IMPROVING THE COMFORT OF MANUAL WHEELCHAIR BACK SUPPORTS

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The back support is an integral wheelchair component for appropriate seating position and trunk support. Compared to sling back supports, rigid back supports provide improved postural support and better function. As such, many clinicians expect rigid back supports to be more comfortable. However, rigid back supports are often reported to be uncomfortable and difficult to adjust or reposition while the user is seated in the chair. In order to address complaints of discomfort, it may be important to evaluate the relationship between the contour of the back support and the shape of an individual's back. Further, difficulty with adjustment could be addressed by designing a mechanism to increase ease of use. The specific aims of this dissertation are to 1) evaluate perceived comfort among wheelchair users using both sling and rigid back supports, 2) use digital anatomic scanning technology to evaluate the backs of wheelchair users in order to classify types of back shapes and compare to back support shapes corresponding levels of comfort, and 3) create a commercial ready prototype of an attachment that increases ease of adjustment – the LightWeight Durable Adjustable Composite (LWDAC) back support bracket. To achieve aim 1, participants were asked to answer survey questions related to level of comfort of the back supports on their personal wheelchair. The questionnaire study shows that the higher discomfort ratings among rigid back support users with tetraplegia may be due to suboptimal shape, fit, adjustment or user experiences. The back scanning study demonstrates that wheelchair users have varying back contours, and commercial products may not be able to provide proper support to fit every individual. The disparity between the shape of the shell and the shape of an individual wheelchair users' back may result in skin breakdown which is a serious concern. In accordance with findings

from previous aims, a commercial-ready prototype the LWDAC back support bracket was developed and evaluated by wheelchair users traversing activities of daily living courses. Participants reported positive impressions of the prototype and the findings of this study assist in establishing areas for improved comfort and heightened function for manual wheelchair users.

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PREFACE

I have appreciated the opportunity to broaden my education and expand my horizons, at the Human Engineering Research Laboratories and the Department of Rehabilitation Science and Technology. I would like to thank Dr. Rory Cooper for his caring, patience and providing me with an excellent atmosphere for doing research. I must also extend my gratitude to the members of my dissertation committees, Dr. Jon Pearlman, Dr. Mark Schemeler, and Dr. Jongbae Kim, for their assistance and guidance. I would also like to thank Dr. Brad Dicianno, for his support with research. Additionally, I would like to thank all the students and staff at HERL for support, patience and friendship, especially Maria Toro, Lynn Worobey, Emily Teodorski, and Mark McCartney for their patient, support, and encouragement.

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1.0 INTRODUCTION

Not only does a chair back support play an important role in increasing comfort while lessening stresses on the vertebra [1], but wheelchair back supports are also very important for increasing function of wheelchair users [2]. Sitting over extended periods of time in combination with the effects of gravity has a tendency to cause spinal deformities among wheelchair users [3]. When the wheelchair back support does not provide proper postural and/or structural support, problems, such as lordosis, kyphosis, scoliosis or some combinations of these postures deformities can develop [3]. Previous studies have evaluated performing functional tasks (timed forward wheeling, forward vertical reach, ramp ascent, and one-stroke push) to compare across several types of back supports in a cross-sectional study [4, 5]. Rigid back supports are superior to sling with performances, but subjects were exposed to each back support design only briefly in the study. It is possible that long-term wheelchair users may have differing opinions on the comfort and functionally on their back supports.

Manual wheelchairs usually come with a sling style back support, but it does not provide appropriate postural support for full-time wheelchair users. With the purpose of improving postural support, rigid back support has been recommended. Conversely, rigid back supports have the lack of adjustment by the wheelchair user and are impossible to reposition while users is in their chairs. This study will collect opinions from wheelchair users about the back supports they have been used over an extended period of time, assess the relation between fit of a back support to the shape

of one’s back and comfort, and collect feedback on a new attachment to improve ease of use of rigid back supports.

1.1 SIGNIFICANCE

Due to the increase in prevalence of wheelchair usage, wheelchair manufactures are required to provide more and better wheelchairs due to secondary conditions such as pain, postural issues, pressure sores and repetitive strain injuries. Among the wheelchair components, the back support is one of the most important parts due to the importance of seating position and appropriate trunk support. Manual wheelchairs usually come with a sling style back support which does not have appropriate postural supports [4, 6-8]. As a result, wheelchair users commonly have back pain or lesser functional capability. In order to improve postural support, rigid back supports have been utilized. However, difficulties have arisen due to the lack of adjustment by the user and difficulties of repositioning from and by the occupant of the wheelchair [4, 6-8]. As a result, identifying comfort and discomfort from current usage of wheelchair back supports and recognizing the differences in individual back structure will be beneficial. Based on these, an adjustable bracket design with a rigid shell back support should be done for providing better postural supports and comfort.

1.2 RELEVANT LITTERATURE

1.2.1 Wheelchair Usage

In the United States, roughly 21.2 million people currently have limitations in basic physical activities, such as walking, climbing stairs, and/or carrying or lifting objects [9]. World-wide, over 65 million people with physical disabilities could benefit from the use of wheelchairs for their primary means of mobility. The use of wheelchairs has increased for several reasons: birth defects, accidents, debilitating diseases, and advanced age. Advances in healthcare have aided individuals with serious injuries and severe disabilities in living longer. Current estimates of persons with spinal cord injuries range between 250,000 and 400,000 [10, 11]. As a result, experts anticipate that the need for wheelchairs worldwide will continue to increase, possibly by up to 22 percent, over the next 10 years [9, 10].

As the rate of wheelchair usage has increased, so too has the demand for wheelchairs, which has led to an expanded market that continually demands better wheelchairs and seating systems. Based on innovations in technology, people are living longer, and are participating in the community at higher rates [12, 13]. Like individuals without disabilities, the demand to maintain an active lifestyle is also present among people with disabilities, wheelchair technology being integral to maintaining individual active life style for those having a disability. Wheelchairs allow people with disabilities to enhance function, increase independence, and provide greater accessibility to the home and community [12, 13]. The lack of a wheelchair is the main reason for limited participation by people with spinal cord injuries [14]. As a result, the wheelchair is the primary mobility component for this segment of society and as the individual begins to adapt to their disability, they consider a wheelchair as an extension of their bodies. The wheelchair is a

critical component necessary to meet users' expectations, preferences, physical needs, and functional requirements [14].

Different types of wheelchairs have different comfort and ergonomic ratings, due to the varying qualities of different wheelchairs [15]. As the supply of manual wheelchairs increases, the demand of making them safer, more effective, and more readily available is more and more necessary [16].

1.2.2 Importance of Back support from Ergonomics

Due to significant increases in the percentage of individuals with seated occupations, office seating has gained a considerable amount of attention due to substantial health costs from low back pain. Among other aspects in office chair design and seating, focus on the back support has been increased [2]. A chair's back support plays an important role in the increase of overall comfort, while decreasing the stresses on the back in general and vertebrae in particular [1]. Certain studies have evaluated comfort with adjustment of several different settings of chairs, car seats, and wheelchairs. Wheelchair back supports are especially important for comfort and function [2]. Recommendations on wheelchair back support prescription are challenging in particular because wheelchair configurations are determined by many factors, not only the wheelchair users' comfort, but also including ability to transfer and propulsion efficiency [17]. Wheelchairs usually have adjustability in axle position, seat depth, height of the foot supports, and the tilting reclining angles [18]. Wheelchairs with greater adjustability have received higher ratings on comfort and ergonomics compared to those with minimal adjustability [15]. Among adjustable features, foot support height and back support angle are important adjustments that can be made to prevent pressure sores, a common secondary condition for wheelchair users. According to studies on the

effects of changing tilt and seat-to-back support angles during wheelchair propulsion, seat angle was determined, by a combination of user comfort and clinical pressure modulation, to minimize the risk of overuse shoulder injuries that may be caused by pressure relieving activities [19]. As the back support provides pressure relief and postural support, it is an essential part of wheelchair configuration [17].

Differences in postural alignment and shoulder flexion range are observed between users of wheelchairs with standard configurations and those with posterior seat inclination and a low back support which was set perpendicular to the floor. Wheelchair users with these adjustments made to their wheelchair had significantly more active flexion to the upper extremities and anterior pelvic tilting resulting from support of the lumbar spine from the back support. Additionally, the angle of the back support provides the wheelchair user space for posterior tilting [20]. In another study, balance control and postural muscle use were tested in various seating conditions. The researchers compared a standard chair (10 degree reclining) to an adjustable chair that tilted 7 degrees and 12 degrees, and reclined 22 degrees. They found that configurations from the adjustable chair provided increases in reaching distance and in individual pressure distribution by decreasing peak pressure. The researchers also found that these adjustments have a positive impact on transfers and wheelchair propulsion [17]. Based on these results, an adjustable back support may have important implications to increase function.

In addition to postural support, the back support protects and supports the spine, one of the most important structural parts of the body. Because the weight of the upper body is sustained through the spine to transfer into the limbs, the spine is an imperative structural component. Therefore, the protection and support of the spine is essential. Boninger *et al*. conducted a study in which a group of individuals with tetraplegia was radiographically measured for kyphosis and

scoliosis. According to this study, people with tetraplegia have higher incidences of kyphosis and scoliosis than people without paralysis [4]. In many cases, wheelchair users have insufficient muscle strength for the support and control of the spine. As a result, the spine tends to be become bent and deformities subsequently develop as a result of the forces of gravity. When the wheelchair back support does not provide proper postural supports to a wheelchair user, problems of lordosis, kyphosis, scoliosis or some combinations of these postures may develop [3].

1.2.3 Comparison of Commercial Wheelchair Back supports

Back supports have different characteristics such as height, shape, stiffness, weight, and adjustability. Based on the height of the back support, wheelchair users are provided with different support and functionality. Lower back supports provide freedom of movement with less stability while higher back supports provide more support, but may limit mobility for propulsion. Additional characteristics are unique depending on the specific type of back support. Manual wheelchairs are commonly fitted with one of three types of back support: sling upholstery back support, rigid back support, and custom molded back support. Most manual wheelchairs come standard with sling upholstery for the back supports which are typically made of fabric or leather. The rigid back support is one of the most prescribed back supports to support user posture as part of a combination of a back cushion on a rigid frame. The custom molded back support is an individualized back support for a person who has a particular deformity. Each back support design has different advantages and disadvantages.

The sling upholstery back support has a rectangular shape based on the frame of wheelchairs' tubing. The materials of sling back support stretch out to create the wheelchair back support. Because of the features of the materials utilized, it has adjustability due to the back support

contouring to the shape of spine. The sling back support is also lightweight relative to other types of back support. An advantage of this type of back support is that it can be used by a wide range of people because of its ability to conform to the back shape and posture of the chair's occupant. As such, it is common and useful. The flexibility of this back support also makes it ideal for folding wheelchairs which are easily transportable. A primary drawback to the sling back support is that it does not provide a stable base of support for posture [7, 8, 21]. Consequently, lack of postural support may cause back pain [6] and/or postural deformity.

The rigid back support has different features compared to the sling back support. The rigid frame is designed to form a trapezoid shape that more closely resembles the shape of the back. Even though there is cushioning on the back support, the frame is firm and adds additional weight. Therefore, it generally has little to no adjustability and is sensitive to the user's body size. However, as it provides a solid base of support for appropriate posture, it is most appropriate for users without a postural deformity.

The custom contour back support is shaped individually and is often big and bulky. This type of back support covers the whole spine and fills spaces to support any deformity of the spine. It is a very individualized product requiring intensive labor, and the quality of the custom molded back support depending on the clinicians' skills [7, 8, 21].

Table 1. Advantages and Disadvantages of Different Types of Back support

Back Support	Advantages	Disadvantages
Linear nylon upholstery back support	1. Adjustability 2. Contours to shape of spine 3. Lightweight	1. Less stable 2. Clinical backgrounds
Rigid back support	1. Good stability 2. Comfort	1. Less adjustable 2. Sensitive to fit
Custom molded back support	1. Individualized 2. Specific to a particular deformity	1. Weight added 2. Intensive labor 3. Affected by clinicians' skills

Among the three types of the back supports, the standard sling upholstery for the back support has been utilized by most wheelchair manufacturers and wheelchair users. As mentioned earlier, the sling upholstery has flexibility and adjustable tension, allowing wheelchair users to periodically use such adjustability assist in pressure relief activities. However, it provides less postural support. In addition, it does not provide sufficient support for wheelchair users backs while participating in dynamic activities, such as propelling up and down ramps, over various surfaces and over obstacles [7, 8, 21].

1.2.4 Important Adjustability of Back support

Pelvic stability affects shoulder mobility, which is crucial to wheelchair users weight-bearing and movement [22]. Wheelchair users have to perform tasks during the day in a seated posture and the seating for each task performance may not be consistent throughout the day. It has been suggested that the seating system allow for changes in posture. The use of a tilt-in-space function during the individual activities is also emphasized [22]. As an analog to the wheelchair, the office chair has become a critical component in determining our overall comfort and health due to the increase of sitting throughout the day. In addition, typical sitting times of 2 hours (or more) in an office chair could facilitate the development of pain even if the office chair is well-designed and ergonomic. Therefore, frequent repositioning while sitting is recommended in an able-bodied population. As such, the chair is not only a device for supporting the body, but also for changing positions [23, 24]. Similar to sitting in an office chair, frequent changes of position in a person's wheelchair are also highly recommended [23-25].

There are other benefits of adjustability for wheelchair users given that they use it all day for mobility and also in the home. For instance, an adjustable back support is an important feature

to provide appropriate trunk support in several different circumstances. For example, while propelling a wheelchair uphill or downhill on a ramp, the wheelchair user should lean into the ramp to minimize the risks of injury or feelings of instability; adjusting the back support angle to provide trunk support would help with this activity. Also, the adjustment of back support angle could help make it easier for users to dress and perform other daily living activities. Further, people may have their own preferences for the postures in daily activities [21, 25-27]. Because of the increasing number of wheelchair users, providing an adjustable back support is necessary due to the importance of seating position and appropriate trunk support and the variability of wheelchair users' needs and back problems.

2.0 BACK SUPPORT QUESTIONNAIRE FOR IMPROVING SEATING INTERFACE

2.1 INTRODUCTION

Almost 3 million people are wheelchair users in the United States, and approximately 5 million people are wheelchair users in Europe. Counting only Western countries, nearly 1 in every 100 people are wheelchair users [28]. The number of people who use wheelchairs has increased as the population has aged and medical care has improved [9, 10]. Wheelchairs enhance function, increase independence, and provide greater accessibility to the home and community for people with disabilities [12, 13]. As an individual adapts to his or her disability, the wheelchair often becomes an extension of his or her body. The wheelchair is therefore a critical component that should meet users' expectations, preferences, physical needs, and functional requirements [14]. Different types of wheelchairs have varying comfort and ergonomic ratings due to their varying features. Wheelchairs that have more adjustability typically receive higher ratings on comfort and ergonomics than wheelchairs with minimal adjustability [15]. The ability to extend one's activity is dependent on one's equipment. Furthermore, the complexity of the intervention and equipment prescribed to a user are more dependent on a user's functional needs than a user's medical diagnosis. Ultra-lightweight wheelchairs not only offer a myriad of options in size and components, but also provide adjustability of seat angle, back support angle, back support height, and axle position. The adjustability of ultra-lightweight wheelchairs is more likely to promote extended activity times. Combinations of seating systems can lead to extended activities since complex systems are better able to meet functional needs [29]. As the number of individuals using

wheelchairs as their primary means of mobility increases, there needs to be more emphasis on making them safer, more effective, and readily available.

A wheelchair back support is essential due to the importance of postural support for wheelchair users. Back support design and functionality can directly impact the comfort and health of the user, because the back support provides pressure relief and postural support. In addition to postural support, however, the back support protects and supports the spine and pelvis. Because the weight of the upper body is sustained through the spine, it is a crucial structural component; therefore, the protection or support of the spine is essential. Boninger et al. conducted a study that radiographically measured kyphosis and scoliosis in a group of individuals with tetraplegia.

According to this study, people with tetraplegia have a higher incidence of kyphosis and scoliosis than people without paralysis [4]. In many cases, wheelchair users have insufficient muscle strength to support and control the spine, so the spine tends to be become bent and deformed due to the force of gravity. When the wheelchair back support does not provide proper postural support for a wheelchair user, combinations of lordosis, kyphosis, and/or scoliosis postural deformities may develop or worsen [3].

Back supports have different characteristics, such as height, shape, stiffness, weight, and adjustability. These characteristics vary depending on the specific type of back support. Most commonly, manual wheelchairs use either slings or rigid back supports. Most wheelchair manufacturers and wheelchair users utilize the standard flexible sling upholstery, which is typically made of fabric, for the back support. Additionally, some sling back supports have adjustable tension, so they can be fitted to the wheelchair user and can be periodically adjusted if necessary or desired. However, because of their flexibility, these back supports provide limited postural support while the user participates in dynamic activities, such as propelling up and down

ramps, over various surfaces, and over obstacles. As a result, sling back supports may not provide sufficient support during all activities, including static sitting [7, 8, 21], so rigid back supports are often prescribed.

Table 2. Advantages and Disadvantages of Different Back Supports

			
Advantages	1. Adjustability 2. Contours to shape of spine 3. Lightweight	1. Good stability 2. Comfort	1. Individualized 2. Specific to a particular deformity
Disadvantages	1. Less stable 2. Poor support	1. Limited adjustability 2. Sensitive to fit 3. Weight added	1. Weight added 2. Intensive labor 3. Affected by clinicians' skills 4. Expensive

In a cross-sectional study by May, L.A., et al. [7], participants with recent spinal cord injuries evaluated three different back support designs while performing four functional tasks. The three different back supports included standard sling upholstery, the Jay J2 back rigid back support, and the Pindot Pax-Bac. Participants used their own wheelchair or one they were loaning. They evaluated each back-support option over 1-3 days to determine the most suitable back angle setting and to increase their familiarity with the back support. The entire testing period occurred over 10 days for each participant. The four functional tasks included timed forward wheeling, forward vertical reach, ramp ascent, and 1-stroke push. Functional performance during the reaching activity was significantly greater when the J2 was used. Participants also reported higher satisfaction scores with the J2 [7, 8, 21]. Although these results support the prevailing opinion that rigid back supports

are superior to sling, subjects were exposed to each back support design only briefly, so it is not clear whether these results represent satisfaction after a period of brief use or after longer-term use in the community.

2.2 HYPOTHESIS

Aim: Evaluate comfort and discomfort from wheelchair users regarding the back support they are currently using.

Objective: Determine if people who have rigid back supports on their wheelchair report different levels of comfort than individuals who use sling back supports.

Hypothesis:

Long-term wheelchair users with sling back supports would report significantly higher comfort levels than those using rigid back supports by using Tool for Assessing Wheelchair Discomfort.

Rationale: Some studies have reported rigid back supports provide more comfort and better functionality of the users [7, 8, 30]. However, results of these studies were from comparisons among several back supports during a short period which may not have allowed for proper time to acclimate to the back support. Additionally, clinical reports claim the rigid back support is one of the best solutions to provide proper seating posture and comfort [31]. Despite these potential benefits of the rigid back support, the rigid form of the back support may not match well to the shape of the user's back, resulting in discomfort, pain and high interface pressures which cause pressure ulcers [4, 5]. Evaluation of comfort, function, and support of wheelchair back supports for long-term usage is needed.

2.3 METHODS

2.3.1 Recruitment

Prior to data collection, the study protocol was approved by the Department of Veterans Affairs Institutional Review Board. Subjects were recruited through the National Disabled Winter Sports Clinic (NDVWSC), the National Veterans Wheelchair Games (NVWG), and the Human Engineering Research Laboratories research registry. Participants were between 18-80 years of age and used a manual wheelchair (ultralight, lightweight, and depot) as their primary means of mobility. Subjects with open wounds that would preclude prolonged sitting in order to fill out the forms were excluded from the study.

2.3.2 Protocol

The Tool for Assessing Wheelchair Discomfort (TAWC) was used to assess the participants' wheelchair seating discomfort levels[32]. Participants were asked to rate the long-term discomfort/comfort related to their back support that they were using on their own wheelchair. The tool has three parts. The first part is a general information survey on activities completed during the day, and which we did not utilize in this study. The second part is the General Discomfort Assessment (GDA), which was used in this study as an overall measure of discomfort. It is comprised of Discomfort Rating Subscale (DRS) and Comfort Rating Subscale (CRS) (See Table 3). The DRS has 8 statements about discomfort, and the CRS has 5 statements about comfort. The summation of the DRS score and CRS score results in the GDA score. This section has a total of 13 statements, each scored on a 7 point Likert Scale. Total possible score ranges from 13 to 91,

with lower total scores indicating more comfort and higher scores indicating less comfort. The third part is The Discomfort Intensity Rating (DIR), which we used to identify locations in the body where discomfort was felt. This portion of the TAWC requires participants to assign a number on a scale from 0 to 10 to explain a discomfort level for each of 8 regions of the body, where a rating of 0 is no discomfort and a rating of 10 is severe discomfort. The regions of the body were the back, neck, buttocks, legs, arms, feet, and hands. Then, participants are allowed to list one additional body part and the discomfort in that region and score it from 0-10. According to the scoring instructions of the DIR a score of "1" is added to the participant's score of each of the first 8 items. Thus the possible adjusted score for each of the first 8 items becomes 1-11. A score of "1" is added to the last question if a body part is listed, but 0 is added if left blank. Thus, the last question can have a total of 0-11 possible points.

Table 3. The General Discomfort Assessment portion of TAWC

Subscales of Discomfort 1 (Strongly Disagree) to 7 (Strongly Agree)	**Subscales of Comfort** 7 (Strongly Disagree) to 1 (Strongly Agree)
I feel poorly positioned	I feel no pain
I feel like I have been in one position for too long	I feel stable (not sliding or falling)
I feel like I need to move or shift my position	I feel comfortable
I feel aches, stiffness, or soreness	I feel good
I feel pressure in some part or parts of my body	I feel able to concentrate on my work or activities
I feel too hot or cold or damp	
I seek distraction to relieve discomfort	
I feel uncomfortable	

2.3.3 Statistical analysis

Statistical analysis was completed using SPSS 20.00 (Chicago, IL). Significance levels were set *a priori* at p=.05.

2.3.3.1 Primary statistical analysis (all participants) Chi-Square and individual t-tests were used to compare baseline demographic factors (gender, age, and years of wheelchair use) between those with sling back supports and those with rigid back supports. Three individual ANCOVA analyses were then performed to compare back support groups with respect to total GDA score and both subscale scores while controlling for significant covariates (age and years of wheelchair use).

2.3.3.2 Secondary statistical analysis (subgroup of subjects with paraplegia and tetraplegia) Because SCI was a large subgroup, a secondary analysis was conducted using only those with SCI. Participants were first divided into paraplegia and tetraplegia groups.

In the paraplegia group, Fishers exact and individual t-tests were used to compare groups with respect to gender, age, and years of wheelchair use. Because no covariates were found, three individual t-tests were used to compare back supports groups with respect to total General Discomfort Assessment score and both subscale scores.

In the tetraplegia group, Chi-Square and individual t-tests were used to compare baseline demographic factors (gender, age, and years of wheelchair use) between those with sling back supports and those with rigid back supports. Three individual ANCOVA analyses were then performed to compare back support groups with respect to total GDA score and both subscale scores while controlling for significant covariates (age and years of wheelchair use).

2.4 RESULTS

2.4.1 Participants

A total of 131individuals (average age 52.7 ± 10.7) participated in this study and completed the questionnaire. Table 4 presents demographic data for all participants.

Table 4. Demographic information of all participants

Demographic measure	Number of participants (Percentage)
Disability	
Spinal Cord Injury	99 (76)
Amputation	5 (3.8)
Multiple sclerosis	7 (5.3)
Traumatic Brain Injury	2 (1.5)
Other	4 (3.1)
Combination of disabilities with SCI	10 (7.6)
Combination of disabilities without SCI	4 (3.1)
Gender	
Male	107 (81.7)
Female	24 (18.3)

On average, participants had been using a wheelchair as their primary means of mobility for 20.6 ± 12.1 years; 71.8% of wheelchair users (n=94) were using a sling back support, and 28.2% (n=37) were using a rigid back support.

One of the largest disability categories was spinal cord injury. Among 99 subjects with spinal cord injuries, 33 participants had tetraplegia, 64 participants had paraplegia, and 2 subjects did not report injury level. (Figure 1)

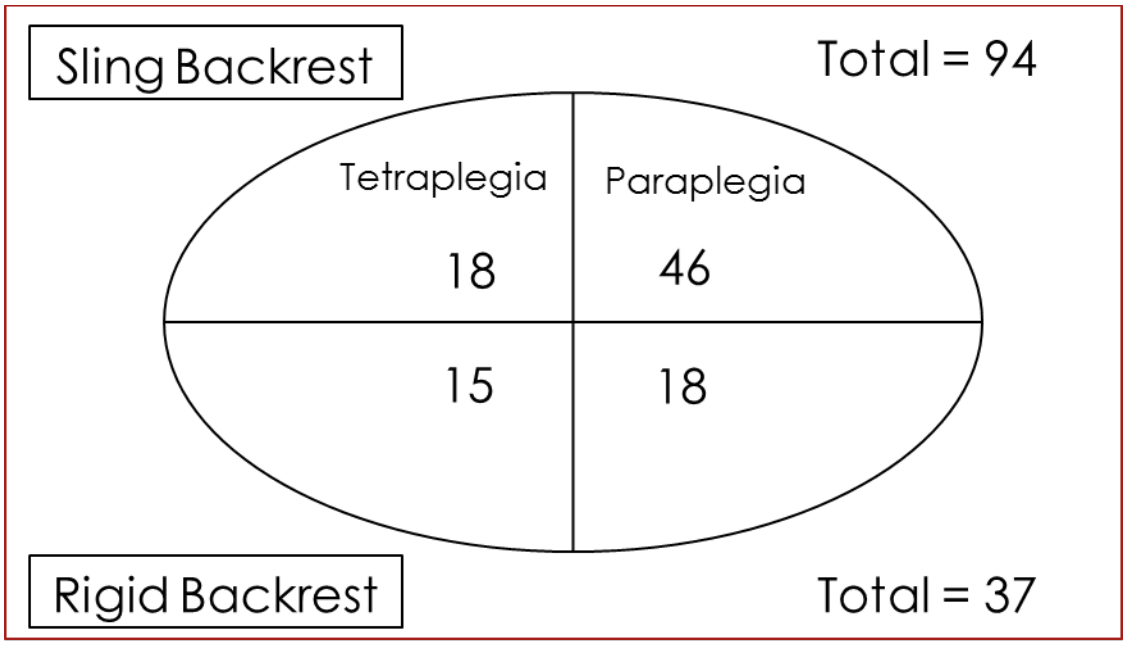


Figure 1. Subgroup of participants with spinal cord injury

2.4.2 Results from Primary Analysis (all participants)

There were no significant differences between back support groups based on gender (p=.130). Significant differences were found between back support groups based on age (p=.003) and years of using a wheelchair (p=.0120). Sling back support users were older (54.1+/-10.6 vs 48.3+/-10.1 yrs) and had spent more years in a wheelchair (22.3+/-12.4 vs 16.4 +/-10.5 yrs) compared to rigid back support users. See Table 5.

Table 5. General Discomfort Assessment (all participants) – (Higher values indicate more discomfort)

Ratings	Mean (SD) Sling (N = 94)	Mean (SD) Rigid (N = 37)	P-Value (2-tailed)
Discomfort Subscale	27.5 (12.0)	29.4 (10.6)	.261
Comfort Subscale	15.9 (7.0)	17.2 (6.1)	.301
Total	43.3 (17.0)	46.6 (15.9)	.210

Total GDA scores (p=0.21) and both subscale scores (DRS: p=0.261, CRS: p=0.301) did not differ significantly across back support groups, when controlling for the covariates of age and years using a wheelchair.

2.4.3 Results from Secondary Analysis (spinal cord injury only)

In those with paraplegia, no differences were seen in back support groups with respect to gender, age, or years in a wheelchair. Likewise, back support groups also had statistically similar total GDA scores (p=0.781) and subscale scores (p=0.510, p=0.662).

In those with tetraplegia, sling back support users were older (53.5+/-9.9 vs 46.1+/-9.0) and had spent more time in a wheelchair (25.4+/-9.1 vs 15.5+/-9.3 years), but back support groups did not differ by gender. Total GDA score and DRS score (p=0.239) were statistically similar across back support groups (p=0.105) but differed significantly with respect to CRS score (p=0.045), when controlling for covariates of age and years in a wheelchair. See Table 6.

Table 6. General Discomfort Assessment (Tetraplegia and Paraplegia) – (Higher values indicate more discomfort)

Ratings	Tetraplegia			Paraplegia		
	Mean (SD) Sling (N = 18)	Mean (SD) Rigid (N=15)	P-Value (2-tailed)	Mean (SD) Sling (N = 46)	Mean (SD) Rigid (N = 18)	P-Value (2-tailed)
Discomfort Subscale	27.8 (10.0)	30.5 (9.8)	.239	26.8 (12.3)	27.7 (10.8)	.510
Comfort Subscale	13.9 (5.0)	17.3 (5.5)	.045*	16.6 (7.6)	17.0 (6.7)	.662
Total	41.7 (13.3)	47.9 (14.6)	.781	43.3 (17.2)	44.7 (–16.4)	.239

Median DIR scores are reported in Table 7. Overall, the back was the body part that received the highest discomfort scores.

Table 7. Median of Discomfort Intensity Rating by area of body and Participant Groups

	Entire Group		Tetraplegia		Paraplegia	
Body Areas	Rating Median Sling	Rating Median Rigid	Rating Median Sling	Rating Median Rigid	Rating Median Sling	Rating Median Rigid
Back	**4** (1-11)	**5** (1-11)	**5** (1-9)	**5** (1-9)	**3** (1-11)	**6** (1-11)
Neck	**1.5** (1-11)	**3** (1-11)	**3** (1-11)	**3** (1-11)	**1** (1-10)	**2** (1-10)
Buttocks	**2** (1-11)	**5** (1-10)	**3** (1-11)	**6** (1-10)	**2** (1-11)	**3** (1-9)
Legs	**2.5** (1-11)	**1** (1-10)	**1** (1-8)	**3** (1-10)	**2.5** (1-11)	**1** (1-10)
Arms	**1** (1-11)	**1** (1-9)	**1** (1-7)	**1** (1-9)	**1** (1-7)	**1** (1-7)
Feet	**1** (1-11)	**1** (1-10)	**1** (1-8)	**3** (1-9)	**1** (1-11)	**1** (1-10)
Hands	**1** (1-9)	**1** (1-10)	**1** (1-9)	**1** (1-8)	**1** (1-7)	**1** (1-10)
Overall Discomfort	**4** (1-11)	**5** (1-9)	**3** (1-8)	**5** (1-8)	**4** (1-9)	**4** (1-9)

2.5 DISCUSSION

Contrary to our hypothesis, there were no significant differences on the Total GDA score based on back support type, when all participants were analyzed, or when participants were analyzed as paraplegia and tetraplegia groups. In fact, the overall trend was for rigid back support users to have

more discomfort than sling users. One explanation is that wheelchair design has been changing rapidly over the past two decades [28, 33]. Therefore, long-term wheelchair users may be less comfortable when switching to a rigid back support at first, since they were accustomed to a sling-style seat, which was the only choice available when they first received their chair.

The most significant finding from this study was that, when GDA subscale scores were analyzed, rigid back support users in the tetraplegia group had significantly more discomfort than sling back support users with tetraplegia. This difference was not seen in the paraplegia group or when participants of all disabilities were analyzed. No differences were found for the discomfort subscale score across any groups. However, all trends were consistent and supported more discomfort with rigid back supports. The first explanation for this finding is that many users with tetraplegia may have had rigid back supports that were sub-optimally fitted or adjusted for the functions that they carry out in daily life. The second explanation is sling upholstery tends to allow the users to reposition themselves more in their wheelchair. The third is that rigid back supports does not allow for adjustment and variation of the user's position, even though it may provide more support. Fourth, despite cushioning on the back support, the back support shell is still firm and fixed in position, which users may find uncomfortable without dynamic adjustment. Finally, the tetraplegia group likely has more compromised trunk and pelvic stability in general [34]. Rigid back supports are sometimes added to provide this stability, but they do not allow dynamic movement. Lack of dynamic movement may be perceived as discomfort. This group may be more reliant on the sling back support, whose fabric may provide more comfort due to allowance of dynamic movement, but less postural support. Individuals with paraplegia have greater trunk control, thereby able to change positions more frequently; as such, the back support may not play as large a role in comfort as it does in tetraplegia. They do not rely on back supports as much,

because they move on their own. However, to reduce the risk of lordosis, kyphosis, and/or scoliosis postural deformities, proper postural support is essential, which might lead one to assume that a rigid back support is superior [3].

On the DIR, the back was one of two body parts that ranked highest for discomfort. This high discomfort level emphasizes the need to focus on improving back support design, specifically to increase comfort while providing adequate postural support.

The trends seen in this study are contrary to previous studies on the short term use of back supports, which favor rigid back supports as having more desirable features [7, 8]. This emphasizes the need to evaluate the long-term performance of back supports with experienced users.

2.6 STUDY LIMITATIONS AND FUTURE DIRECTIONS

This study is limited by sample size. According to our power analysis, 315 subjects in each group are necessary to demonstrate significance at 80% power. This may suggest that the TAWC is not sensitive enough to detect differences in discomfort in this population. The TAWC asks broad questions about overall discomfort, which may be caused by issues and components other than the back support. Also, the TAWC questionnaire asks questions only about discomfort and comfort, not other symptoms or the impact discomfort may have on functional tasks. Wheelchair back supports are also important for supporting functional abilities, so future work should examine the long-term functional outcomes from using back supports. It is important to note that the TAWC has been used in previous studies to evaluate discomfort after sitting for approximately 4 hours. Participants in this study were asked to rate their long-term discomfort using the TAWC since no other measure for long term seating discomfort exists. Development of such a measure is needed.

It would also be helpful to design a questionnaire to ask participants about their reactions to comfort, appearance, and texture/material of seating systems, as these also play a role in back support selection. Unfortunately, we did not ask how long the wheelchair users had been using the back support supports in their current wheelchair. Additionally, controlling for type and setup of the wheelchair may help elucidate differences based on back support type. Clinicians play a critical role when ordering and fitting rigid back supports [35, 36]. As we do not know the experience of the clinicians who prescribed the wheelchairs to the users in this study, it is possible that our participants obtained their wheelchair through untrained clinicians, which may have influenced the findings of this study.

2.7 CONCLUSION

Although rigid back supports should theoretically provide a more stable base of support for the spine, this study shows that long term (>20 years) wheelchair users with sling back supports trend toward having more comfort than those using rigid back supports. Discomfort ratings for back supports were significantly higher for those with tetraplegia who used rigid back supports than those with tetraplegia who used sling back supports. The higher discomfort rating among rigid back support users may be due to sub-optimal shape, fit, adjustability or user preferences due to length of disability. However, back supports are often selected because of their impact on function, adjustability, or ability to provide dynamic support. More work is needed to design and develop better rigid back supports that are functional but provide adequate comfort.

3.0 IDENTIFYING CHARACTERISTIC BACK SHAPES FROM ANATOMICAL SCANS OF WHEELCHAIR USERS TO IMPROVE SEATING DESIGN

3.1 INTRODUCTION

Due to aging populations and the increased prevalence of disability, experts anticipate that the need for wheelchairs worldwide will continue to increase for the foreseeable future [9, 37, 38]. Increases in the demand for wheelchairs have directed attention to the importance of developing better products for current and expected wheelchair users. Consumers of this technology expect wheelchairs to fit their personal needs, physical abilities, and functional requirements [14]. For health and comfort, it is important that these features be considered in the ergonomic design of wheelchairs.

Several studies evaluating back supports in chairs, car seats, and wheelchairs have indicated that back supports are a significant factor in determining seating comfort and function [2]. Office chair seating has garnered a considerable amount of attention due to its ties to low back pain and associated health costs. Specifically, focus has been placed on back support design [2]. A chair's back support plays an important role in not only increasing comfort, but also reducing stresses on the spine [1]. The same is true for wheelchairs. Moreover, to improve function and increase level of comfort, anthropometric data such as body size, function, structure, and composition is commonly analyzed in the design of well-fitted products such as shoes and clothes. Clothing sizes, for example, are designed in consideration of a wide spectrum of anthropometric and functional data. Anthropomorphically-shaped back supports of vehicle seats and office chairs have similarly been proposed [39].

Most manual wheelchairs come standard with a sling upholstery back support. A basic sling conforms to the part of the back wherever most of the weight is transferred from the user's back to the back support. However, over time, the upholstery may gradually stretch. Although an adjustable tension sling compensates somewhat for anatomy and progressive change, sling back supports may become loose due to the flexibility of the material itself or slippage of straps [40]. This can be detrimental as wheelchair users require proper trunk support to maintain good posture and a firm basis for propulsion [3]. Lack of postural support can lead to the development of back pain, postural deformity, or arm injuries [3]. A rigid back support is often recommended to provide better support for a user's posture and is a combination of a back cushion and a rigid frame. The cushion is designed to form a close fit to the shape of the user's back with a firm frame that provides a stable base for the spine. Rigid back supports are generally not user-adjustable and must be selected based on the user's body size. Therefore, since differences in back shapes are not accounted for in a standard rigid shell, a rigid back support is most appropriate for people without fixed postural deformities [4, 5]. People with spinal cord injuries (SCI) and other disabilities commonly do have spinal deformities and other pelvic asymmetries [5, 24] that may differ from the back support shell and lead to different sitting positions [41, 42]. As a consequence of shape differences, improper contacts to users result in discomfort and high interface pressures which can lead to pressure ulcers [43-45]. Therefore, it is important to classify back shapes of wheelchair users in order to determine the seating needs of a wide range of wheelchair users.

3.2 HYPOTHESIS

Aim: Characterize and classify groups of back shape from wheelchair users by digital anatomic scanning technology.

Objective: Classify back shapes and the pelvic obliquity of wheelchair users by using digital anatomic scanning technology in order to determine the seating needs of a wider range of wheelchair users.

Hypothesis a:

Individuals in two different postures would have significantly different back contours and pelvic obliquity measurements.

Hypothesis b:

Within the two different posture groups, the various back contour classifications identified would be significantly different with respect to the age, years of injury, disability, and pelvic height of the individuals within those groups.

Hypothesis c:

The back contour measurements would be correlated with the pelvic obliquity measurements.

Rationale: People with spinal cord injuries commonly have spinal deformities [5, 24]. Sitting positions are also different between those with spinal cord injuries and non-injured groups [41, 42]. Due to spinal deformities, individuals with spinal cord injuries might have different back shapes that differ from the back support shell.

3.3 METHODS

This study utilized the scanning technology known as the FastScan System (Polhemus Co., Colchester VT, USA), which features rapid recording of three-dimensional surfaces. This system has been used previously in clinical settings to measure the skin surface of amputees in the process of fitting prosthetics and orthotics. Instead of qualitatively comparing 3D scans of the surface contours, as has been done in the past, this study used quantitative methods to categorize back shapes. We applied a technique similar to that used in geographic studies, which compare surface contours [46], evaluating RMSE to compare back shapes.

3.3.1 Recruitment

This study was approved by the VA Pittsburgh Healthcare System Institutional Review Board. Participants were recruited at the National Disabled Veterans Winter Sports Clinic (NDVWSC) and the National Veterans Wheelchair Games (NVWG). The inclusion criteria of this study were that participants must (i) be between 18-80 years of age, (ii) be athletes or instructors with a disability necessitating use of adaptive ski equipment in order to ski, and (iii) be able to give informed consent. Those not eligible for this study were (i) participants with open wounds that precluded them from prolonged sitting, and (ii) participants with any injury or illness diagnosed by the on-site clinic medical team that precluded them from participating in adaptive skiing.

3.3.2 Protocol

Each participant was asked to wear a wrinkle-free tight white t-shirt and 1) transfer to a massage chair and lean against the chair on the chest or 2) transfer to a postural support frame and sit upright. The massage chair was used to simulate forward leaning, and the postural support frame was used to simulate and standardize upright position, even for those with poor trunk control. The three dimensional (3D) locations of bony landmarks, including the bilateral inferior scapulae, acromia, iliac crests, and several vertebral processes (C7, T7, T12, Sacrum), were digitized when participants were in position, using a mechanical wand linked to the FastScan system commonly used to measure surface contours. It took approximately 20 minutes to digitize the bony landmarks and complete the surface mapping of each participant's back in position.

3.3.3 Data Analysis

Surfaces were generated in the FastScan program using Basic Surface Processing (Smoothing: 2.50 mm; decimation: 2.00 mm, limit object to 1; surface simplification: 0.10). Overlapping scans with distances less than 2.50 mm apart were merged, resulting in one continuous representation of each participant's back. Each back model was oriented the same relative to the others by alignment and rotation. A local coordinate system was fit to each back surface contour, centered at the T12 bony landmark, with x,y, and z axes oriented in the transverse, coronal, and sagittal planes, respectively.

Back contour for comparison was processed by taking a thin axial slice of the scanned 3D shape of each individual's back. First we located the T12 landmark as a point, and the rostral and caudal boundaries of the axial slice were set at 5mm above and below T12. The lateral

boundaries were defined by the lateral edges of the lowest rib. The scans were trimmed according to boundaries as this area might be most representative of the area of the body which interfaces with the back support. After the processing was completed, the scanning data were normalized using a scaling factor. The scale was calculated by the ratio of individual measures to the average across all participants for distances between scapulae distance horizontally and the T7 – T12 distance vertically. After normalization, the data for each participant were overlaid with a uniform grid with a resolution of 1mm. The RMSE was calculated with grid structure. The grid structure of the T12 areas for comparing back contour were fixed to 277×11 (x×y) after grid with a resolution of 1mm and trimming the region of T12, and only z data were calculated for the RMSE. To allow for evaluation of back shape symmetry, the grid structure was divided into left side data (x: 1-138) and right side data (x: 140-277). RMSE was defined as the square root of the distances between the coronal plane (z=0) and the back contour surface. RMSE is usually used for measurement of differences between values, such as when comparing values actually observed or comparing between a model and estimator [46, 47]. The absolute values of the differences between right and left sides data were calculated and divided into 5 contour classifications based on the ranges of RMSE (0-50, 51-100, 101-150, 151-200, and $\geq$201). Greater values of RMSE therefore indicated greater asymmetry in back contour. Average horizontal surfaces at the level of T12 from each group were exported to a Solidworks file and extruded more thickly for visualizing each 5 contour classifications.

Pelvic obliquity was then measured. First we drew a horizontal line through T12 and measured the distance between the horizontal line and the posterior superior iliac spine on each side. The absolute value of the difference between these two distances was used to represent

pelvic obliquity. These distances were calculated in the sagittal plane (x=0, z=0) using only y data.

3.3.4 Statistical Analysis

Alpha levels were set *a priori* at 0.05. Frequency distributions were used to describe the demographic data. Because the two postural conditions contained different participants, the two groups were first compared with respect to age, years of using wheelchair, gender, and disability using a Mann-Whitney test, Chi-square test, and Fisher's Exact test to identify any potential confounding variables. To address Hypothesis 1, A Mann-Whitney test was conducted to compare back contour and pelvic obliquity between the two postural conditions. For Hypothesis 2, two individual Kruskal-Wallis tests were conducted to compare the contour classifications within each postural group with respect to age, years of injury, back contour and pelvic obliquity. Chi-square tests and Fisher's Exact tests were used to compare groups with respect to disability and gender. To test Hypothesis 3, Kendall's tau_b correlation was used to test whether the relationship between back contour and pelvic obliquity was linear. All statistics analyses were completed using SPSS 20.00 (Chicago, IL).

3.4 RESULTS

3.4.1 Participants

A total of 129 individuals (average age 53.2 ± 12.0 years) who use wheelchairs as their primary means of mobility participated in this study. Information on gender and reason for using a wheelchair is summarized in Figure 2 and Figure 3.

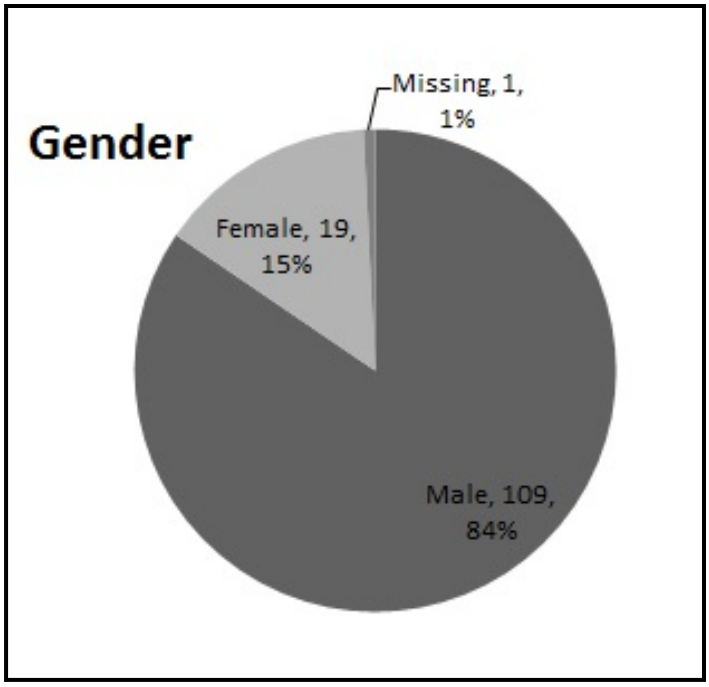


Figure 2. Gender

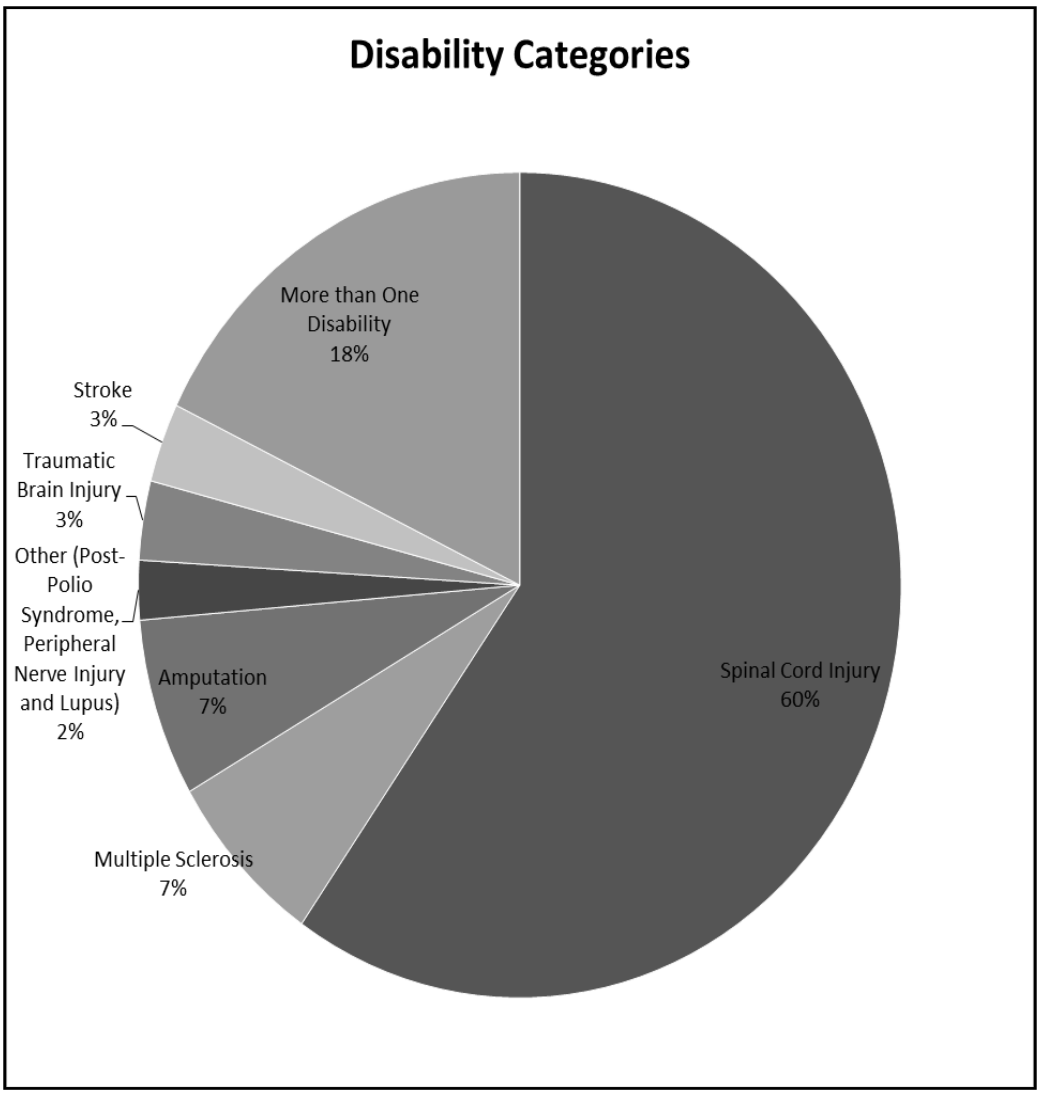


Figure 3. Disability Categories

There were no significant differences between the two seated position groups based on age (p=.078), years of using wheelchair (p=.293), gender (p=1.000), or disability (p=.580). In terms of Hypothesis 1, back contour (p=.500) was also not significantly different between the two groups. However, a significant difference was found between the groups with respect to pelvic obliquity. Participants measured on a massage chair (21.1±16.8mm) had a larger measure of pelvic obliquity, or less equal pelvic heights, compared to those on a postural support frame (4.9±5.2mm) (p<.001). Within each of the two seated position groups the back contour classifications did not differ in terms of age (M: p=.329, P: p=.588), disability (M: p=.066, P: p=.699), and years of injury (M:

p=051, P: p=.169). However, there was a significant difference in terms of gender (M: p=.023, P: p=1.000) among the back contour classifications of those seated in a massage chair. Table 8 displays the demographic information for those in each group.

Table 8. Demographic Information by Group

	Massage Chair		Postural Support Frame	
	Gender – N (%) Male Female	Age – Years (SD)	Gender – N (%) Male Female	Age – Years (SD)
Group 1	16 (84.2) 3 (15.8)	51.8 (15.5)	9 (90.0) 1(10.0)	57.1 (15.9)
Group 2	12 (85.7) 2 (14.3)	59.4 (8.3)	16 (84.2) 3 (15.8)	48.4 (10.2)
Group 3	12 (92.3) 0 (0.0)	50.9 (12.5)	5 (83.3) 1 (16.7)	49.7 (12.4)
Group 4	3 (42.9) 4 (57.1)	60.2 (7.6)	7 (87.5) 1 (12.5)	54.1 (12.8)
Group 5	21 (91.3) 2 (8.7)	54.1 (10.0)	8 (80.0) 2 (20.0)	50.1 (9.0)

* The 5 various back contour classifications based on the ranges of RMSE

3.4.2 Analysis Scanning

The average RMSE value for differences between the right side and left side on the x-axis was 167.2±196.0 (mm) over all participants. The average difference in distances between T12 and right and left PSIS's for the pelvic obliquity was 14.4±15.5 (mm) over all participants. Back contour, as quantified by RMSE, did not correlate significantly with pelvic obliquity, r = -.061, p=.307. Table 9 displays the variance observed in each group with different seated positions.

Table 9. Evaluation of the Back Analysis

Group (Ranges)	Massage Chair			Postural Support Frame		
	Number of Participants	RMSE (mm) Mean (SD)	Distances (mm) Mean (SD)	Number of Participants	RMSE (mm) Mean (SD)	Distances (mm) Mean (SD)
1 (0-50)	19	22.4 (15.0)	23.9 (16.9)	10	31.3 (12.9)	3.6 (1.8)
2 (51-100)	14	78.1 (10.2)	18.6 (14.1)	19	73.1 (16.3)	4.9 (5.5)
3 (101-150)	13	123.0 (15.2)	24.5 (20.4)	6	126.6 (16.4)	3.5 (2.0)
4 (151-200)	7	167.3 (14.3)	28.3 (17.6)	8	173.1 (11.8)	6.8 (8.1)
5 (≥201)	23	423.9 (292.7)	16.1 (15.4)	10	368.4 (147.6)	5.5 (5.7)
	76	184.7 (228.6)	21.1 (16.8)	53	142.1 (134.4)	4.9 (5.2)

The average back shape for groups can be seen in Figure 4 and Figure 5. The average differences among groups showed asymetrical shapes with different seated positions.

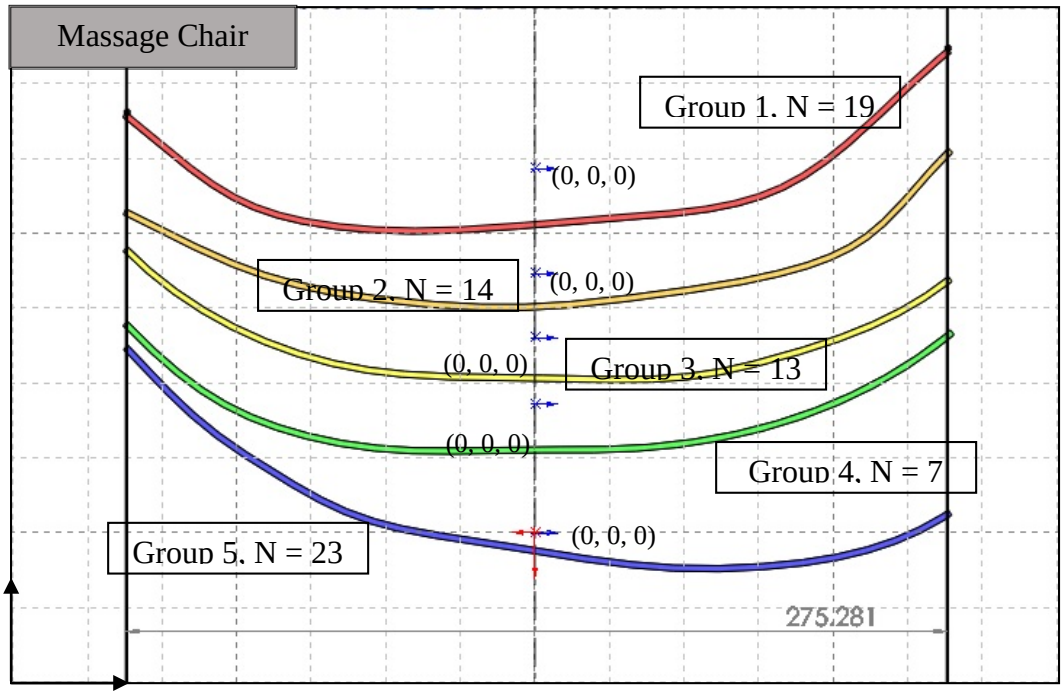


Figure 4. Average Back Shapes Obtained from Grouping with Massage Chair (lengths: mm)

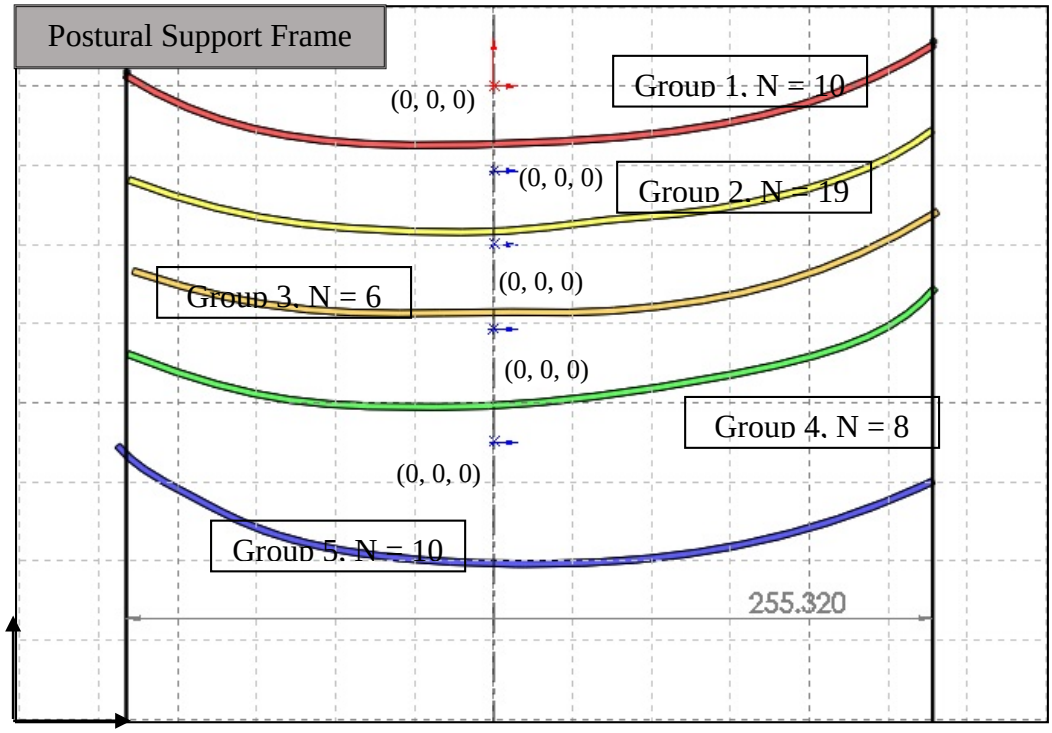


Figure 5. Average Back Shapes Obtained from Grouping with Postural support Frame (lengths: mm)

3.5 DISCUSSION

Back contour did not significantly differ between the two seated posture groups, but pelvic obliquity did differ as expected. It seems clear that posture impacts the amount of obliquity of the pelvis more than it does back contour. Participants who were leaning against a massage chair had a more kyphotic position, which in turn may have exaggerated a pelvic obliquity associated with a scoliosis or hip contracture [48]. On the other hand, the postural support frame supported a position of more neutral alignment which may have lessened the effects of scoliosis or contractures. Providing lateral trunk support to assist upright sitting may help to lessen pelvic obliquity.

The various back contour classifications differed significantly with respect to gender within the massage chair group only, but not other variables identified. This difference can be explained because of a high predominance of females in one specific back contour group. This particular group may have been predominantly female because different skeletal structure could affect back contour. The variability in back shapes seen in this study highlights the importance of matching a person's back shape to the back support. A lack of postural support can lead to the development of postural deformity [3]. Because people with SCI have compromised trunk and pelvic stability [34], asymmetric back shapes, such as those resulting from scoliosis or postural deformities, may develop or worsen when the wheelchair back support does not provide proper postural support [3]. To reduce the risk of progression of postural deformities, proper postural support is essential [3]. Our study showed that the anatomy of many individuals' backs is not symmetric, whereas all commercialized rigid back support shells offer symmetric support. Other studies have shown rigid back support shells might not meet the needs of individual wheelchair users, especially for people with spinal deformity [4, 5]. Therefore, rigid back supports may

result in discomfort and high interface pressures or lead to pressure ulcers. Just as cushions are used to evenly distribute pressure to prevent pressure ulcers [18, 45], it is essential to provide adequate pressure distribution over individuals' backs as well.

An example of a mismatch between back shape and the back support is a back support shell with a deep contour and a wheelchair user with a wide, flat back shape. In this instance, the wide flat back is forced to squeeze into a narrow, deep contour back support. This disparity in shapes may lead to skin breakdown on the sides of the back. Skin breakdown may also occur on bony landmarks of the spine when the wheelchair user has a narrow, round back shape but is seated with an open back support shell. In this case, there may be high contact forces where the bony landmarks of the spine meet the back support, leading to pressure sores on the spine. Therefore, providing wheelchair users who has a flexible deformity access to wheelchair back supports with shapes suitable to their individual back shape would increase the contact area of the back support with users' backs by matching the user's back contour. Although choosing a suitable wheelchair back support is complicated by the different and unique back shapes of users, effectively distributing pressure might reduce the risk of pressure ulcers or discomfort by better simulating the spine shapes of users by enlarging the contact area [49-51].

Finally, we expected back contour to be correlated with pelvic obliquity, but results did not support this hypothesis. However, pelvic stabilization is essential for appropriate posture in order to maintain correct back shape and comfort. Thus, appropriate back support is essential to comfortably sustain the pelvis and its natural tilt in an upright posture [52, 53]. Clearly, maintaining adequate posture is important for balancing and positioning [54]. However, most commercial back supports have vertically flat surfaces. Since the lumbar lordosis curve is not properly supported by back supports with flat surfaces, the sacrum and pelvis areas are sometimes

unstable. In addition, there may be problems with a more structurally supportive fixed angle back support. For example, if the back supports were correctly fixed to account for a wheelchair users' lordosis, wheelchair users might have difficulty obtaining relaxed or comfortable positions while sitting in the wheelchair. Similarly, while sitting upright for long periods of time with a fixed back support for lordosis support would be good for the posture, it may not be as comfortable. Therefore, angle adjustable back supports may be a solution to achieve both relaxed and comfortable positions and healthy postures and allow for existing shell shapes to better fit users.

3.6 STUDY LIMITATIONS AND FUTURE DIRECTIONS

The main limitation of this study was that all participants were recruited from NDVWSC and NVWG. Therefore, they were all active wheelchair users and as such, not necessarily representative of the general wheelchair user population. Also, only 18 bony landmarks were identified from the scans in this study. It is possible that increasing the number of bony landmarks on the spine could have allowed us to obtain more detailed information about spine shapes. Moreover, in this study users' backs were scanned while they were positioned in a postural support frame or a massage chair. It is likely that users may assume a wide variety of postures during sitting and functional positions, and based on their own individual wheelchair setup. Thus, further studies are warranted to evaluate a number of different seated postures; however, we would anticipate, based on the findings from this study, which an even higher number of back shapes would be found, lending more credence to the need for a wider range of back support contours and options for adjustability. Finally, data on which type of back support

each participant used as part of his or her own wheelchair was not collected, but should also be investigated in prospective studies on posture and wheelchair back supports.

3.7 CONCLUSION

The results of the present study indicate that individuals have different back shapes, and commercial products may not be able to provide proper support to fit every individual. We therefore conclude that a wider range of contour rigid back support shells, and adjustability, is needed to provide appropriate postural support and prevent the skin breakdown that can result from the disparity between the shape of the shell and the shape of an individual wheelchair user's back.

4.0 EVALUATION OF A LIGHTWEIGHT, DURABLE, ADJUSTABLE, COMPOSITE BACK SUPPORT MOUNTING BY MANUAL WHEELCHAIR USERS

4.1 INTRODUCTION

Making recommendations for wheelchair back support prescriptions is challenging because wheelchair configuration must take into consideration many factors including the wheelchair users' comfort, their ability to transfer and to propel efficiently [17], and perform other daily living tasks. Wheelchairs with greater adjustability have received higher ratings for comfort and ergonomics compared to those with minimal adjustability [15]. Among the adjustable features, foot support height and back support angle are adjustments that can be made to prevent pressure sores, a common secondary condition for wheelchair users. According to studies on the effects of changing tilt and seat-to-back support angles during wheelchair propulsion, seat angle was determined by a combination of user comfort and clinical pressure modulation to minimize the risk of shoulder injuries that may be caused by wheelchair push-up for pressure relieving activities [19]. Because the back support provides pressure relief and postural and functional support, it is an essential part of wheelchair configuration [7, 17].

Wheelchair users must perform many tasks during the day in a seated posture, and the seating for each task performance may not be consistent throughout the day. It has been suggested that a wheelchair seating system should allow for changes in posture [22]. The inclusion of a tilt-in-space function to use during an individual's daily activities is also emphasized [22]. In one study, differences in postural alignment and shoulder flexion range were observed between users of wheelchairs with standard configurations and those with posterior seat inclination with a low

back support set perpendicular to the floor. These adjustments resulted in more active flexion to the upper extremities and anterior pelvic tilting resulting from support of the lumbar spine by the back support. Additionally, the angle of the back support provided the wheelchair user space for posterior tilting [20]. In another study, balance control and postural muscle use were tested in various seating conditions. The researchers compared a standard chair (10 degree reclining) to an adjustable chair that tilted 7 degrees and 12 degrees, and reclined 22 degrees. They found that the configurations of the adjustable chair provided increases in reaching distance and pressure distribution by decreasing peak pressure. The researchers also found that these adjustments had a positive impact on transfers and wheelchair propulsion [17]. A conclusion drawn from this work is that an adjustable back support is important for wheelchair users to increase performance.

In addition, an adjustable back support is an important feature to provide appropriate trunk support in several different circumstances. For example, while propelling a wheelchair uphill or downhill on a ramp, the wheelchair user should lean into the ramp to minimize the risks of injury or feelings of instability; adjusting the back support angle to provide trunk support would help with this activity. Also, adjustment of the back support angle could help make it easier for users to dress and perform other daily living activities. Further, people may have their own preferences for postures in daily activities [21, 25-27]. Because of the increasing number of wheelchair users, the importance of seating position and appropriate trunk support, and the variability of wheelchair users' needs and back problems, providing an adjustable back support is crucial.

4.2 HYPOTHESIS

Aim: Create a commercially-ready prototype of the LWDAC back support bracket that meets the following design criteria.

Objective a: Improve the design to maximize functionality and ease of use.

Objective b: Verification of Design Criteria a – d and ISO testing.

Design Criterion a:

Incorporate quick release mechanisms for use on folding wheelchairs to make them possible to remove without tools.

Design Criterion b:

Refine the increment of adjustments conforming to some of the consumer focus group members' indications of 5 degree of adjustment being too fine a resolution.

Design Criterion c:

Expand upon the accommodation of and fitting of the LWDAC back support bracket to a wider variety of types and models of ultra-light wheelchairs.

Design Criterion d:

Enhance the aesthetic look and add features necessary for achieving commercial readiness.

Objective c: Verify full functionality of the LWDAC back support prototype and all necessary related features through human subjects testing and evaluation in the lab.

Hypothesis a:

The LWDAC back support bracket will receive favorable overall performance ratings on LWDAC performance questionnaire in each of the following: dimensions, stability, ease of use, and overall comfort.

Rationale: Two focus groups were held for gathering feedback on the current prototypes. The LWDAC back support led us to assume that 70% was a standard percentage of a favorable response. Three categories of single hand operation (81.41 ± 22.86), overall comfort (76.53 ± 18.11), and willingness to purchase (70.41 ± 23.47) received ratings greater than 70, representing a strong rating. Based on feedback from the focus group and discussion of the design team at HERL, design issues needing to be addressed for better production are as follow; a quick-release mechanism for the entire back support mounting system, remote control or push buttons for angle adjustment, durability of cord and spring, and pre-set and range of angle adjustment. Therefore, the LWDAC back support and bracket will receive favorable ratings overall when it meets the above design criteria.

4.3 BACK SUPPORT DESIGN

4.3.1 Design and Prototyping Methods

A traditional iterative design development protocol was undertaken and completed. All components were designed and reviewed in 3D using SolidWorks. The “looks-like/works-like” models were fabricated using a Stereo Lithography Apparatus (SLA) machine. After several iterations, a final working design strong enough to meet ISO testing standard was fabricated using aluminum and steel components.

4.3.2 Design and Prototyping Results

The previous design of angle-adjustable back support hardware has been patented (No. US8, 376,463). After about six times of major iterations (Figure 6) with more than twenty iterations (Appendix C), the final prototype was derived.

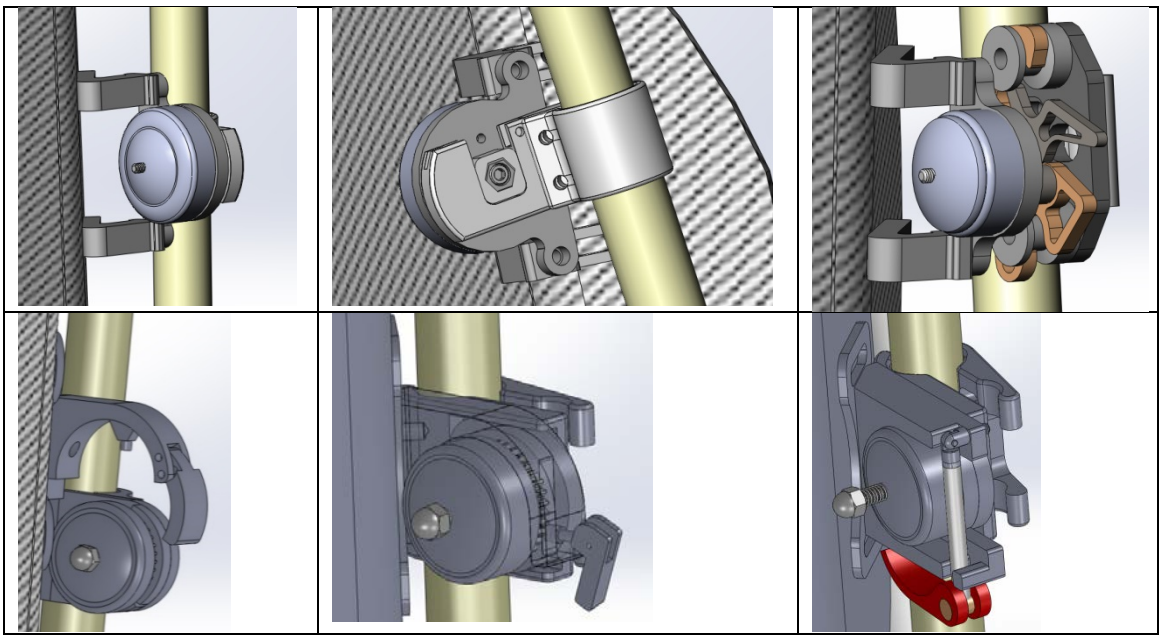


Figure 6. Major design iterations

The design uses gears that have 36 patterned teeth that allow adjustments in 10 degree increments. There are two gears on each side: the inside gears rotate with the back support shell and the outside gears remain stationary. To affix the back support shell position, the gear covers are spring-loaded to slide over both sides of the two gears and lock the gears in place. The two gear covers are connected to each other by a string. As the string is pulled and the covers slide off of the inside gears, the two gears and back support shell are permitted to rotate relative to each other. (Figure 7 and Figure 8)

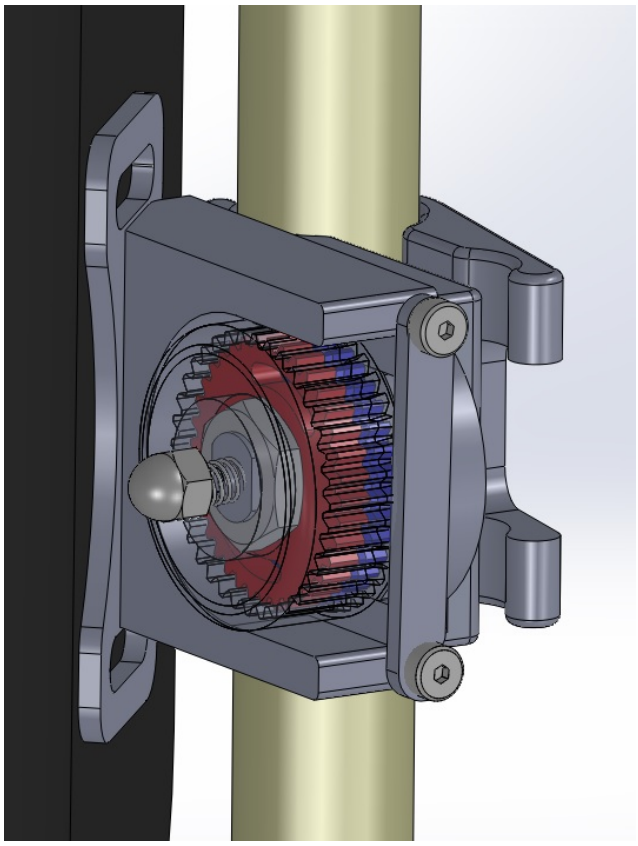


Figure 7. Prototype

Figure 8. Prototype (Left : Forwarded back support, Right : Back warded back support)

A quick-release system for the entire back support mounting was integrated into the prototype. The composite uses a saddle-and-latch concept. The latch connects the two shoulder bolts and keeps the angle-adjustment composite in place (Figure 9).

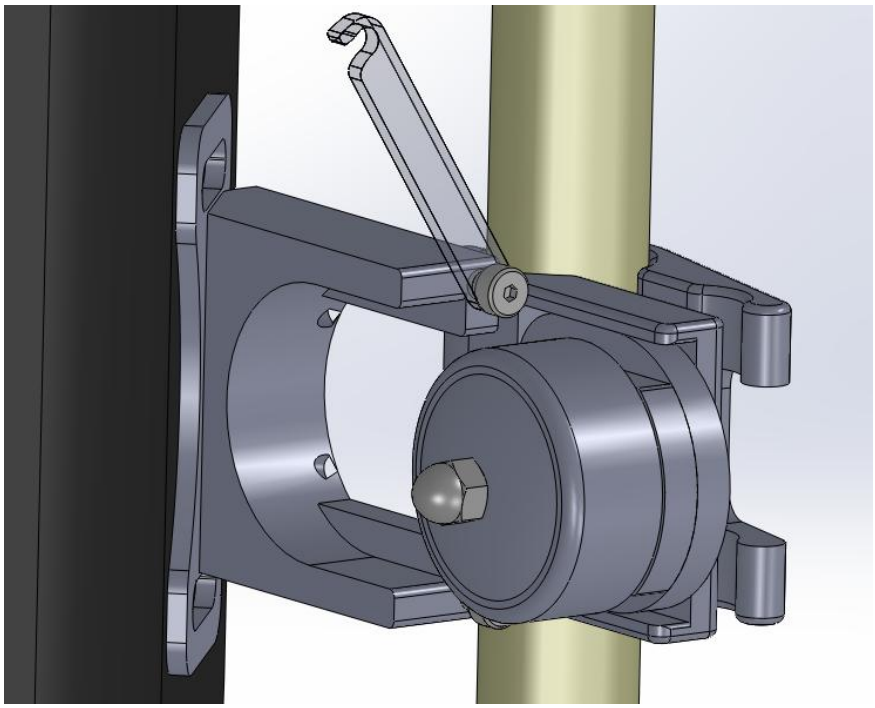


Figure 9. Assembly device with a quick-release system

4.3.3 Testing Methods – International Organization for Standardization Testing (ISO 16840-3)

Evaluation of the angle-adjustable back support was performed in strict accordance with ISO testing standards. The testing involved mounting the angle-adjustable back support to rigid test fixtures to emulate the conditions of an actual wheelchair. In accordance with ISO 16840-3, the postural support device (PSD) was subjected to static, impact and repeated load tests until a specific force caused one or more failures. A new PSD was used for each test following failure to ensure accuracy of results. For the purposes of this testing, failures were defined using the ISO specifications for failure of a device. Static strength tests and repeated load tests used a Material Testing System (MTS) Model 858 Bionix II Test System. The MTS software allows simple

monotonic and cyclic tests by defining the rate, frequency, and amplitude. (MTS Systems Corporation)

Static strength tests measured the amount of constant force the back support could endure. Testing of the angle-adjustable back support device for static strength was completed by applying a force at a rate not exceeding 100 N/s, for a duration of no less than 5 s, until any of the specifications for failure were met. The posterior force test involved the application of force to the midline of the top of the back support surface, using a concave loading pad at an angle of 45º ± 5º to the surface (Figure 10).

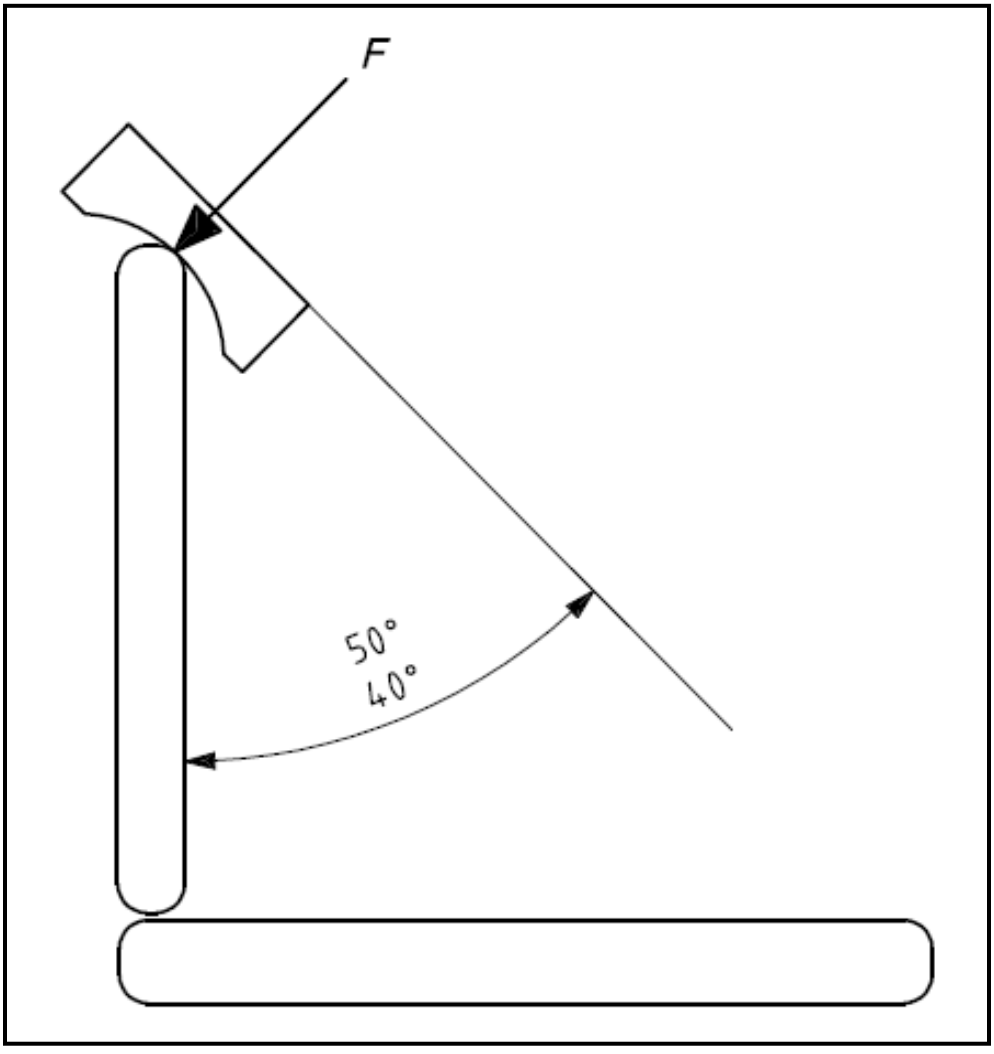


Figure 10. Posterior force application to back support (from ISO 16840-3)

The anterior force test involved the application of a force to the midline and perpendicular to the back support surface at an area 30 mm ± 10 mm below the top by a convex hemispherical loading pad (Figure 11).

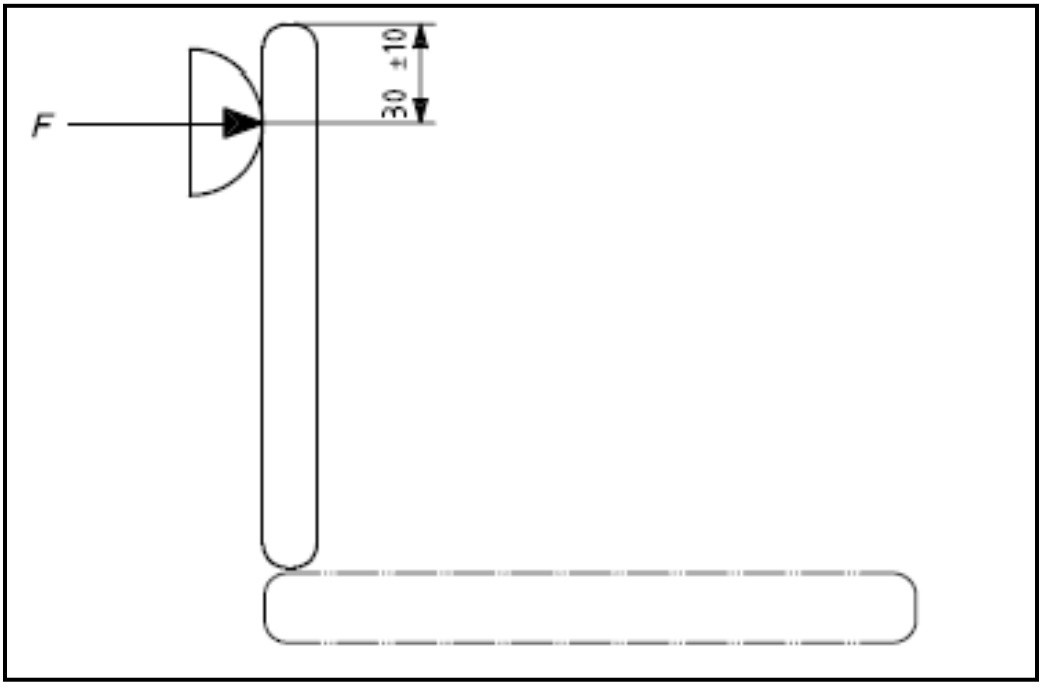


Figure 11. Anterior force application to back support (from ISO 16840-3)

The impact test was designed to assess the strength of the back support upon being struck by a 25-kg pendulum vertically upon impact. Pendulum release angles were varied in 5º increments ranging from 5º to 90º, with the angle-adjustable back support composite being assessed on a pass/fail basis for each angle (Figure 12).

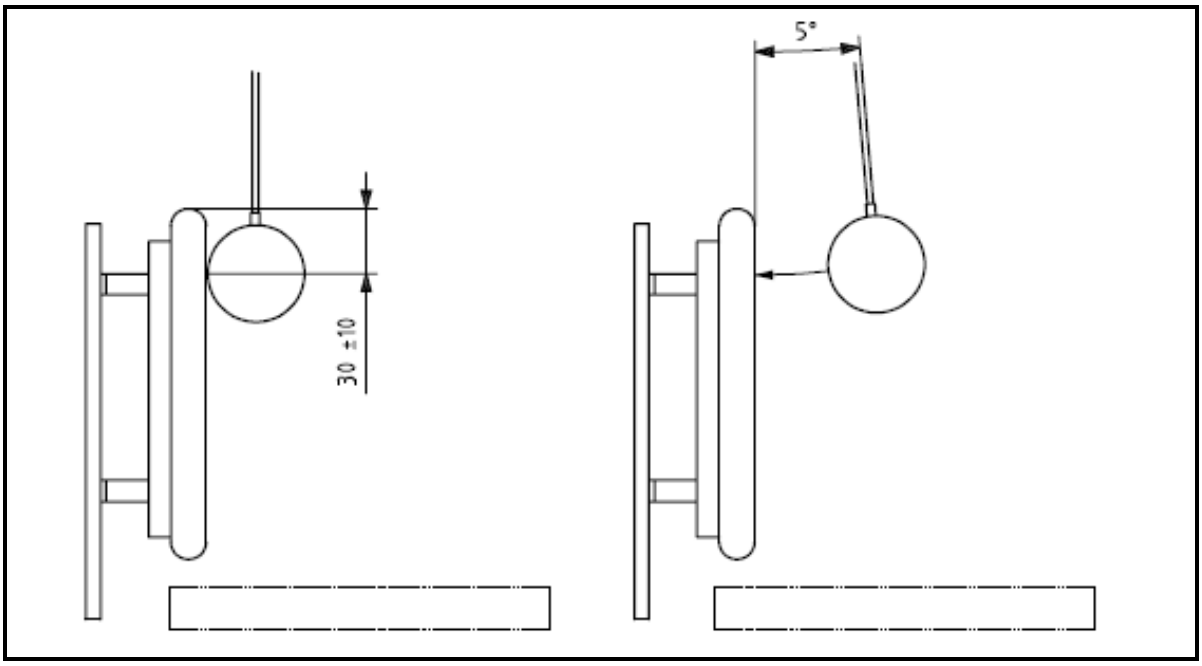


Figure 12. Back support impact test alignment and set-up (from ISO 16840-3)

Following impact testing, repetitive load testing was used to determine the durability of the back support. Repetitive load testing, using a test load within 10% of 10000 N, was completed using the same specifications for failure; periodic pass/fail checks were used to assess the structural integrity of the angle-adjustable back support device. The force was applied using a variable convex loading pad of over 100 kg at a rate of <100 N/s for 1000 cycles.

4.3.4 Testing Results – International Organization for Standardization Testing (ISO 16840-3)

The devices were compliant with the ISO testing. The anterior force test was stopped at a force of 1003 N and a maximum axial displacement of 164.9 mm with a failure mode of fracture on the back support shell. However, the angle-adjustable back support device maintained the function of angle adjustment. The back support was impacted with the pendulum released from 5º to 75º without any type of failure. The back support was considered to fail with slippage in adjustment

from the impact testing at the pendulum release angles from 80º-90º. Even though the back support moved, the device maintained function in this case as well. A variable convex loading pad for 100kg was used to apply a force to the back support for 1000 cycles. Four integrity checks were done at 0, 686, 876 and 1000 cycles by Co-Investigator and the angle-adjustable back support device was found to be intact for each check, so the 1000 cycles were successfully completed.

4.4 FOCUS GROUP EVALUATION

4.4.1 Focus Group Methods

4.4.1.1 Recruitment This study was approved by the University of Pittsburgh Review Board. Participants were recruited using the Human Engineering Research Laboratories registry and involved mailing flyers to qualified people in the registry. Our participants were asked to contact study investigators if they were interested in this study. The inclusion criteria of this study for manual wheelchair users were that participants must (i) be between 18-80 years of age, (ii) self-propel wheelchairs as their primary means of mobility, and (iii) transfer independently. Those not eligible for this study were (i) subjects with pressure sores, and (ii) subjects who require the use of specialized or custom seating for trunk support.

4.4.1.2 Protocol Participants were given a thorough introduction to the angle-adjustable back support prototype. After a demonstration of how to perform adjustments, the focus group participants were encouraged to transfer into the wheelchair mounted with the angle-adjustable back support and experience making adjustments for themselves. Upon becoming familiar with

the prototype, the participants were asked to complete a questionnaire and to elaborate on what modifications should be done to improve the prototype. Participants also had a discussion about the future directions with an investigator.

4.4.1.3 Questionnaire The questionnaire (Appendix A) was designed to elicit participants' opinions on the adjustability, function and appearance of the angle-adjustable back support device. Participants were asked to check a box on a five-point Likert scale to indicate their opinion: strongly agree, agree, neutral, disagree, and strongly disagree. Using open-ended questions elicited more comprehensive comments that enabled us to improve the next prototype of the angle-adjustable back support device.

4.4.1.4 Analysis For consistency, some categories' scores were reversed so that all of the results reflected responses to positively phrased questions. As a result, higher scores indicate more positive responses. Frequency distributions and measures of central tendency were used to describe the data. Information on overall performance and comfort were measured using a five-point Likert Scale. Ratings greater than three were considered favorable responses.

4.4.2 Focus Groups Results

4.4.2.1 Participants A total of 8 manual wheelchair users (Male: 6, Female: 2) participated. On average, the participants were 38.3 ± 11.4 years old.

4.4.2.2 Evaluation of Angle-Adjustable Back support Taking ratings greater than 3 as favorable responses, only four categories – requirement of strength to operate (2.5), and simplicity to operate (2.5) – received a negative response. Figure 13 shows the median of ratings for each category.

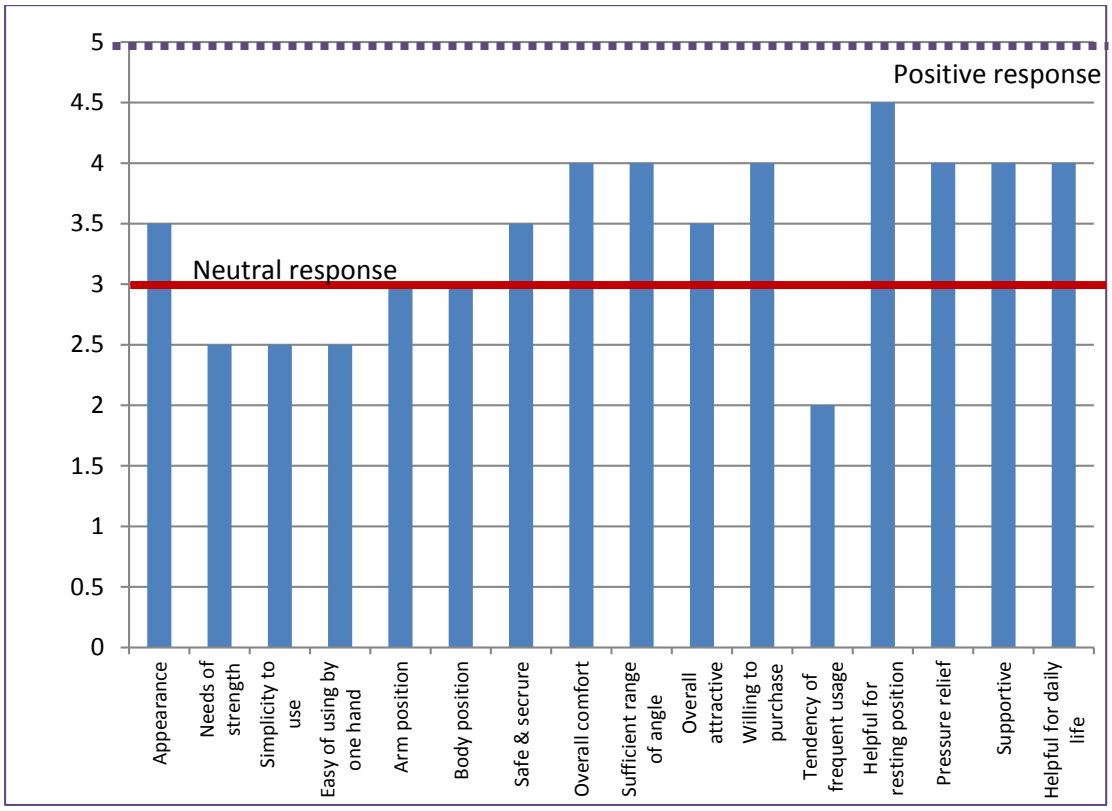


Figure 13. Median of ratings for each category

Participants were asked to explain what three things they most liked and they most disliked about the prototype. Table 10 shows the lists for these two.

Table 10. List of like and dislike

Things that participants like best	Things that participants most dislike
Comfort – 6	Problem with string – 6
Support (Function/Activities) – 6	Reaching back position to adjust – 6
Adjustability – 4	Appearance – 1
Support (Posture) – 3	Quick release system – 1
Lightweight – 2	Weight added – 1
	Hard to know how much was tilted – 1

Also, participants were asked to choose three items from the following list that they consider to be the most important to them when they purchase a back support or wheelchair: dimensions, weight, adjustments, safety, durability, easy to use, comfort, and effectiveness. Figure 14 shows the features most important to participants when they choose a back support or wheelchair.

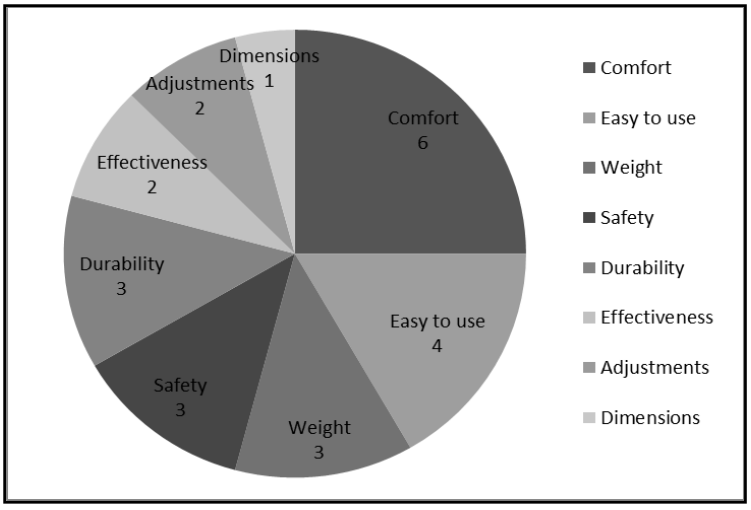


Figure 14. The most important items

Participants also had a discussion about the remote release lever with an investigator. Most of the participants had difficulties with pulling the string, but they agreed that using a string for people with lower level injuries would be useful if the operation were smoother. However, they concurred that a remote lever is important for people with higher level injuries, and also this product is more valuable for them. Further discussion of the remote release lever revolved around the removability of the system. Because it required too many steps to remove, participants did not like the remote removable system. For example, transferring in/from a car, an already difficult task, would require adding another step and take more time and effort. A remote lever system on a cane was suggested as one way to solve this design challenge, but there was one concern about interfering with backpacks/bags hanging on a cane. Since the remote lever would be for people with higher level injuries, participants concurred that the design of the lever for dexterity is important and that a sliding (up/down) release would be the best.

4.5 DISCUSSION

From the results of median of ratings for each category, “tendency of frequent usage” is the lowest, but “willingness of purchase” is higher than neutral response. The reason could be that the participants had no experience with the possibility of changing the back support angle. That is, they might not have considered when and how to change angles, as they are used to having no option to adjust the angle of their back supports. However, this prototype would provide the benefits of angle adjustment when users become familiar with changing angles to adjust to different environments. Being able to change angles could result in less fatigue. It has been shown that even though sitting is a kind of rest, it may cause fatigue with too much physical stability, too

much physical freedom, uncomfortable pressure, monotonous environment, wrong chair for an activity, and sitting for too long [54]. In other words, wheelchair users may get fatigued just from sitting in a fitted wheelchair all day. Since the participants agreed that the adjustable back support composite is helpful for resting position, helpful for daily life, supportive, overall comfortable, and helpful for pressure relief, the adjustable back support composite may prevent fatigue.

The results show that the most important items polarized into the best and the worst. The most important item to consider when participants purchase a back support or wheelchair was comfort, which is what they liked best about this prototype. However, the second most important item was ease of use, which is what participants most disliked about it. Overall, participants had a positive feeling about the concept of the design. Most of the categories related to function, comfort and support received a positive rating. However, they did not have a very favorable impression of the back support's operation method or usability. The prototype fails if it is too difficult to operate. Therefore, the prototype might have received better responses if its operation method had been less difficult.

4.6 STUDY LIMITATIONS AND FUTURE DIRECTIONS

First, only three wheelchairs were available: one 16inch wide wheelchair of medium height, one 16inch wide wheelchair of low height, and one 18inch wide wheelchair of medium height. Therefore, since these wheelchairs were not individually fitted, participants may have felt less comfortable. Also, because pulling the cord to slide off the gear covers and change angles did not work as smoothly as it should have for those in the focus groups, the results from the focus group may be slightly biased.

Based on feedback from wheelchair users, design issues for improvement of usability need to be addressed before further in-depth evaluation. The next prototype was redesigned with spring-loaded male gear instead of using female geared cover. The design uses one male gear and the gear is spring-loaded to slide into female gears plates and lock the gears in place. The two male gears are connected to each other by a string. All parts and their movement for engagement and disengagement are concealed beneath a cover. Also, the string was guided by the cover for pulling any directions to disengage. According to design changes, the process of manufacture became simplified (Figure 15).

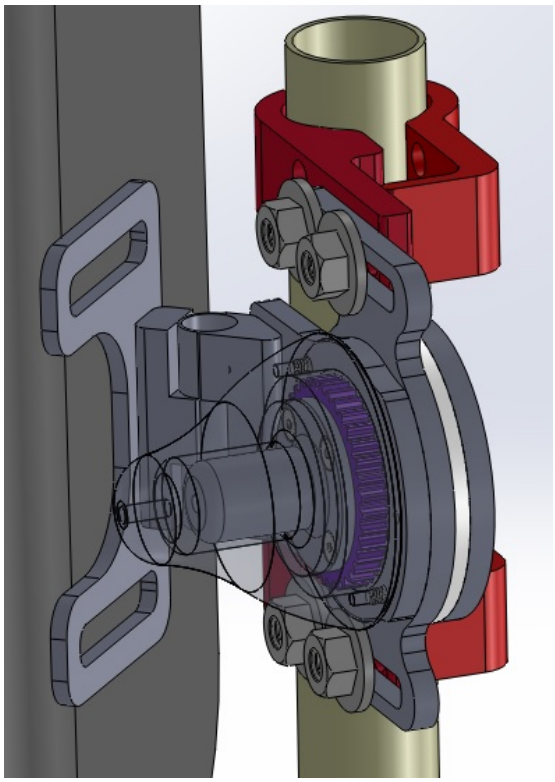


Figure 15. Next Prototype

4.7 CONCLUSION

An angle-adjustable composite back support that successfully met ISO testing standards was tested and rated by participants in two focus groups. Most of the subjects agreed that the angle adjustment provides comfort, support, functionality, and better posture. Overall, the device had a positive impression on participants. However, improvements on the operation method and usability were suggested.

5.0 IMPACT AND USAGE OF ANGLE ADJUSTBLE BACK SUPPORT COMPOSITE

5.1 INTRODUCTION

The number of people using wheelchairs is increasing every year [9, 10, 28]. As the market for wheelchairs continues to expand, manufacturers and companies must offer more varieties of wheelchairs and seating systems to match the variety of people using them. The primary function of a manual wheelchair is to provide effective seating and mobility for people with limited lower extremity function [12-14]. Despite important advances in manual wheelchair technology and design, manual wheelchair users still experience seating issues that cause discomfort or limit their functioning [14]. Seating issues are particularly prevalent with active individuals who use ultralight manual wheelchairs[29]. Much of the focus of research and development has been on making wheelchairs light and easier to propel, with insufficient attention being paid to quality seating for ultralight wheelchairs; the back support most notably requires additional development [7, 8, 21, 29].

One of the functions of a back support is to help movement of the pelvis and to provide support to the spine in the presence of gravity and external loads [54, 55]. Gravity has the tendency to compress the torso; to counterbalance the forces of gravity, the spine must respond, and in the absence of skeletal muscle, it often deforms. Specifically, without adequate support the spine has a tendency to develop lordosis, kyphosis, scoliosis or some combination of these postures [42]. If left unchecked postural deformities can lead to pain, obstructions, and loss of function [4].

Not only the back support itself but also the angle of the back support is important for wheelchair users. The angle of the back support affects mobility, stability and function. According to a study by Sprigle, S., et al. [55], pelvic tilt, which the back support helps to determine, significantly affects upper extremity reach tasks. Also, stability and function were shown to be increased among people with spinal cord injuries when they sit with greater posterior pelvic tilt. However, posterior pelvic tilt brings risks such as pressure ulcers on load-bearing body areas like the sacrum and coccyx, and a slouched kyphotic posture which causes spine and neck pain. The results of Sprigle et al.'s study, then, show that mobility is at odds with stability/function. One possible way to alleviate this conflict would be to provide an adjustable back support angle.

An adjustable back support angle would allow the user to find the seating position that, for them, maximizes benefits while minimizing risks of injury or feelings of instability. For example, while sitting still, a more vertical back support posture is desirable. However, when propelling the wheelchair, it is desirable to recline the back support between 5-10 degrees to reduce the weight on the front casters. The ability to change the back support angle by the user would allow tuning of posture for specific activities. For example, while dressing in the wheelchair a greater recline (up to 20 degrees) is useful in order to make it easier to pull on pants without the back support digging into the users' spine. However, when seated at a computer desk a nearly upright posture may be preferred. Additionally, a user adjustable back support would allow individuals who have great difficulty with pressure-relieving posture changes throughout the day to achieve more effective skin relief. Thus, it should be up to the user to strike the appropriate balance for the activity that s/he is performing. Consistent with these assumptions, a number of empirical studies have demonstrated a significant relationship between seating position and biomechanics [25-27]. Manual wheelchairs and adjustable seating systems that are constructed from lightweight materials

will reduce to the stress on the user while going-up/down slopes, while starting/stopping, and when transferring the wheelchair (e.g., into a car).

The lightweight, durable, adjustable composite (LWDAC) back support for ultralight manual wheelchairs that we built and tested here addresses each of the shortcomings of earlier back supports for ultralight manual wheelchairs. Most importantly, this LWDAC back support has been designed to incorporate other design features that empirical research has indicated are beneficial to the wheelchair user, not only by being light-weight but also by providing seated posture support and base of propulsion. That is, it offers features that promote a healthier and more functional interface between the ultralight wheelchair and the user. These features include an adjustable back support, selectable seat angle, the use lightweight materials, and a solid base of support to strike the balance that will minimize the risk of pain and injury and maximize function and comfort. Conducting a research of activities daily living course (ADLC) trials with the LWDAC back support will provide a more in-depth understanding of the use of the adjustable back support.

5.2 HYPOTHESIS

Aim: Create a commercially-ready prototype of the LWDAC back support bracket that meets the following design criteria.

Objective a: Evaluate the performance of the back support in the natural environment of the end-user.

Hypothesis a:

Subjects will rate the LWDAC back support bracket as superior to their own personal back support on dimensions related to appearance and comfort as measured.

Hypothesis b:

Subjects will report LWDAC back support bracket improves certain functional tasks (reaches, up and down ramps, dressing, pressure relief, and seat at table) on LWDAC performance questionnaire and during performance itself.

Hypothesis c:

Subjects will rank angled positions of the LWDAC back support bracket as superior to their own personal back support on certain functional tasks on LWDAC performance questionnaire and during performance itself.

Hypothesis d:

Subjects' adjustments to their wheelchair with the LWDAC back support bracket (e.g., number of adjustments, setting to best position) will continuously increase.

Hypothesis e:

Subjects' adjustment of their wheelchair with the LWDAC back support bracket (e.g., number of adjustments, setting to best position) will exceed 5 times by the end of the 10-week study period.

5.3 METHODS

5.3.1 Recruitment

This study was approved by the University of Pittsburgh Institutional Review Board. Participants were recruited using the Human Engineering Research Laboratories (HERL) registry, and involved flyers being mailed to qualifying people in the registry. Our participants were asked to contact study investigators if they were interested in this study. The inclusion criteria of this study for manual wheelchair users were that participants must (i) be between 18-80 years of age, (ii) self-propel ultralight manual wheelchairs with a rigid frame as their primary means of mobility, (iii) transfer independently and (iv) have the ability to use a back support that is either 10'' or 14'' high. Exclusion criteria include (i) subjects with pressure sores, (ii) subjects who require the use of specialized or custom seating for trunk support, and (iii) subjects who use a wheelchair that does not have a nominal back support width of 14'', 16'', 18'' or 20''.

5.3.2 Protocol

Participants made three visits to perform the study procedures to allow for an in-depth understanding of the use of the back support.

5.3.2.1 Visit 1 On their initial intake visit, subjects were given an explanation of the research study and asked to provide informed consent. After informed consent was obtained, all subjects were asked to complete an intake questionnaire. In addition, measurements and photographs were made of the subject's own personal wheelchair so that the LWDAC back support prototype could

be set to match the settings on their personal wheelchair. Subjects were then asked to complete some activities of daily living tasks on the Activities of Daily Living Course (ADLC) with their own back support, including 1) a Modified Functional Reach Test, 2) a Reach, 3) Propulsion on up and down ramps, 4) Demonstration of dressing, 5) Pressure relief and 6) Typing on a computer.

All participants had data loggers attached to their wheelchair that would monitor the total distance they traveled over the course of the first two-week period. Participants were asked to go about their normal routine for the first two-week period in order to establish a baseline dataset of their activity level.

5.3.2.2 Visit 2 After two weeks participants returned to the lab to have data collected from the dataloggers and to have the LWDAC back support installed on their manual wheelchair, set to match the settings on their personal wheelchair as best as possible. Settings include those for back support angle, back support vertical position, back support horizontal position, and back support height. Although subjects obviously were familiar with the features of their own wheelchair back support, they were not familiar with the features of the LWDAC back support. Thus, before they were asked to complete the ADLC again, subjects received an introduction to the LWDAC back support and its functionality. Specifically, they were given detailed descriptions and hands-on demonstrations of 1) how the LWDAC back support reclines, including the mention of any possible pinch points, etc., 2) how the adjustments are made, and 3) how the fitting to their wheelchair is executed.

They were asked to complete the same ADLC tasks as in Visit 1, but while using the LWDAC back support on their wheelchair. Following completion of the ADLC each participant was asked to complete a questionnaire regarding the ADLC. At the end of this visit, another datalogger was added to the wheelchair, attached to the LWDAC back support. This datalogger

was added to measure information such as the number of times the angle of the back support was adjusted and the angle of adjustment. Participants were asked to go about their daily routine for the next two weeks while using the LWDAC back support.

5.3.2.3 Visit 3 After two weeks, participants returned for a final visit. The dataloggers were removed from their chairs and they were asked to complete questionnaire about overall post-device trial. Following that, they were asked to again complete the ADLC tasks as performed in Visit 1 along with the ADLC and the task rating questionnaire which asks preference positions with tasks. They were given the option for payment or to keep the back support.

Table 11. Protocols

Visit 1	Visit 2	Visit 3
- Informed Consent - **Questionnaire** (Initial Intake-Demographic/WC data) - Back support Measurements and photograph of the person's wheelchair setting - Introduction to the LWDAC - Activities of daily living tasks with their own back support - **Questionnaire** (Post-ADL Course) - *Datalogger for in-home trials*	- *Datalogger check* - Setting LWDAC back support to participant's' wheelchair - Training on how to use angle adjustment - Activities of daily living tasks with the LWDAC back support (1st) - **Questionnaire** (Post-ADL Course) - *Datalogger to the LWDAC back support for in-home trials*	- *Collection of Datalogger from the LWDAC back support* - **Questionnaire** (Post-Device Trial Overall Back support) - Activities of daily living tasks with the LWDAC back support (2nd) - **Questionnaire** (Post-ADL Course) - **Questionnaire** (Task Rating)

Overall, during the four week period participants were asked to fill out a brief online survey twice a week detailing their wheelchair and LWDAC back support usage, their overall feelings

towards the device, and the effect they perceive the device as having on their activity and participation levels.

5.3.3 Questionnaires and Dataloggers

The main outcome variables evaluated in this study are changes in total amount of travel by participants, frequency of angle adjustments as determined by analysis of data collected from the dataloggers, and changes in participant quality of life, pain, and community participation as determined by self-report questionnaires.

All questionnaires were designed to elicit participants' reactions to the ADLC using the adjustment function of the LWDAC. The questionnaire used a 5-point Likert scale. It also asked participants to rate their ability to adjust the back support angle when performing certain activities. Additionally, open-ended questions were included to elicit any future directions for the LWDAC.

5.3.4 Statistical Analysis

For consistency, some categories' in questionnaire scores were reversed so that all of the results reflect responses to positively phrased questions. Higher scores indicate more positive responses. Frequency distributions and measures of central tendency were used to describe the data. Information on overall performance and comfort were measured using 5-point Likert Scale. Ratings greater than 3 were determined to be favorable responses. Information on certain activities were measured using a 4-point Likert Scale with a "No Opinion" option. A Wilcoxon signed ranks test was used to compare ratings from questionnaires given when participants were with and without the LWDAC back support. A paired t-Test Performance was used on results from

functional tasks when data were normally distributed. Quantitative data collected by the datalogger on each MWC (e.g. time, distance traveled, etc.) was evaluated using a paired t-Test to determine if any significance existed between a participant's activity levels (and the type of activity) with, and without, the LWDAC back support.

5.4 RESULTS

5.4.1 Participants

A total of 9 manual wheelchair users (Male: 7, Female: 2) participated. Among them, 8 participants completed all 4 weeks' protocols. One person withdrew between the second and third visits. On average, the participants were 37.1 ± 9.6 years old and had been using a wheelchair as their primary means of mobility for 15.67 ± 8.3 years.

5.4.2 Evaluation of Angle Adjustable Back support

In terms of hypothesis a, participants rate the LWDAC back support as superior to their own personal back support on comfort as measured, but not on appearance. Participants were generally satisfied with their own personal back supports, especially with the overall appearance and the ease of transferring in and out of chair. They were moderate in pelvis and trunk stability while dressing/adjusting clothing with their own personal back supports. Figure 16 show the median of ratings for each category.

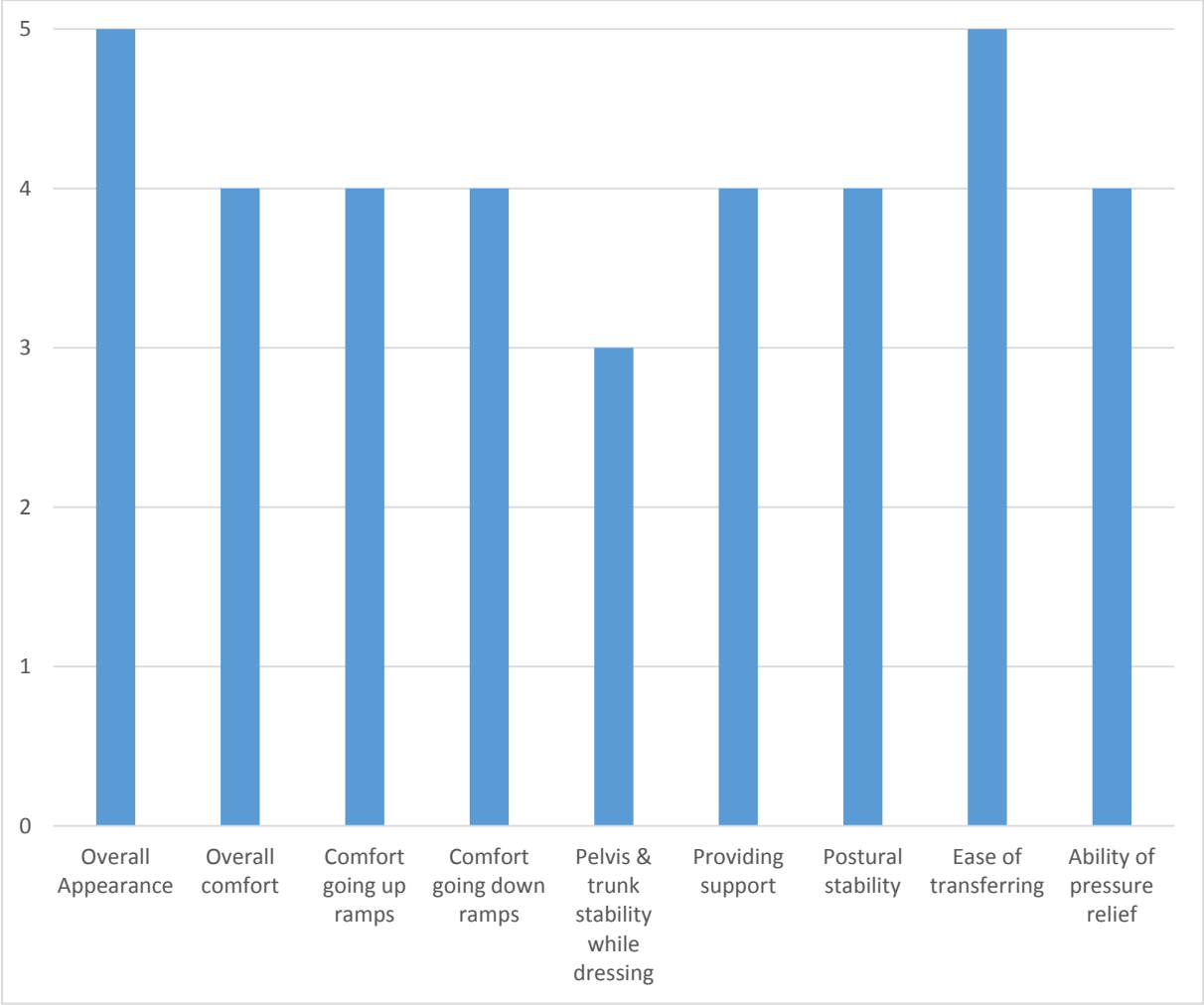


Figure 16. Median of ratings for each category with personal back support

Taking ratings greater than 3 as favorable responses, the LWDAC back support received a positive response with for appearance (4) and comfort (5). Overall, the participants had positive feedback on the LWDAC back support. Table 12 shows the specific feedback on the LWDAC back support, with the main feature being examined underlined for each question. The blue color means positive phrased answers for the statements. Arrows on the left column shows more positive, moderate, or more negative responses. Most of statements have more positive responses with the LWDAC back support.

Table 12. Feedback on LWDAC Back support

	Statements	FALSE	TRUE	Missing
↑	I like the way the LWDAC Back support looks on my manual wheelchair		8	1
↑	Based on the performance of the device, I would buy the LWDAC Back support if it were commercially available	3	5	1
↑	I benefited from having the LWDAC Back support installed on my manual wheelchair.	1	7	1
↑	Having the LWDAC Back support on my manual wheelchair improved the quality of my life	3	5	1
↑	The LWDAC Back support was comfortable while propelling my wheelchair		7	2
↑	The LWDAC Back support provided sufficient support		8	1
↑	I felt stable in my wheelchair with the LWDAC Back support attached	2	6	1
↑	It was easy to transfer into and out of my wheelchair with the LWDAC Back support		8	1
↑	I felt stable in my wheelchair while adjusting the LWDAC Back support	2	6	1
–	I felt comfortable in my wheelchair while adjusting the LWDAC Back support	4	4	1
↑	The range of angle adjustments on the LWDAC Back support was sufficient for my needs		8	1
↑	The ability to adjust the angle of the LWDAC Back support was useful in my daily activities		8	1
↓	My arm was in a comfortable position while making adjustments to the angle of the LWDAC Back support	5	3	1
↑	My body was in a comfortable position while making adjustments to the angle of the LWDAC Back support	3	5	1
–	I worried about the LWDAC Back support malfunctioning while I was using it	4	4	1
↑	I would not recommend the LWDAC Back support to other manual wheelchair users I know	7	1	1
↑	When adjusting the LWDAC Back support, I often found it difficult to find the angle that I wanted to use	5	3	1

For hypothesis b, Paired-sample t-tests were conducted to compare the performance of tasks in their own back support and the neutral position of LWDAC back support, in their own back support and the forward position of LWDAC back support, and in the neutral position and the forward position with LWDAC back support. There were no significant differences in the reaching heights and timed down ramps with any different back supports set-up. However, there were significant differences in functional reach tasks and timed up ramps between their own back

support and LWDAC back support (both of for neutral position and forward position). Figure 17 shows the mean of functional reaching (cm), reaching heights (cm), and times (seconds) of going up and down ramps for personal back support and LWDAC back support with neutral and forward positions.

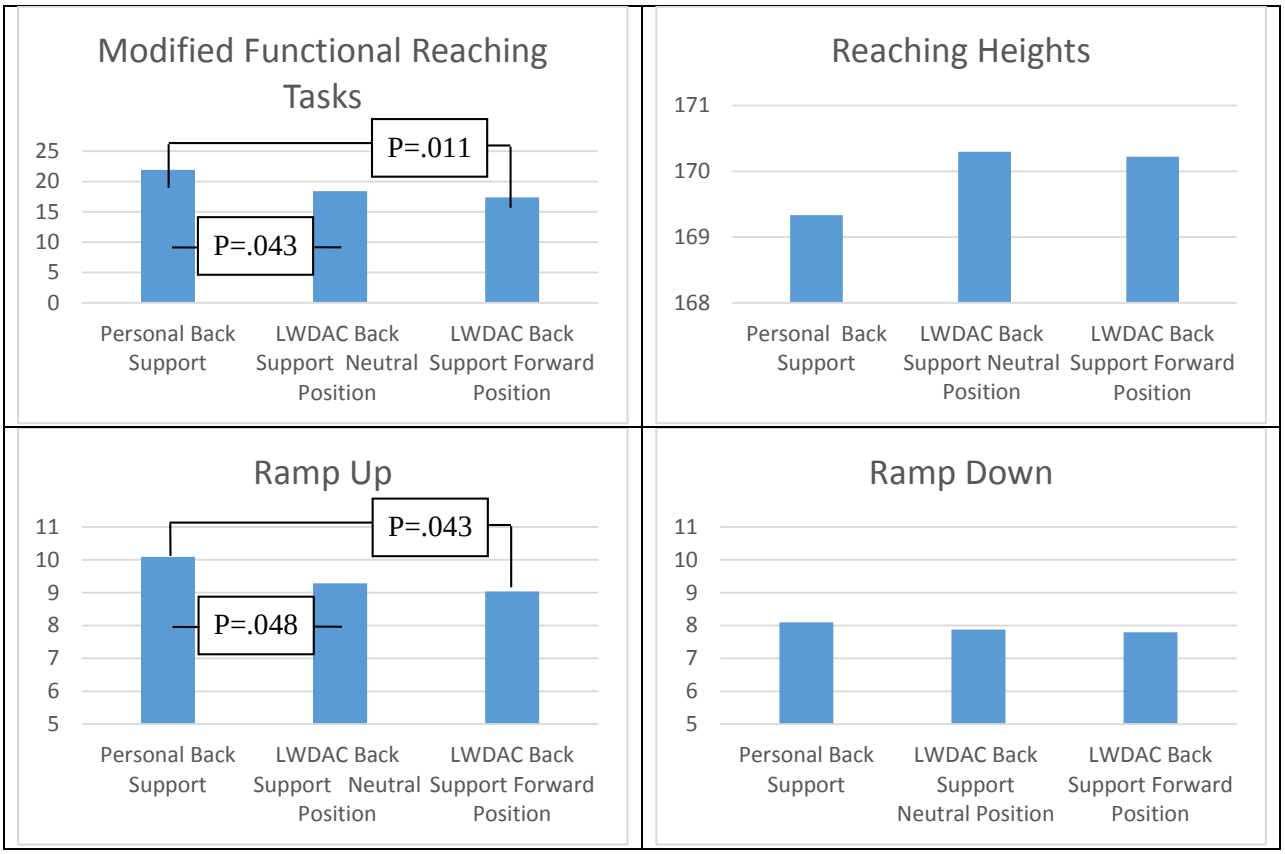


Figure 17. Each tasks with different back supports

Participants somewhat agreed that changing the angle of the back support improved their ability, comfort, stability, and balance control while doing tasks. Participants strongly agreed that changing the angle of the back support was helpful, especially with regards to comfort while going up a ramp, ability to dress/adjust clothing while they were seated, and position while seated a table or desk. However, the ratings for ability and comfort while performing pressure relief was an even split, fifty-fifty, for each agreement and disagreement from participants.

For hypothesis c, frequency distributions measures of central tendency were used to see which back support set-up was preferred for specific functional tasks. Some participants choose both their own back support and the LWDAC back support instead of choosing only one. Also, there were vague answers such as not choosing which back support they preferred to use with the option of LWDAC. When participants ranked exactly the LWDAC back support as superior to their own personal back support, the results show that the LWDAC back support was superior on going up a ramp, putting on a shirt, reaching forward, reaching a shelf above the head, pressure relief, and adjusting position while seated in a wheelchair. Table 13 shows which angled position was preferred with specific tasks.

Table 13. Superior Rank with Certain Functional Tasks

	Own Back support(n)	LWDAC Back support (n)		
		Reclined	Neutral	Forward
Which back support did you prefer for going up the ramp?	3	4		
		1	1	2
Which back support did you prefer for putting on your shirt?	3	4		
		-	3	1
Which back support did you prefer for the task that required you to reach forward?	2	5		
		-	1	4
Which back support did you prefer for the task that required you to reach a shelf above your head?	2	5		
		-	1	4
Which back support did you prefer for pressure relief?	3	4		
		3	1	-
Which back support did you prefer for adjusting your position while seated in your wheelchair?	2	5		
		2	3	1

A comparison between the time and speed of wheelchair activities using their own back support and the LWDAC back support was conducted using the information collected using the manual dataloggers. As the data was not normally distributed, Wilcoxon Signed-ranks tests were conducted. There was no significantly different distance traveled when comparing their own back support (median=1996.71) to the LWDAC back support (median=1934.36) in the in-home trials,

Z= -.140, p=.889. There was also no significantly different drive time and speed when comparing their own back support (Drive Time: median=44.45, Speed: median=.66) and the LWDAC back support (Drive Time: median=43.05, Speed: median=.75) in the in-home trials, Drive Time: Z= -.296, p=.767, Speed: Z= -1.481, p=.139.

Subjects' adjustment of their wheelchair with the LWDAC back support bracket was observed by dataloggers. Figure 18 shows usage of position for entire period of having the LWDAC back support bracket with each participants. Majority of usages was different from each participants. Three participants used 40° backward angled position, two participants used 10° forward angled position, two participants used 90° vertical angled position, and two participants used 20° backward angled position most of time.

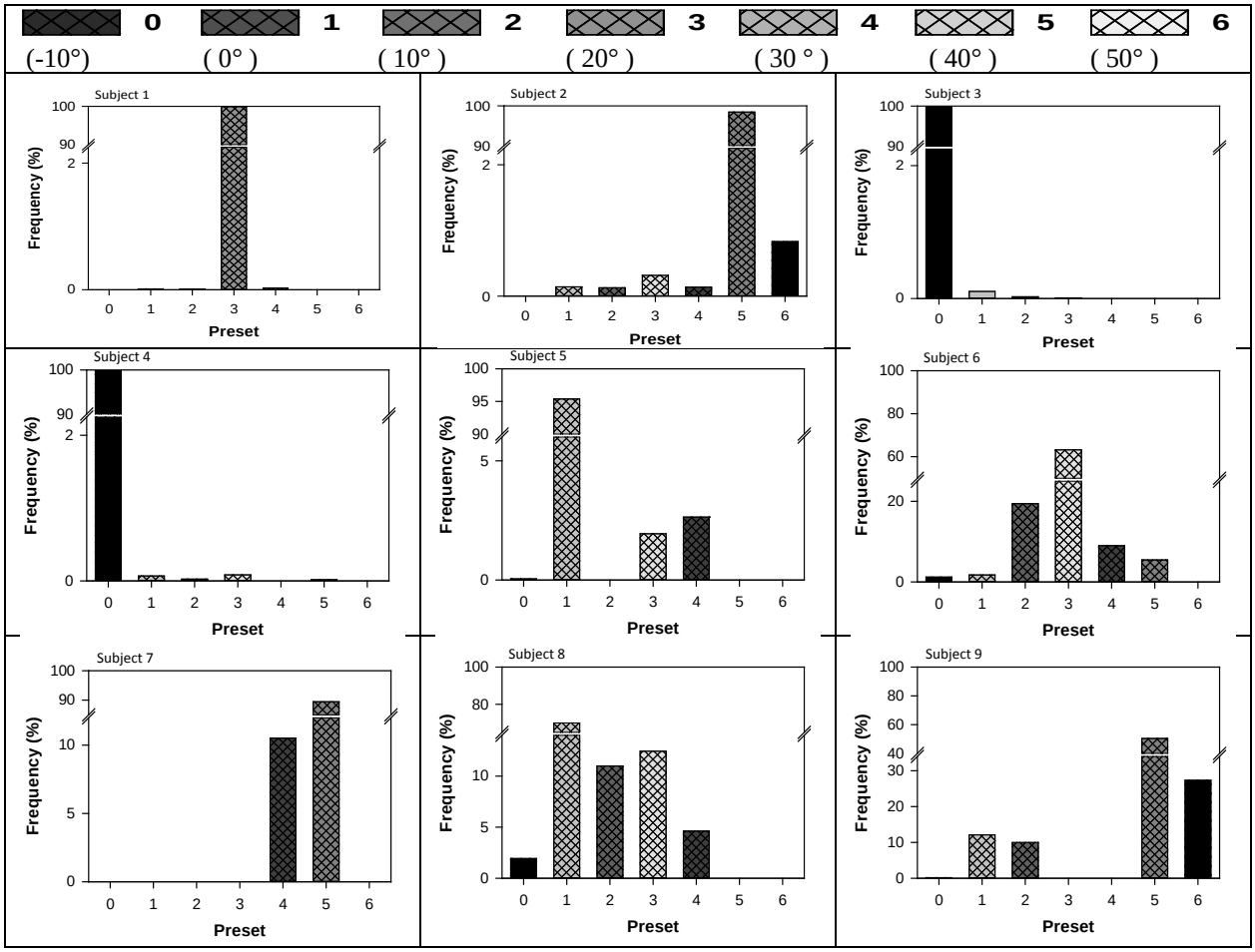


Figure 18. Each position usage for all participants

5.5 DISCUSSION

From comparing results from functional tasks, there were significant differences with changes in the angle of back supports with a modified reach test and going up a ramp. The LWDAC back support increased ability to go up a ramp, but it decreased ability to perform a modified functional reach test. Participants reported similar results, strongly agreeing that changing the angle of the back support improved their comfort while going up a ramp and that they could go up ramps in less time. Even though there were no significant differences with changing the angle of back supports with reaching heights and going down a ramp, there were trends that supported increased ability to perform reaching height and going down a ramp with the LWDAC. However, as the modified functional reach test is reaching as far as they can forward, the LWDAC forward position might not be helpful because a different setting of back support might make wheelchair users uncomfortable to do the tests.

For the category “while seated at a table or desk”, participants strongly agreed their position was improved by using the LWDAC. When people sit at a desk to work, they tend to bring their head forward. However, the recommended posture is the back fully supported with appropriate lumbar support to maintain neutral body posture such as sitting vertically or leaning back slightly [56, 57]. Sitting all the way back in a wheelchair with the LWDAC would support the body appropriately.

Participants answered they benefited from having the LWADC back support installed on their manual wheelchair, the LWDAC would provide the benefits of angle adjustment with better position and comfort when users meet different environment like using a smart phone. Smart phone has lots of functions in a small box - making phone calls to access to email, internet, navigation, and so on. People use smart phones differently for different situations. Previous other studies have

shown a relationship between seating position and biomechanics already [25-27]. However, those studies were conducted in different settings like separate pieces such as having laptop, navigation or phone. The LWDAC will allow the user to change angles to maximize biomechanical benefits for different situations.

Unfortunately, even though an adjustable back support does show benefits with respect to having options and results of functional tasks, wheelchair users may not find it useful at first. First, they are used to having no option to adjust wheelchair back support setting for different environments. Therefore, they might not think about back support adjustment before they automatically go up or down a ramp. Second, they are used to doing tasks without changing settings. Therefore, they automatically adjust their posture instead of making a back support adjustment, even though that posture change may be bad for them. As a result, even though the LWDAC is beneficial, it is hard to change wheelchair users' behavior in a short time, especially given the study's short duration and the short time it takes to do the tasks. It would take some time to use LWDAC options appropriately.

Dataloggers collect positions every 0.01666 seconds. Even while adjusting angles and finding proper angles, those positions were collected. Even though they might not be in a wheelchair, all positions were collected, too. Therefore, it was hard to track exact numbers of adjustment. With this consideration, the usage of all positions were calculated to see how much each positions were used. The positions of 10° forward angle and 90° vertical angle would be used for daily life and seating at a table to work as it mentioned previously that participants strongly agree their positions were improved using the LWDAC from questionnaire. Other backward angled positions could be used most of time while relieving pressure because participants answered backward angled positions were preferred position for pressure relief about superior rank

questions. Wheelchair users would be in wheelchairs except sleeping, so the LWDAC back support could help using wheelchairs for a long period with backward angled positions which give relieving pressure.

Overall, current design development needs to be undertaken in response to participants; specific feedback on arm position and difficulties adjusting the back support angle. Also, developers need to consider what options to offer with regards to increment of adjustment. The current design has -10 degree to 50 degree adjustment capability, allowing for adjustment at 10 degree increments. However, when participants used the back support for long periods of time, such as when sitting on a table, resting, or changing clothing, they do not need such fine adjustment. Therefore, the ability to adjust in 10 degree increments may not be necessary.

5.6 STUDY LIMITATIONS AND FUTURE DIRECTIONS

This study is limited by sample size since recruitment is ongoing. Unfortunately with a small sample size, we were not able to control for type of the back support, which may have helped to clarify differences of perspectives between sling back support users and rigid back support users. More participants would have more valuable feedback on the LWDAC back support. It would be great that dataloggers were able to collect when positions were adjusted and how long those positions last. Also, it could be better to detect when a wheelchair is occupied or not.

5.7 CONCLUSION

Participants agreed that changing the angle of the back support improved their comfort, ability, balance control, and position. Also, overall trends were for participants with LWDAC to have high reaching ability and less time to go up and down ramps than personal back support. Overall, the LWDAC made a positive impression on participants.

6.0 CONCLUSION

6.1 SUMMARY

According to Chapter 2 and Chapter 3 with questionnaire study and comparison study of back shapes and back supports, we concluded that back supports design and develop are needed. Based on results from questionnaire study of Chapter 2, long term (>20years) wheelchair users with sling back supports trend toward having more comfort than those using rigid back supports. However, rigid back supports should theoretically provide a more stable base of support for the spine. Participants with tetraplegia who used rigid back supports rated discomfort for back supports significantly higher than participants who used sling back supports. Among rigid back support users, the higher discomfort rating may be due to sub-optimal shape, fit, adjustment or user preferences due to length of disability. However, wheelchair users consider their impact on function, adjustability, or ability to provide dynamic support, when back supports are selected. Designing and developing better rigid back supports are essential to provide function and adequate comfort. The results of the Chapter 3 present individuals have different back shapes, and commercial products may not be able to provide proper support to fit every individual. The disparity between the shape of the shell and the shape of an individual wheelchair users' back results in minimizing pressure distribution to cause skin integrity. Therefore, a wider range of contour rigid back support shells is essential to provide appropriate postural support and prevent the skin breakdown.

An angle-adjustable composite back support has been developed with results of Chapter 2 and 3. It has angle adjustment by single hand operation while in a chair that also provide the

benefits of rigid back supports. Findings from Chapter 4 shows the angle-adjustable composite back support that successfully met ISO testing standards was tested and rated by participants in two focus groups. Most of the subjects agreed that the angle adjustment provides comfort, support, functionality, and better posture. Overall, the device had a positive impression on participants. However, improvements on the operation method and usability were suggested.

After focus groups, the LWDAC back support has been developed and tested by ISO standards to make sure the device qualify for in-home trials. Participants agreed that changing the angle of the back support improved their comfort, ability, balance control, and position. Also, overall trends were for participants with LWDAC to have high reaching ability and less timed ramps than personal back support. Overall, the LWDAC made a positive impression on participants.

6.2 FUTURE WORK

The questionnaire was not sensitive enough to detect differences in discomfort based on back support. The questionnaire included broad questions about overall discomfort, and reported issues may have been caused by issues and components other than the back support. Wheelchair back supports are important for enhancing functional abilities, so future work should examine the long term functional outcomes of using back supports. It would also be helpful to design a questionnaire to ask participants about their reactions to comfort, appearance, and texture/material of seating systems, as these also play a role in back support selection. However, the inherent limitation to questionnaires is they only allow for the collection of subjective data. Objective data such as performance evaluation would increase validity and reliability and complement the subjective

data. Therefore, future studies should also incorporate performance tasks which correspond with questionnaires.

Based on the back scanning study, although nearly 20 bony landmarks were collected, there was a need for additional landmarks for analysis. Increasing the number of bony landmarks, especially on the spine, could have allowed us to obtain more detailed information about spine shapes. Also, participants' backs were scanned while they were positioned in a postural support frame or a massage chair. It is likely they might have various postures during sitting and functional positions based on their own individual wheelchair setup which differ from the scanned posture. Therefore, future studies need to evaluate different seated postures, including the participants posture in their own seating system.

Based on feedback from wheelchair users with the LWDAC back support, design issues for improvement of usability need to be addressed for the future. It was challenging for participants to determine whether the device was ready to adjust angles of the back support (disengaged) or not (engaged). This is a feature that should be added to future iterations of the device. Additionally, while the string that was used to disengage the locking mechanism allowed for pulling in any direction, subjects still reported it was difficult to use. Therefore, the mechanism of activation for adjustment need to be improved for ease of use.

The current LDWAC design permits adjustments from -10 degrees to 50 degrees of extension with 10 degree increments. However, preferred adjustment sets may be needed by users instead of every 10 degree increment. They would use for long period of time such as sitting on a table, rest, and changing clothing. Therefore, it might need to have -10, 0, 10, and 50 degree instead of every 10 degree increment, when they use for those situations.

Recruiting manual wheelchair users to participate in-home trial of the LWDAC was challenging as the backrest support shell used in the study was rigid and inhibited the folding feature when on a wheelchair. To be able to allow for the wheelchair to fold, it is necessary the system be easily removable. However, for the in-home trials completed in the study, users did not have the option to remove the back support unit from their wheelchairs. To accommodate users with folding wheelchairs, one of most important design improvements would be the quick-release mechanism for attachment of entire system.

The LWDAC back support only allowed for adjustment in the angle of the back support. However, the back scanning study revealed the ability to modify the shape of back supports is also essential. As technologies develop, 3D rapid prototyping is applicable to provide different shape inserts in a short time. Current 3D rapid prototyping machines allow for different material textures or rigidities. Therefore, using new technologies would be another consideration to provide comfort for wheelchair users. Also, length of back support and height position of back support would affect comfort and function to wheelchair users. Most commercial back supports have vertically flat surfaces and recent trends are towards shorter backrest heights. To improve comfort back supports could be modified to allow for adjustable vertical positioning to match the lumbar lordosis curve of the user. Such adjustability could provide improved structural support and comfort.

For the evaluation of the LWDAC back support, many new questionnaire were created instead of using existing questionnaires. The new created questionnaires were relatively easy to analyze and straightforward to collect information, but lack validity, reliability, and feasibility. Therefore, future studies should either evaluate the psychometric properties of these new questionnaires, using existing questionnaires that may be less specific to this particular device but

are validated for assistive technology in general, or use matched task measurements which could provide objective measures to supplement the questionnaires.

In addition to design changes, it would beneficial to measure the user's center of gravity and complete pressure mapping with back support adjustment. Current studies measured comfort and ability with changing back support angles. However, it would be beneficial to see actual movement of center of gravity and distribution of pressure with adjusted angles of back support.

APPENDIX A

FOCUS GROUP QUESTIONNAIRE

The following questionnaire was made for the evaluation of the LWDAC back support for focus group. The questionnaire is for wheelchair users.

Subject ID:_____

Lightweight, durable, adjustable composite (LWDAC) backrest:
Focus Group Questionnaire

Date: ____/____/____

Age: _____

Gender: ☐ Female ☐ Male

Veteran: ☐ Yes ☐ No

Ethnicity:

☐ Black or African American ☐ Asian ☐ White or Caucasian

☐ Hispanic or Latino ☐ American Indian or Alaskan Native ☐ Native Hawaiian or other Pacific Islander

☐ Two or more races

<u>If you are a wheelchair user:</u>

Injury Level or Disability: _____

Date of Injury or Onset of Disability: ____/____/____

What is the make and model of your primary wheelchair?

Make: _____ Model:_____

What is the make and model of your current backrest used on your primary wheelchair?

Make: _____ Model:_____

What do you like most about your current backrest? Please explain your answer.

_____

_____

What do you like least about your current backrest? Please explain your answer.

_____

_____

What is the reason you use your current backrest?

_____

_____

Subject ID:_____

If you are a rehabilitation professional:

What is your professional background? Please check all that apply.

- ☐ Assistive Technology Practitioner (RESNA certification)
- ☐ Assistive Technology Supplier (RESNA certification)
- ☐ Occupational Therapist
- ☐ Certified Occupational Therapy Assistant
- ☐ Physical Therapist
- ☐ Physical Therapy Assistant
- ☐ Physiatrist
- ☐ Rehabilitation Engineer
- ☐ Rehabilitation Tech Supplier
- ☐ Other: _____

How many years of experience as a rehabilitation professional do you have?

- ☐ Less than 1 year
- ☐ 1-3 years
- ☐ 4-6 years
- ☐ 7-9 years
- ☐ 10 years or more

We are interested to know the range of backrests you provide and the relative proportion. Please, fill in the column to the right with the percentage of the backrests you provide for manual wheelchair users, and add any style(s) that we have not listed in the 'other' row. The total percentage should add up to 100.

Rigid	
Sling	
Adjustable – Tension Sling	
Custom-molded	
Other:_____	
Total Percentage	**100%**

We are interested in learning about any concerns or complaints you have heard from wheelchair users about currently available backrests?

_____

_____

_____

If yes, which style of backrests are most concerns/complaints related to? (rigid, sling, etc.)?

_____

_____

_____

Subject ID:_____

Please tell it like it is – we want your honest opinion of the LWDAC. Only through your honest responses can we make it better. For each statement below please select how strongly you agree or disagree with the following statements.

****

1) The backrest adjustment mechanism and hardware looks big and bulky.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

2) The adjustment mechanism does not require much strength to operate.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

3) The adjustment mechanism is simple to operate.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

4) The adjustment mechanism can be operated easily with one hand.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

5) When operating the adjustment mechanism, my arm position was comfortable.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

6) When operating the adjustment mechanism, my body position was comfortable.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

7) I would feel safe and secure operating the adjustment mechanism while seated in a wheelchair.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

8) Overall, I would feel comfortable sitting in the LWDAC backrest.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

9) The available range of backrest angle adjustment (-10 to 50) would be sufficient.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

Subject ID:_____

10) The overall appearance of the LWDAC system and hardware is attractive.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

11) If the LWDAC was available for purchase, I would like to use it.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

12) If I had the LWDAC system on my chair, I would need to change the backrest angle forward and backward frequently.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

13) The backrest in the reclined position would be useful for putting me in a resting position.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

14) Changing the angles of backrest would give me pressure relief.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

15) The rigid backrest was supportive.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

16) Overall, the LWDAC system would help me with my daily life.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

17) What price would be reasonable for the LWDAC system accessory?

- ☐ $10~$50
- ☐ $50~$100
- ☐ $100~$150
- ☐ $150~$200
- ☐ $200~$250
- ☐ More than $250

Subject ID:_____

What are the three things that you like best? Please explain your answer.

1) _____
_____

2) _____
_____

3) _____
_____

What are the three things that you most dislike? Please explain your answer.

1) _____
_____

2) _____
_____

3) _____
_____

PLEASE SELECT THE THREE ITEMS that you consider to be the most important to you when you choose a backrest or wheelchair.

Please check the 3 boxes of your choice.

- ☐ Dimensions
- ☐ Weight
- ☐ Adjustments
- ☐ Safety
- ☐ Durability
- ☐ Easy to use
- ☐ Comfort
- ☐ Effectiveness

Thank you very much for your time!!

APPENDIX B

FOCUS GROUP TRANSCRIPTION

The following transcriptions were recorded during two focus groups dated August 27th and 28th, 2014 as part of evaluation with the LWDAC back support. Those are included here as evidence of the focus group.

LWDAC focus group transcription (Aug. 27, 2013)
C=focus group coordinator speaking
S=Clinician Subject Speaking

....(Inaudible)

C That might be a way
W You can... right handed....(Inaudible)
C You are saying like behind of backrest behind cane still just actual physical problem rather than string.. or only one side
W .... or still ... cables... pushing handle. ... If I felt uncomfortable, my left hand pushing it put it in this side...

C Do you think it is any benefits of having it? That is really good feedback.
W Only reason my opinion.. If I have to removed backrest, ... I have 7 years old chair that cable.
... (Inaudible)
C That's my question..
so let's say we go with cable operation or remote operation we called remote operation which is anything different from actual physical pulling the string
Do you think it is sufficient to have right here on your right or is it would your want to have on your frame or somewhere you don't have to reach back
W Anywhere other than reaching back
C Reaching back is including right here?
W oh no! I mean completely back all the way back

C Something like here
W That would be fine!
C What do you think?

... (Inaudible)

W Because you just doing this you do not have to look at it
You just have to put your hand here
C Just tap or something put you down this and spring back up reaching like this
W Yes exactly
Now you allowed you don't want to hit to a lot of ...
... (Inaudible)
W I don't want shear game...
If you see, let it not be seen
C We call it some clever device push down here... potential
You think it is better to have it underneath somewhere/here

W I think so
C Are you still okay with reaching back?
W As long as it was...I don't know... I can use it, maybe I wouldn't have a problem.
(Inaudible)
C Something we can explore maybe even push elbow on something
W Yeah. Don't you even have a lever?
That lever is put right on that bar right there that will be really convenient
Not even think about bring on set
(Inaudible)
C Do you want to sit other chair?
First of all, you have... foot supports down lower and taller cushion.
That chair is not the right chair for you to question. Let me take a step back
Backrest itself so for you.. Do you feel right that adjust ability?
So, pretend like it was no more comfortable on stand point
Maybe, just backrest it fits you little bit better but you've been using your backrest for a long time
W Yes
C What these feature help to improve do you think something you want to get or upgrade?
W Do you want to be quite honest on this?
If I had that particular backrest and I was able to adjust, I probably wouldn't use it.
Only because this is adjustable, and I actually like it down.
Reserve up higher and I probably it wouldn't make me any different now
Let me correct those words.
If when you are sitting like that yesterday leaving here or going to shopping I had to wait for somebody come and get me.
I will take that
C Adjustability?
W Right
C Okay
W Just rest my back because butts are already there and my back is there
Even if I was able to leaning backward little and bring myself back
You are sitting on ball in this chair
Both be still connected on my butts are tired and back is tired.
W butts are tired...
(Inaudible)
W Exactly right in your ...
That would be... because I would oh I forgot I cannot see...
... was back sit little
C Okay
Do you feel like we would improve the seating system to go..
W I think so
I wouldn't use too often

I will only use because I am tired and I have been in chair too long, because I am..
I do within this chair from sitting up straight when I expect
I weight.. leaning back little bit
just take pressure off on my butt and back

.... (Inaudible)

C back little bit...
Digging on you back little bit on leaning?
W No not at all
W This back is actually comfortable. Yes it is.
C So, is there any example of getting dress up and down...?
W Undress I am pretty much do this unlike this
I am never lean using this... ,and the put on actually don't get dressing...
But I can get undress I never use this because I am doing this
C Okay
W Some people not on dress in their chair?
C I think
Maybe not all
W Are you dressing in a chair?
W Yeah
W Yeah? You do? Okay man is more...

C So, different questions for you guys.
Since you have experience of rigid backrest
So first of all, compared to sling backrest do you like the support provides?
W Yes definitely
sling.....
(Inaudible)

C What do you think about rigid vs sling?
W I like the regular sling... wheelchair
This one is... Maybe I just used to it
C You just focus on the backrest the chair does not fit well
Backrest just thinks about back support
Is that better than your current? You feel you want to rigid system you still prefer to using sling
W I do not have problems before
C what features about sling ... rigid make it better?
W Probably... that is stiff...round for it
I am T3 and T4 injury class is hard...
It is hard for all the way up
W Are you slouch?

W Yes

W You know why I see your back, and I do not know what to do with that
But want you turn around I can see your support on your back
If you continued that you already have curb for and your back
That is comfortable because you are used to it
Looked I am seat that is just how
You can tell when you seat in there you can turn
I can instantly see the support different than shear

C Yes it is interesting thing
It's probably worthwhile for both you guys little more look at something fit perfect
So one of thing is hard to image system like that we don't... chair is not fit perfect
The backrest size there is different height and there is height and width adjustable so you probably have benefits when you have more better fit

W I was going to....

C It would be more focus on your lumbar. You still have upper ability up here

W Do you like that

C You can get really short one
There are 30 different sizes

W Because I prefer a lower one, but with some support?

C You should probably need to go back to clinicians

W You know what... the clinicians said "Do not change backrest..."

C I think your back is good I might just person find something just moving around maybe it is not perfectly adjustable but..
So given you said sling preferred... sling over rigid right now you have mobility
Do you think allowing user adjust that position make more attractive having a rigid backrest versus traditional one which you can't move around

W ... (Inaudible)

C Is that more attractive or is that mean better product? Do you more likely use?

W no

W No me neither. I mean...

C Earlier you said there is a remote control would be convenient

W Oh! You are talking about hands

C I just talking about only feature

W oh okay. Definitely versus to string?

C Versus to rigid..

W Oh right...

C Yeah. This is one of things some people just prefer sling...

W So just these are two prototype, do they come with sling types of form? Like there
That is hard and more support

C Yes or no there is a lot different variety to choose

We work with clinicians other chances sort of injury levels what type of injury what posture support
So if you are looking this direction here's all different things you get
You can also chair size top view
You can get different contours you can get flat one or you can get deeper contours.
So there are lots of different variety that way also
You definitely different dimension you can get also. Different cut outs can be different. You can have some nice brace on your spine, but cut out also your shoulder blade so still has room for motion. So this is not one size fits all.

W Okay. That is nice.
If you came with sling back like that, would you like it that
It won't support, would you still prefer using it? I mean your back your back hurts
I feel just form just it is more sling back type of...

W I like most about this is cushion

.... (Inaudible)

W It is pushing... sit up...

... (Inaudible)

C Have you compared two things the system rigid you can change in control versus this kinds of adjustability
It sounds like that inclusion of product... company...

C The other takes a way I want to this idea having a...
Everybody wants though
Reaching back here even though you can save half pounds of something on a chair rather more convenient?

W yeah yeah

C would be more convenient put a side?
Does anybody think it is an option to put under a frame?

W You said that great idea for some that doesn't have to fold a wheelchair
If you liked there, ...
If you have to take out of backrest, ...

(Inaudible)

C You have to make sure you describe when you transfer in your car took everything put on several locations in your case

W My cushion comes off for my folding wheelchair... then; I have to do one more thing...
If I had to take 5 minutes around store and it takes twice....

C In your case, it is removable then some kinds of switch on a side you can easily... efficiently...

W Right... right or left side on a back just something...

C That is good to know

I just listed things of going up to hill downhill dressing relaxing is there anything did I miss to count. Think about sitting thru a day working uncomfortable time changing postures just make sure covered everything

W I just said earlier staying seating for a long
W Yeah. I just remember I said that...
W You can get comfortable...
..... (Inaudible)
W That would work.
If you can trust that leaning back in you can actually come over particular with that position leaning back... post...
Are you in here all day? I kinds of fall asleep last night
(Inaudible)
If you are waiting and you are out all day, it back starts get tired...
Yes! That would work... you adjust chair...that leaning back post sitting that...

C Did I miss anything?
Let's talk about weight for a minute
How affects your chair what you guys... brought this idea assuming for a moment that would work
What is influence about that affect decisions to this product?
W Weights...
C Weight sensitive on your chair
(Inaudible)
C I mean if I said....
(Inaudible)
You know what I am saying is you currently have the current system rigid backrest
If I told this is 2 pounds,
(Inaudible)
How about you? Would you rather to have adjustable back support or you just stay with 2 pounds?
W I would say stay with 2 pounds
Because I do not know just because other people put in chair in and out at the car
The weights would like make difference. Because it's already ultra-lightweight chair pretty much...
Nobody get frustration... because I move a lot in and out of car
Somebody needs.. I can take the wheels off, put that back up for taking cushion off put that back up for taking wheels off and your body in... too many things... just thinking about somebody wants instead of I don't travel I don't put in car in and out myself they do I am concerned that again.
C How about you? ....2 pounds...?
W No...

C How heavy are we?

(Inaudible)

In terms of.., there are sorts of two levels of weight increasing.

First is the putting even carbon fiber backrest. This is carbon fiber backrest. Still weight more than sling backrest. It's not going to weight more than your backrest.

Yours is aluminum. This will be lighter, so probably you can get lighter backrest.

Maybe you get a heavier hardware. it will be the same weights.

...(Inaudible)

W Okay. That's insane. mine doesn't come up. it sits it raise seat.

... It will make differences when you weights a chair

C No. You have removable hardware on your chair, but you don't use it.

So that's actually you are in dimensions.

W ah...

W For me to add it, it is ....

(Inaudible)

W Is it too late to get a new...

C No. You can just change hardware.

Can I ....

(Inaudible)

C All right! Are there any more questions, comments or feedback?

W No

C Go head and fill out the final questionnaire.

LWDAC focus group transcription (Aug. 28, 2013)
C=focus group coordinator speaking
S=Clinician Subject Speaking

C Let's just go around table talk about what would you like or dislike the adjustment system.
W Don't do aesthetic?
C You can bring up aesthetic, but I also... I just said earlier I don't want you focus too much on it because...
W I am trying to make a joke... because last time...
C I will show a picture (ADI's New design)

C What would you guys like?
W Different adjustments
W I like a lot back only
C Is that positive?
W Oh yeah I mean obviously having adjustments seating that is design to do and being able to user for different positions I think being able to be useful dressing things like that so that is not fixed one position in a backrest
So obviously adjustment is big ....
C So for all you guys feel like the adjust functionality adjustment help you.

W Yes Yes

C Hard for you because you are using sling which probably...
Do you think so?
W I used to sling before that but I hate those things... it bent over use all rounds out I put fillers back there. Horrible
C Can you use you tried rigid backrest before do you think this adjustability would make it more likely for use rigid backrest?
W Oh yeah! I liked it. That was it.
W I liked how it adjust all the way back it just closing all that just need to be easier to be in clinic (?)
A lot of get out of it
C Dressing I have a list it down. As a feature of it, where the adjustment would be helpful?
What other things do you think?
W I liked how comfortable I was.
C It is sort of day to day changing it to adjust comfort
W Probably somehow bathing washing makes adjustment
W Job at the computer
W Changing the position
C During work
W I like back forward go up the ramp
C So it helped position pushing it backrest

W Tension my off back
C Is that during up a ramp? Or just in general?
W In general
W I think some people maybe slouch begin with it when they start going up to ramp when they leaning back even more this can help even get even neutral position going up ramp or more even more forward position up the ramp so than can be a beneficial for some people
W ... pressure off
W For some reason I like when I lean the chair lean the back I like how much power (?) in like How much ability I have stop going down the hill
W Also it gives different positioning
Go back in to chair mine wouldn't be like that
...One position go further to up hill
C So I guess what I understand a lot of cases brake going downhill you have to do wheelie
W Hmmm
C Because your position is too far forward you just try to stop backrest
But if you leaning back little bit you have more...
W Or also too depending on your level trunk control let's say you are going really really steep hill. Let's say you are neutral begin with now you are going up steep hill now you are (peech) forward and I know up and this situations I won't disclose
and I almost would fall forward just because such a steep hill and I did not have ability really tilting back that much unless I scoop in forward slouched so that can definitely help going down really steep hill something really trunk control gives mobility

... (Inaudible)
W Once all your weights are going down
W Yes! I feel scary.
W Same with it I am going uphill I did not move balance when I was forward at all
W Keep the chair activity... bounces leaning forward

C Before we get to the right side in terms of dislike
Can we just rank maybe 1 2 3 award this name using this applications related to adjustment
What do you think it is going to be the most beneficial?
What is the first one?
downhill uphill dressing
W I think comfort
C General comfort...
W Adjust comfort
W Adjustment comfort
C Straight comfort... that sounds like...
W This comfort really applies all those.

If you dressing, it is for comfort, you know at work leaning back that's for comfort certainly. it is little bit safety mobility up and down hill but it also provides comfort because you are not scared of come forward or leaning back that is comfort

C Let's separate that.
I know .. You are right
Let's separate comfort aspect from dressing versus going up and down.
So comfort is at work you are working on computer doing something else you are at home watching TV sitting in a chair you adjust/ use this feature to adjust comfort
Let's assume is that still number one benefit you get

W The main I think come up with

C Okay. Let's stick with it. That's great.

C What's the number...

W It is too expensive charming wheelchair like that

W Which is comfort some...?

C Okay... great!
What is number two thing for using the other benefits the second downhill uphill

W Dressing? Hygiene?

W Dressing Hygiene

C Okay

W I like that... going up and down ramp too

C Okay so that means it is going to be number 3
People agree?

W Yes...

C What didn't like about?
What concerns you about?

W The only things I've seen for me you guys working on that kinds of positioning isn't bad for me. I can handle. Back to position pulling to string some wasn't...
The basically the only thing that I am seeing I have concern with right now there is pulling string and shipping and positioning all the way back.

W Definitely string is way too difficult.

C Couple of you, I guess you, changed it, so it can go easier.
Let's say couple things that probably never be solved with this string situation.
One is that you have to relief pressure off backrest you have to lean forward little bit you still obviously reach behind of you
Even if we got other things worked out... struggle to use string with that

W String struggle just itself kicking

W For me, I can only tell two levels. One is forward and one is back between two levels.
I don't think I can ever you give a money even hit it

W Yes, it's more feel the number

C Do you think...

So that.. This is interested bring out
Do you think that... Let's say string problem is solved
Is that enough? You just leaning back and forth move with your arm to get the position.
Do you want.. Do you think it is better to feel I am calling detent but you feel kinds of bumbumbum like three clitch back that would be better to hear?

W Yes Yes

W I was going to ask do you know how to bring it back because I am pulling back pulling
I am still figuring out where I was.
She came over to help... "Here is what you were"...

(Inaudible)

W Stable... I'd like to hear click one side of thing like that

(Inaudible)

W I was like in a few awards...
When I go up first, I was weird position that isn't feel right but then it was fine
but like I say you want keep adjust like you know how different position you said going uphill
That would get little bit of annoyed just keep adjusting that and it not working

C Yeah. Okay

W Do more hill...

C That's agree things same back to company about that clicking
You know one position and then maybe you know it is kinds stuck release it you feel with arm click click click you know three place forward.

W Tack towel feedback things

C Great idea. Okay. Anything else...?

W I didn't... We're just talking about I just never felt like stable and always...

C Usability...?

W Even if I had it upfront near here, definitely clicking it didn't feel something hear at

W Hear where you are at

C Anything else I can skip from positive stuffs we just look thru adjustment.
This is kinds of shop mechanism something else am I missing
Like there is nobody that provide clinical care do you provide chairs?
you guys are same level

W Me? OVR just sponsored the choice half go to CAT or half go thru vendors Blackburn's or ....

C One other things we heard that people from is that this could be useful for setting a chair taking measurement in the clinic, you basically have one this like a dial line maybe not getting the adjustable back support system but you setting up the chair

W You know that is really good point
Because I know someone is especially if someone is going from adjustable back to rigid frame my back is completely rigid and it is almost guessing game of well this is height my position in my chair for a long time so I like that I want to go this degree but some might not know that they might want try out little bit so they might be able to use their backrest and try different positions to see more comfortable then say okay If I want to go with rigid back rigid frame this is angle what I want that is good start with it.

C Okay

W Better condition... backrest... adjust all the time... they feel like in it ... something before even they order... that's little better of idea

C This is maybe a question whether or not this product should be part of chair maybe ...
Should be a part of chair upgrading your current system or is it possible that adjust your backrest perfectly they use in clinic they evaluate it and adjust existing backrest hardware dialing perfectly

W Is that how more level?

C 10 degrees.. Maybe you want continuous adjustment

W Yes...

C 5 degree

W Anywhere during that ... find best seat angle

W They are using it as a measurement, then you probably would continuously adjustment possible .....
(Inaudible)

C Anything else...?
Other thoughts related to

W String itself you said it is going to be another type of string
Maybe something not like so thin just different

C Little bit more

W Substantial...

W Yes

C Okay

W Maybe it cause a problem to adjust

W I know... this is more talking about function here than aesthetics doesn't look as nice as if you have simple hard as long I know it is stream ... ware it doesn't look like bulky lots of function

C I want to show something There is the quick-release lightweight... similar mechanism just smaller package,
so this is quick-release, but this is basic... this is the system pops out. Adjustment is similar mechanism
This can be aesthetic colors in computer.

W String should be more substantial

W Thicker string?

W Something

C Maybe even like rubber handle middle of something

W Yes

W Yes something like that. It feels it needs to work for it

W Too coarse for some hands... well if it is lighter to pull, then it wouldn't be issue. but...

W It also if whole string not gonna actually give you bounce you need, maybe it is not right there it is not going to be a middle that is not going to be middle that is pulling in middle

yes sometimes we pull here ... maybe little bar...

C like a form or ... rubber something like you can grip

W You pull there

W Even what about like engage or disengage of switch on each side instead of having a cord pulling single in middle about you just switch back click click and then it is engaged so you can move around whatever you want you get it just right engage that way

C Hmmm

W I know that is completely redesign whole concept...

C That is not the reason. That was earlier version of that
One of tricks... one of concerns that came out of that since these two separate the only thing Two mechanisms is connected by string right now
if you have locking mechanism on right and left and unlock both adjust lock one side and put a weight to lock the other one and twist little bit and it tweak the backrest cause the trouble

W Yes

C Now your suggestion of ... this is what I am going to address next is the remote handle that could operate that way meaning that you could have on so remote handle pulling both side you could have flip on and release it you find sweet spots and flip off you do not need to hold anything it is spring loaded working it is pop

W Right Right

C So there is an option for that I assume remote handle there is some people work fine, but for others there is tendency... there isn't good example of this... if you have to lock two of them locking one is kinds of sufficient? we are concerning about also another possible issue somebody just need one lock all the time rely on just the other one then the backrest little floppy one side you don't care because since it is a lot easier to unlock only one side and then it is crazy stress on backrest and it will break
So we do want to make sure both side locking and unlocking at the same time

W Okay

C But it is good point we talk about usability like what you said is important sense
it kinds of speaks this idea you don't like the idea when you release the cord automatically lock you could still develop a lever for instance basically either flop down both string at the same time and you release

W Even what about one pulling a string release it and then it is engage and the second pull locks the place

C Yes...Hmmmm
That is interesting thing um

W Then now is you don't have to hand back there ... you know....

C so it is kinds like ballpoint pen

W I just gonna say just exactly like that

C You pull it once click and second time latches back then

C When I was a kid, I was ...

W Always twist my mind, cannot figure it out.

C Okay
The other option was sort of a...
Okay cool...
Let's move on to this remote lever somewhere on wheelchair...
For you guys, would you choose to have remote lever?
But say you didn't need one like you don't need a for a moment just think about
You don't need removable backrest you're
Would you want a remote lever? Let's say remote lever option is that have it down on a frame or something
You need to reach one place it can either be like you suggest floppy it on or release it or you just spring lever this is spring loaded you pulled it.
Would you prefer the remote lever?
Over spring release just kinds of prospected?

W Myself, whatever balance ... work out best
C What design wants for you?
W I mean string... string... string is don't pulling a string it's in the middle right or left work with us...
C Assuming you got reach retry to middle of your back pull up and down
W Right
There is a lever on my side that will be much easier than pulling a string
I will take remote
C So the consequences of remote are that's little more weights to chair it would be break but usability stand point is that more important than that
W I will probably say you know if the string is prospected where just pulling one click engage and adjust and easy click I mean it is not hard for me to reach back here it is pretty easy to do, so it prospected it didn't use frank for a cord because again I am always want that less of half lever system more things break down that's more weight for a chair so a cord is very easy to use for that
C Okay
W I am exactly around
I think the cord is probably easier but listening time like I said pass things I don't like a lot of stuffs on my chair I like minimalism amount of I don't more things to break get dirty just I rather to have string
If it is prospected, it is right this?
C Yes
W Yes... string I can see how I can be affected how affect could be
C Okay
W String also...
W Other one is a lot easier, but i think ....

C Okay
Let's talk about other people somebody that maybe higher level injury
W I think it will be harder for somebody to reach back all the time.
....(Inaudible)
C You think that the product is still really valuable for somebody higher level injury
W I think this is special needs kind of for higher level injury it depends on especially.
I know a lot of people have the chairs reclined that is providing people considered to make difference
W Yes especially for going up and down hill because I just mentioned before someone has really really need trunk control if you are going down even mild slope you instantly change angle of backrest so that push forward if you going downhill so they may not have disability to hold self up and the other way too if you go up hill you know chair can be more tipsy so back and support that little bit more ... moving up the hill so...
C So that the moral of the underlying things it needs to work on...
because the product is really helpful somebody higher level of injury also hard to reach back
W ... lost balance...

C Actually sort of undermined the problem kinds of solved in terms of balance
W ... (Inaudible)
C What about removable release removable system so we are talking about folding wheelchair like yours?
Maybe somebody higher level of injuries you know the question is do you try to would be accepted? what if the product adapted the lever is down here but you had removable backrest you have one or two choices either make sure backrest never those apart from the chair because of tether the cable or that handle comes off the backrest it is another thing you have to do
Like one option here is the company just decide listen we are not gonna offer remote lever with removable backrest system only have a cord so the question I have for you guys
Is that should I do that or is it too converse to have the removable handle?
W I can think that definitely get pretty converse because it definitely one thing that's converse begin with you gotta take cushion off you gotta pull the chair you gotta get in when you go the place when you are in hurry you know so you don't want to spend time more than what you have to do so if you got this removable backrest removable lever so then you put backrest in then you have front you got extreme all the way down thru get that place in secure however when you secure it hopefully without tools you got tools then skill break no here so it is not happen...
but...
W You said early
We are talking about giving that option for people with higher disabilities then that means they are not doing it depends on who do it
W Damage to it
W and

taking off...
...
(Inaudible)

W Just image if you travel and pull apart you gotta all that to in the car and get out those... you chopped ...
It is way too much

W ... a problem

C Okay

W If they use backpack they need all the time

W Yes...

W They adjust once, and they gonna adjust again it might take off all backpacks

C Yeah..

W A lot of people do backpacks...

C That is good questioning how the things going to effect

W People like me go to shopping theses are the bags never want a trouble I do not want to have.....

(Inaudible)

C Let me throw another sort of thing
Let's say that this group can design remote lever.
The other option was I mentioned is maybe remote lever is actually attached the backrest and so... what if they can come up with design let me pull out of this chair
rather than
so it calls sort of remote lever but it is not that remote meaning the it's not attached anywhere attached somewhere attached here...okay
so maybe it's like you know a piece of metal that just pin back there
if you bring the chair you hits the elbow here and then it adjusted and released it was remote because it wasn't a cord, but it is also not... we have reach right back here and it something to be in left or on the right I don't know what looks like I am kinds of coming up with little flies
maybe it is like a tap
Here like this maybe lever.

W Even if it ... some lever

W Yeah

W Yeah

W Works from the front for this

C Something like this
Where you just reach back cane

W Yeah. It fits right here back cane or close to it then it certainly a lot more accessible than reaching back here
so...

Small lever flip that switch activate both time
That can be a beneficial

C That can be a game changer from last slide had in terms of whether you are choosing a cord let's say you are going to add a half pound on your chair with lever
Right here

W I can't get a fit a further look at my back. I can see that really like ...getting in a way.

C Do you want to avoid getting in a way? Because you just wanna string cross the tube both cane
She has to avoid

W I should avoid I can not have extra

C For some so
That issue is definitely known it

W ... hard of piece of plastic almost cord...

W ... option ...

C Yes Remote things are always optional just question of whether it made you know it is convenient on side of the other with that means how all of them should be listened

W oh no you get rid of ...

W: It's definitely something consider because I think it is little bit more accessible reaching back pulling that cord making sure you are in the middle of a cord

W .... individual needs

W I am not sure how can go back and forth on that

W I think actually...

W I am fine with middle of string in the back

W I think if it is remote lever you guys pulling Velcro on your side it's like what you are talking about it is useful people with higher level of disability not without these on your side basically

W Yes I think that would be consider as far as hand function is that would be easier to use the cord grip the cord or to use a sort of lever system
so I am not so sure how someone using then a thin piece of grip arm a cord do you able to do that basically or easier to use a lever I am not so sure... work best

C Okay

W .. need for.. mean design for individual 50 bucs more

W Customizing little bit more

C If I were you know If I have one choice from designing pushing up and down or something hits with elbow which would you guys
Let's take three options
so I only don't have enough money to design all the thru... either sort a something that hitting by my elbow it is kinds of flat something slides up and down or a lever that's more like you know the pathlock lever
Which one would you guys think is has them highest probably is helping

W I think something elbow ...

W slide up and down?

W Yes. A lever definitely gets in a way back you know back there

You know my elbow swing that area when I am pushing
so yeah and then also too I can very … bump kinds of little tap there with my arm potentially
something that you mentioned something slide up and down

W Maybe slide makes the slide up and down on the feature….

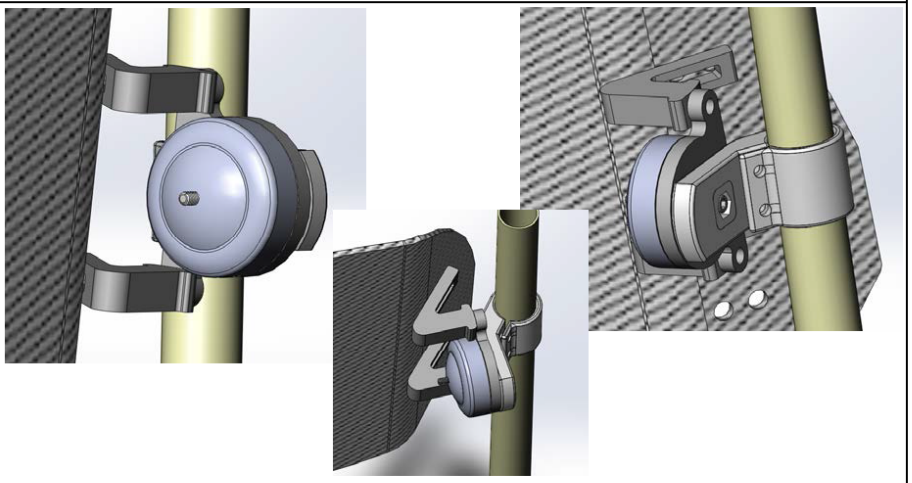
C This is really helpful
Any other thoughts considerations
Cool. It sounds like another… it was really helpful

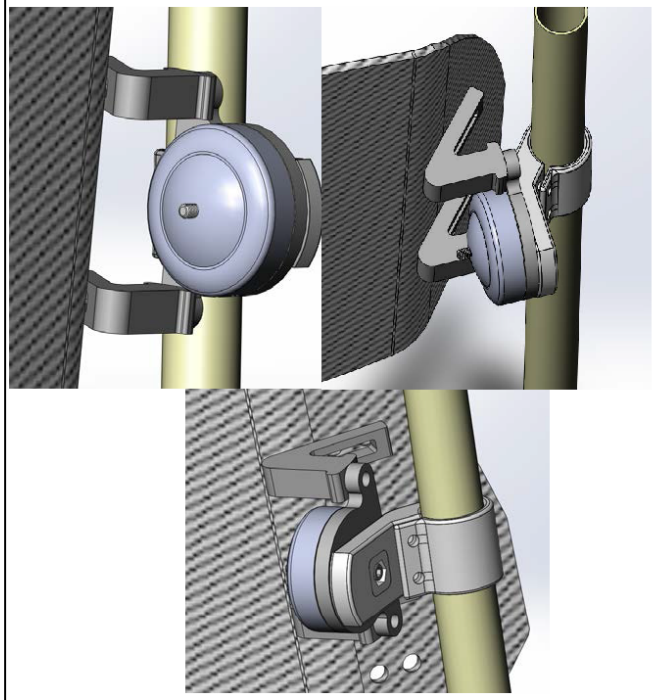
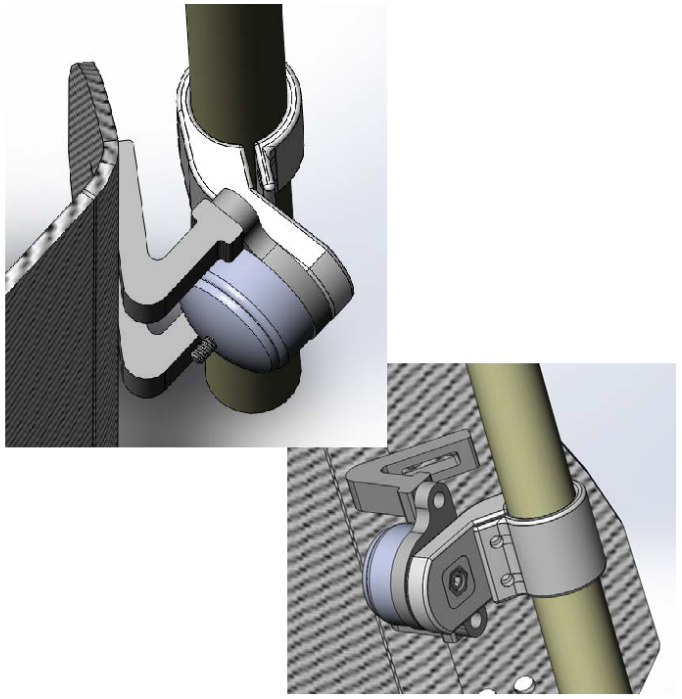
W It is for user; rather for clinicians I think it is beneficial

APPENDIX C

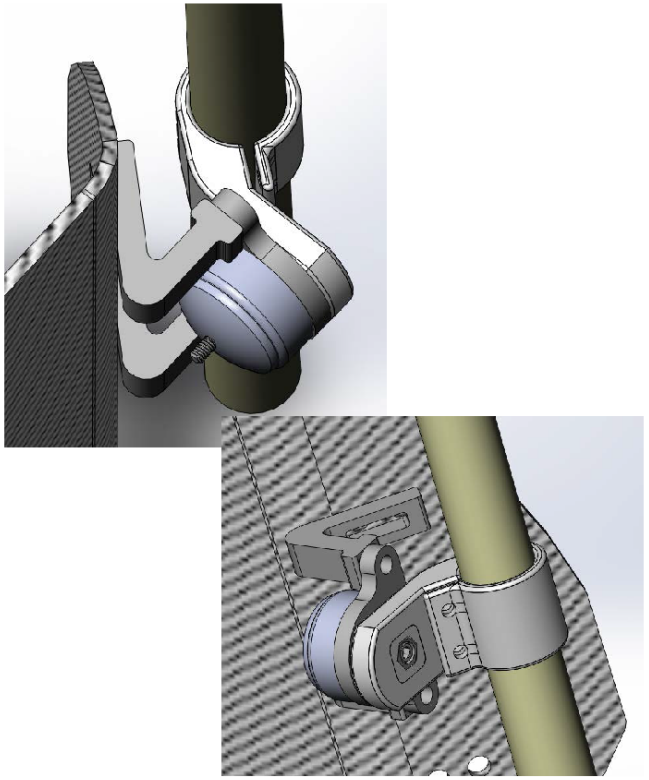
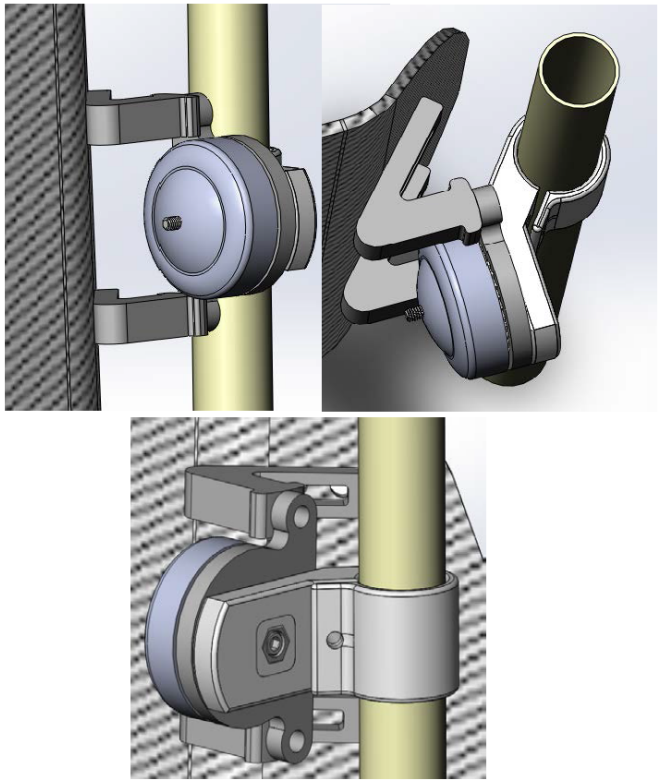
DESIGN ITERATION EXPLANATION

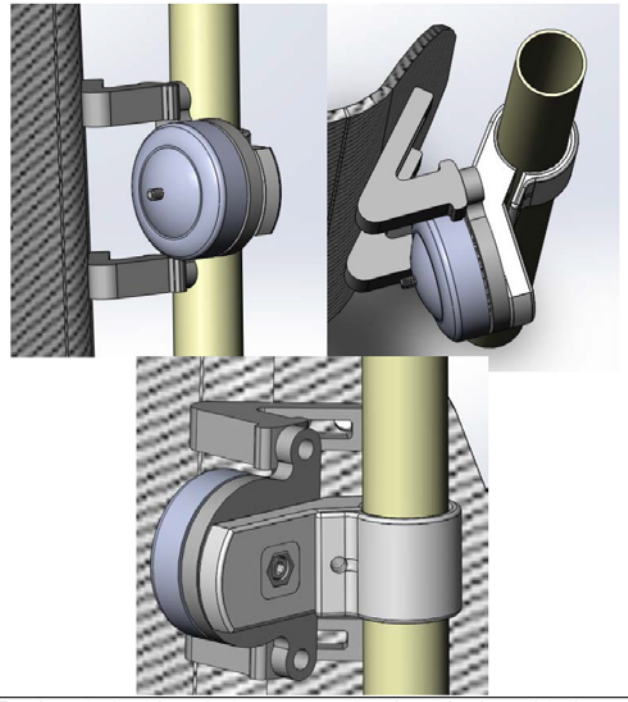
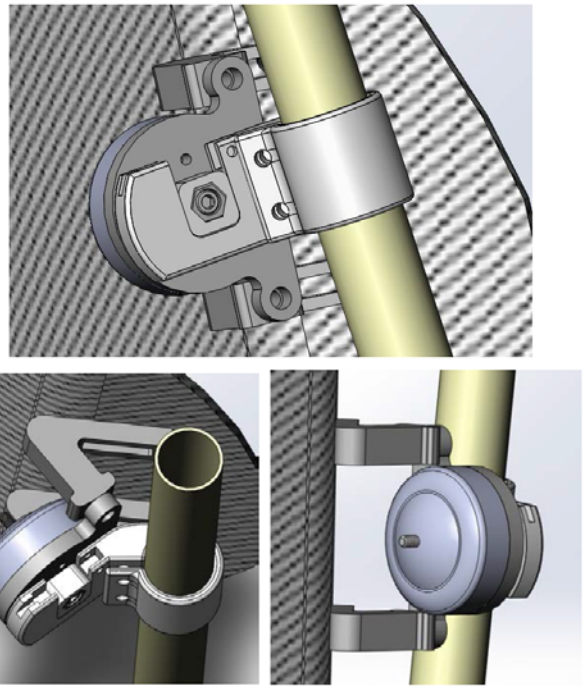
The following information is design iteration of LWDAC back support. Throughout the design process, we went through a series of many prototypes in order to provide the best end-user experience. Most of the design changes were done with respect to aspects such as structural integrity, ease of use, simplicity and aesthetics.

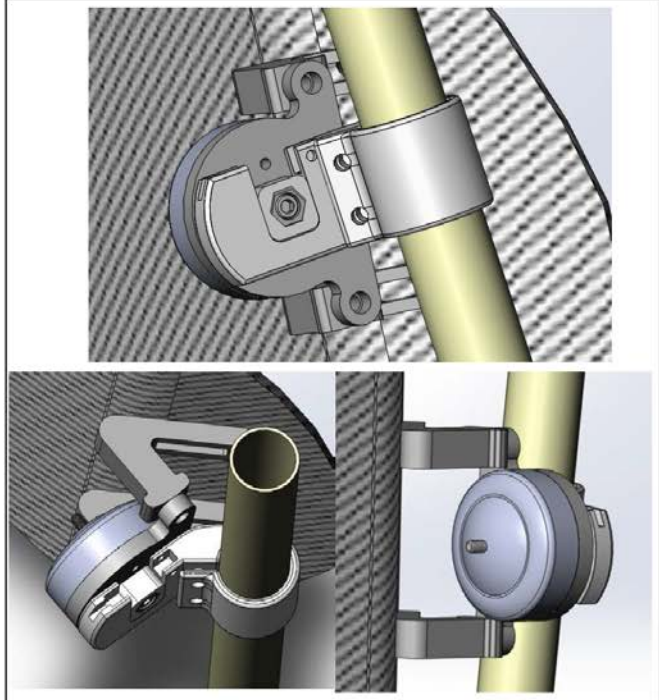
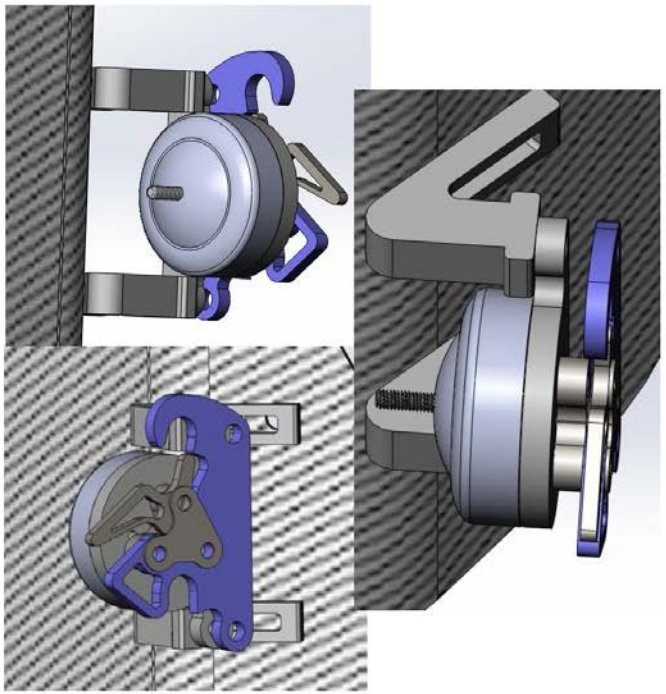
Original	A
	
-The design was changed from longer, wider rectangular-shaped pivot bar (3.75 in length; 2in width) to a much more streamlined, sleek and form-fitting piece (3 in length; 2in width) that takes up less space, while protecting the gears better from dust and debris. The pivot bar slots for fore-aft adjustment were removed from the design. The large central hole, as well as the four holes positioned around the central hole all remained unchanged. -Hex rod was shortened to eliminate its protrusion past the clamp cap that attaches to the two vertical tubes of the wheelchair frame (toward outside of chair) -It was changed backrest pivot bracket clamps (onto vertical wheelchair bars) slightly to trim off some excess material and create a more aesthetically pleasing design by changing the design from two pieces to a single circular piece. This reduces the number of movable parts etc. -Gear cap (female piece) underwent a slight design change; the gear was reduced in size and the top was also slightly altered aesthetically to look more appealing -Gears (with round) were slightly smaller. Also, another larger hole was added to the central hole, but it was not drilled down all the way to facilitate the other gear, which limited recline angle, to fit inside for a better fit. -Moving gears were also changed to have a slightly raised part around the central hole, in order to make a better fit with the other gear.	

A	B
	

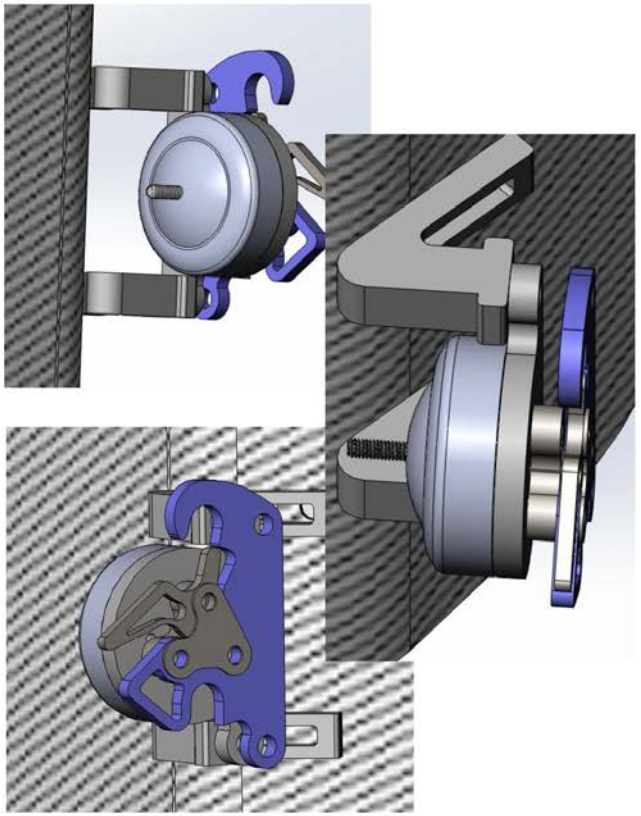
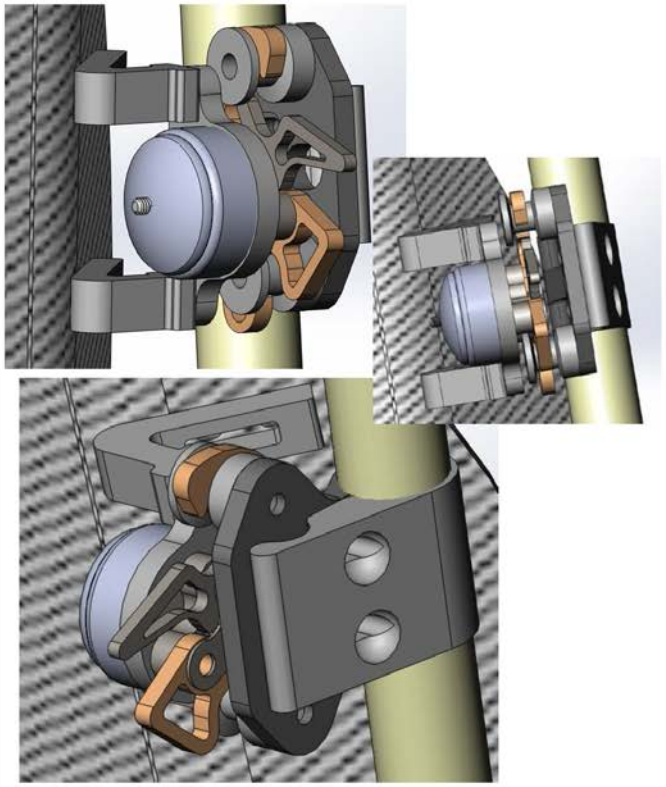
-It was modified the pivot bar to a smaller one with smaller size of gears (1.7” to 1.25”). The overall design concept stayed very similar with one minor change to make the tapering around the side holes.
-The backrest pivot bracket was shortened the end into a slightly smaller object in order to accommodate the resizing of the gear-lock gears and pivot bar
-The redesign of the gears and gear-lock system caused the entire mechanism to be shrunk to a more manageable and less bulky.

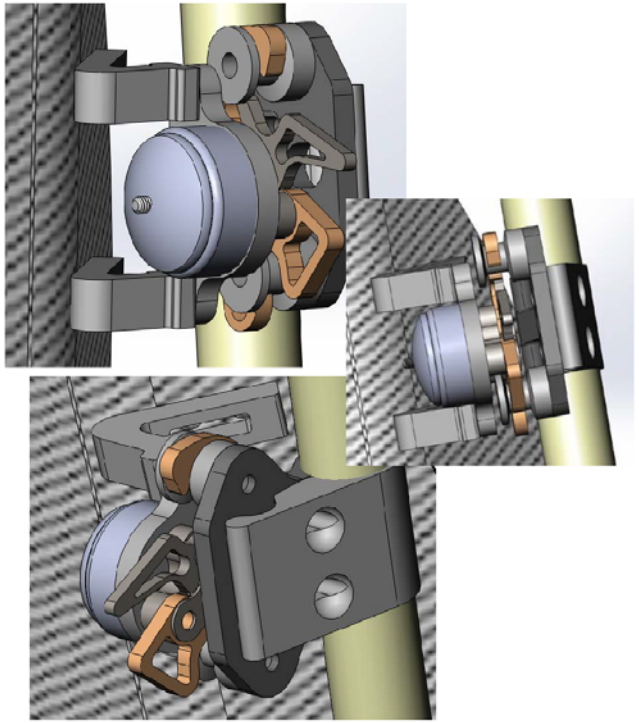
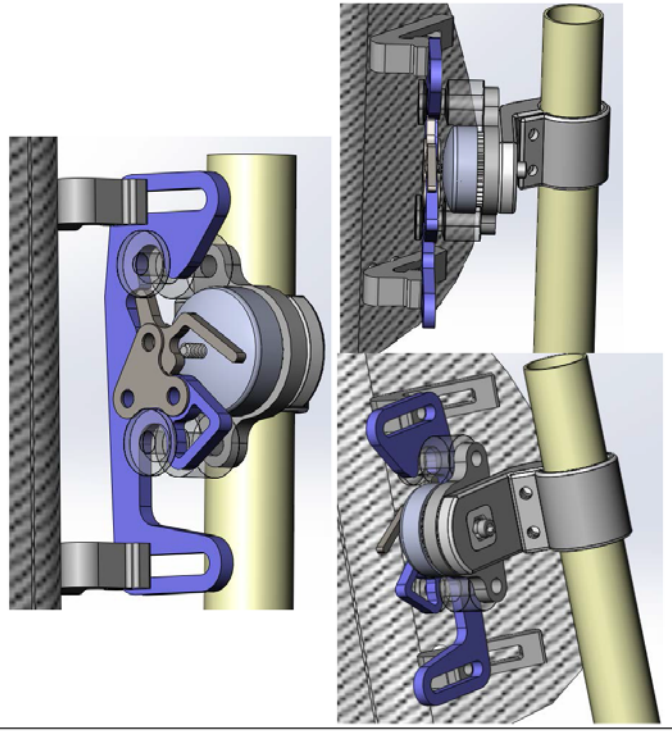
B	C
	
-The clamp part of the backrest pivot bracket was redesigned to have one screw hole instead of two holes. This makes for quicker assembly/disassembly. -Pivot bar was slightly modified again, back to the shape it was in Concept A. -Ultimately the design was made a little less bulky and better aesthetic.	

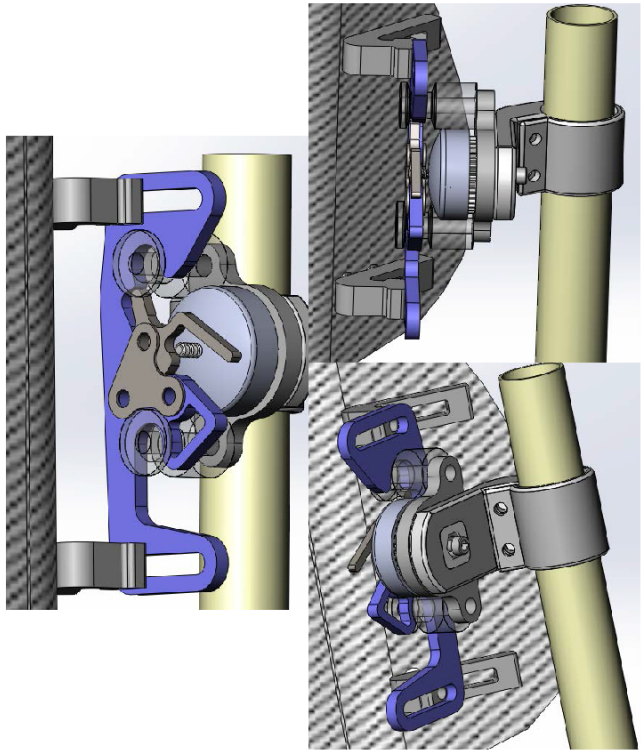
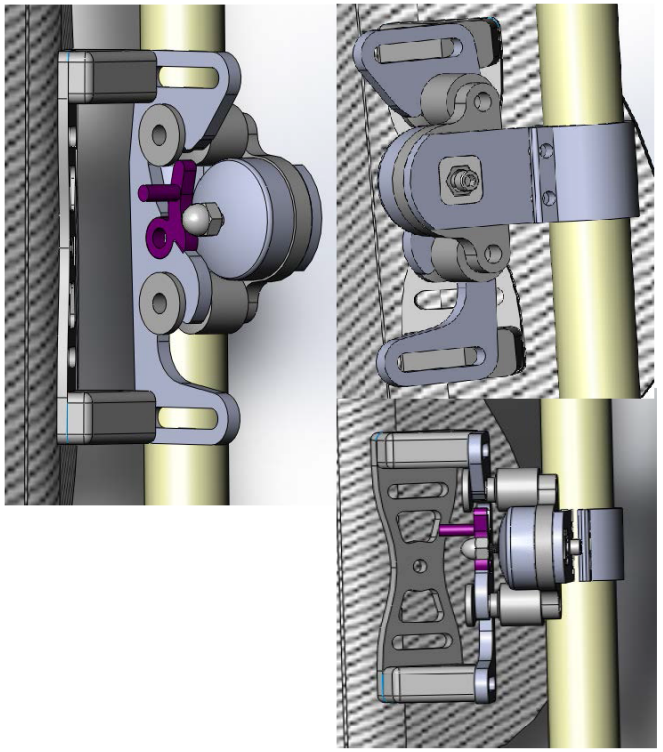
C	D
	
-Backrest pivot bracket was completely redesigned to incorporate a sliding and locking system. This retooling consisted of cutting a section in the bracket near the point of attachment to the vertical wheelchair tubes. The hole is made to fit to the brass ring, so that the angle adjustment apparatus may slide into place and rest snugly against each other. This sliding and locking system facilitates taking off and putting on the backrest angle adjustment mechanism. Additionally, the bracket was changed back to the older design by incorporating two holes. -With the addition of the sliding and locking system for the wheelchair backrest, the entire mechanism became much more efficient by allowing for the apparatus to be removed/replaced quickly.	

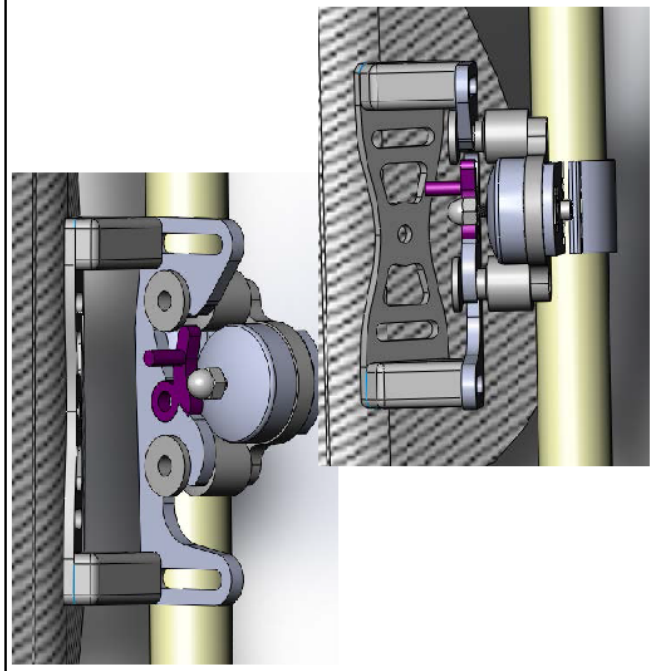
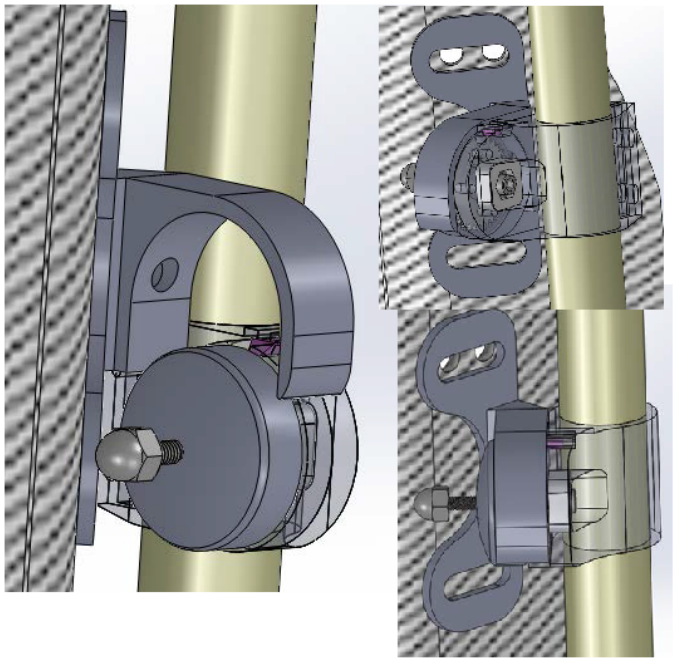
D	E
	

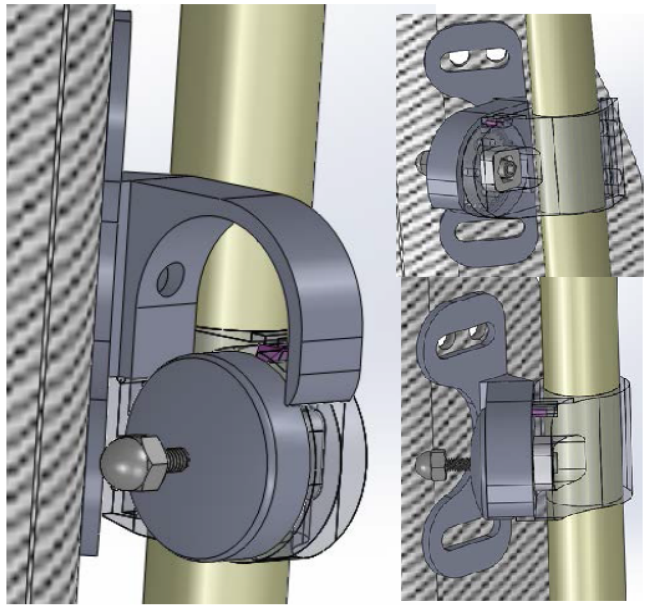
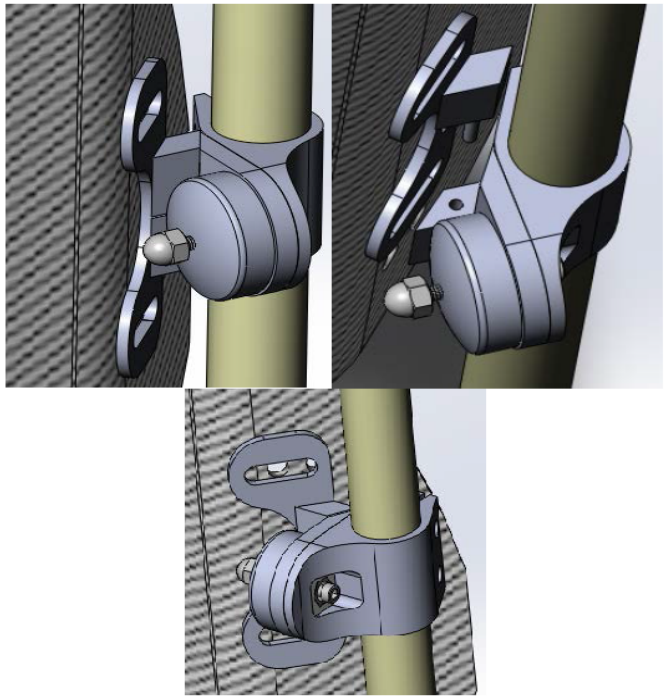
-The two main gears of the apparatus were retooled to be slightly larger. This was done in order for them to work smoothly in conjunction with the newly designed quick-release system.
-The quick-release system that was separately designed by ADI was attached to the vertical wheelchair bars. It works by locking the reclining mechanism in place, under normal conditions. To release the backrest and reclining mechanism, leverage is exploited to free the apparatus from the wheelchair bar.
-Sliding and locking system using the brass ring and the backrest pivot bracket has been replaced with the quick-release system

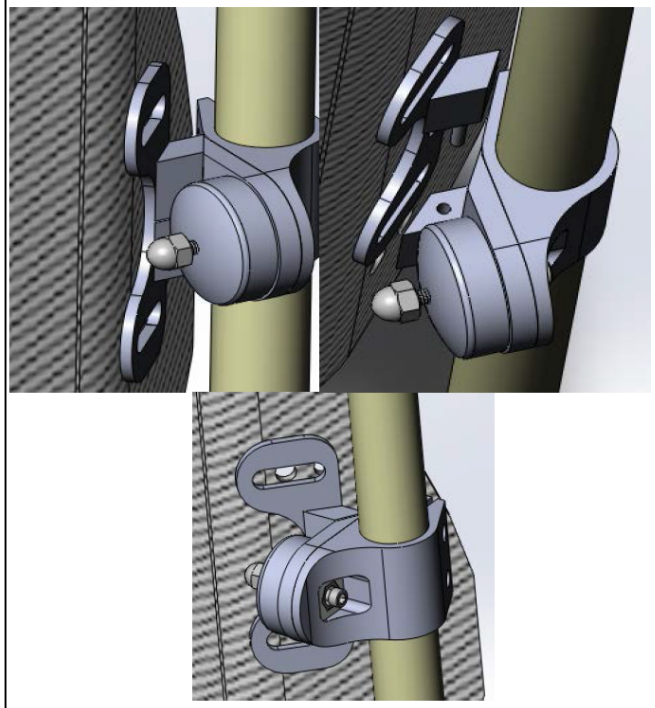
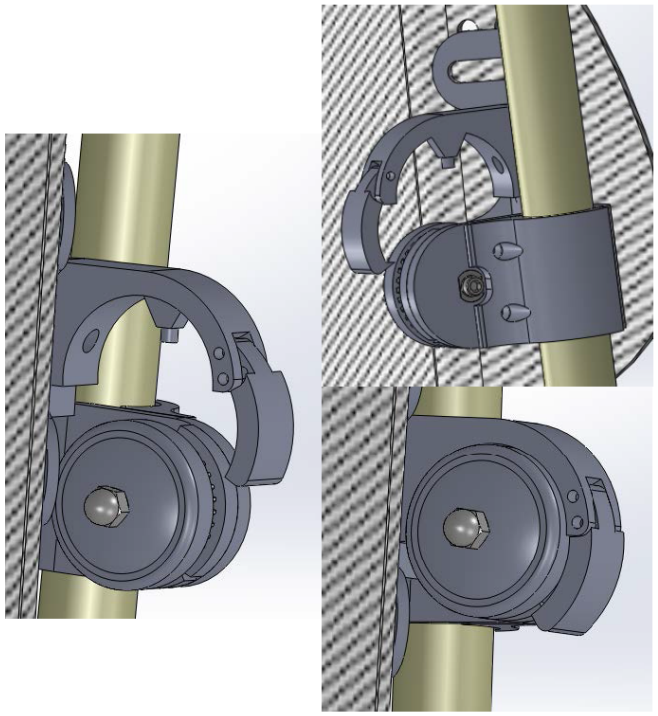
E	F
	
-Nothing has changed from the previous design, except for making both the gears in the gear-lock system smaller -This serves to make the entire system more contained and easier to handle	

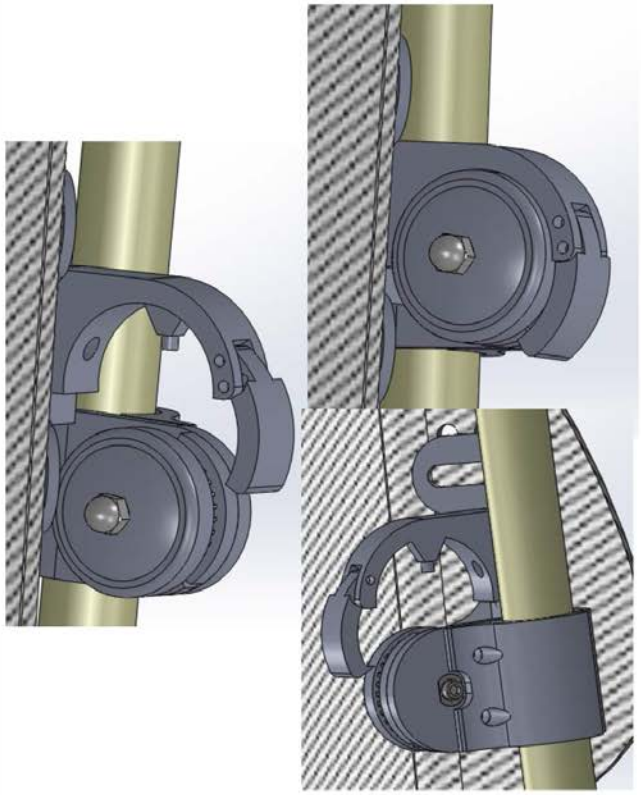
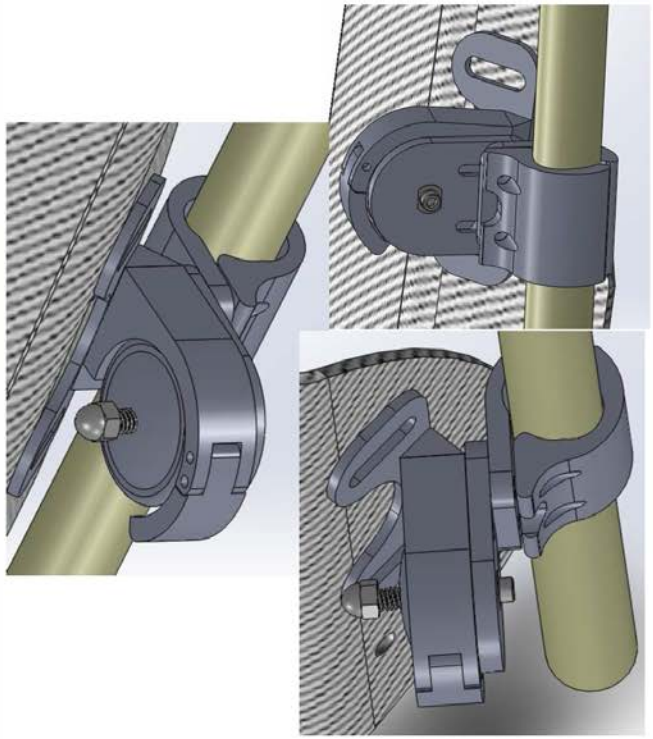
F	G
	
-The quick release system was integrated onto the vertical wheelchair tubes, allowing the angular adjustment to stay in the same place, even when backrest shell is taken out. -The quick release system was reimagined for this concept. It was switched from the pivot bar side of the apparatus to the gear cap side. The original backrest pivot brackets were restored because of this movement. All the pieces of the quick release system were moved and attached to the J brackets which are belonging to backrest shell. This movement added slots to the quick release system, which restored the ability for fore-aft movement of the backrest.	

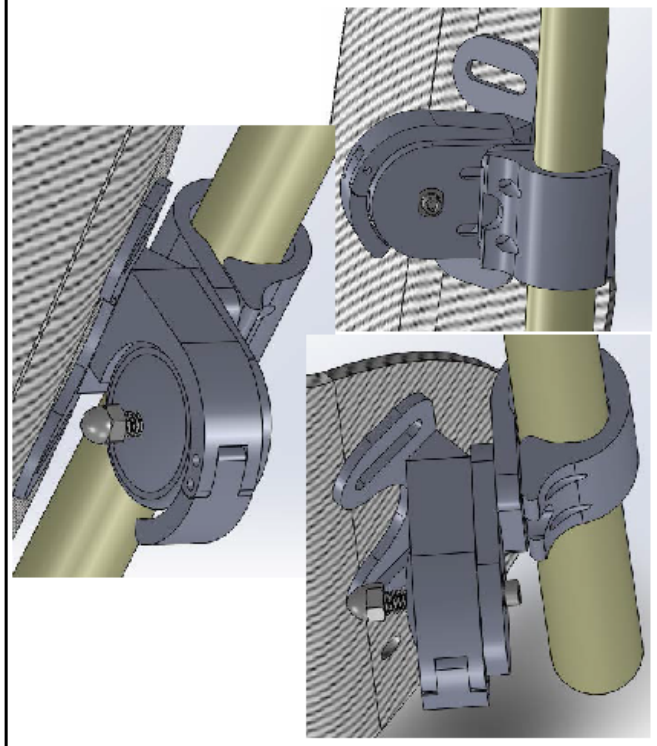
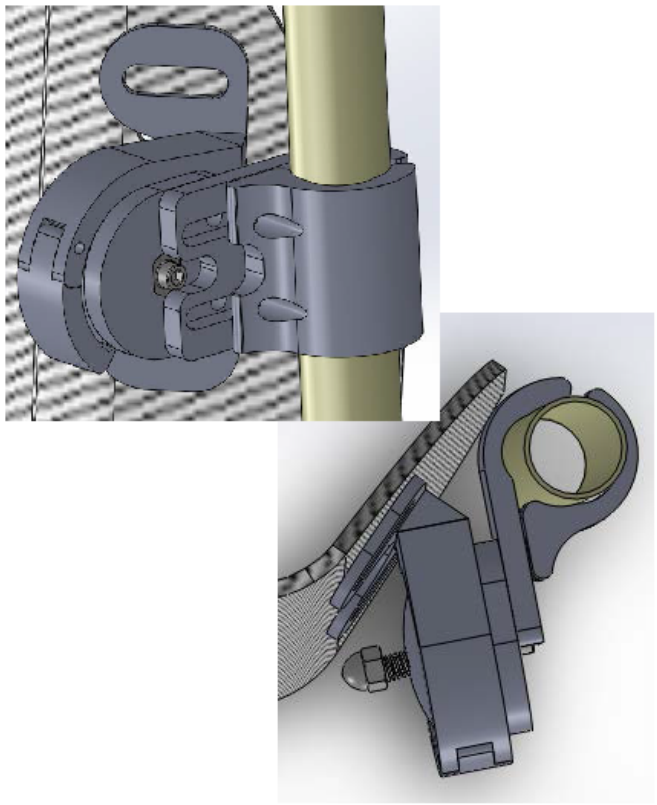
G	H
	
-According to the quick release mechanism was redesigned by ADI, the quick release mechanism was only changed.- The J brackets have been tossed in favor of two triangle brackets attached to a reinforcement bar. Fore-aft movement is still available and the quick release mechanism still works in the same manner. -Both the bracket that holds the quick release mechanism, and the actual moving quick release part, has been slightly altered to make the entire system operate more efficiently.	

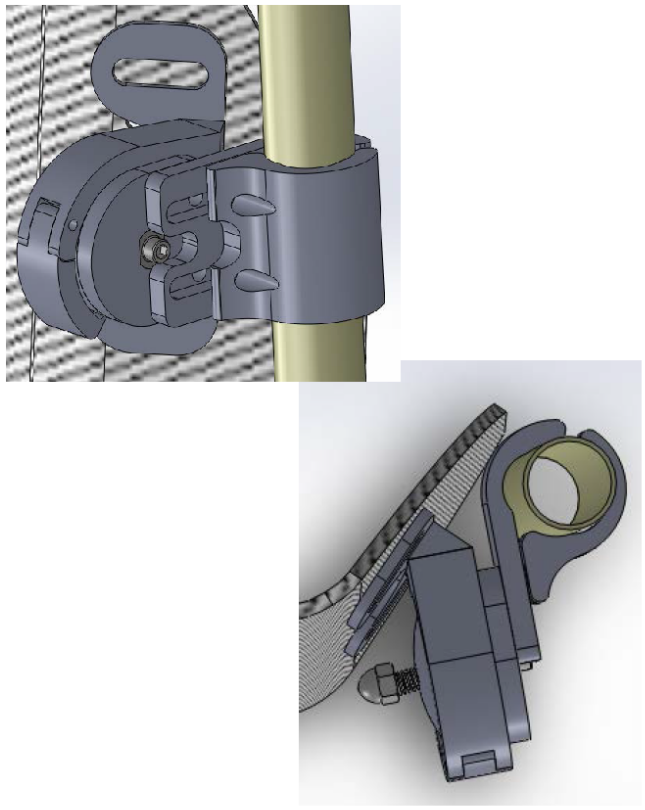
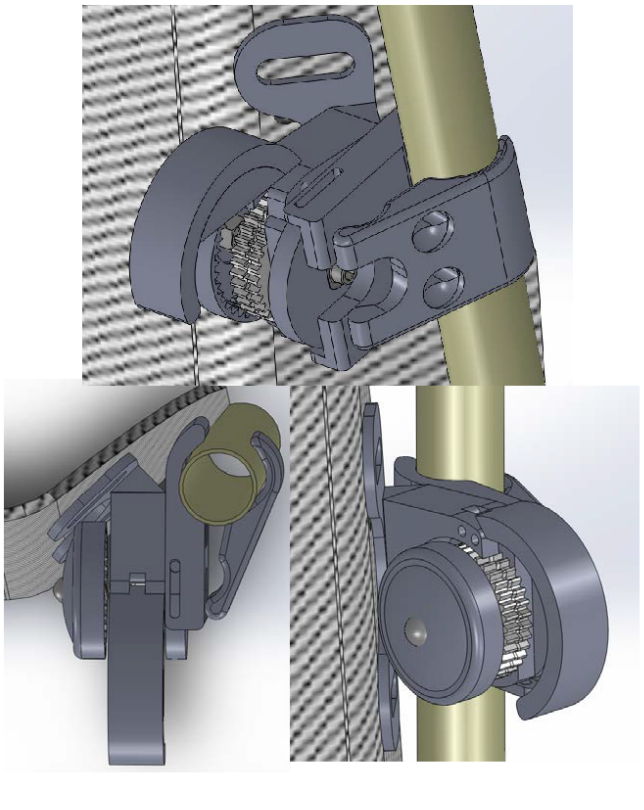
H	I
	
-The quick release mechanism was once again completely reimagined into a pin & snap concept. -The triangle brackets and the reinforcement bar have been swapped with a doggy part. This part keeps the fore-aft adjustment ability and offers consolidation because the entire system is now just directly connected to the doggy part. -Attached to the backrest pivot bracket is a metal disk that supports the gear-cap mechanism and is attached directly to the hook part of the doggy part. -Backrest pivot bracket has been redesigned with a more tapered, ergonomic look to it. The tightening/untightening is now completely away from all other moving parts (on the opposite side of the vertical wheelchair tube), allowing for greater ease of use.	

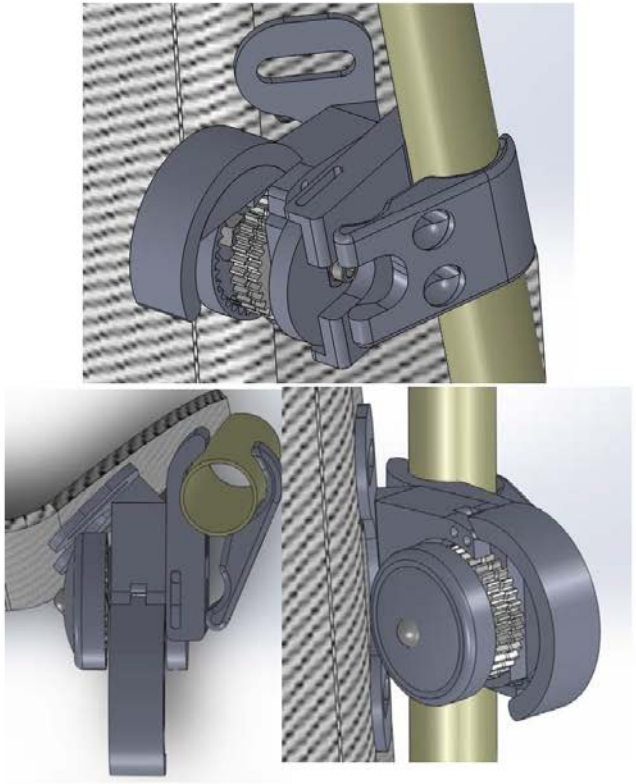
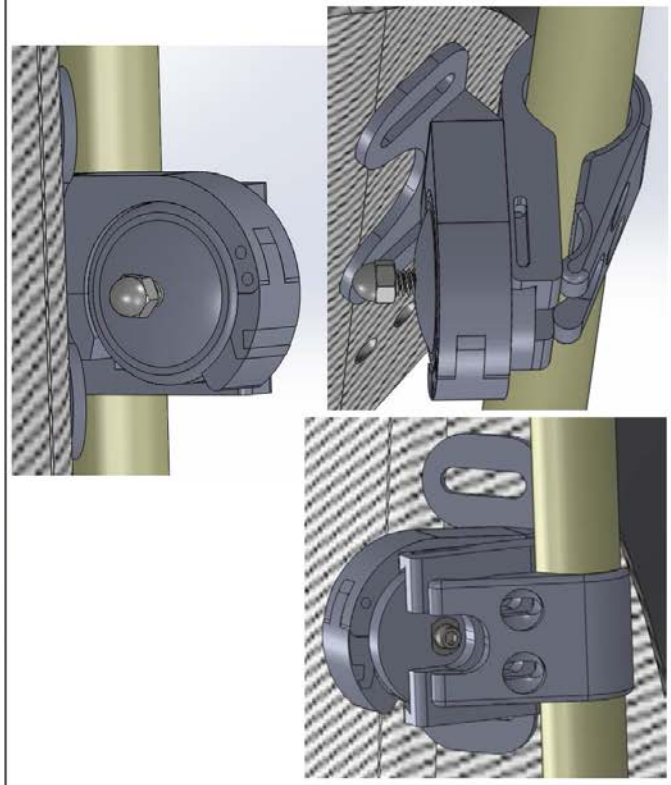
I	J
	
-The backrest pivot bracket remained virtually the same design. -The doggy part that connected the apparatus to the backrest for support was kept in the same format. However, the hook was removed. The replacement was a pin locking concept, using a fixed metal pin to allow for attachment/release of the angle adjustment system. -The pin locking works by using a metal bar attached to a triangle bracket, which is attached to the doggy part. This fixed metal bar then slides into another triangle bracket that is attached to the angle adjustment system and they're connected.	

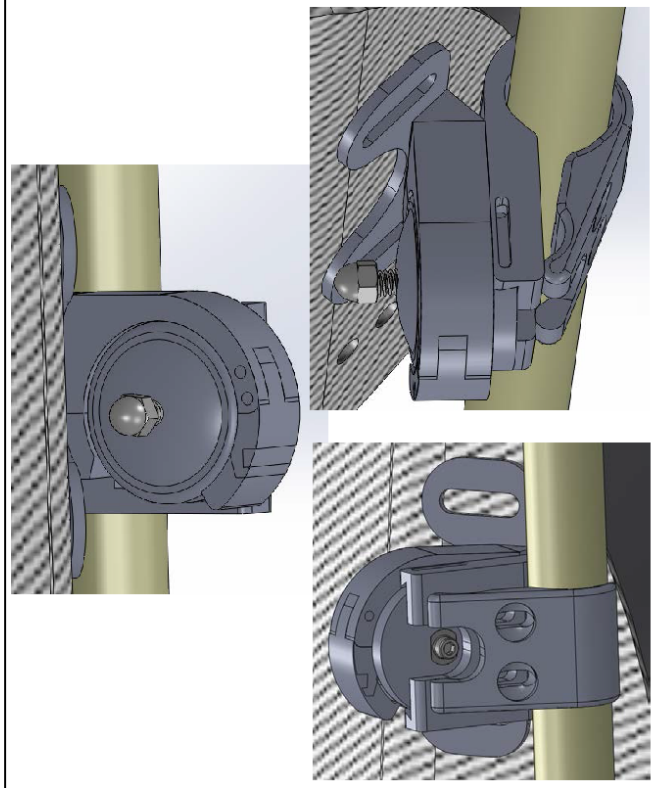
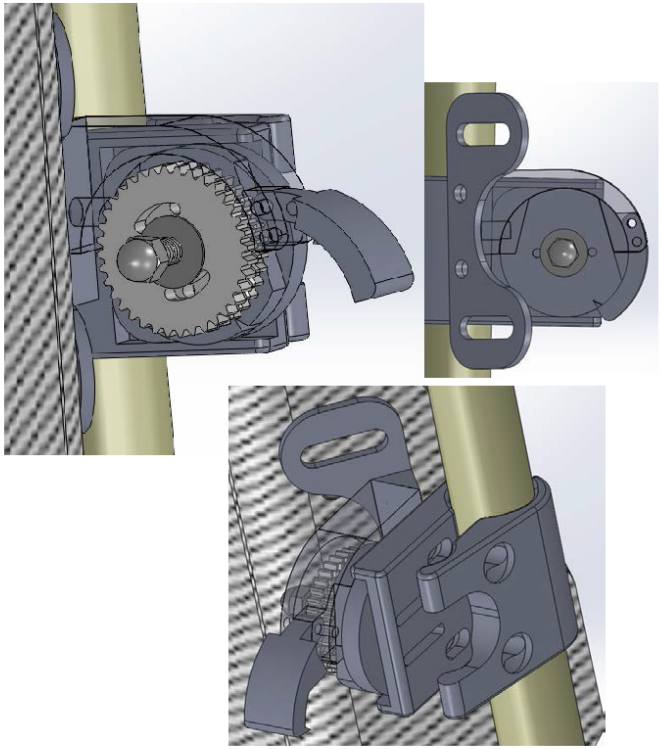
J	K
	
-Brackets attaching to vertical wheelchair tubes were modified to be able to fit different tubes(.75'' and 1.00''). - The backrest pivot bracket remained virtually the same design, except for a slight trimming of the piece to make the entire system more lightweight and easier to manipulate - The doggy part that connected the apparatus to the backrest for support was kept in the same format as "Concept I", with the hook attaching to the angle adjustment system. However, the hook contains a pin and latching concept. In order to release the angle adjustment system from the backrest, one must unlatch the hook holding it in place.	

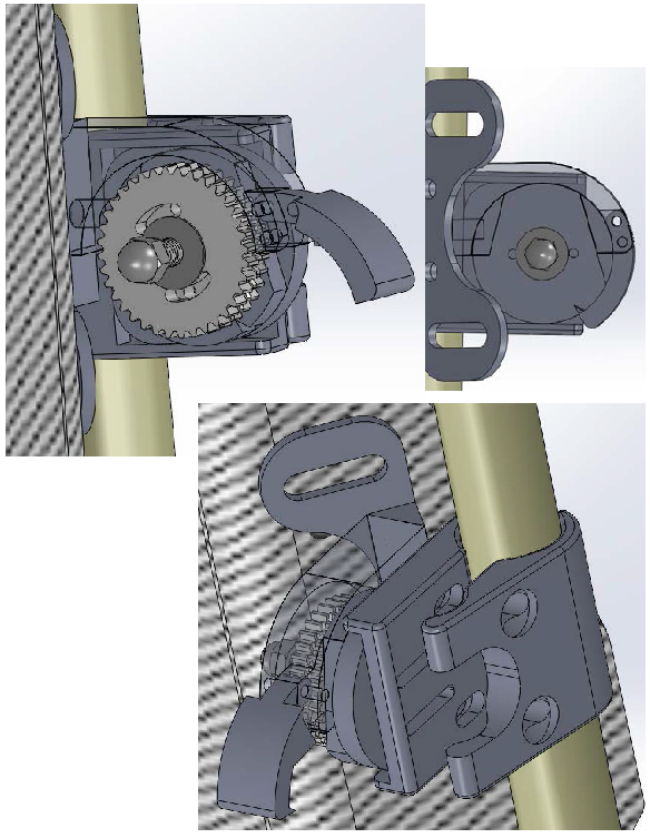
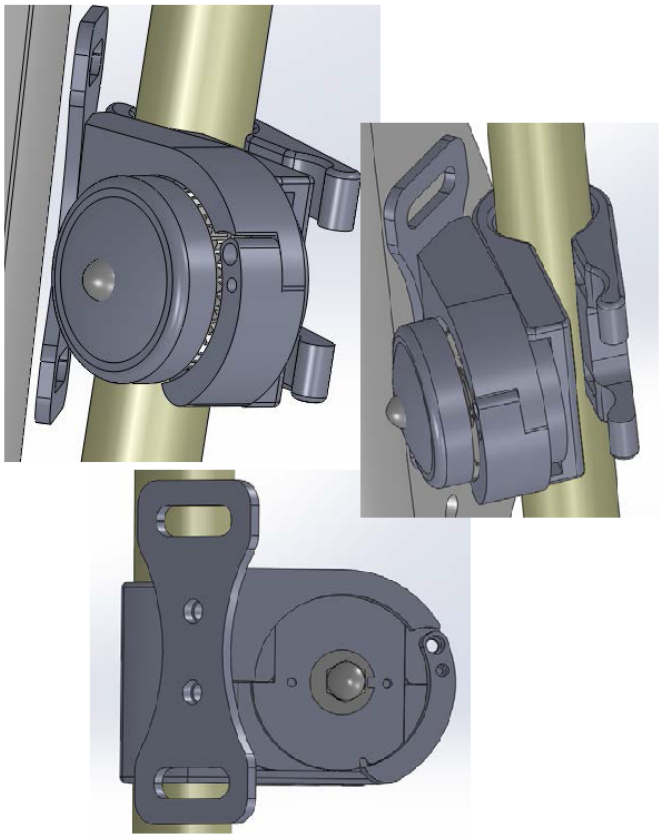
K	L
	
-This design has same pin and latching design as Concept K. -Staying piece has slots for fore-aft adjustment of the wheelchair backrest.	

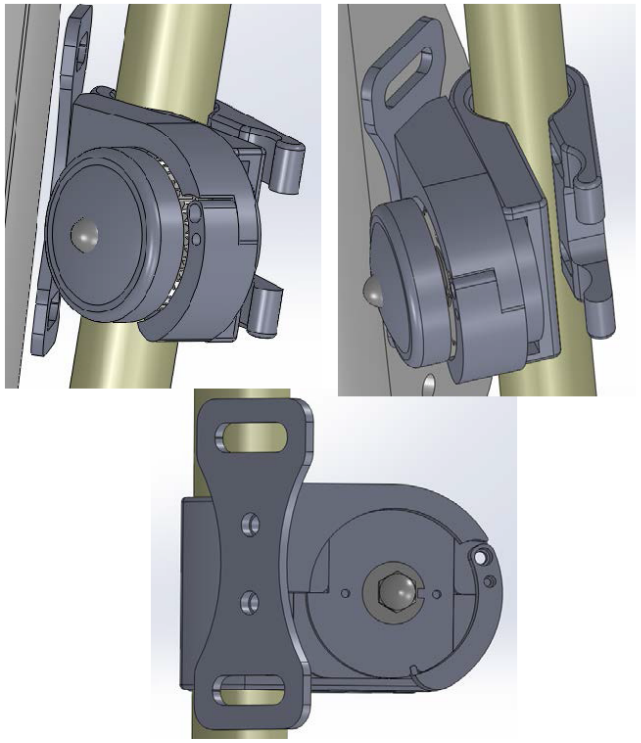
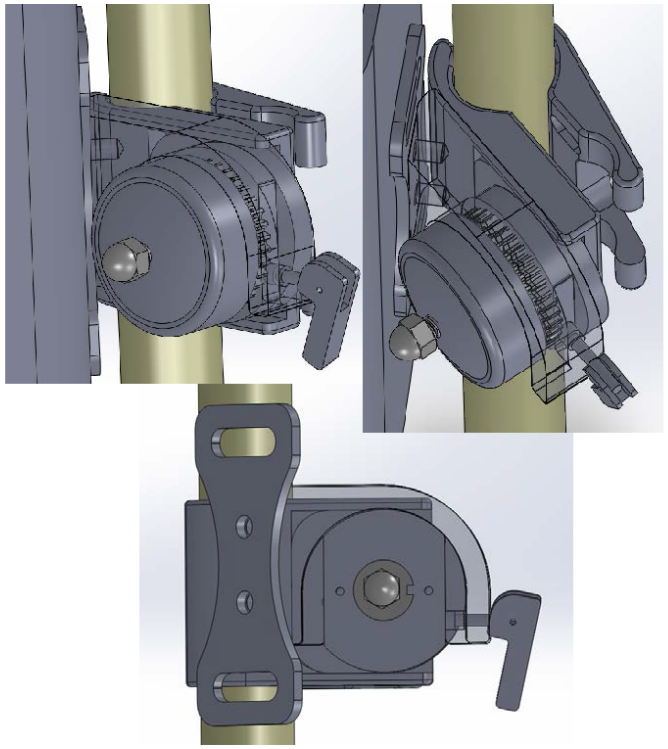
L	M
	
- Slight modification was for fore-aft adjustment of the wheelchair backrest. Brackets attaching to vertical wheelchair tubes have slots instead of staying piece. -Everything else unchanged, this design has same pin and latching concept as previous version.	

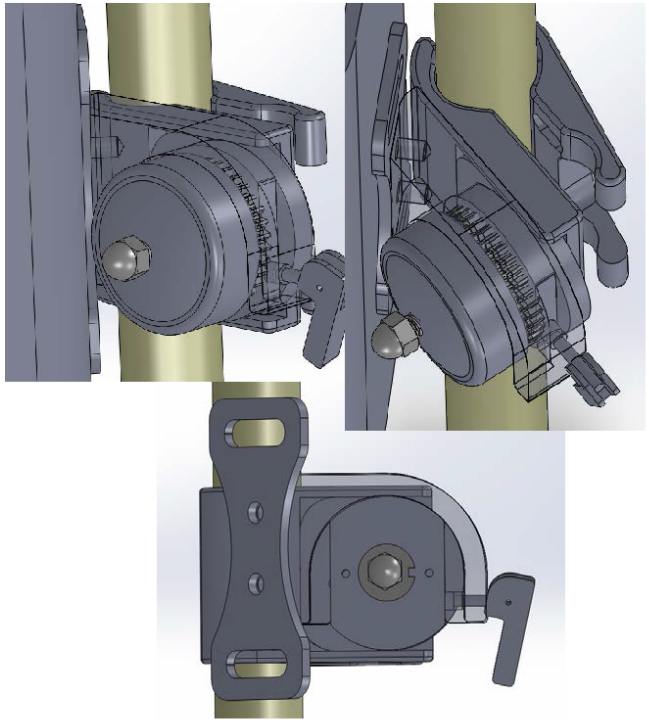
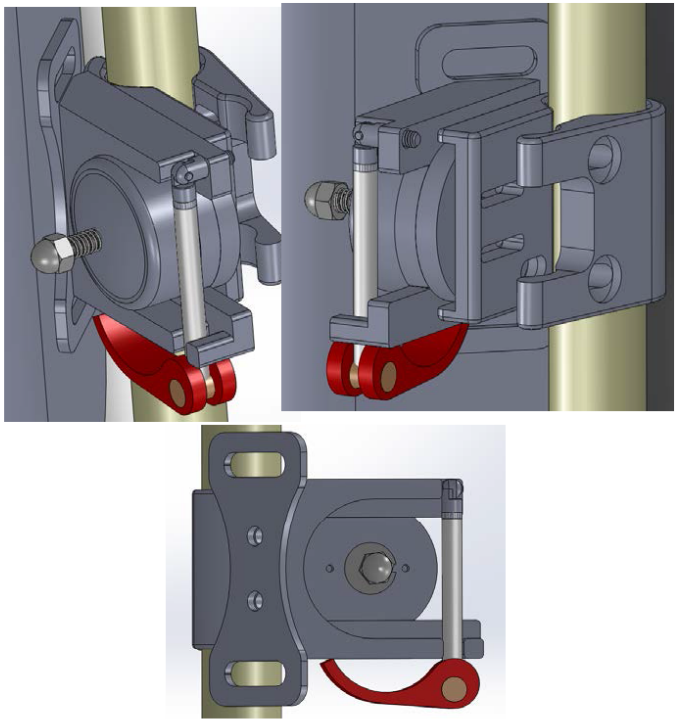
M	N
	
-The bracket was modified fore fore-aft movement as a covering concept. -The latch part of the hook on the doggy part is larger now, spanning half the circumference of the angle adjustment system for quick-releasing system.	

N	O
	
-The long latching concept was ditched, but this design maintained the pin & latching concept. This is using the previous smaller latch design which is identical to Concept M. -The bracket with a covering concept is identical to N.	

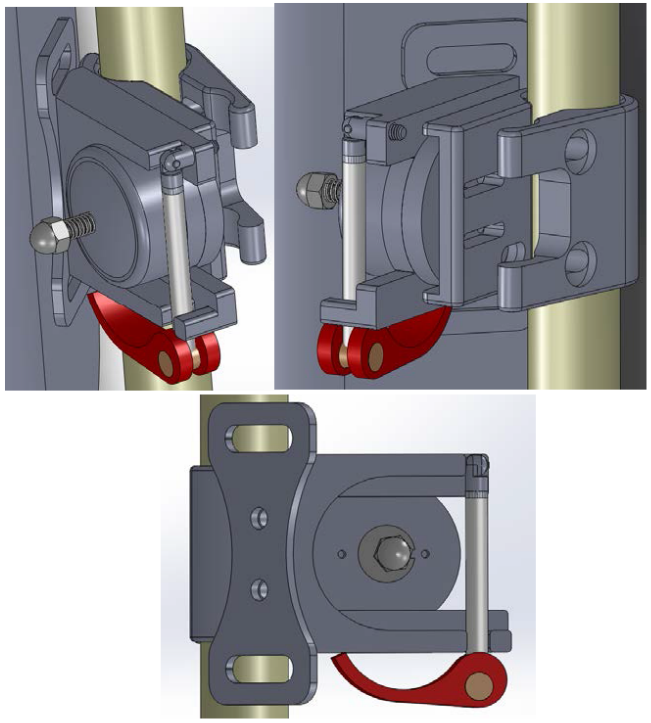
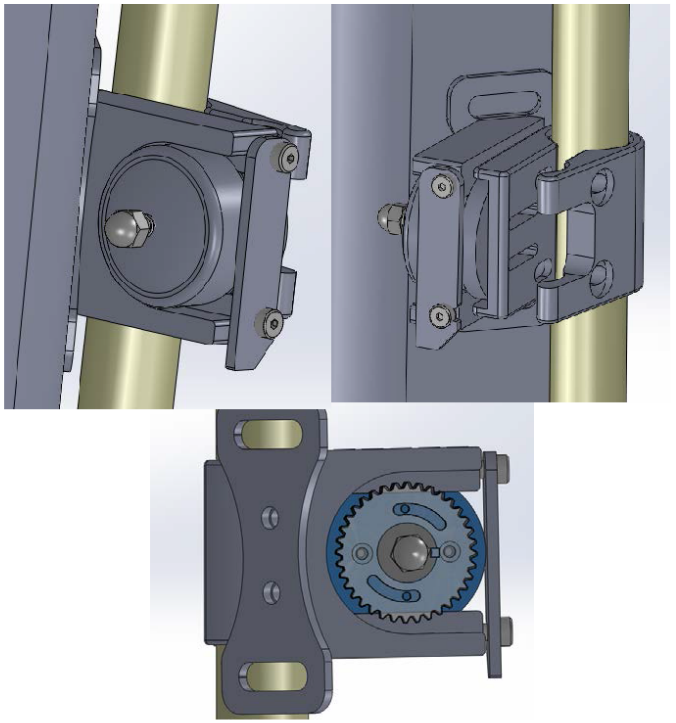
O	P
	
-This design maintained the Pin & latching concept (It is similar to Concept O, but it is angle of saddle style.) -The bracket was redesigned with slots which are offering the range of fore-aft motion. The slots have been moved from the top and bottom of the device to the inside. This change lessens the change for any kind of dust or debris from entering the mechanism, which leads to increased longevity.	

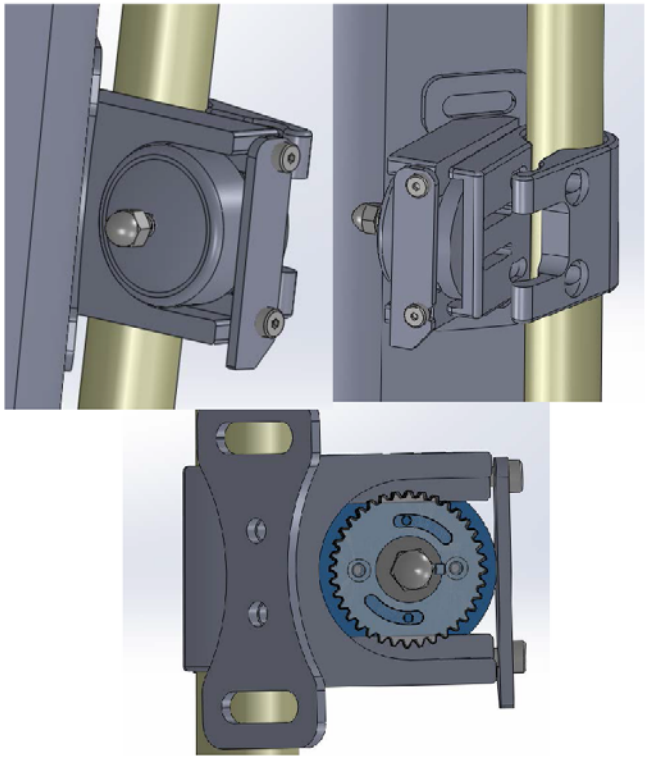
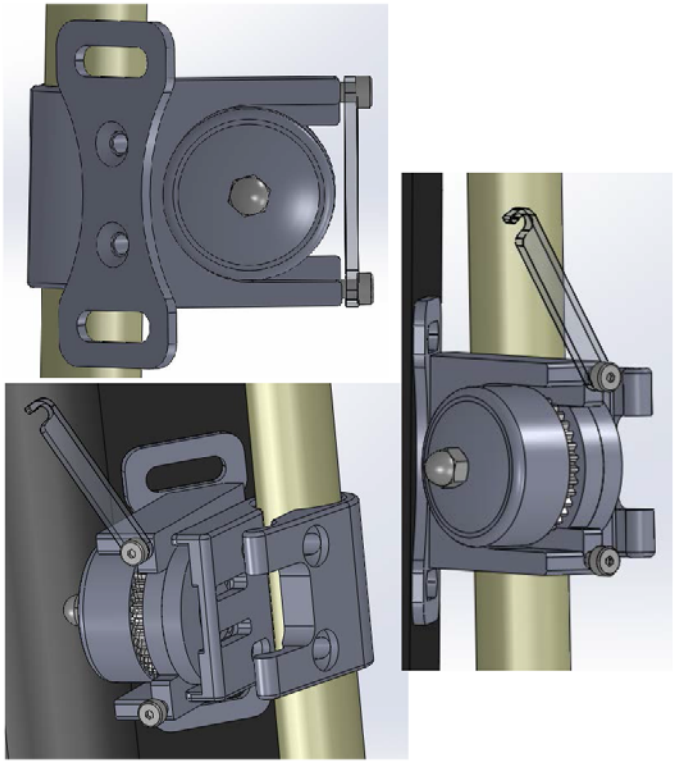
P	Q
	
-This design maintained the Pin & latching concept (similar to Concept P). -Nearly all of the parts of the concepts remained the same, except on saddle shape from trapezoid to rectangle.	

Q	R
	
-This design has Saddle & Pin lock concept, but the locking system was changed. The pin and latching concept was discontinued in favor of the hook, with a saddle and pin which is locking mechanism going through a hole. -The saddle and pin works by using the saddle to lock the pin and forcing the angle adjustment system to stay in place. -This change once again redesigns the locking method for the angle adjustment system.	

R	S
	

-The entire locking mechanism was redesigned, as well as some of the pieces.
-The removable semicircular part was rotated, 90º so that the open side of the part faces away from the wheelchair backrest. This enabled the angle adjustment system to be slid in and out, as opposed to up and down.
-The saddle and pin locking concept was ditched in favor of a quick-release locking system that uses a cam rod to keep the angle adjustment system in place. Movement of the rod will allow the release of the angle adjustment system.
-Everything else remained the same.

S	T
	
-The same premise behind the quick-release system in Concept S was used for Concept T, with some slight changes. -The cam lock has been replaced with a latch. This latch is connected to two shoulder bolts. It is attached permanently to the top bolt, but it can be released from the bottom bolt, allowing it to swing freely. When this latch is opened, the angle adjustment system can be released quickly. -This redesign makes the quick-release system much more efficient by effectively removing clutter and reducing the complexity of the part.	

T	U
	
-Everything design-wise is the same as Concept T -One minor change was the alteration of the latch which is connecting the two shoulder bolts and keeping the angle adjustment system in place. This design change provides more space for sliding the angle adjustment system in and out served to strengthen the apparatus overall.	

APPENDIX D

SUBJECT TESTING QUESTIONNAIRE

The following questionnaire was made for the evaluation of the LWDAC back support for in-depth home trial.

Lightweight, durable, adjustable composite (LWDAC) backrest Subject testing Questionnaire: CHECKLIST

Date: ____/____/_____

Visit 1

□ Informed Consent (signed and dated by both the subject and investigator)

□ Documentation of Informed Consent

□ Inclusion/Exclusion Criteria Form

□ Payment Certificate Completed

□ Orientation to the LWDAC

□ ***Questionnaire:*** Initial Intake – Demographic Questionnaire

□ ***Questionnaire:*** Wheelchair & Backrest Measurement Form

□ Tasks for subject testing with their own backrest - Tasks Records

□ ***Questionnaire:*** Post-ADL Course Questionnaire (own backrest)

Visit 2

□ Collect Datalogger from their own backrest

□ Set LWDAC backrest to participants' wheelchair

□ Train how to use angle adjustment

□ Tasks for subject testing with the LWDAC backrest (1^{st}) – Tasks Records

□ ***Questionnaire:*** Post-ADL Course Questionnaire (ADI backrest)

□ Datalogger attached to the LWDAC backrest for task-home trials

Visit 3

□ Collect Datalogger from the LWDAC backrest

□ Tasks for subject testing with the LWDAC backrest (2nd) – Tasks Records

□ ***Questionnaire:*** Post-ADL Course Questionnaire

□ ***Questionnaire:*** Post-Device Trial Overall Backrest Questionnaire

□ Extended Interview – Keep or not

Follow up

□ ***Questionnaire:*** FollowUp_phonecall

LWDAC Backrest
Wheelchair Measurements

Wheelchair Data

Wheelchair:

Make: _____

Model: _____

Backrest:

☐ Sling ☐ Rigid ☐ Adjustable-Tension ☐ Customized

Make: _____

Model: _____

Cushion:

☐ Foam ☐ Air ☐ Gel
☐ Honeycomb ☐ Custom ☐ Other _____

Make: _____

Model: _____

Wheelchair Backrest Measurement

1. Backrest height _____ inches
2. Backrest width _____ inches
3. Wheelchair width _____ inches

Tasks for subject testing

- Modified Functional Reach Test
  - Distance of Linear Reach
- Reach
  - Forward vertical reach
    - Height (measure from the floor)
    - Hold a measuring stick in a horizontal position with both hands
    - Raise the stick forward and up as far as possible
- Up and down ramps
    - Time to wheel as quickly as possible
- Demonstration of dressing
- Pressure relief
  - It would be depend on how they used to do. Angle adjustment might allow to change center of gravity. Therefore, it could be helpful.
- Typing 10 minutes on computer
  - Working position and relaxed position would be different.
  - Use one of computer Pitt side

Modified Functional Reach Test

Distance of Linear Reach _____ cm _____ cm _____ cm

Reach Test

Height of Vertical Reach _____ cm _____ cm _____ cm

Up and down ramps

1. _____
2. _____
3. _____

Pitt IRB# PRO13060396 **Subject ID _____**

LWDAC Backrest
Initial Intake Questionnaire

Date: ____/____/____

Demographic Information

Age: _____

Gender: ☐ Male ☐ Female

Race:
- ☐ Black or African American
- ☐ Asian
- ☐ White or Caucasian
- ☐ American Indian or Alaskan Native
- ☐ Two or more races
- ☐ Native Hawaiian or other Pacific Islander

Are you of Hispanic, Latino or Spanish origin? ☐ Yes ☐ No

1. What is your injury and/or diagnosis?

- ☐ Spinal Cord Injury (Tetraplegia: _____ Paraplegia: _____)
- ☐ Amputation
- ☐ Cerebral Palsy
- ☐ Muscular Dystrophy
- ☐ Stroke
- ☐ Multiple Sclerosis
- ☐ TBI
- ☐ Other _____
- ☐ Spina Bifida

2. What year did you receive this diagnosis (or injury)? _____

Wheelchair Data

3. What year did you start using a wheelchair? _____

4. Is your current wheelchair your first wheelchair?

- ☐ Yes
- ☐ No

5. How long have you had current wheelchair?

- ☐ Less than 1 month
- ☐ 1 month to 1 year
- ☐ 1 year to 3 years
- ☐ 3 years to 5 years
- ☐ 5 years or longer

6. Who recommended the wheelchair to you? *(please check all that apply)*

- ☐ Doctor
- ☐ Therapist (e.g. OT, PT, etc)
- ☐ Other: _____
- ☐ Vendor
- ☐ Family Member

7. Have you ever used a type of backrest different than what is currently on your wheelchair?

- ☐ No
- ☐ Yes

If yes, what type of backrest?

- ☐ Sling (fabric)
- ☐ Rigid (has a hard plastic shell)
- ☐ Adjustable-tension (sling with Velcro straps)
- ☐ Custom

How long did you use this type of backrest?

- ☐ Less than 6 months
- ☐ 6 months to 1 year
- ☐ 1 to 3 years
- ☐ More than 3 years

What were your reasons for changing the type of backrest that you use?

_____

_____

_____

_____

8. Which of the following methods do you typically use for pressure relief?

- ☐ Push up
- ☐ Leaning side to side
- ☐ Bending forward
- ☐ Transfer out of wheelchair
- ☐ Other, please specify: _____

9. How would you rate **your personal backrest** on the following factors…

…overall appearance

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

…overall comfort

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

…comfort while going up ramps

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

…comfort while going down ramps

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

…pelvis and trunk stability while dressing/adjusting clothing

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

… the support it provides

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

… the postural (i.e. trunk) stability it provides

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

… the ease of transferring in and out of your chair

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

… the ability to perform pressure relief

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

10. What do you like most about your current backrest? Please explain your answer.

_____

_____

11. What do you like least about your current backrest? Please explain your answer.

_____

_____

12. Thinking back during the last two weeks, how many **hours a day**, on average, were you in your manual wheelchair?

- ☐ Less than 3 hours
- ☐ 3 – 5 hours
- ☐ 5 – 10 hours
- ☐ 10 – 15 hours
- ☐ More than 15 hours

13. During the last two weeks, how many **hours a day**, on average, would you estimate you spent actively propelling (not stationary) your manual wheelchair?

- ☐ Less than 30 minutes
- ☐ 30 minutes to 1 hour
- ☐ 1 – 2 hours
- ☐ 2 – 3 hours
- ☐ More than 3 hours

14. How far, on average, would you estimate that you traveled **each day** during the last two weeks?

- ☐ Less than 1 football field length
- ☐ 1 - 2 football field lengths
- ☐ 2 - 4 football field lengths
- ☐ 4 - 6 football field lengths
- ☐ More than 6 football field lengths

15. Do you own a secondary (back-up) personal mobility device?

- ☐ No
- ☐ Yes

If **yes**, how many hours, on average, did you use your secondary (back-up) personal mobility device each day?

- ☐ I did not use it
- ☐ Less than 1 hour
- ☐ 1 - 2 hours
- ☐ 2 - 3 hours
- ☐ More than 3 hours

16. During the last two weeks, how many **hours a day**, on average, would you estimate you spent participating in community activities (e.g. church events, sporting events, participation in team sports, volunteer work, etc.)?

- ☐ Less than 30 minutes
- ☐ 30 minutes - 1 hour
- ☐ 1 - 2 hours
- ☐ 2 - 3 hours
- ☐ More than 3 hours

17. For the following questions, please select the option that **best describes** your current level of independence:

In-Home Activities (e.g. self-care, housework, family activities, etc.):

- ☐ I am completely independent at home.
- ☐ I am mostly independent at home, but require assistance with some activities.
- ☐ I require assistance with most activities in the home.
- ☐ Prefer not to say.

Community Activities (e.g. work, shopping, religious or community events, etc.):

- ☐ I am completely independent in the community.
- ☐ I am mostly independent in the community, but require assistance with some activities.
- ☐ I require assistance with most activities in the community.
- ☐ Prefer not to say.

Thinking about your current backrest, please tell us how much you **agree or disagree** with the following statements:

18. I have difficulty maintaining stability while going up and down a ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

19. My pelvis and trunk sometimes feel unstable.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

20. I **do not** have trouble dressing and adjusting clothes while seated.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

21. I have trouble performing pressure relief while seated in my wheelchair.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

22. I have trouble finding a comfortable position while sitting in my wheelchair at a table or desk.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Thank you for your assistance in completing this questionnaire.

Personal Backrest

Activities of Daily Living Course - Task Ratings Questionnaire

Think about your current backrest.

Please rate your answer on the following scale (Please circle your answer):

Ramps

Up the Ramp

I **was able** to go up the ramp without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** going up the ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Down the Ramp

I **was able** to go down the ramp without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** going down the ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Demonstration of dressing

I **felt stable** (i.e. pelvis and trunk stability) while dressing and/or adjusting clothing.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **was able** to dress and/or adjust my clothing without difficulty while seated in my wheelchair.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Reaching Tasks

Forward

I **was able** to reach forward without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** while reaching forward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Backward

I **was able** to reach backward without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** while reaching backward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Above Head

I **was able** to reach a shelf above my head without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** while reaching a shelf above my head.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Floor

I **was able** to reach down to the floor without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** while reaching down to the floor.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Pressure Relief

I **was able** to perform pressure relief without difficulty.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **felt comfortable** while performing pressure relief.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

I **was able** to control my balance while performing pressure relief.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Seated at table

I **was seated comfortably** while at the table and/or desk.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

LWDAC Backrest

Activities of Daily Living Course - Task Ratings Questionnaire

Think about how you feel having the ability to adjust your backrest angle.

Please rate your answer on the following scale (Please circle your answer):

Ramps

Up the Ramp

Changing the angle of the backrest **improved my ability** to go up a ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while going up a ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Down the Ramp

Changing the angle of the backrest **improved my ability** to go down a ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while going down a ramp.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Demonstration of dressing

Changing the angle of the backrest **improved my pelvis and trunk stability** while dressing/ adjusting clothing.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my ability** to dress/adjust clothing while I am seated.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Reaching Tasks

Forward

Changing the angle of the backrest **improved my ability** to reach forward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while reaching forward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Backward

Changing the angle of the backrest **improved my ability** to reach backward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while reaching backward.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Above Head

Changing the angle of the backrest **improved my ability** to reach a shelf above my head.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while reaching a shelf above my head.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Floor

Changing the angle of the backrest **improved my ability** to reach down to the floor.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while reaching down to the floor.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Pressure relief

Changing the angle of the backrest **improved my ability** to perform pressure relief.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while performing pressure relief.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my balance control** while performing pressure relief.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Seated at table

Changing the angle of the backrest **improved my position** while seated at a table or desk.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Changing the angle of the backrest **improved my comfort** while seated at a table or desk.

Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	No Opinion

Pitt IRB# PRO13060396 **Subject ID _____**

Backrest Preference Questionnaire

Activities of Daily Living Course – Backrest Configurations

For each statement below please check the response that best indicates your opinion:

Ramps

Which backrest did you prefer for **going up the ramp**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **going down the ramp**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Demonstration of dressing

Which backrest did you prefer for **pulling up your pants**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **zipping/buttoning your pants**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **reaching into your pocket**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **taking off your pants**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **putting on your shirt**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Reaching Tasks

Which backrest did you prefer for the task that required you to **reach forward**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for the task that required you to **reach backward**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for the task that required you to **reach a shelf above your head**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for the task that required you to **reach down to the floor**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Pressure relief

Which backrest did you prefer for **pressure relief**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Which backrest did you prefer for **adjusting your position while seated in your wheelchair**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Seated at table

Which backrest did you prefer **while seated at a table or desk**?

- ☐ My own backrest
- ☐ Adjustable backrest

Which **angle did you prefer** to use during that task?

- ☐ Reclined angle
- ☐ Neutral
- ☐ Forward angle

Comments:

LWDAC Backrest

Post Device In-Home Trial - LWDAC Overall Questionnaire

Date: _____/_____/_____

Community Participation and Manual Wheelchair Information

1. At any point, during the last two weeks, were there any days that you were **unable to engage** in your normal level of activity or community participation (this might be the result of injury, illness, travel, equipment breakdown, etc.)?

☐ No
☐ Yes

If **yes**, how many days during the past two weeks were you unable to engage in your normal level of activity or normal community participation?

☐ 1 day or less ☐ 3 days
☐ 2 days ☐ More than 3 days

2. Do you own a secondary (back-up) personal mobility device?

☐ No
☐ Yes

If **yes**, how many hours, on average, did you use your secondary (back-up) personal mobility device each day?

☐ I did not use it ☐ 2 - 3 hours
☐ Less than 1 hour ☐ More than 3 hours
☐ 1 - 2 hours

3. During the last two weeks, how many **hours a day**, on average, would you estimate you spent participating in community activities (e.g. church events, sporting events, participation in team sports, volunteer work, etc.)?

☐ Less than 30 minutes ☐ 2 - 3 hours
☐ ½ hour - 1 hour ☐ More than 3 hours
☐ 1 - 2 hours

4. How far, on average, would you estimate that you traveled **each day** during the last two weeks?

☐ Less than 1 football field length ☐ 4 - 6 football field lengths
☐ 1 - 2 football field lengths ☐ More than 6 football field lengths
☐ 2 - 4 football field lengths

LWDAC Backrest Specific Feedback: (To Be Completed After Device Trial ONLY)

5. How would you rate **the LWDAC Backrest** on…

… overall appearance

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

… overall comfort

☐ Very Poor ☐ Poor ☐ Moderate ☐ Good ☐ Very Good

6. I **like** the way the LWDAC Backrest looks on my manual wheelchair.

☐ False
☐ True

7. I **worried** about the LWDAC Backrest malfunctioning while I was using it.

☐ False
☐ True

8. Based on the **performance** of the device, I would buy the LWDAC Backrest if it were commercially available.

☐ False
☐ True

9. I **would not** recommend the LWDAC Backrest to other manual wheelchair users I know.

☐ False
☐ True

10. I **benefited** from having the LWDAC Backrest installed on my manual wheelchair.

☐ False
☐ True

11. Having the LWDAC Backrest on my manual wheelchair **improved** the quality of my life.

☐ False
☐ True

12. I used the **reclined position** of the LWDAC Backrest for…
(please check all that apply)

- ☐ Pressure relief
- ☐ Getting dressed
- ☐ Resting
- ☐ Sitting (i.e., stationary, not propelling) for a long period of time
- ☐ Other *(please explain)* _____
- ☐ Other *(please explain)* _____
- ☐ Other *(please explain)* _____

13. I used the **forward position** of the LWDAC backrest for…
(please check all that apply)

- ☐ Going up ramps
- ☐ Reaching
- ☐ Transfers
- ☐ Other *(please explain)* _____
- ☐ Other *(please explain)* _____
- ☐ Other *(please explain)* _____

14. Which of the following method for pressure relief did you use while the LWDAC backrest was attached to your chair?

- ☐ Push up
- ☐ Leaning side to side
- ☐ Bending forward
- ☐ Transfer out of wheelchair
- ☐ Other, please specify: _____

15. The LWDAC Backrest was comfortable while propelling my wheelchair.

- ☐ False
- ☐ True

16. The LWDAC Backrest provided sufficient support.

- ☐ False
- ☐ True

17. I felt stable in my wheelchair with the LWDAC Backrest attached.

☐ False
☐ True

18. It was easy to transfer into and out of my wheelchair with the LWDAC Backrest.

☐ False
☐ True

19. How difficult was it for you to make the following angle adjustments on the LWDAC Backrest:

…from straight/upright (i.e. 90°) to reclined angles

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

…from straight/upright (i.e. 90°) to forward tilt angle

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

…from reclined angles to straight/upright (i.e. 90°)

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

…from reclined angles to forward tilt angles

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

…from forward tilt angles to straight/upright (i.e. 90°)

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

…from forward tilt angles to reclined angles

☐ Very Easy ☐ Easy ☐ Difficult ☐ Very Difficult

20. I felt **stable** in my wheelchair while adjusting the LWDAC Backrest.

☐ False
☐ True

21. I felt **comfortable** in my wheelchair while adjusting the LWDAC Backrest.

☐ False
☐ True

22. The **range of angle adjustments** on the LWDAC Backrest was sufficient for my needs.

- ☐ False
- ☐ True

23. The **ability to adjust the angle** of the LWDAC Backrest was useful in my daily activities.

- ☐ False
- ☐ True

24. My **arm** was in a comfortable position while making adjustments to the angle of the LWDAC Backrest.

- ☐ False
- ☐ True

25. My **body** was in a comfortable position while making adjustments to the angle of the LWDAC Backrest.

- ☐ False
- ☐ True

26. When adjusting the LWDAC Backrest, I often found it **difficult** to find the angle that I wanted to use.

- ☐ False
- ☐ True

27. At any point did you have physical difficulties adjusting the LWDAC Backrest (e.g. you physically couldn't reach the string, a device component was stuck or sticking, etc.)?

- ☐ No
- ☐ Yes

If **yes**, please explain: _____

_____

_____

_____

_____

_____

_____

Based on your experience with the LWDAC backrest, what were the things you liked ***most*** about the LWDAC backrest? Please explain your answer.

_____

_____

_____

Based on your experience with the LWDAC backrest, what were the things you liked ***least*** about the LWDAC backrest? Please explain your answer.

_____

_____

_____

Thank you for your assistance in completing this questionnaire!

LWDAC Backrest
Bi-Weekly Questionnaire – With Own Backrest

Manual Wheelchair Usage:

1. During the last two days, how many **hours a day**, on average, would you estimate you spent actively propelling (not stationary) your manual wheelchair?

   ☐ Less than 30 minutes
   ☐ 30 minutes to 1 hour
   ☐ 1 – 2 hours
   ☐ 2 – 3 hours
   ☐ More than 3 hours

2. How far, on average, would you estimate that you traveled **each day** during the last two days?

   ☐ Less than 1 football field length
   ☐ 1 - 2 football field lengths
   ☐ 2 - 4 football field lengths
   ☐ 4 - 6 football field lengths
   ☐ More than 6 football field lengths

3. Over the last two days, has pain **affected** how much you have used your manual wheelchair?

   ☐ Yes ☐ No

4. During the last two days, how many **hours a day**, on average, would you estimate you spent participating in community activities (e.g. church events, sporting events, participation in team sports, volunteer work, etc.)?

   ☐ Less than 30 minutes
   ☐ ½ hour - 1 hour
   ☐ 1 - 2 hours
   ☐ 2 - 3 hours
   ☐ More than 3 hours

LWDAC Backrest

Bi-Weekly Questionnaire – With Adjustable Backrest

Manual Wheelchair Usage:

1. During the last two days, how many **hours a day**, on average, would you estimate you spent actively propelling (not stationary) your manual wheelchair?

   ☐ Less than 30 minutes
   ☐ 30 minutes to 1 hour
   ☐ 1 – 2 hours
   ☐ 2 – 3 hours
   ☐ More than 3 hours

2. How far, on average, would you estimate that you traveled **each day** during the last two days?

   ☐ Less than 1 football field length
   ☐ 1 - 2 football field lengths
   ☐ 2 - 4 football field lengths
   ☐ 4 - 6 football field lengths
   ☐ More than 6 football field lengths

3. Over the last two days, has pain **affected** how much you have used your manual wheelchair?

   ☐ Yes ☐ No

4. During the last two days, how many **hours a day**, on average, would you estimate you spent participating in community activities (e.g. church events, sporting events, participation in team sports, volunteer work, etc.)?

   ☐ Less than 30 minutes
   ☐ ½ hour - 1 hour
   ☐ 1 - 2 hours
   ☐ 2 - 3 hours
   ☐ More than 3 hours

LWDAC Backrest System Feedback:

1. How many times a day, on average, have you adjusted the angle of the backrest on over the course of the last two days?

   ☐ Less than 2 times ☐ 4 – 6 times
   ☐ 2 – 4 times ☐ More than 6 times

2. Has the LWDAC backrest been useful?

   ☐ Yes ☐ No

3. Has the LWDAC backrest been a burden?

   ☐ Yes ☐ No

4. Has the LWDAC backrest been easy to use?

   ☐ Yes ☐ No

5. Has the LWDAC backrest made it more difficult to use your manual wheelchair?

   ☐ Yes ☐ No

6. Are you happy that the LWDAC Backrest is on your manual wheelchair?

   ☐ Yes ☐ No

LWDAC Backrest
Follow-Up Questionnaire

____2 weeks; specify date: _____
____4 weeks; specify date: _____
____6 weeks; specify date: _____

1) Of your total time using a wheelchair in the last two weeks, what is your best estimate of the percent of time you were using:

the LWDAC backrest? _____
your own personal backrest? _____
Other _____ (Please Explain Your Answer)

2) If you are using the LWDAC backrest *more* than you used to at the beginning of the trial period, please explain why you think this is the case. Be specific in your answer.

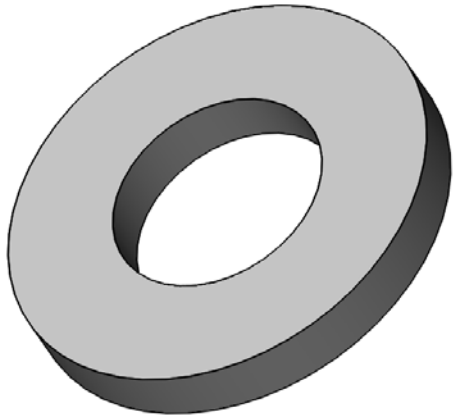
3) If you are using the LWDAC backrest *less* than you used to at the beginning of the trial period, please explain why you think this is the case. Be specific in your answer.

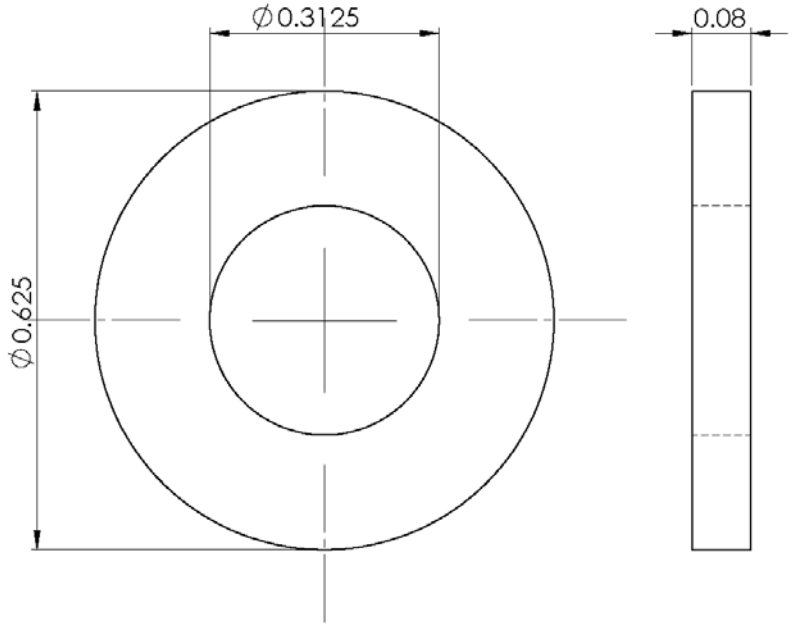
4) Do you have any other thoughts about the LWDAC backrest?

APPENDIX E

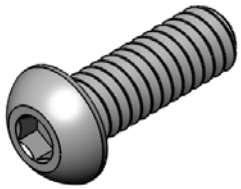
CAD DRAWINGS

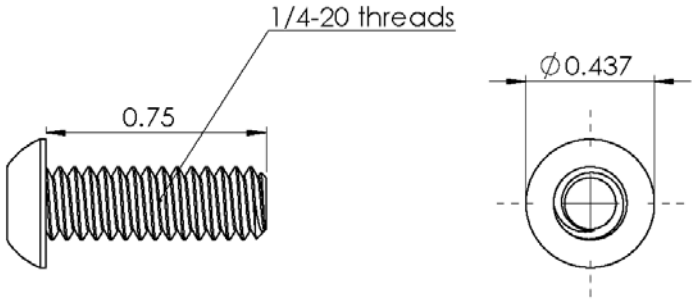
The following drawings were done with SolidWorks program for the LWDAC back support. .



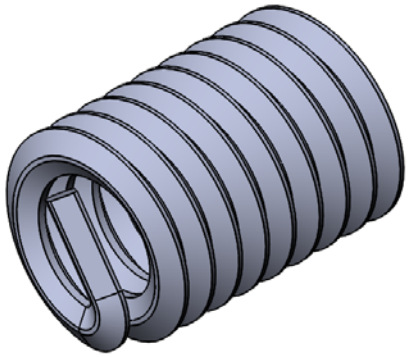


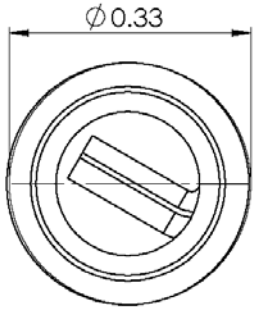
PART NAME:	1/4 Washer
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

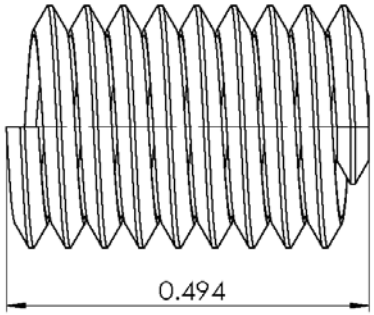




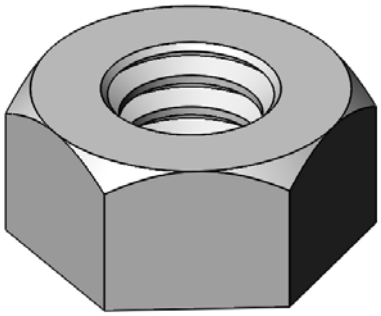
PART NAME:	1/4-20 Button head screw
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

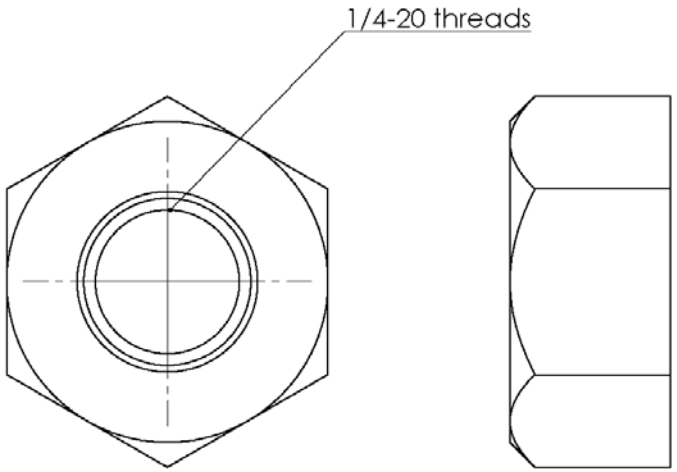




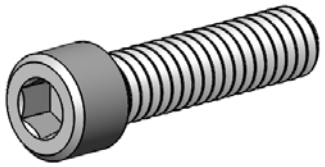


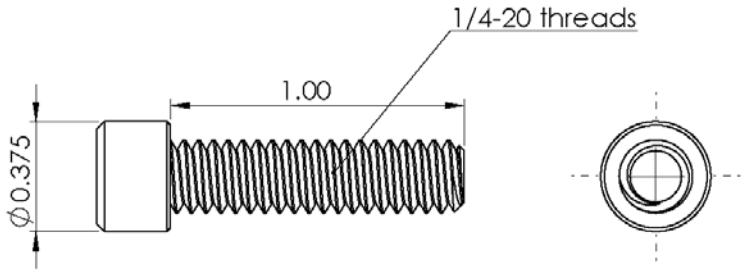
PART NAME:	1/4-20 Helicoil
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	



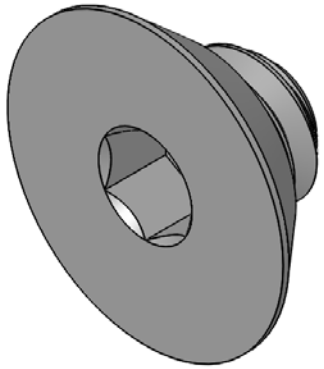


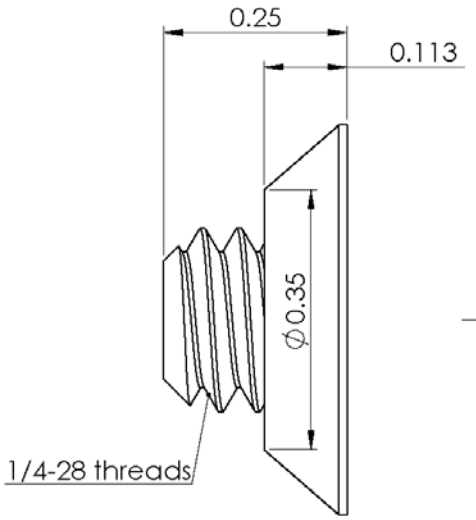
PART NAME:	1/4-20 Hex nut
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

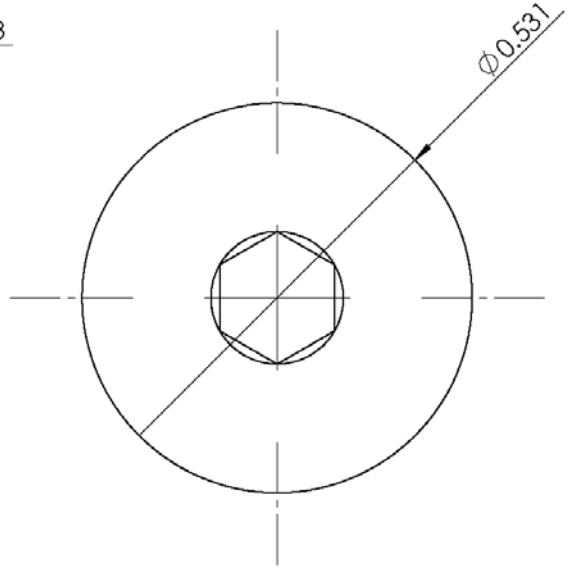




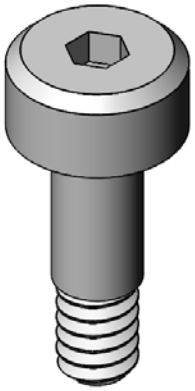
PART NAME:	1/4-20 Socket head screws
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

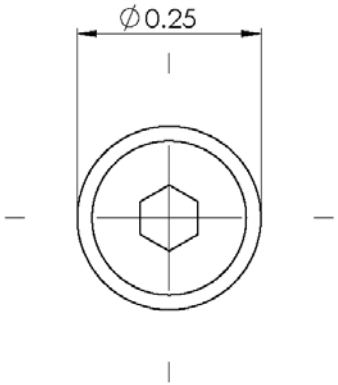


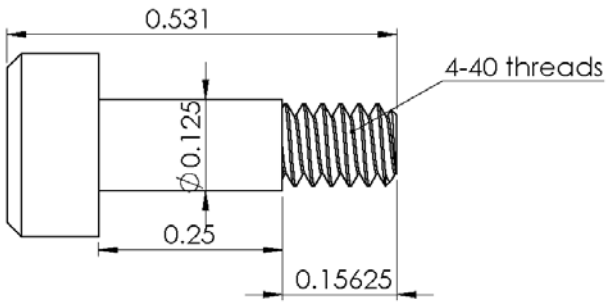




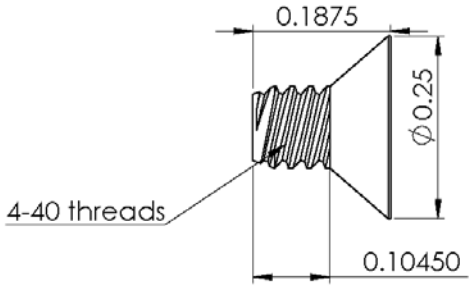
PART NAME:	1/4-28 Flat Head Screws
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

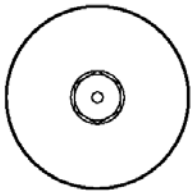






PART NAME:	4-40 Shoulder bolt
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	





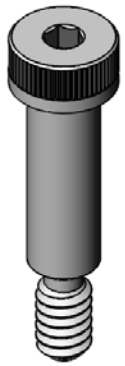
PART NAME: 4-40 Flat head screws

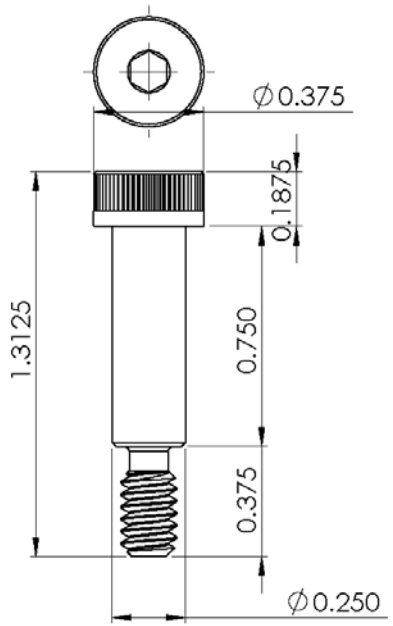
PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Purchased Hardware

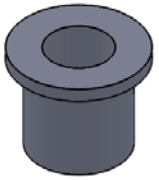
Principal Investigator : Dr. Rory Cooper

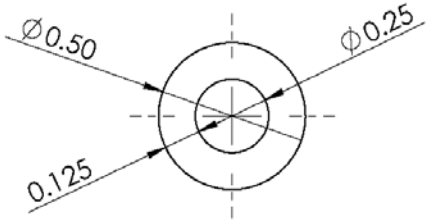
HUMAN ENGINEERING RESEARCH LABORATORIES

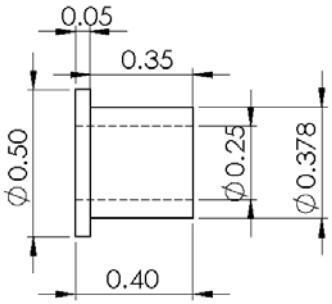




PART NAME:	10-24 Shoulder Bolt
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	



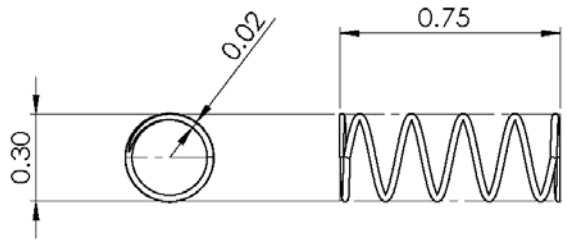




HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME:	Bushing
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Purchased Hardware
Principal Investigator :	Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES



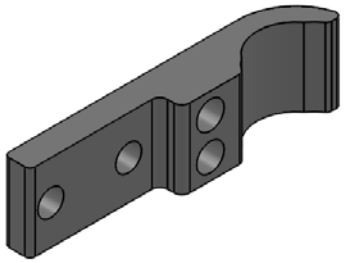
PART NAME: Spring

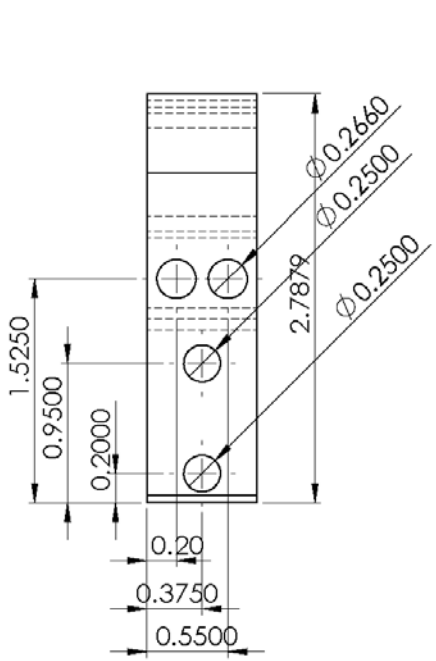
PROJECT TITLE: LWDAC backrest Phase II

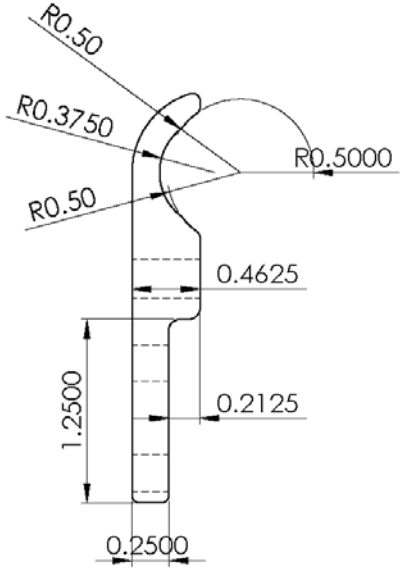
Drawn By: Purchased Hardware

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES



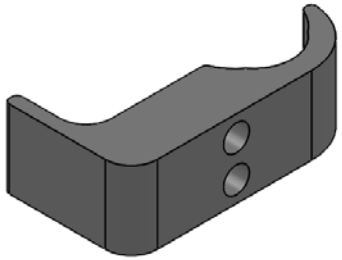


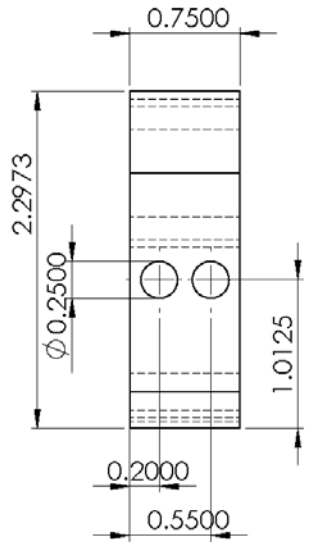


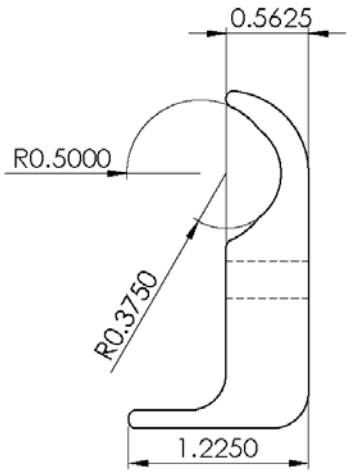
HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME:	Clamp 1
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper

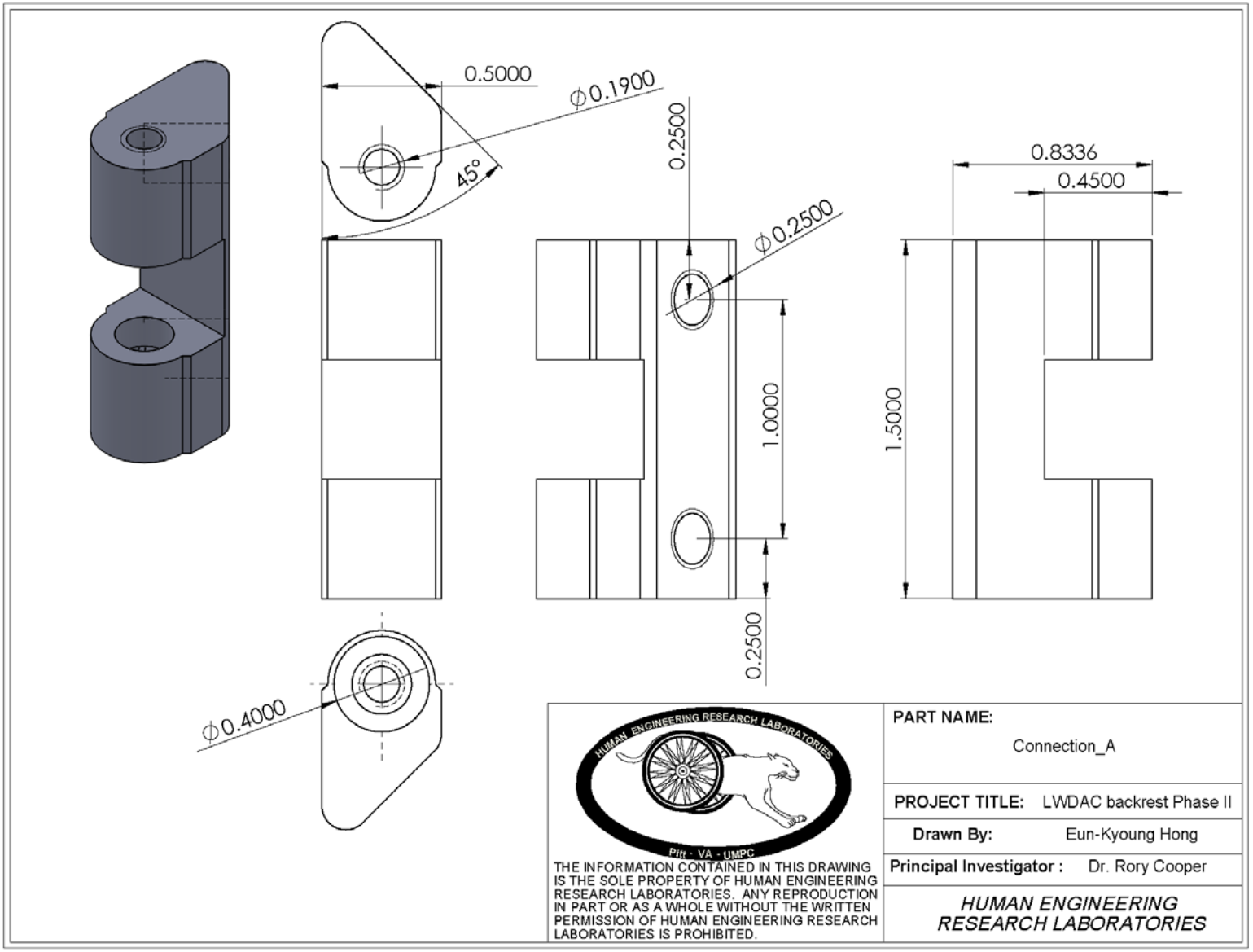
HUMAN ENGINEERING RESEARCH LABORATORIES







PART NAME:	Clamp 2
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	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ϕ0.1900
45°
0.2500
ϕ0.2500
1.0000
0.2500
0.8336
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1.5000
ϕ0.4000
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Pitt - VA - UMPC
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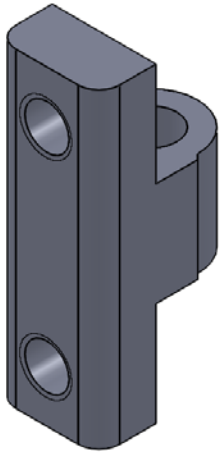
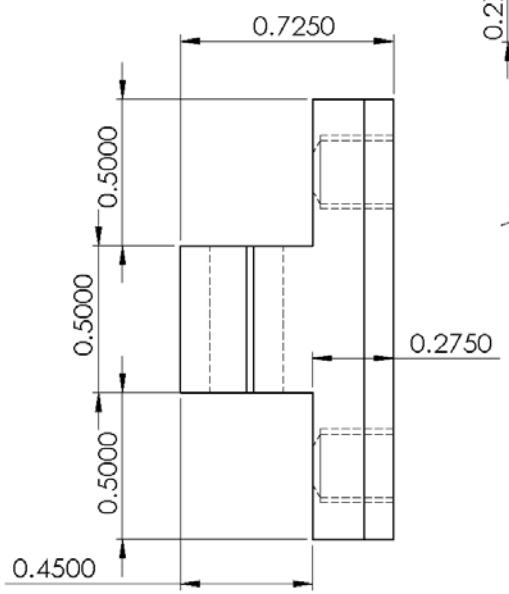
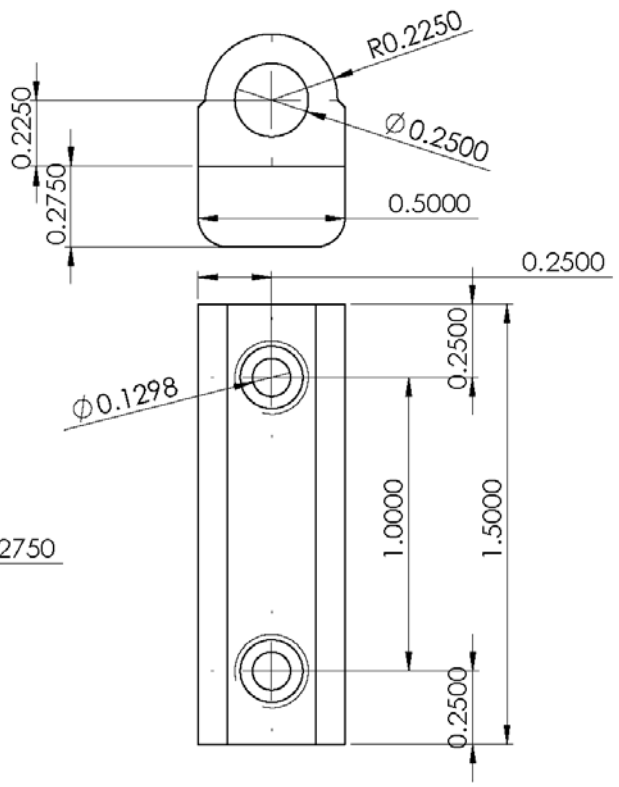
PART NAME:
Connection_A
PROJECT TITLE: LWDAC backrest Phase II
Drawn By: Eun-Kyoung Hong
Principal Investigator : Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES







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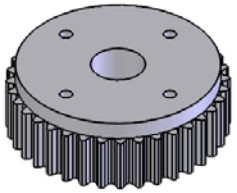
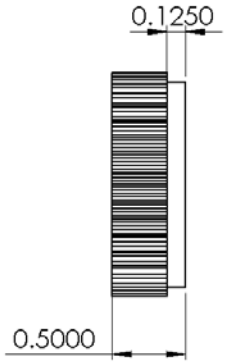
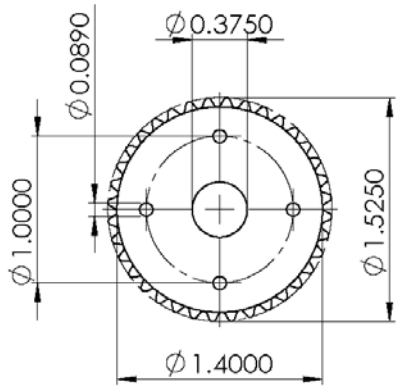
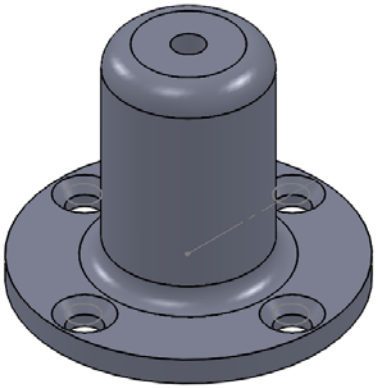
PART NAME:	Connection 2
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

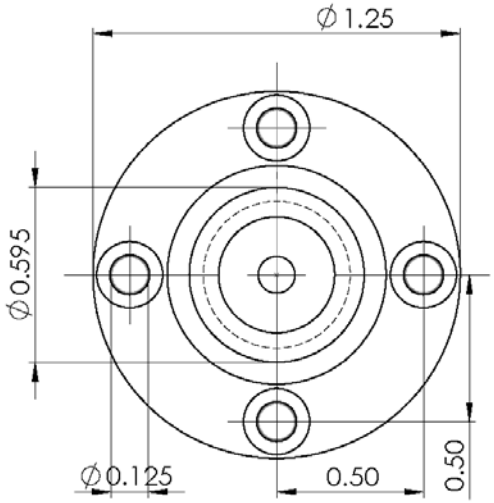


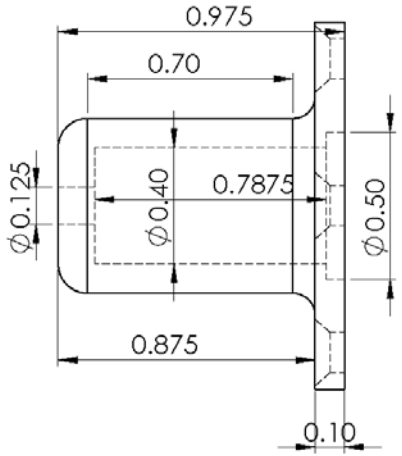




PART NAME:	Gears
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	







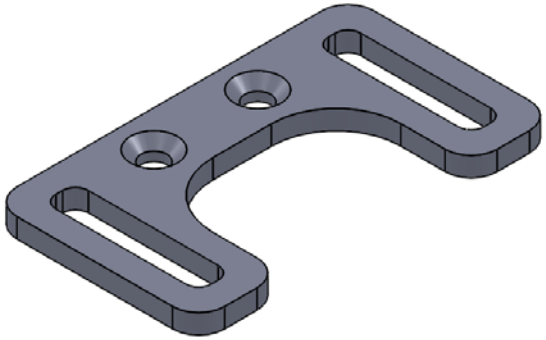
PART NAME: Inside Cover

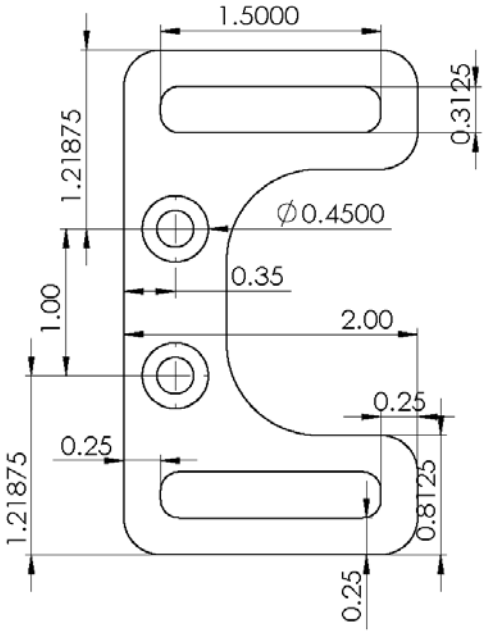
PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES

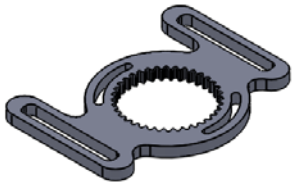


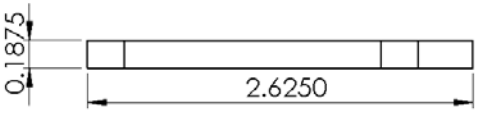


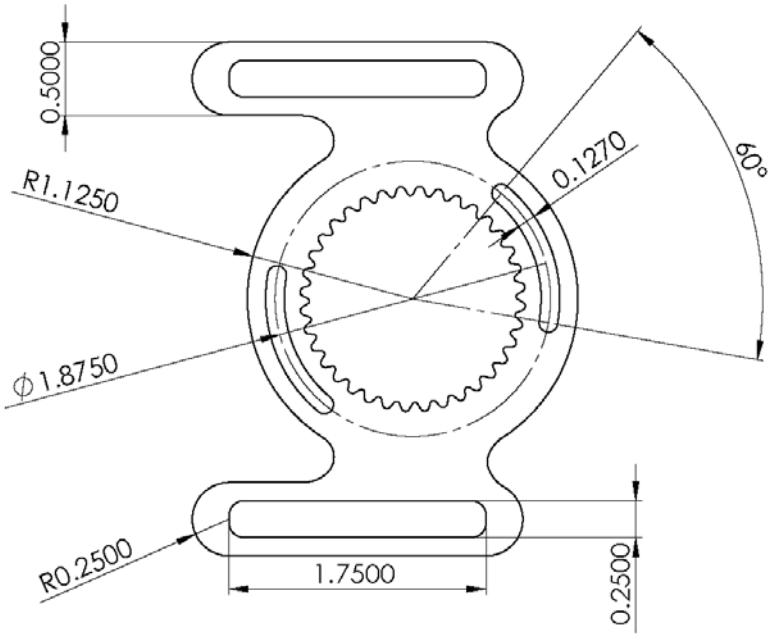
HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME:	Modified_Doggybone
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES

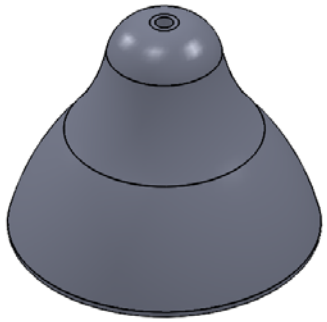


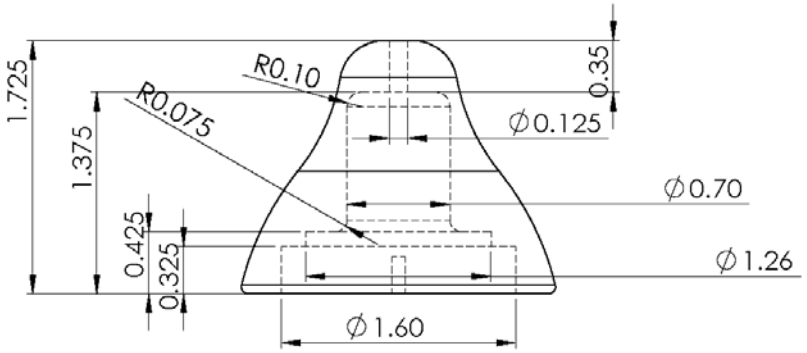


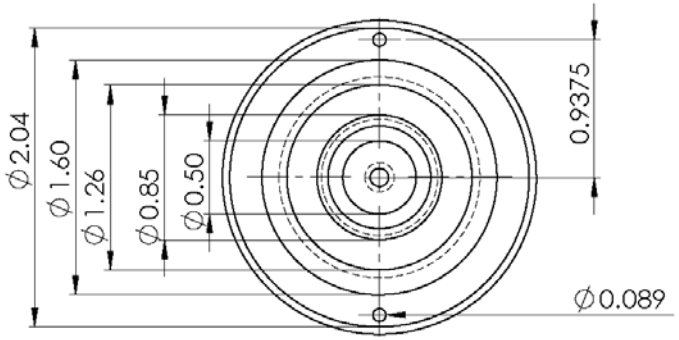


HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME:	Modified Movement Plate
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	



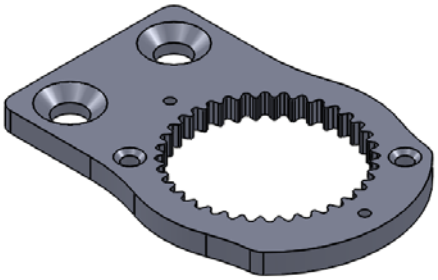


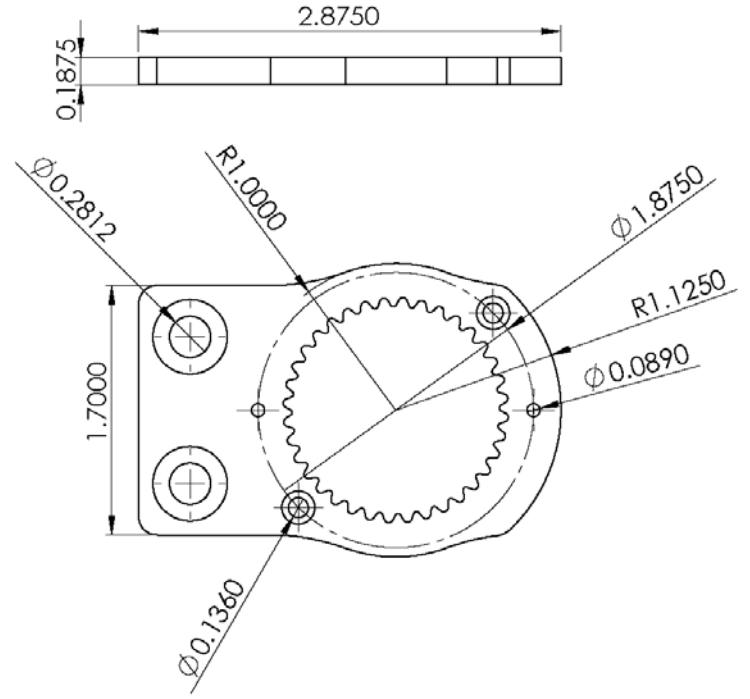


HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME:	Outside Cover
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper

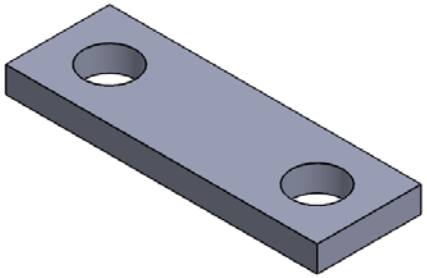
HUMAN ENGINEERING RESEARCH LABORATORIES

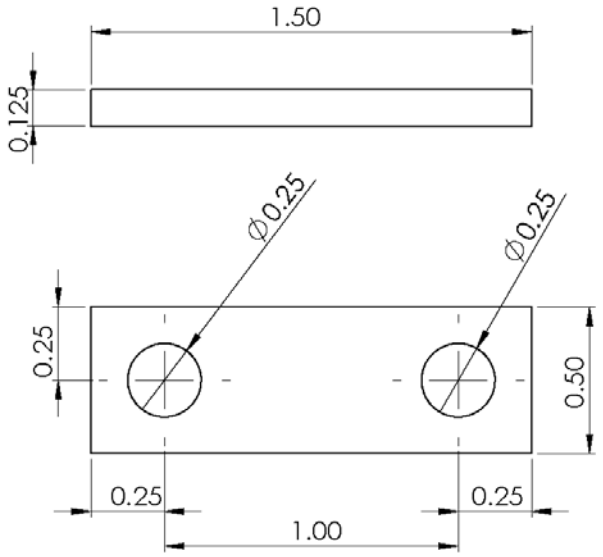




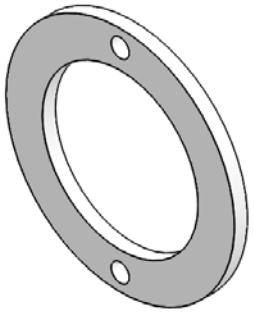
PART NAME:	Plate
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper

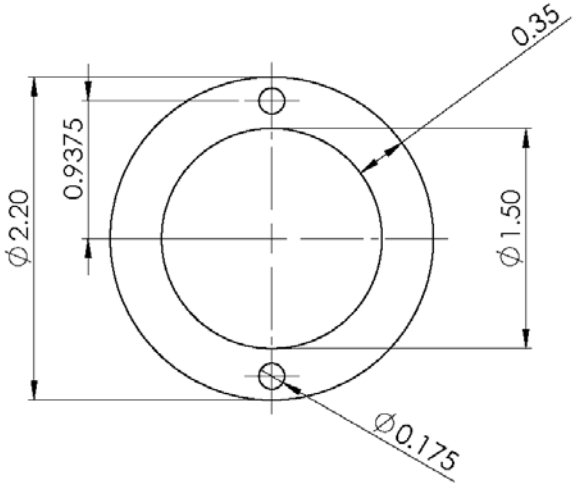
HUMAN ENGINEERING RESEARCH LABORATORIES



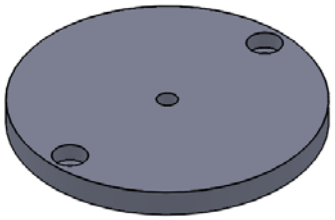


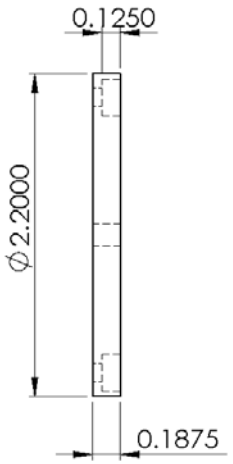
PART NAME:	Rectangle Spacer
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	

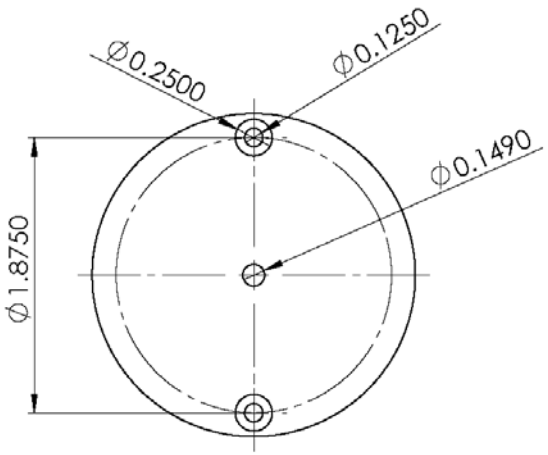




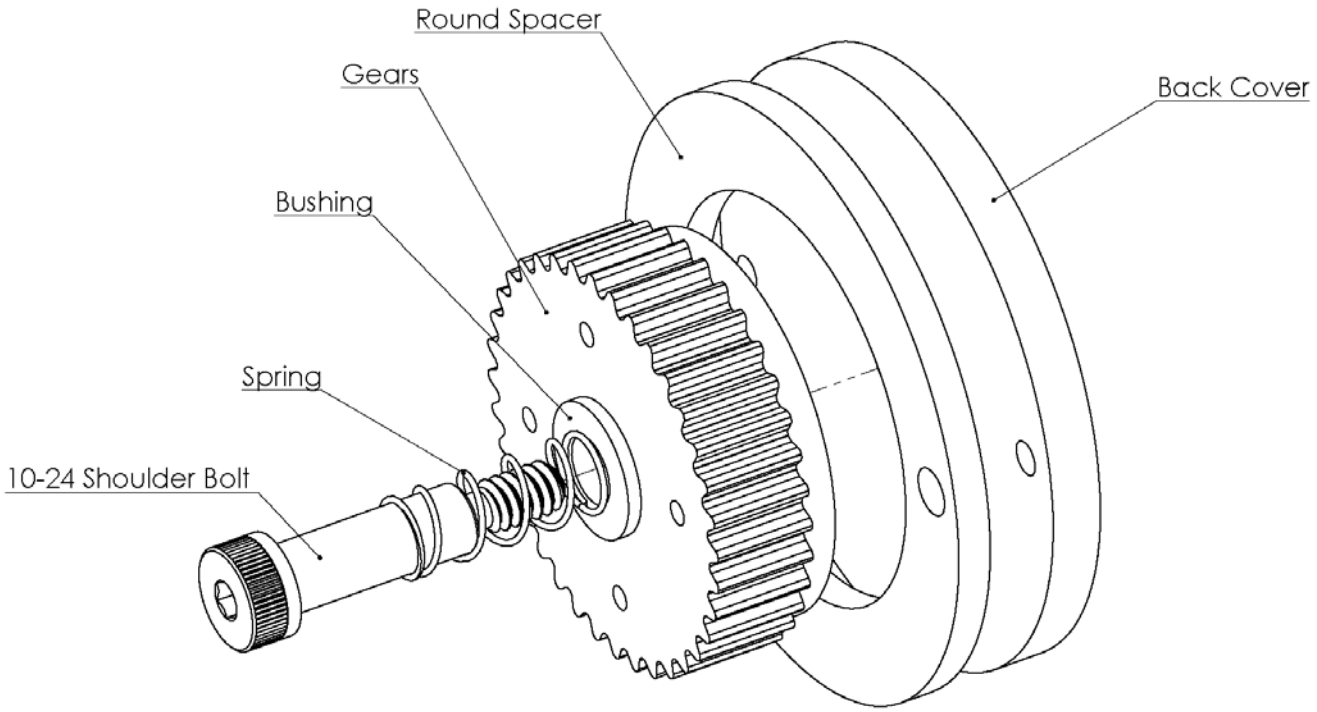
PART NAME:	Round Spacer
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	







PART NAME:	Back Cover
PROJECT TITLE:	LWDAC backrest Phase II
Drawn By:	Eun-Kyoung Hong
Principal Investigator :	Dr. Rory Cooper
HUMAN ENGINEERING RESEARCH LABORATORIES	



HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

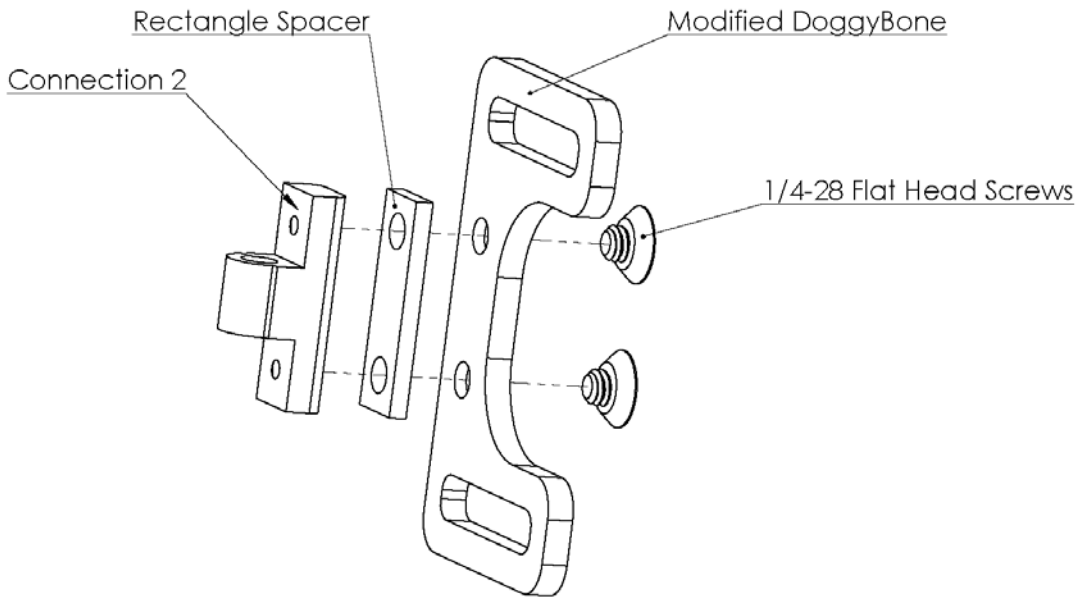
PART NAME: Assemble Process 1

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES



HUMAN ENGINEERING RESEARCH LABORATORIES
Pitt - VA - UMPC

PART NAME: Assemble Process 2

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

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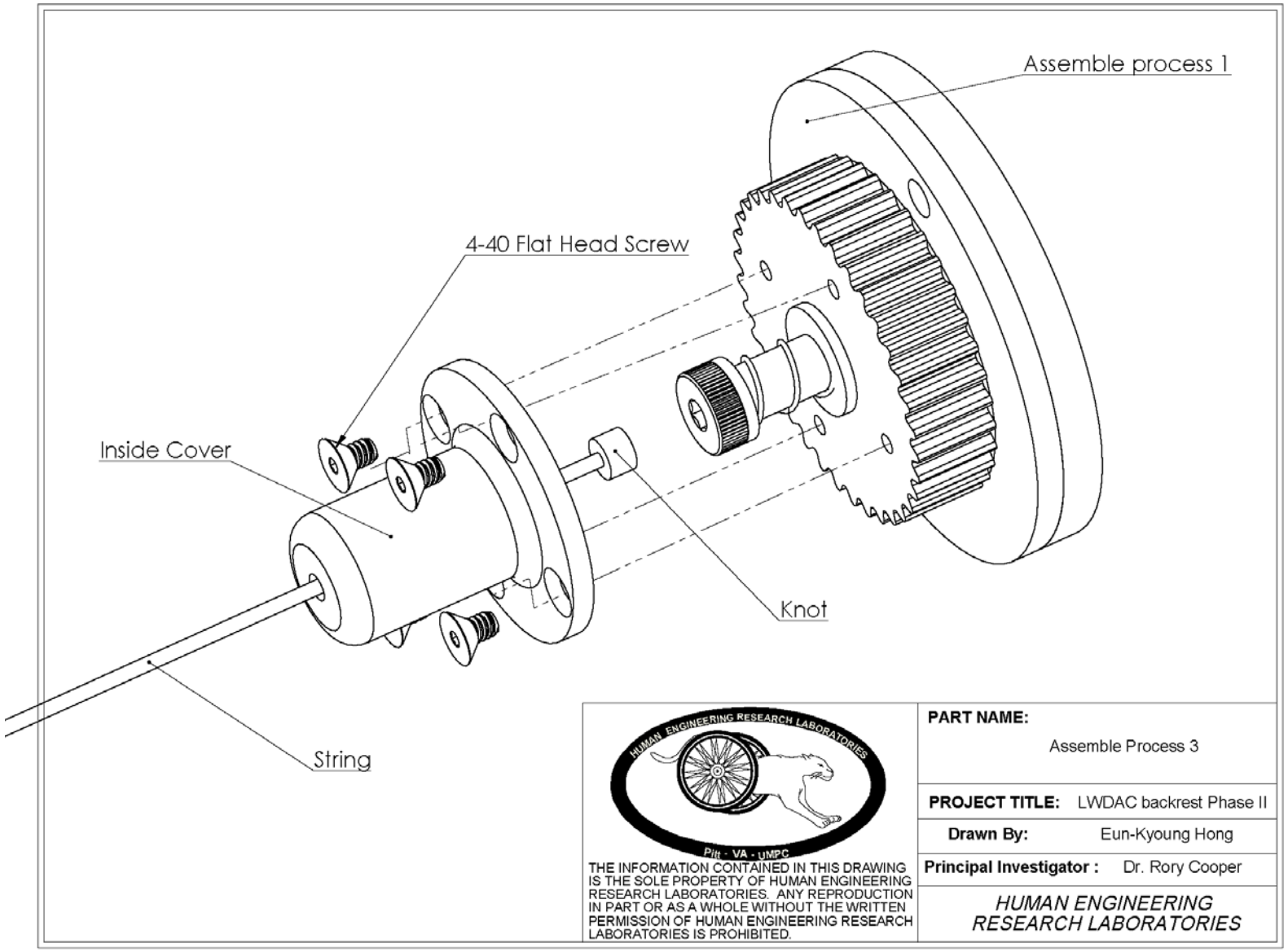
Assemble process 1
4-40 Flat Head Screw
Inside Cover
Knot
String
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PART NAME:
Assemble Process 3
PROJECT TITLE: LWDAC backrest Phase II
Drawn By: Eun-Kyoung Hong
Principal Investigator : Dr. Rory Cooper
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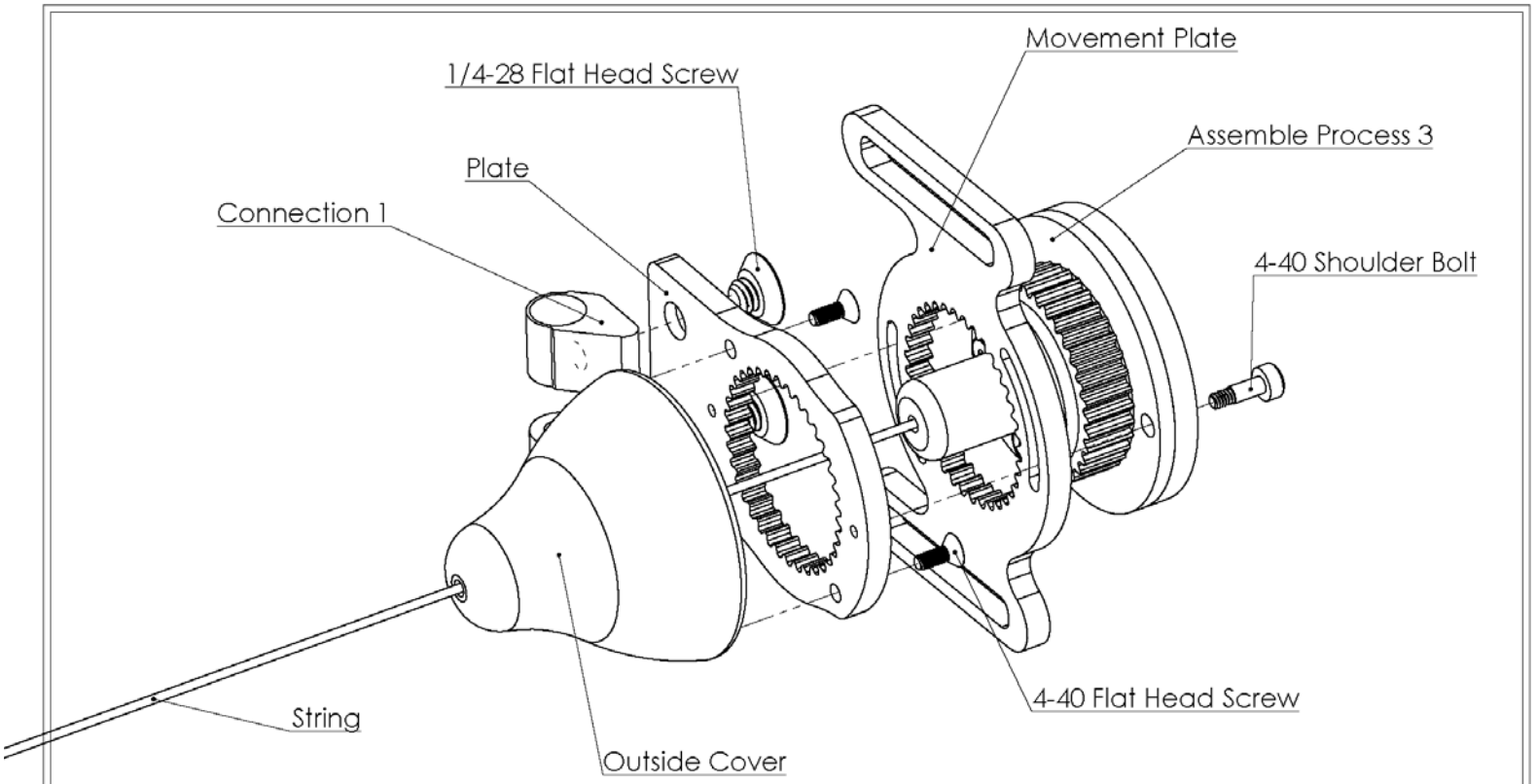

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PART NAME: Assemble Process 4

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

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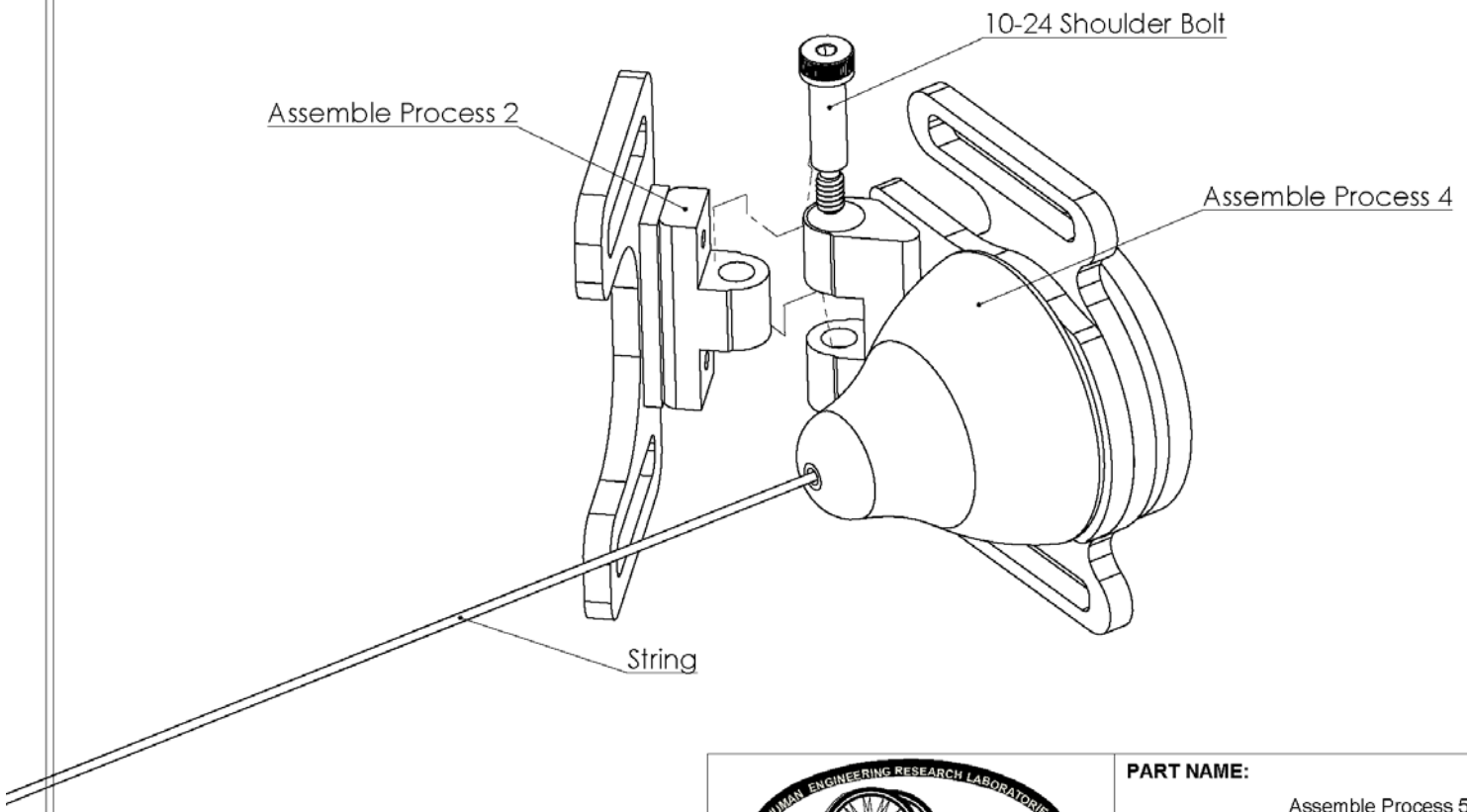


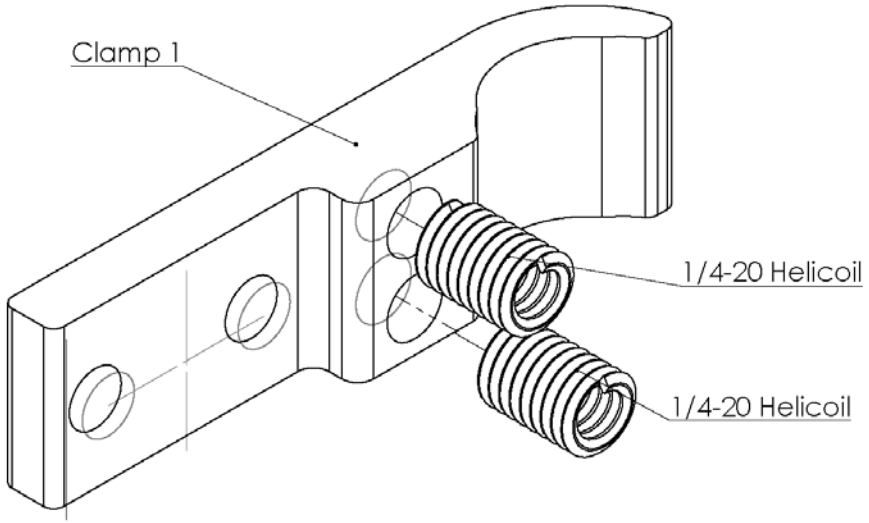
PART NAME: Assemble Process 5

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES



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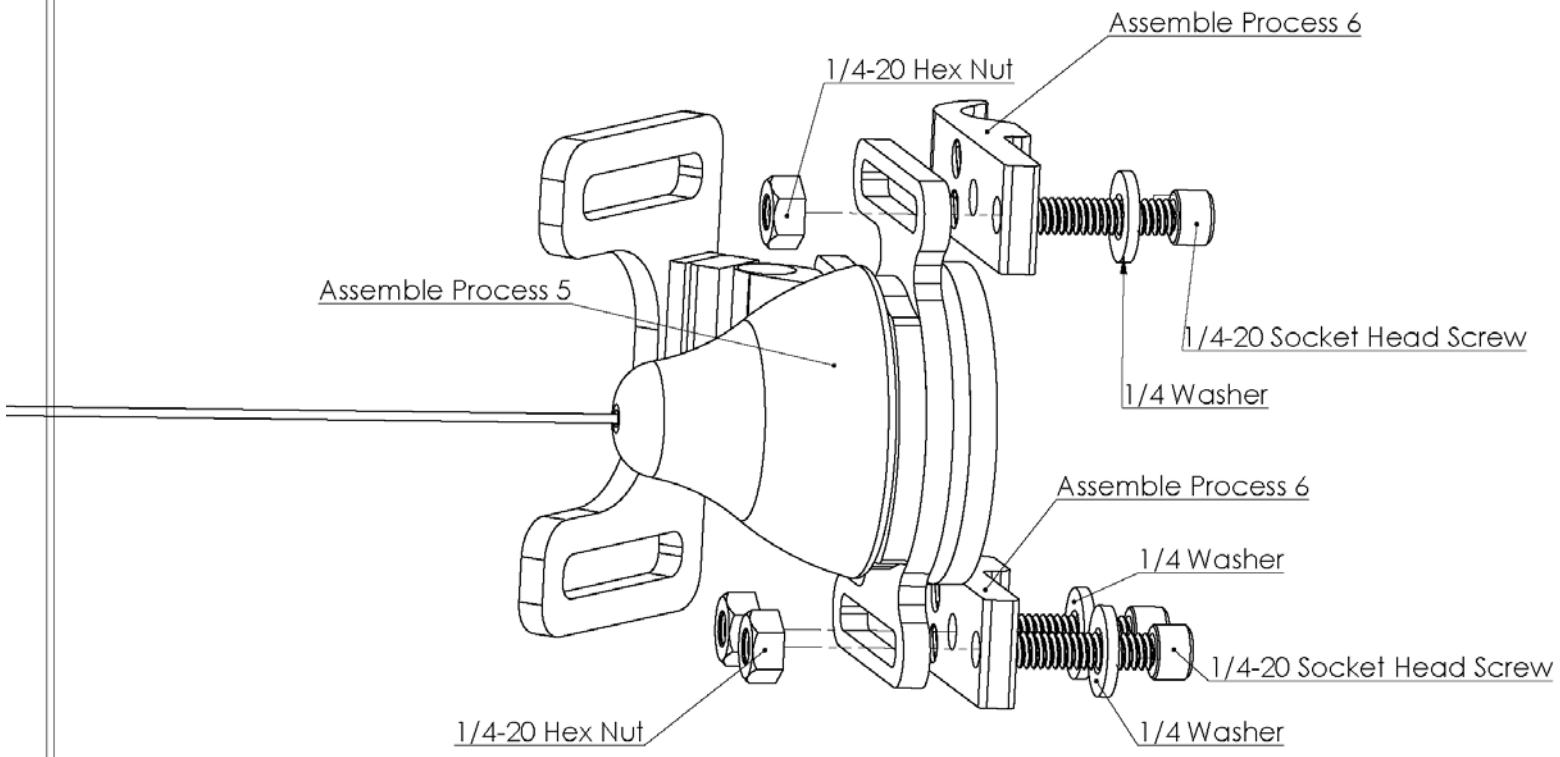
PART NAME: Assemble Process 6

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES



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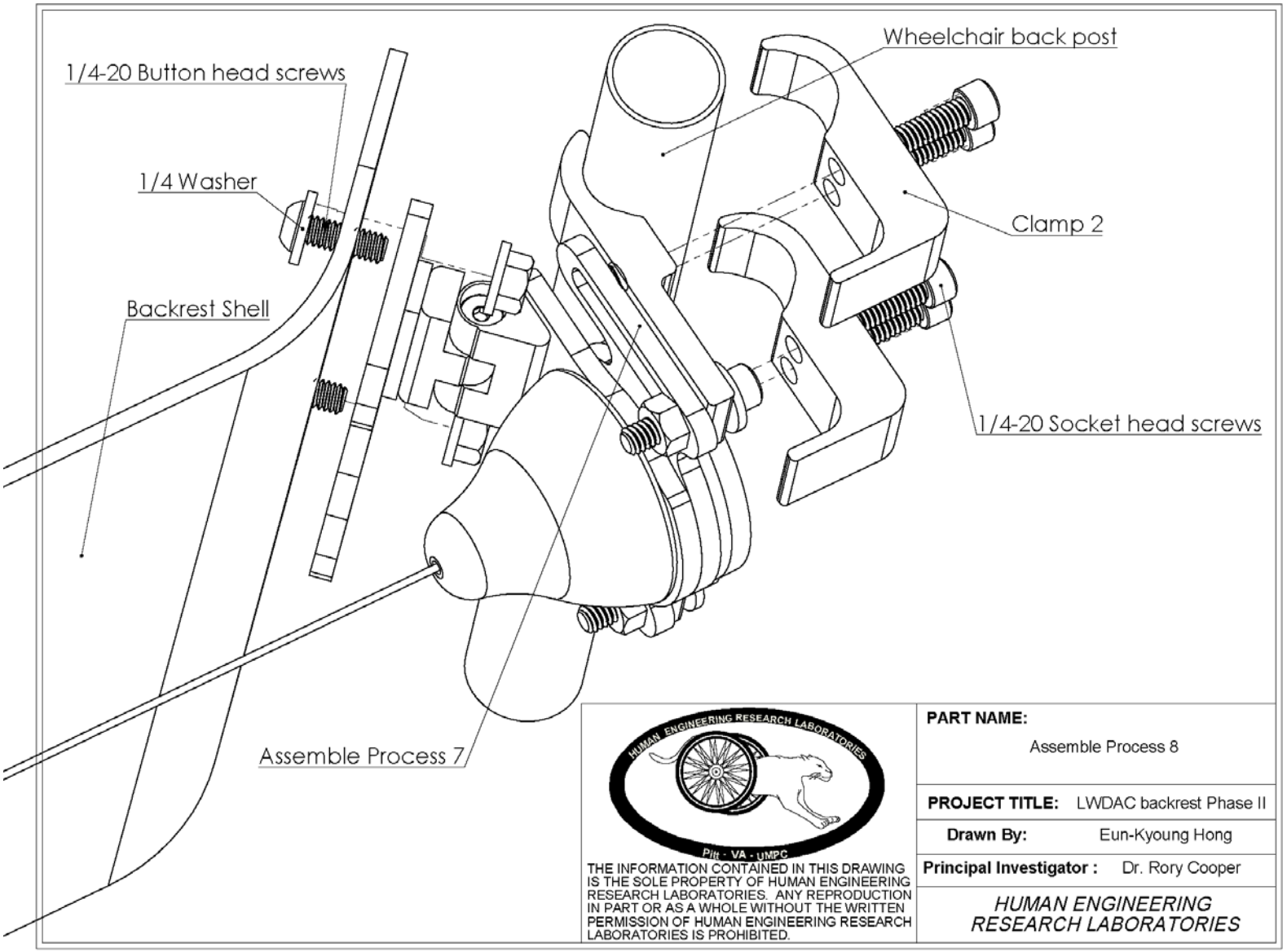
PART NAME: Assemble Process 7

PROJECT TITLE: LWDAC backrest Phase II

Drawn By: Eun-Kyoung Hong

Principal Investigator : Dr. Rory Cooper

HUMAN ENGINEERING RESEARCH LABORATORIES


1/4-20 Button head screws
Wheelchair back post
1/4 Washer
Clamp 2
Backrest Shell
1/4-20 Socket head screws
Assemble Process 7
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PART NAME:
Assemble Process 8
PROJECT TITLE: LWDAC backrest Phase II
Drawn By: Eun-Kyoung Hong
Principal Investigator : Dr. Rory Cooper
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