration regarding unintended consequences from activities using a wheelchair are injuries from falls, which are alarmingly common in people with SCI. Specifically, in community-dwelling Veterans with SCI, the incidence of wheelchair-related falls has been reported at approximately 31% per year, with almost half these falls resulting in injury.[13] Although falls are multifactorial,[13] we believe many could be avoided with the use of currently available wheelchair seatbelts or chest harnesses.[14] If such a "restraint" were transformed to a device the user could control to improve function, they may be more inclined to regularly wear it and thus potentially prevent dangerous falls.

While there are a variety of low- and high-tech strategies to increase trunk stability, to our knowledge, there are no commercially available options to facilitate dynamic control while simultaneously freeing both the upper extremities to reach and achieve an effective forward lean for pressure relief. Multiple studies have implemented functional electrical stimulation (FES) via either implanted or transcutaneous electrodes to back or hip muscles in order to achieve improved trunk stability.[15–20] These methods have had some success; however, many people prefer to avoid invasive procedures requiring implanted electrodes. Similarly, non-invasive transcutaneous stimulation to the large muscles of the trunk at a level which is clinically useful may not be tolerated by some people with intact sensation. Meanwhile, those with denervation of lower motor neurons may not respond to FES.[21]

While FES is promising and has been shown to improve trunk stability,[15–20] FES has not been assessed for its ability to improve either functional reach or pressure relief for persons with SCI. Additionally, a recent systematic review of trunk stability literature concluded: "… there is a need for dynamic orthoses that allow the trunk movements necessary to perform seated activities, while at the same time ensuring trunk stability".[1] Thus, the objectives of this pilot study were to (1) gather stakeholder desires regarding necessary features for a trunk control system and (2) subsequently develop and test a first-generation trunk control prototype.

Materials and methods

The study took place at the Minneapolis VA Health Care System (MVAHCS) in Minneapolis, MN. Approval was obtained from the MVAHCS Institutional Review Board prior to initiation.

Study design

This multi-staged study used a mixed methods approach. See Fig. 1 for study overview.

Initial focus group

A sample of convenience of Veterans from the MVAHCS Spinal Cord Injury and Disorders (SCI/D) Center as well as non-veteran individuals with SCI from local SCI organizations were recruited to participate in a structured focus group. The following inclusion criteria were used: persons who lacked trunk control, spinal injury level between C5-T8, motor complete injury (ASIA A or B), and at least two years post injury. Focus group participants were presented the overall concept of a trunk control system and were then asked by qualitative research experts several prompting questions (Table 1) resulting in a full discussion of desirable features a trunk control system might have. Participant feedback was obtained regarding desired mechanisms

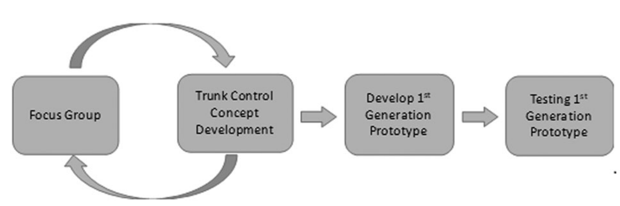

Figure 1 Study design overview.

Table 1 Focus group questions related to desirable characteristics of a trunk control device.

1. What kinds of upper body movement are common for you in day-to-day life?
2. What other things do you like to do that call upon these movements?
3. What would the technology *do* that would remove limits you currently experience?
4. For someone in a chair, what is the ideal or "perfect" range of motion for life?
5. What would be "deal breakers"?

for both ease of use and control (e.g. voice control, push buttons, joysticks, etc.). A rapid assessment process (RAP) approach[22,23] was used to code main themes of the focus group discussion. The rapid assessment approach was conducted by JE, MS, an expert qualitative researcher and CO, PhD RN, a nurse scientist with experience in qualitative data analysis. This approach is ideal when a multidisciplinary team needs practical information to move forward with project goals. It is also a favorable approach when the issues are relatively well-known and other project activities supplement data gathering and interpretation – such as technical expert opinion. Perhaps most important, RAP focuses on what was actually said and limits excessive interpretation and induction – it provides a fully auditable data trail, even for team members with limited qualitative experience.[22,23] Specific focus group questions are shown in Table 1.

The main themes from the initial focus group were subsequently shared with our design team comprised of members of the Minneapolis Adaptive Device & Engineering (MADE) Program at MVAHCS ($n = 5$; engineers, clinicians, and medical device experts) and two industry consultants (LEVO USA), who assisted with brainstorming potential design solutions. The itinerary for the brainstorming session included providing the focus group summary; followed by a 15-minute period in which each engineer did conceptual drawing (s) based on the pushed information. Each member then presented their idea(s); which was followed by robust discussion, resulting in new design conceptions and concluding with a consensus of which designs to present. The design team discussed multiple ideas before choosing their top four concepts.

Volunteers ($n = 5$) from the initial focus group reconvened to discuss and rank order these four concepts (Fig. 2). Images of the four design concepts were shown to the focus group members. A power point presentation pushed information to the focus group, each design presentation started with a slide covering an overview of the design concept, how it functions and some pros and cons for discussion points followed by a series of drawings depicting how it would function. All design concepts were shown, followed by a discussion among the focus group members. After deliberation, each member was then asked to verbally state their preference aloud.

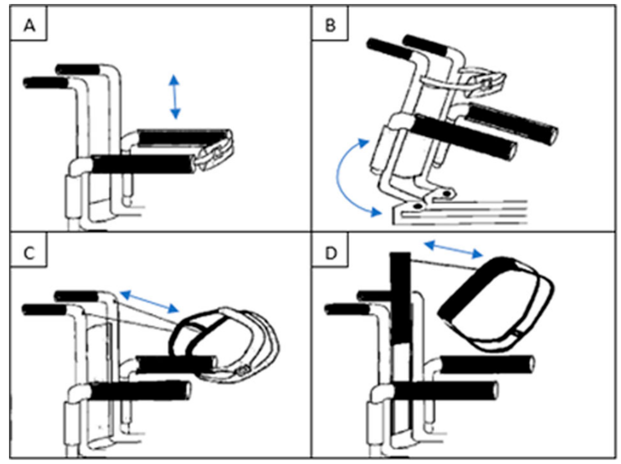

Figure 2 A. Moving canes and chest strap; B. Hinged back; C. Harness with two cable; D. Backpack straps with 1 cable.

Device design and pilot testing

A first-generation prototype of the highest stakeholder ranked design concept (Fig. 2D) was fabricated for powered wheelchair use at the MVAHCS (Figs 3 and 4). Although only one participant was planned for the pilot testing, during the second focus group, two members wanted to do the testing. After considering whether the information would be more robust by having two volunteers, the study team decided they were different enough in their trunk limitations that the study should accept both volunteers to test the prototype. Both participants and their seat cushions were transferred to a study power wheelchair in order to

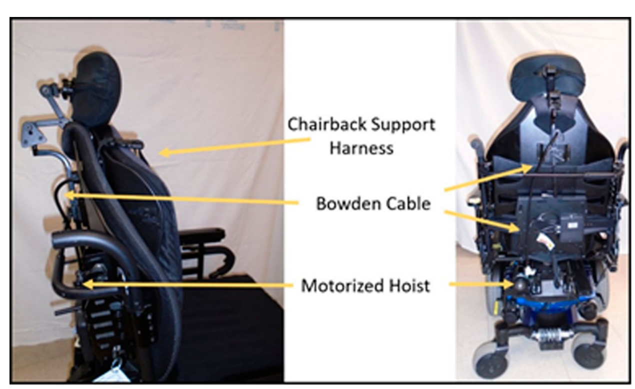

Figure 3 First-generation trunk control prototype.

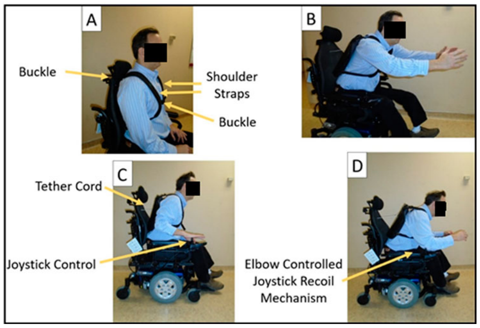

Figure 4 Shows use of the harness (A), ability of device to improve bilateral reach (B) and use of joystick (C and D).

test the first-generation prototype. Subjects were provided up to thirty minutes to familiarize themselves with the trunk control device before any testing occurred.

Bimanual workspace

A 10-camera Qualisys motion capture system was used to quantify bimanual functional reach capacity both with and without the use of the first-generation trunk control prototype. Reflective passive markers were placed on a coffee can as well as bilaterally on the participant's 2nd and 5th metacarpal, ulna, radius, medial and lateral epicondyle, acromion, humeral head, and sternum. The participant was asked to grasp the empty coffee can with both hands. The participants started with the coffee can (250 grams) on their lap and then were asked to perform a series of maximal reaches to following positions: (1) overhead, (2) reach out in front and (3) toward feet. After each maximal reach, the participant returned the coffee can to their lap before continuing to the next position. In between each position, the participant was asked to bring the coffee can back to their lap before moving to the next position. This sequence was repeated three times. This test was conducted first without and then with the trunk control device with a five-minute rest between test conditions. The motion data were post-processed in Qualisys QTM and then exported to MATLAB. Functional reach was quantified in the sagittal plane using custom MATLAB Code to calculate the relative distance from the sternum marker when the participant was sitting upright to the center of the coffee can throughout the range of motions completed by the participant with and without the trunk control prototype.

Pressure map relief

A pressure mat (XSensor Pressure Imaging System, X3 Display) was used to measure pressure distributions over a range of trunk flexion angles using the protype trunk control device. Both participants were transferred into the test chair with the pressure map positioned on top of their own cushion. After settling into their normal seated position, the participant was asked to demonstrate a forward lean using the trunk control device. The pressure mapping data were post-processed in X3 MEDICAL V6 and the dispersion index (DI) over the ischial tuberosities and sacrum was calculated along with the locations of peak pressure, which are defined as follows.[6]

- *Dispersion Index*: the sum of the pressure distributed over the ischial tuberosities and sacrum regions divided by the sum pressure readings over the entire mat, calculated as a percentage.
- *Peak Pressure*: the highest pressure within a 24–25 in^2 area in the ischial region.

Note: no attempt was made to reoptimize pressure distribution of their cushion on the test chair, since the primary purpose of this was to quantify the change in pressure distribution not absolute pressure.

User feedback

Once their individualized pilot testing was completed, both participants were asked to provide feedback on: the difficulty donning the trunk control system; the comfort of the chest harness while sustaining a forward leaning posture; the ease of use of the control system; and whether this system would be useful for pressure relief. Other open-ended feedbacks from users were obtained, including usability and likelihood of using a refined product in the future. Finally, satisfaction with the technology was measured using the Device Subscale Score of the QUEST 2.0.[24] Of 12 satisfaction items listed in the QUEST 2.0, both participates ranked their three most important assistive device features.

Results

Demographic characteristics of the eight focus group participants are provided in Table 2. Five of the eight

Table 2 Characteristics of focus group participants.

	Focus Group 1	Focus Group 2
Sex		
Male	7	5
Female	1	0
Level of injury		
Above C6	3	2
C6-C8	3	2
T1-T8	2	1
Wheelchair type		
Power	7	4
Manual	1	1

Table 3 Characteristics of participants who returned to test prototype.

Participant	Level of injury	Control method	Primary goal
1	C6	Joystick	Cooking
2	C4–5	Sip/puff	Pressure relief

original focus group participants returned to discuss, rate, and ultimately select one of the design concepts for prototype development. All five of these participants were men with four being power wheelchair users, and one manual wheelchair user. Two participants returned to test the first-generation trunk control prototype (Table 3).

Qualitative research results

The focus group participants identified multiple issues (Table 4) in their daily lives related to poor trunk control, including:

- inability to perform desired daily tasks (such as lifting mixing bowls)
- stability during transport and attempted tasks contributing to fear of falls (e.g. leaning to obtain parking ticket)
- inability to perform adequate weight shifting

Additionally, major themes regarding desired trunk control system characteristics are shown in Table 5.

Trunk control concept development

The design team's brainstorming session yielded four potential designs (Fig. 2). The first design functions as normal armrests with optional seat belt when not deployed (Fig. 2A). When deployed, the armrests raise to chest level and the chest strap extends to allow supported forward lean. The second design involves stationary chest strap with a hinged seat back to allow forward lean (Fig. 2B). The third design involves a chest harness with two extendable cables to allow forward lean (Fig. 2C). The final design involves a single extendable cable to backpack style harness that can raise up to chest level and extend to allow forward lean (Fig. 2D). All four designs included a battery powered recoil drive system.

Table 4 Issues related to trunk control identified by focus group.

- Unable to conduct normal daily activities such as pick up fallen TV remote
- Unable to lift cooking or baking bowls
- With limited hand function, need to use whole arm/hand to grab and move items
- Stability problems on bumpy terrain
- Inability to do good weight shifting
- Risk and fear of falling and being unable to get back up/in chair
- Issues when turning around corners and leaning lateral (as when taking a parking ramp ticket)

Table 5 Desired characteristics of a trunk control device for a powered wheelchair.

Power source:
- From chair battery*

Trunk support:
- Lightweight vest (wide straps) or harness-like*
- Connected to back of wheelchair*
- Buckles in front*
- Padded shoulder*
- Washable/replaceable*
- Customizable appearance

Mechanism (to move forward and back):
- Sip and puff
- Clicker method (in mouth)
- Dedicated joystick or button*
- Paddle(s) near head/headrest to command

Maintenance:
- Low maintenance – do not want to do regular check-ups

Purchase:
- Prefer that it be through prosthetics (OT product with small motor)

Deal Breakers:
- Should not have hand requirement to operate*
- Should not restrain user*
- Straps should not hang low (caught in wheels or hard to reach)*

*Design criteria that were used for our initial prototype.

The focus group members voted on the backpack straps with a single cable design as the most desired option (Fig. 2D). They preferred the single cable design because it was simple, with fewer failure possibilities, and would potentially allow for lateral movements. Concerns with the other designs presented by the design team included arm rests interfering with transfers, additional weight, and positioning with use.

First-generation prototype

The first-generation trunk control prototype was integrated into the back of a power wheelchair (Q6 Edge® Power Wheelchair from Quantum Rehab® with tilt- in-space) via chairback-supported harness connected to a Bowden cable (Fig. 3). The Bowden cable extended down to a motorized hoist which was powered off the wheelchair battery and controlled via the joystick. Forward lean was accomplished by bending head and arms forward so gravity caused trunk to lean forward into the chest strap. The user controlled the extent of lean by the amount of cable slack

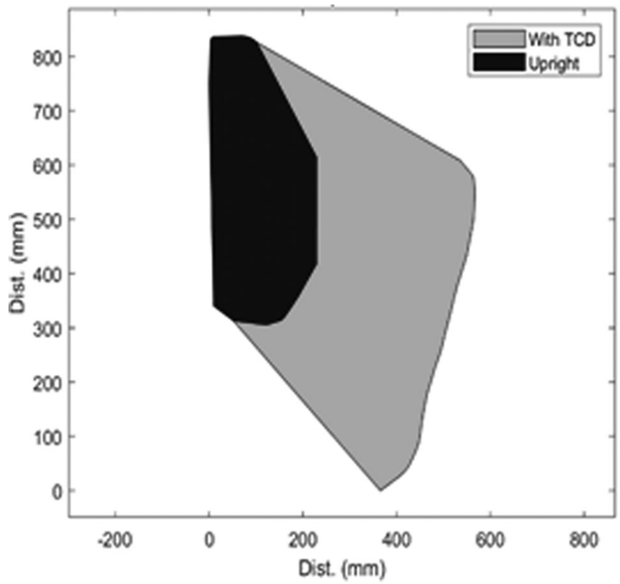

Figure 5 The black (darker) shaded area depicts the bilateral reach of participant 1 in the sagittal plane without the trunk control device. The gray (lighter) shaded area depicts his bilateral reach in the sagittal plane with the trunk control device.

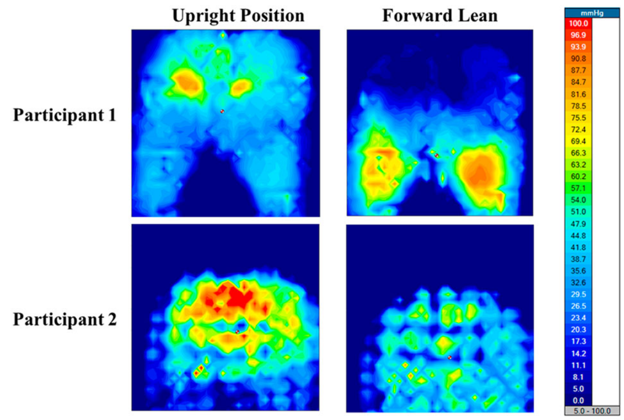

Figure 6 Pressure maps demonstrating the changes in the pressure from upright seated position (Left) to a forward lean (Right) using the first-generation trunk control prototype. Where red depicts pressures ranging ≥100 mmHG and dark blue 5 mmHG. Values less than 5 mmHG are depicted as 0.

released. Recoil of the cable was assisted by the powered hoist back to a midline neutral trunk posture.

Testing of first-generation prototype

Participant 1's personal goal was to increase his bimanual workspace while performing ADLs as well as improve his pressure relief during a forward lean. Thus Participant 1 underwent both the bimanual testing and pressure relief protocol. Participant 1's bimanual workspace was increased by 311% in the sagittal plane using the trunk control device as compared to without (Fig. 5). In addition to his increase in bimanual workspace, Participant 1 also received ischial pressure relief using the trunk control device (Table 7) with an overall dispersion index (DI) reduction of 87.6% (Fig. 6). The raw pressure mat data has been provided in the supplemental material, Pressure_Mapping_Data_20200409.xlsx.

Participant 2's injury level prohibited him from performing bimanual tasks, but his personal goal was to improve his pressure relief during a forward lean, hoping the device would offer him enough support to safely allow a full forward lean without risking falling from his wheelchair. Thus Participant 2 forewent the bimanual testing and completed the pressure relief protocol. Participant 2's forward lean was shown to provide ischial pressure relief with the trunk control device (Table 7) with an overall DI reduction using the first-generation trunk control prototype of 27.7% (Fig. 6).

Usability and product design feedback

In addition to measures of bimanual workspace capabilities ($n = 1$) and pressure map relief changes ($n = 2$) during supported forward lean, both participants were also asked to provide feedback on the trunk control devices usability. Both participants reported transferring into the trunk control system went smoothly as well as feeling overall secure and comfortable with the harness when the trunk is held in a flexed posture. However, both participants were unable to don and doff the harness independently. Table 6 shows a summary of likes and concerns related to the device from each participant. The QUEST 2.0 Device Subscale Scores (score of 1 indicates "not satisfied at all" and 5 indicates "very satisfied") for Participant 1 and 2 were 2.75 and 4.625, respectively. The three most important device features from the Device Subscale Score were the following: "adjustments," "easy to use," and "effectiveness" for Participant 1 and "comfort", "easy to use", and "adjustments" for Participant 2.

Discussion

Trunk control is considered a critically important concern for many people with chronic neurological impairments due to the numerous upper extremity functional activities that rely on trunk support. Thus, we felt it was critically important to base our development project on stakeholder input from the outset given the variety of goals elicited by potential users

Table 6 Summary of responses to interview questions when testing the device prototype.

Participant	Likes	Concerns
1	• Is comfortable and centered • Speed of retraction is good • Felt safe • Single cable good • Would use for cooking • Would wear all day	• Prefer sip and puff • Strap needs adjustability and larger buckle like a three-point harness • Suggested a tilt • Wondered about the seat back wrapping around more for side to side support • Harness has too much slack • Wondered if it could be switched between chairs • Wondered if it would hold up in weather
2	• Harness "feels good" • Can move freely • Likes slack but would want tighter when driving • Would be open to assistance pushing forward but doesn't need that • Would use for pressure relief and help getting back • Liked ease of donning and doffing the straps	• Would want something a bit more aesthetic • Concerned about the side to side movement • Noise of the motor • Wants to be able to adjust the speed of retraction • Sip and puff or remote switch

(Table 4). Accordingly, the stakeholders ultimately determined which design concept our team pursued (Fig. 2D). We successfully elicited desired features for a trunk control device from stakeholders, which subsequently informed our effort to develop a first-generation trunk control system prototype. Given the varied goals noted by our stakeholders, we opted to allow our two subjects to determine which features of the trunk control they wanted to test and attempted to setup pilot outcomes measures that coincided with these goals.

The current first-generation trunk control prototype can return from the forward lean state via a wheelchair joystick, which controls the hoist motor for an assisted return to an upright position. The user is thus able to work with both hands while in a forward flexed position. Participant 1's personal goals centered on improving his bimanual reach capacity. When using the current first-generation trunk control prototype, Participant 1 demonstrated a substantial increase, 311%, in bimanual workspace (Fig. 5), as well as excellent pressure relief (Table 7 and Fig. 6). Most pressure relieving maneuvers (i.e. backwards tilt) tend to remove the person from participation in desired activities, which may explain the demonstrated poor compliance with recommended frequency and duration of pressure relieving strategies.[25]

Some newer powered wheelchair models come equipped with an anterior tilt function that has been shown to improve bimanual workspace; however the majority of persons in a recent study reported that they would not request this feature.[26] Two subjects in this study of anterior tilt mentioned the required knee blocks as undesirable.[26] The system we developed should not require knee blocks to prevent forward sliding as the seat does not tilt forward. So, while both devices may improve bimanual workspace and provide a forward lean. The trunk control device can provide a deeper forward lean due to the cable

Table 7 Pressure mapping results[β] using the first-generation trunk control prototype to complete a forward lean in a test wheelchair.

	Right Ischial (mmHG)		Left Ischial (mmHG)		#Dispersion Index (%)	+Dispersion Index Reduction (%)	Contact Area (in2)	Contact Area % Change
	Average	Max	Average	Max				
*Participant 1								
Upright Position	69.3	89.1	57.5	84.7	41.7%	–	259.75	–
Forward Lean	8.9	15.9	9.0	12.1	5.2%	87.6%	220.25	−15.2%
*Participant 2								
Upright Position	78.4	111.3	74.7	106.7	55.7%	-	196.25	–
Forward Lean	34.6	69.0	40.7	71.3	40.3%	27.7%	169.5	−13.6%

[β]Pressure mapping raw data are attached as supplemental material to this publication: Pressure_Mapping_Data_20200409.xlsx.
*Participants seating cushion was used but not optimized in test chair.
[#]Dispersion Index (DI) (%) = (Ischial & Sacrum Sum)/(Total Contact Area Sum) *100.
[+]DI Reduction (%) = $|DI_{(Forward\ Lean)} - DI_{(Upright\ Position)}| / DI_{(Upright\ Position)}$ *100.

system. Both systems may provide the benefit of performing work and other daily activities in a forward leaned posture.

Stinson *et al.*[6] recently demonstrated a significant reduction in interface pressure over the ischial tuberosities of approximately 52% as a result of having participant complete computer usage during a forward lean. The significance of this finding is highlighted by the same participants performing a median of five movements (range 0–28 movements) during a 1-hour computer work period.[6] These finding corroborate other studies finding many wheelchair users reposition less than once per hour.[27,28]

Additionally, Stinson *et al.*'s [6] findings demonstrate that providing wheelchair users' circumstances to increase their bimanual workspace as a result of a stable forward lean also increases pressure relief. We also believe pressure relief strategies that promote participation are more likely to achieve successful compliance. Unfortunately, one third of Stinson's participants were unable to tolerate their forward leaning computer work posture because of trunk instability and another one third of participants found maintaining the posture difficult or uncomfortable. Our current first-generation trunk control prototype allows persons with limited trunk stability to achieve a forward lean while their hands are free to engage in bimanual reaching activities.

Participant 2's personal goal for using the trunk control device was to improve pressure relief and only underwent the pressure relief protocol. His usual method of pressure relief was by tilting and while this maneuver has been shown to be effective at reducing pressure on the ischial tuberosities, it does so by transferring the load to the backrest,[29] where other bony prominences, namely the sacrum, lie. With forward leaning pressure relief maneuver, the pressure on the ischial tuberosities is transferred to the thighs, which are at less risk for pressure injury than the sacrum.[6,30] Due to impaired trunk stability, the second participant normally performs a very limited forward lean to avoid falling out of the wheelchair. However, using the first-generation trunk control prototype, this participant was able to safely achieve a deep forward lean with an overall DI reduction of 27.7% (Fig. 6 and Table 7).

Both participants had generally positive views on the first-generation trunk control prototype (Table 6). Participant 1 (who had the lower QUEST 2.0 Device Subscale Scores) wrote notes on his survey, and each item rated below a score of 5 was related to either not being tested in his own chair or related to future refinements he hoped to see. Both participants were adamant of a sip and puff control mechanism in future iterations. Despite these concerns, both participants stated it was comfortable and they would be willing to test future designs.

In this pilot study, we successfully elicited stakeholder desired features for a trunk control device and also successfully developed and pilot tested a first-generation trunk control system prototype. However, this study has some limitations. First, we initially sought enrollment of a wide spectrum of levels of injury, but most of the volunteers in the focus group meetings used powered mobility. This may indicate trunk control is more of a limiting factor for people who use powered mobility, and our sample may be reflective of this motivational bias. However, we cannot exclude sampling error or a skewed focus toward development of a prototype powered by the battery of a power wheelchair. Further investigation is warranted to determine if our focus group was truly representative and whether non-motorized or self-powered solutions should still be considered.

Although we were able to perform some pilot testing in two participants, the study was limited by both individuals having differing personal perceptions to what trunk stability meant. Thus, we conducted two different tests (bimanual workspace and pressure relief) to allow participants to test the first-generation trunk control prototype in the manner that best fit their unique goals. While both tests were performed in an easily expandable manner, the main goal of this pilot testing phase was to allow our stakeholders an opportunity to test and provide feedback on our first-generation trunk control prototype.

Additionally, we did not have Participant 2 perform a forward lean pressure relief in their current chair, due to concerns of falling. Thus, we were unable to make direct pressure relief strategy comparisons. However, this limitation does demonstrate the first-generation trunk control prototype may improve the user's independent ability as well as provide an additional pressure relief strategy.

Another recognized limitation of this study was our approach of allowing participants to control the trunk control device using a joystick. This was particularly problematic for people with limited hand grasping function and was reflected in our stakeholder feedback. Although we were aware of this limitation going into this design, we also realized it would be relatively easy to adapt a joystick with other user interfaces supporting handsfree operation. In future development and testing we intend to implement a handsfree control system to our trunk control device.

Conclusion

This pilot study successfully elicited desired features for a trunk control device from stakeholders and developed a first-generation trunk control system prototype. Stakeholders were given the opportunity to test this prototype to accomplish their unique goals. This pilot study provided valuable stakeholder input for further design work and a more robust study in the future.

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Disclaimer statements

Contributors None.

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Declaration of interest A patent application has been filed for this technology by the Department of Veterans Affairs Technology Transfer Program, with several of the authors listed as inventors. The system has not yet been licensed and none of the authors are currently receiving royalties from sales of this system.

Conflicts of interest Authors have no conflict of interests to declare.

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