Improving Poor Posture in College-aged Backpack Users

BMED 2310 D

Bag to the Future

Brady Bove brady.bove@gmail.com

Rush Leigh rush.a.leigh@gmail.com

Shravanan Ravi shravanan.ravi@gatech.edu

Conor Wesolowski cwesolowski3@gatech.edu

Executive Summary

The device design was centered around improving user posture when wearing heavy backpacks by reducing the impact of the backpack on the Center of Mass (CoM) of the user. The target users were American college students (ages 17-24 years old) who wear two-strap backpacks due to the high amount of users in this demographic .[1,2] These users are at a high risk of developing back pain and other negative ailments due to maintaining a state of poor posture while wearing backpacks .[2,3] In the development of the device, research was conducted on the relationship between posture and backpacks as well as methods to analyze posture. In addition, strength testing was performed on the materials and prototypes. For the final prototype, comfort tests and Craniovertebral angle (CVA) measurements were performed, and user feedback was obtained about the perceived effectiveness and fashionableness of the device. The final device is a backpack attachment with velcro attachment points and a central buckle. The buckle has four strap entry points that pulls the backpack closer to the user, which increases the user CVA and improves posture.

Problem Statement

Proper posture aligns the head, shoulders, hips, and feet in a vertical plane .[4] Deviations from this position shift weight away from the core muscles and skeletal system, resulting in undue stresses on the joints, which can lead to joint pain, muscle fatigue and weakness, trouble breathing, and pinched nerves .[5] A common cause of poor posture involves carrying heavy loads for extended periods of time, such as when using a backpack. Backpacks shift the CoM of the user, forcing them to assume a poor postural position to avoid falling over. College students use their backpacks to carry school supplies, and its use can vary depending on course load, study habits, and extracurricular activities. Students wear their bags while walking, scootering, biking, skateboarding, and riding on public transportation. In the fall of 2018, the National Center for Education Statistics projected enrollment levels of 19.9 million American college students .[6] With 66% of college students reporting to always use a backpack, 13.1 million students are expected to have used their backpack whenever they need to carry school supplies from place to place this fall, whether that be to class, study sessions, or home. [2] 29.2-47.7% of those users

(3.8-6.2 million students) report annual back pain, and with every 4kg increase in backpack weight these students' odds of developing annual back pain increase by 25%; therefore, it is recommended that users do not carry more than 15% of their body weight in their backpack . [2, 7] This prevalent usage of heavy backpacks among college students places them at risk to develop poor posture, as well as its associated negative health effects. Therefore, a device that mitigates this risk would be desirable and directly beneficial to its users.

Design Specifications

Based on the physiological need for this device, the primary objective is to create an attachable system that offsets the change in CoM caused by the weight of the user's backpack, thereby preventing hunching and improving the user's posture. To achieve this goal, critical constraints were made to ensure the device is hands-free and strong, can withhold 38.6lbs (15% body weight of the 95% American college-aged male) with negligible deformation, and increases the user's CVA by two degrees .[8] Two degrees was chosen as the design input to offset the average decrease in user CVA of 1.67 degrees while wearing a backpack .[9] The device was designed to be attachable and adjustable, catering to the needs of all types of physiques and accessible to all users of standard double-strap backpacks.

In addition to this, comfort and desirability were highly prioritized constraints in the design process. From consistent user feedback, it was determined that these two factors had the biggest impact on the user's willingness to use or purchase the device. Therefore, a comfort scale that ranged from 1-10 ('1' being the least comfortable and '10' being the most comfortable) was developed to assess the user's comfort level while wearing the device. It was assumed that users will be more likely to buy a comfortable and aesthetically pleasing product; hence, an average user rating of 6 was set as a design input. Another development that was drawn from the user feedback was to simplify the device, minimizing confusion in applying the device and avoiding discomfort. In accordance with the user profile, it was also assumed that American college students only carry up to 15% of their body weight and will be more likely to buy a device that is at or below the average backpack attachment price of $7.14, ensuring affordability.

Design Concepts

Many design concepts were considered during the ideation phase of this project. These included a cross strap bag, a bag with zipper straps, bags that incorporate electronics, bags that were fitted to bikes or scooters, and more (Figure 1). To narrow down the various design concepts, the aforementioned design inputs were generated. The device had to be: feasible, affordable, fashionable, portable, strong, simple, and comfortable. Moving into testing of the initial prototypes, several quantitative criteria were set to allow for refinement of ideas.

The first idea tested was a bag with the normal backpack straps crossed (Figure 2). Although this device failed because of its low comfort rating, users reported that the distribution of weight felt better with the crossed straps. Another design that had an influence on the final design was the zipper strap attachment (Figure 3). This bag attachment, although not fashionable, showed that as the area of straps increased, the weight of the bag was distributed more evenly across the chest and back, improving comfort and posture. To combine the benefits from both concepts, the next prototype design was a bag with two buckles, sewn onto the straps of the bag that crossed each other in the shape of an X (Figure 4). This design showed promise for reducing posture, but was reported to be uncomfortable, because the buckles placed pressure on the user's chest. After this, a x-shaped buckle was designed that solved the problem of comfort and maintained the effectiveness of reducing poor posture (Figures 5,6).

One set of designs with potential was discarded. Testing revealed that a strap connected from the side of the backpack to the front straps of the backpack reduced poor posture (Figure 7). Although this device was effective, users reported it to be complicated and uncomfortable; therefore, it was not incorporated in the final design.

Design Solution

The final design for this project includes a male and female end of a polypropylene buckle, four polypropylene straps, and four two-sided segments of Velcro (Figures 5,6). Polypropylene was chosen for its high durability and low environmental impact and price .[10] All the material costs can be found on Table 1 .[11,12,13] Additionally, the device will be packaged in a 5"x 6" low-density polyethylene bag at a cost of $0.02 per bag.[14] The straps have Velcro attached to the ends, which will be wrapped and attached around the front straps of the user's backpack. The opposite end of the straps will be weaved through the buckle attachment points, and the buckle will be clasped across the user's chest. The buckle will be manufactured via injection molding, and is properly drafted and filleted to optimize production. Each buckle end contains two slots, offset at a 45-degree angle, for the insertion of each strap. Likewise, each strap is bent and sewn at a 45-degree angle so that the tension can be distributed over a larger distance on the user's chest.

The function of this device is to reduce poor posture experienced by carrying heavy loads on one's back. This can be done by bringing the CoM of the bag closer to the back and by distributing the force experienced by the shoulders onto the chest. The X-buckle mechanism will effectively reduce the negative effects caused by heavy loads and can be measured using a CVA test. This device should be used every time the user transports heavy loads in a backpack to ensure its effectiveness.

Engineering Analysis

When wearing a backpack, its mass, weighted by its distance from the center of the user by the equation in Figure 8, shifts the user's overall CoM backward. To compensate for this, the user leans forward, returning their CoM to normal so that they do not fall down. However, this forward lean compromises their postural position, and places them at risk of developing poor posture. The device reduces the impact of the backpack on the CoM of the user, allowing the user to maintain a better postural position.

When the device is attached to the backpack with the buckle engaged, it draws the straps of the backpack closer together. This pulls the backpack closer to the back of the user, reducing its contribution to the CoM. The effectiveness of this design was evaluated by comparing user CVA under a load of 15% of their body weight both with and without the device engaged. CVA is a measure of the degree of forward lean, with a higher CVA indicating less lean and therefore a better postural position. Therefore, CVA is a more accurate measure of the effect of the device on posture than the metric from last phase, which consisted of distance of the backpack from the back of the user. CVA was measured by taking pictures of the users from multiple views, overlaying a grid, and determining the angle based on the trigonometric relationships between the line from the seventh cervical vertebrae and the middle of the ear and the horizontal. On average, the device increased the user CVA by 4 degrees, more than double the negative impact of a typical backpack, demonstrating that it is effective in improving user posture.

Conclusion

As stated in the problem introduction, users transporting heavy loads in backpacks are at risk for poor posture. The device improves posture by drawing the backpack straps closer together, pulling the bag closer to the user's back which then decreases the backpack's CoM contribution allowing the user to hold a better postural position without accommodating for a drastically adjusted CoM. Better posture means that users are less at risk for the negative health effects (annual back pain) associated with poor posture and backpacks .[2,3] This device meets the design inputs with an average comfort rating of 9/10, an approval rating of 70%, an application time of 45 seconds, and a CVA increase of 4 degrees (double the desired outcome). However, the current device does have some issues that could be improved upon. While users would wear the device, there is still a wish for an improved aesthetic design. Currently the excess straps are very obvious; while users could cut them, a seat belt-like containment system of the adjustable straps would appear much more cohesive and pleasing. In addition, the straps are currently difficult to adjust, so the buckle design would need to be adjusted to increase the width of the clasp attachment point. Throughout this process we learned that every aspect of product design matters, from deciding what material to use, to the shape and feel of the device to users, to prototype testing and refinement, to how testing is done. It is important to weigh the benefits and costs of different aspects of the device to come up with an aggregate of the most advantageous device for users in regards to cost, effectiveness, and marketability; the device meets the input specifications for all of these categories.

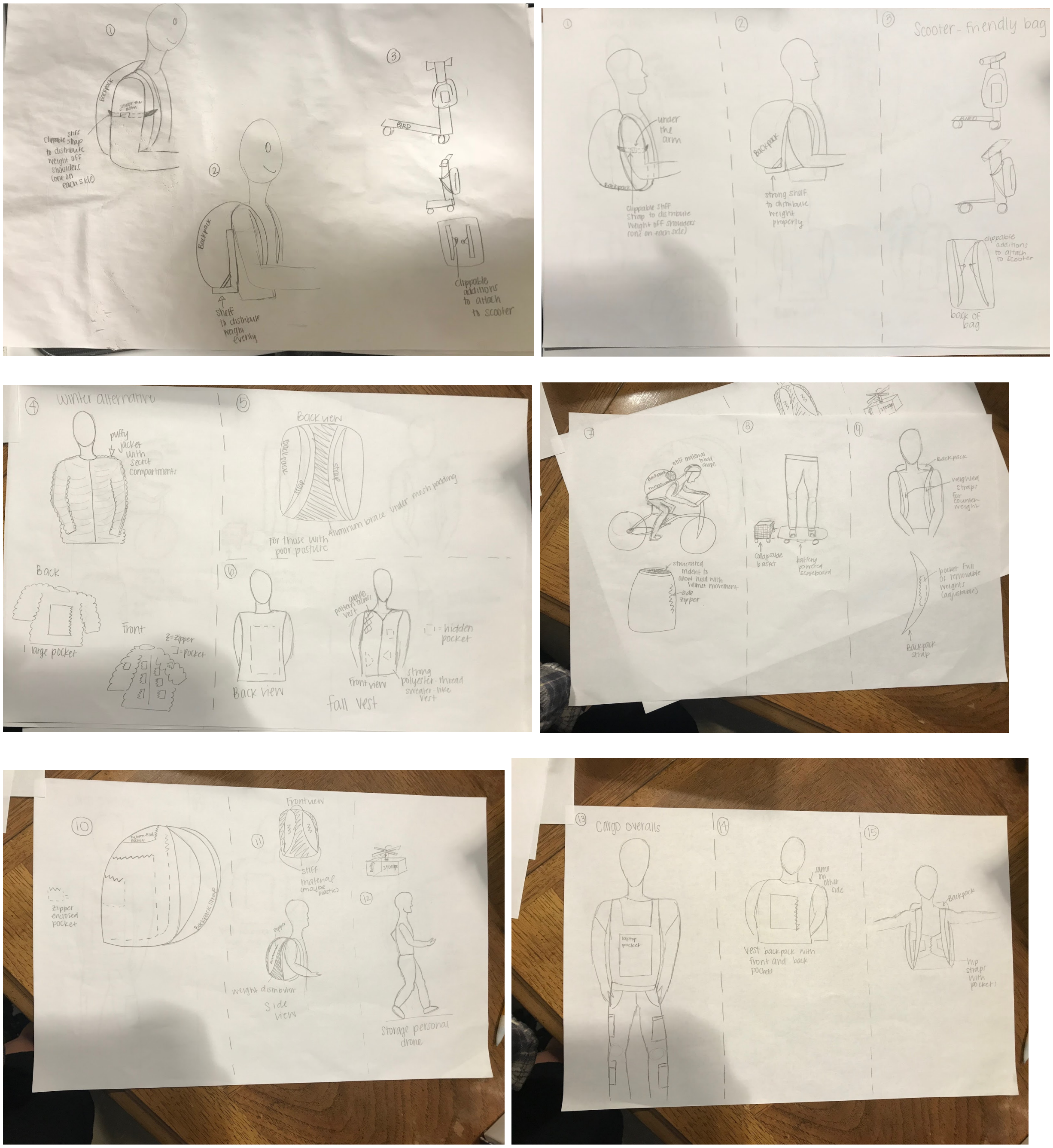
Bibliography

1. Wickman F. The Eternal Backpack Question, Answered: Is It Cooler to Two-Strap or to One-Strap? Slate Magazine. http://www.slate.com/articles/life/cool_story/2013/10/two_straps_on_a_backpack_or_one_strap_what_s_cool.html. Published October 31, 2013. Accessed September 25, 2018.
2. Heuscher Z, Gilkey DP, Peel JL, Kennedy CA. The Association of Self-Reported Backpack Use and Backpack Weight With Low Back Pain Among College Students. Journal of Manipulative and Physiological Therapeutics. 2010;33(6):432-437.
3. Scary Facts About Poor Posture. Nebraska Spine Hospital. https://nebraskaspinehospital.com/scary-facts-poor-posture/. Published October 17, 2017. Accessed August 29, 2018.
4. Llewellyn J. What Type of Posture Do I Have? Kyphosis, Flatback, Swayback, or Forward Head. What is Lordosis? Lumbar & Cervical Spine Swayback Symptoms & Causes. https://www.braceability.com/blogs/articles/types-of-posture-and-spinal-curves. Published August 9, 2016. Accessed August 29, 2018.
5. Hein JT. Posture: Align yourself for good health. Mayo Clinic. https://www.mayoclinic.org/healthy-lifestyle/adult-health/in-depth/posture-align-yourself-for-good-health/art-20269950. Published December 13, 2016. Accessed August 29, 2018
6. Fast Facts. National Center for Education Statistics (NCES) Home Page, a part of the U.S. Department of Education. https://nces.ed.gov/fastfacts/display.asp?id=372. Accessed December 8, 2018.
7. Carrying Work Home- Painlessly. Tufts Environmental Health and Safety In Case You Haven't 'Herd' About. https://publicsafety.tufts.edu/ehs/files/October2014.VI2-Backpacks.pdf. Accessed December 12, 2018.
8. Fryar CD, Gu Q, Ogden CL. Anthropometric reference data for children and adults: United States, 2007–2010. National Center for Health Statistics. Vital Health Stat 11(252). 2012.

9. San Agustin CT, Wilmarth MA, Raymond J, Hilliard TS. The Amount and Variation of Craniovertebral Angle Changes in College-aged Students Using One-strapped and Two-strapped Backpacks and Bags Orthopaedic Practice.15(3):4.
10. Worth J. Top 5 Most Common Plastic Resins for Injection Molding. The Rodon Group. https://www.rodongroup.com/blog/top-5-most-common-plastic-resins. Published May 31, 2018. Accessed December 12, 2018.
11. 1-Inch Polypropylene Webbing | Lightweight Polypropylene Webbing. strapworks.com. https://www.strapworks.com/Lightweight_Polypropylene_p/lwp1.htm. Accessed December 12, 2018.
12. Plastic Injection Mold Online Quotes | ICOMold. - Custom Plastic Injection Molding & CNC Machining. https://icomold.com/icoquote/?gclid=CjwKCAiAodTfBRBEEiwAa1hausp7XIio1jzsyJf7sneR5RjCJpRPgHCerTdzzmPwJIBthymtkSfAMhoCtroQAvD_BwE. Accessed December 12, 2018.
13. Velcro® Brand Industrial Trade Range. Velcro. https://www.velcro.com/business/products/velcro-brand-industrial-trade-range/. Accessed December 12, 2018.
14. 5" x 6" 2 Mil Poly Plastic Bags Flat Clear 1000/case S-1726. 5" x 6" 2 Mil Flat Poly Bags. http://www.interplas.com/5x6-2mil-flat-poly-bags-p-pb20506. Accessed December 12, 2018.

Addendum

Figure 1.



Six examples of initial brainstorming design concepts

Figure 2.

A normal backpack with straps crossed

Figure 3.

Zipper Strap Attachment prototypes, short and long versions

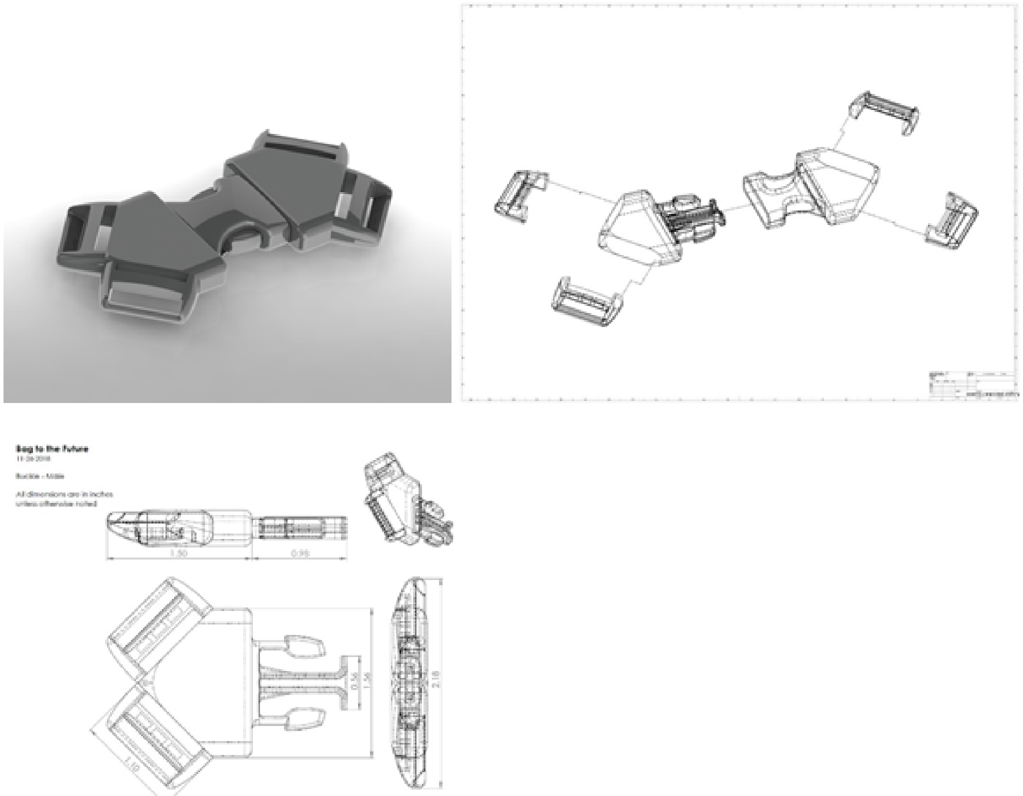
Figure 4.

A backpack with 2 buckles across each other.

Figure 5.

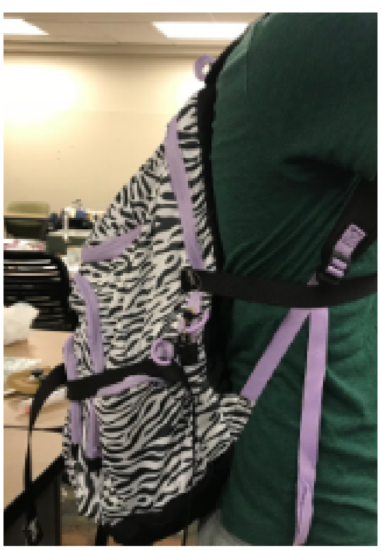
Final design of a backpack with velcro strap attachment points and a 3D printed x-shaped buckle.

Figure 6.



Solidworks drawings of final buckle design

Figure 7.



Straps connected from back of backpack to the backpack straps.

Table 1.

Name/function	Quantity Required	Supplier and Catalog Number	Material	Manufacturing process	Estimated cost
1” Polypropylene Solid Webbing	4 segments	StrapWorks.com LWP1	Lightweight Polypropylene Webbing- 1” width, .040” thick	1. Melt Spinning. 2. Weaving on a loop	$0.15 per foot (5’ needed per device = $0.75)
X-shaped buckle	1	DNA - made in house	Polypropylene (chosen for price, durability, and environmental impact)	Injection Molding	$0.69 per device
Velcro	4 x 2 sided segments	Velcro Hook 81 loop 9000 155412	Polyester	Knitting; injection molding	$8.97 for 10’ (6” per device = $0.45)

Figure 8.

2D

$$m_x = \iint_R y \cdot p(x,y)\,dA$$

$$m_y = \iint_R x \cdot p(x,y)\,dA$$

3D

$$m_{xy} = \iiint_Q z \cdot p(x,y,z,)\,dV$$

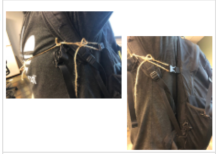
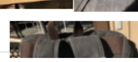
$$m_{yz} = \iiint_Q x \cdot p(x,y,z)\,dV$$

$$m_{xz} = \iiint_Q y \cdot p(x,y,z)\,dV$$

Center of Mass calculations

Table 2. DEEM Table.

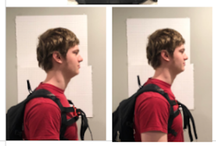
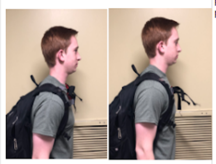
DESIGN EVOLUTION AND EVALUATION MATRIX		BMED 2310 Fall 2018	
		Team Name: Bag to the Future	
KEY DESIGN INPUT METRICS	**Tested?**		
Can carry 38.6 lbs with minimal deformation	x		
Increases user CVA by 2 under 15% bodyweight load	x		
Device has comfort rating > 6 on scale of 1-10	x		
Reduces distance of bag from user's back by 50%	x		
Device can carry 38.6 lbs when wet	x		
Device is Portable without needing hands	x		
Device appearance is acceptable by a majority of users	x		

#	PURPOSE	TARGET METRIC(S) & TESTING PLAN	PROTOTYPE	MATERIALS/PROCESS DOCUMENTATION	MEASURED RESULT (QUANTITATIVE)	FINDING/LEARNING (QUALITATIVE)
1	To test the ease of use and qualitative effectiveness of a cross-strapped backpack.	**Procedure** : Cross the straps of a typical backpack by exchanging the clasps. Observe a user putting on, standing normally, and taking off the cross-strapped backpack. Then ask user to talk about their experience and rate how comfortable the device was on a scale of 1 to 5 with 1 being extremely uncomfortable and 5 being extremely comfortable. **Metrics:** Comparability between putting on cross-strapped backpack and regular backpack. Comparability between posture while wearing a cross strapped backpack and regular backpack		**Material:** Polyester backpack with straps crossed	**User Comfort Rating:** 2.2/5	User says the cross strap backpack feels better (with less weight on the shoulders) than regular backpack. It appeared to put more pressure on neck to observers. It was very difficult for the user to put on and take off; it appeared to take twice as long to put in and the user was obviously exerting much more effort. This appeared to be caused by the fact that the straps were the same length as typical straps, and thus were too short to comfortably cross the chest. This discomfort should be alleviated if the straps were made longer. Users complained that the device caused choking if tightened enough to bring the backplack flush with their back, but that they felt very secure when tightened.
2	To test the comfort level and determine the best placement of a strap that connects the two backpack straps across the chest.	Procedure : Wrap a pipe cleaner around each strap of a typical backpack, 6 inches from the top of the strap. Have the subject put on the backpack, which weighed 15 pounds, then twist the two pipe cleaners together to form a continuous strap. Ask the subject to rate the comfort of the current strap location, then to move the strap to where it was most comfortable. The subject was then asked for additonal comments regarding their thoughts as to what would make it more comfortable. Metrics: Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. Then, the distance from the top of the strap in inches that the subject said was most comfortable was recorded.		**Material:** Polyester backpack, pipe cleaners	**User Comfort Rating:** 2.0/5 **User Preferred Distance:** 8.05 in	Subjects reported that the initial strap placement was much too high, and that it felt like it was choking them. They reported that the strap was more comfortable when moved down their chest, and still felt effective. This indicated that the final strap location shoud be located in the upper half of the chest, but closer to the middle of the chest than the shoulders. Subjects also reported that the how thin the strap analogue was contributed to their discomfort, meaning that further designs should make the straps have more surface area to distribute the force and make it more comfortable.
3	To test the effectiveness of using a single strap with a clasp connecting the straps across the chest to pull the backpack closer to the back of the subject, as well as assess its comfort level.	**Procedure** : Tie twine around one end of a nylon clasp, then tie the other end of the twine to the strap of the backpack, 8.05 inches from the top of the strap, repeating this for the other end of the clasp. Have the subject put on the backpack, which weighed 15 pounds, and measure the largest distance from the back of the subject to the front of the backpack without engaging the clasp. Measure again with the strap clasp engaged. Ask the subject to rate the comfort of the strap. The subject was then asked for additonal comments regarding their thoughts as to what would make it more comfortable or effective. **Metrics:** Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. The largest distance from the back of the subject to the backpack fron was measured with and without the strap clasp engaged.		**Material:** Polyester backpack, twine, nylon clasp	**User Comfort Rating:** 3.75/5 **Average Backpack Distance From Back Without Clasp:** 2.15 in **Average Backpack Distance From Back With Clasp:** 1.28 **Percent Change:** 40.5%	The strap was effective in reducing the distance between the backpack and the subject, reducing its impact on the center of mass and making it easier for the user to maintain proper posture. The user reported no discomfort as a result of the placement of the strap, however did say that the very small width made the strap feel as if it was cutting into them. This is consistent with the findings from the previous prototype, indicating that the width of the strap should be increased to distribute the reaction force over a greater surface area, making it more comfortable. User retained full use of hands while wearing device.
4	To test the ease of use and qualiltative effectiveness of using three straps to pull the straps together and pull the bag closer to the back.	**Procedure** : Tie a piece of twine around the straps to pull them forward and closer. Tie a piece of twine around each open clips on the side of the bag and around the strap after user puts bag on regularly. Ask user to discuss their experience. **Metrics**: Comparability between posture while wearing a twine strapped backpack and regular backpack		**Material:** Polyester backpack, Twine	**N/A**	Our prototype was tied unevenly between the two sides of the backpack from the bag to the straps). User says the twine tied backpack improved posture by pulling the bag closer. User did attempt to take off and put on the backpack, reporting great difficulty when compared to a regular backpack. Thus, we conclude that any front strap must have a mechanism that allows it to be opened and closed easily.
5	To test the effectiveness of using weighted front straps to counteract the change in center of mass.	**Procedure** : Tie a piece of twine around each front strap to a 10lb dumbell. Ask user to put on the device and discuss their experience. **Metrics**: Comparability between posture while wearing a weighted strapped backpack and regular backpack weighing 20lbs.		**Material:** Polyester backpack, Twine, Dumbells (10 lbs)	**User Comfort Rating (without): 3.5** **User Comfort Rating (with): 3**	User claimed that the backpack felt more snug against their back. They also reported slight discomfort in the shoulder area due to vertical pull of the dummbell. This suggests that a single lateral force could be replaced by distributed forces across the front strap to relieve shoulder compression and additional cushioning should be used for extra comfort. User retained full use of hands while wearing device. Although device was effective in improving posture by reducing center of mass changes caused by backpack, it violates our design input which requires the device to be lightweight and portable. The extra weight makes moving awkward and more difficult, rendering its potential use ineffective.
6	To test the comfort and effectiveness of small fabric straps that zip across the chest.	**Procedure** : Place the two small fabric straps across the chest. Pull the straps tight, and zip them together. Measure the change in distance from the backpack to the back with and without the strap present. Ask user the level of comfort both before and after using the strap. Measure for 3 users and find averages. **Metrics:** Distance from backpack to back, in inches. Comfort level rating, from 1 - 5.		**Material:** Jacket material. Cotton and Polyester blend. Stitching fabric, zipper straps	**User Comfort Rating (without):** 2.5 **User Comfort Rating (with):** 3 **Distance - Back to backpack - without straps:** 1.65 in **Distance - back to backpack - with small straps:** 1.18 in **Change:** 0.47 in (28.5%)	Users claimed that the bag was slightly more comfortable, because it became more snug with the back. This was confirmed with the distance measurements. This device is effective in bringing the backpack closer to the user, however it did not satisfy our cost criteria. User retained full use of hands while wearing device.
7	To test the comfort and	**Procedure** : Place the two large fabric straps across the		**Material:** Jacket material. Cotton and Polyester	**User Comfort Rating (without):** 2.5	The larger straps were able to pull the backpack closer to the

7	To test the comfort and effectiveness of large fabric straps that zip across the chest.	**Procedure** : Place the two large fabric straps across the chest and velcro them together. Pull the straps tight, and zip them together. Measure the change in distance from the backpack to the back with and without the strap present. Ask user the level of comfort both before and after using the strap. Measure for 3 users and find averages. **Metrics:** Distance from backpack to back, in inches. Comfort level rating, from 1 - 5.		**Material:** Jacket material. Cotton and Polyester blend. Stitching fabric, zipper straps, velcro attachments	**User Comfort Rating (without):** 2.5 **User Comfort Rating (with):** 3.5 **Distance - Back to backpack - without straps:** 1.65 in **Distance - back to backpack - with small straps:** 0.83 in **Change:** 0.82 in (49.7%)	The larger straps were able to pull the backpack closer to the user, was more comfortable, and distributed the force more. User retained full use of hands while wearing device.
8	To test the efficacy of using a staple as an attachment method to the backpack.	**Procedure** : Sew loop into unnattached end of strap, move twine through the loop and tie around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks. 		**Procedure** : Place polypropylene strap at desired location on the bag. Use an office stapler to attach the strap onto the bag. **Material** : 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing	**Force at which strap broke (N):** 27 N	At 27 N, the staple popped off of the bag, but stayed in the strap. Possibly a stronger staple or more staples could be effective in holding the strap down, or a method that more securely attaches to the backpack, like a safety pin?
9	To test the efficacy of using a safety pin as an attachment method to the backpack.	**Procedure** : Sew loop into unnattached end of strap, move twine through the loop and tie around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks.		**Procedure** : Place polypropylene strap at desired location on the bag. Use a safety pin to attach the strap onto the bag. **Material** : 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing; safety pin (1 and 1/16 inch long)	**Force at which strap broke (N):** 84 N	At 84 N, the safety pin bent apart, releasing the bag. It stayed attached to the strap. Again, maybe a stronger safety pin or a method that more securely attaches to the backpack, like a regular pin?
10	To test the efficacy of using a pin as an attachment method to the backpack.	**Procedure** : Sew loop into unnattached end of strap, move twine through the loop and tie around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks. 		**Procedure:** Place polypropylene strap at desired location on the bag. Use a pin to attach the strap onto the bag. **Material** : 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing	**Force at which strap broke (N):** 33 N	At 33 N, the back of the pin popped off. This was a step back from the safety pin, and did not have a stronger back attachment.
11	To test the efficacy of using two magnets as an attachment method to the backpack.	**Procedure** : Sew loop into unnattached end of strap, move twine through the loop and tie around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks. 		**Procedure:** Place polypropylene strap at desired location on the bag. Use a magnet to attach the strap onto the bag by putting one magnet inside the bag and then one magnet on the outside of the strap. Allow the two magnets to connect. **Material** : 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing. 2 neodymium disk magnets: .472 in diameter x .118 in thick	**Force at which strap broke (N):** 3 N	At 3 N, the strap slid out from under the magnet off of the bag. Maybe attaching the magnet on the outside of the strap more securely to the strap would be better.

12	To test the efficacy of using two magnets as an attachment method to the backpack with one magnet sewn into the strap.	**Procedure** : Sew loop into unnattached end of strap, move twine through the loop and tie around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks. 		**Procedure:** Fold end of strap over itself, sew two of the sides shut. Insert one magnet into pocket and sew close. Use a magnet to attach the strap onto the bag by putting it inside of the bag and place the strap so that both magnets connect. **Material** : 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing. 2 neodymium disk magnets: .472 in diameter x .118 in thick	**Force at which strap broke (N):** 3 N	At 3 N, the strap slid off of the bag. Either the magnets weren't strong enough, or this problem will be faced no matter what type of magnet you use. Best to move away from magnets in the future.
13	To test the efficacy of using sewing as an attachment method to the backpack with one magnet sewn into the strap.	**Procedure** : Sew loop into unnattached end of strap, move a zip tie through the loop and attach around a force gauge. Pull the backpack down around the attachment point to measure the force at which the attachment breaks.		**Procedure:** Place strap onto desired location of backpack. Sew multipe stitches (into a square shape). **Material:** 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing.	**Force at which strap broke (N):** N/A **Force at which zip tie (attachment to force gauge):** 204 N	At 204 N, the zip tie snapped. The strap and attachment points were not affected. Our strap only needs to hold 38.6 lbs (~172 N), so this attachment method meets a Key Design Input Metric. Unfortunately, this is more difficult for a user to attach to their backpacks on their own, since it requires sewing skills. In addition, you can not adjust the location of the strap attachment when it is sewn on. There are pros and cons to this method. However, it is the only method tested to meet User Design Needs.
14	To test the strength of polypropylene strap when wet.	**Procedure** : Sew loop into one end of strap. Soak strap for 5 seconds. Move a zip tie through the loop and attach around force gauge. Pull backpack down until breakage.		**Material:** 12 inches long, 1 inch wide, 0.048 inches thick polypropylene webbing.	**Max force measured (N):** 253 N	The wet strap was able to withstand a force of 253 newtons with no visible deformation. This demonstrates that polypropylene exceeds the design requirements, as our calculations indicate that it must withstand a maximum of 171.7 newtons without deformation.
15	To test the effectiveness of using two crossed straps, each with a clasp, connecting the backpack straps across the chest to pull the backpack closer to the back of the subject, as well as assess its comfort level.	**Procedure** : Attach 2 polypropylene straps to each backpack strap, so that the clasps can be attached diagonallly across the chest, forming a shape resembling the letter X. Have the subject put on the backpack, which weighed 15 pounds, and measure the largest distance from the back of the subject to the front of the backpack without engaging the clasp. Measure again with the strap clasp engaged. Ask the subject to rate the comfort of the strap. The subject was then asked for additonal comments regarding their thoughts as to what would make it more comfortable or effective. **Metrics:** Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. The largest distance from the back of the subject to the backpack fron was measured with and without the strap clasp engaged.		**Material:** a typical backpack, four 3 inch long, 1 inch wide, 0.048 inch thick polypropylene webbing, 2 nylon clasps	**User Comfort Rating:** 3.2/5 **Average Backpack Distance From Back Without Clasp:** 2.1 inch **Average Backpack Distance From Back With Clasp:** 0.96 in **Percent Change:** 54%	The device was able to effectively reduce the distance from the bag to the user's back by more than fifty percent, thus reducing the contribution to the center of mass of the backpack. Users reported that the device was more comfortable than previous prototypes, with the increase in strap width reducing discomfort. Users also reported that the device felt secure, and that they were aware that they were standing up straighter after engaging the clasps.
16	To test the effectiveness of a strap attached to the front edge seam of the backpack that connects across the chest of the user to pull the backpack closer to the back of the subject, as well as assess its comfort level.	**Procedure**: Sew a polypropylene strap to the front edge seam of the left and right side of the backpack, and attach one end of a clasp to each strap. When the user puts on the backpack, measure the largest difference from the back of the user to the front of the backback without engaging the clasp. Measure again with the strap engaged. Ask the subject to rate the comfort of the strap attachment, and for additional comments regarding how the device feels and what changes they think would improve the comfort or effectiveness of the attachment. **Metrics:** Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. The largest distance from the back of the subject to the backpack fron was measured with and without the strap clasp engaged.		**Material:** Polyester backpack, two 6 inch long, 1 inch wide, 0.048 inch thick polypropylene webbing, one nylon clasp.	**User Comfort Rating:** 3.88/5 **Average Backpack Distance From Back Without Clasp:** 3.08 inch **Average Backpack Distance From Back With Clasp:** 1.83 inch **Percent Change:** 40.5%	The device was able to reduce the distance from the back of the user to the front of the backpack, drawing it closer and decreasing its contribution to the user's center of mass. However, it only reduced the distance by 40.5%, falling short of the design input of 50% reduction of distance from back to backpack. The device exceeded the required value of comfort indicating that it is not prohibitively uncomfortable for use. The clasp and strap design allowed for the user to be able to adjust the strap tightness to suit their comfort level and individual morphology. The effectiveness of the device seemed to change based upon the location on the back that the user preferred to wear their backpack, with effectiveness decreasing as the backpack was positioned lower on the back. This design seemed less intuitive than previous prototypes, likely due to the fact that the attachment point on the backpack meant the straps dangled low and out of sight when not engaged, causing a momentary delay while users initially located them. Once the straps were located, however, the device was put on and taken off quickly and easily, without requiring extensive instruction.

16	To test the effectiveness of a strap attached to the front edge seam of the backpack that connects across the chest of the user to pull the backpack closer to the back of the subject, as well as assess its comfort level.	**Procedure**: Sew a polypropylene strap to the front edge seam of the left and right side of the backpack, and attach one end of a clasp to each strap. When the user puts on the backpack, measure the largest difference from the back of the user to the front of the backback without engaging the clasp. Measure again with the strap engaged. Ask the subject to rate the comfort of the strap attachment, and for additional comments regarding how the device feels and what changes they think would improve the comfort or effectiveness of the attachment. **Metrics:** Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. The largest distance from the back of the subject to the backpack fron was measured with and without the strap clasp engaged.	 	**Material:** Polyester backpack, two 6 inch long, 1 inch wide, 0.048 inch thick polypropylene webbing, one nylon clasp.	**User Comfort Rating:** 3.88/5 **Average Backpack Distance From Back Without Clasp:** 3.08 inch **Average Backpack Distance From Back With Clasp:** 1.83 inch **Percent Change:** 40.5%	The device was able to reduce the distance from the back of the user to the front of the backpack, drawing it closer and decreasing its contribution to the user's center of mass. However, it only reduced the distance by 40.5%, falling short of the design input of 50% reduction of distance from back to backpack. The device exceeded the required value of comfort indicating that it is not prohibitively uncomfortable for use. The clasp and strap design allowed for the user to be able to adjust the strap tightness to suit their comfort level and individual morphology. The effectiveness of the device seemed to change based upon the location on the back that the user preferred to wear their backpack, with effectiveness decreasing as the backpack was positioned lower on the back. This design seemed less intuitive than previous prototypes, likely due to the fact that the attachment point on the backpack meant the straps dangled low and out of sight when not engaged, causing a momentary delay while users initially located them. Once the straps were located, however, the device was put on and taken off quickly and easily, without requiring extensive instruction.
17	To test the effectiveness of a strap attached to the back face of the backpack that connects across the chest of the user to pull the backpack closer to the back of the subject, as well as assess its comfort level.	**Procedure**: Sew a polypropylene strap to the back face of the left and right side of the backpack, and attach one end of a clasp to each strap. When the user puts on the backpack, measure the largest difference from the back of the user to the front of the backback without engaging the clasp. Measure again with the strap engaged. Ask the subject to rate the comfort of the strap attachment, and for additional comments regarding how the device feels and what changes they think would improve the comfort or effectiveness of the attachment. **Metrics:** Subject rated the comfort level of the strap in its initial position on a scale of 1 to 5 with 1 as extremely uncomfortable and 5 as extremely comfortable. The largest distance from the back of the subject to the backpack fron was measured with and without the strap clasp engaged.		**Material:** Polyester backpack, two 9 inch long, 1 inch wide, 0.048 inch thick polypropylene webbing, one nylon clasp.	**User Comfort Rating:** 3.63 /5 **Average Backpack Distance From Back Without Clasp:** 3.08 inch **Average Backpack Distance From Back With Clasp:** 2.45 inch **Percent Change:** 20.5%	The prototype only reduced the distance from the user's back to the backpack by 20.5%, less than half of the design input of a 50% reduction. The attachment point on the back face of the backpack was closer to the ground than the previous prototypes, resulting in the the clasp location to be lower as well, typically resting on the user's lower stomach as opposed to upper and middle parts of the chest, where the clasps of previous prototypes were located. This change in position had two important consequences. The first was that it appeared to pull the bottom of the backpack flush to the back of the user, but not the upper and middle portions of the bag, leaving space between the back of the user and these parts of the bag. Secondly, the lower placement of the clasp was less comfortable to users, who reported that the clasp dug into their stomach much more than the placement of the previous prototype for the placement of the side straps. Each of these indicates that a higher side strap placement is preferable. Like the previous prototype, the effectiveness of the device was dependent on the height at which the user wears the backpack, seeming more effective when the backpack was worn higher on the back. The clasp tightness could be adjusted, allowing for increased user comfort and allowing for users from a wide range of body dimensions to be accomodated. When not in use, the straps hang down out of sight,causing users to initially have slight difficulty location them. Once located, the use of the device appeared to be easy and intuitive.
18	To test the effectiveness of using an industrial grade safety pin as an attachment method to the backpack	**Procedure**: Disengage the safety pin and insert through the strap and reengage the pin. Pull attached strap downward with safety pin vertical (clasp up and down) and horizontal. **Metrics:** Force withstood before deformation or pin disengagement		**Material:** 0.048 inch thick polypropylene webbing, industrial grade safety pin	**Force at which failure occurred for vertical, clasp up:** 150 N until unlasped **Force at which failure occurred for vertical, clasp down:** 39 N until strap slid off end of clasp **Force at which failure occurred for horizontal:** 70 N until bent significantly	The vertical, clasp up configuration is able to withstand the most force, however it is unable to withstand the necessary amount. However the pin did not break, it unclasped, so if we are able to find a way to secure the clasp, this pin should withold more force.
19	To test the effectiveness of using an industrial grade safety pin as an attachment method to the backpack	**Procedure**: Disengage the safety pin and insert through the strap and reengage the pin. Secure safety pin clasp with pipe cleaner by wrapping around clasp. Pull attached strap downward. **Metrics:** Force withstood before deformation or pin disengagement		**Material:** 0.048 inch thick polypropylene webbing, industrial grade safety pin; 2 standard pipe cleaners	**Force at which failure occured:** 240 N	A safety pin wrapped around the clasp works, but is there a way that we can effectively and fashionable make this in the final product? It needs to be easily added and removed without disrupting the desirability of the device.
20	To test the stregth of each strap when bent at a 45 degree angle.	**Procedure:** Cut the ends of both straps so that they form a 45 degree angle, then sew the straps together while maintaining the angle. Attach one end of the prototype to a force gauge and apply force until the strap fails. **Metrics:** Force withstood before strap deformation or stitching failure.		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing	**Strap easily withstood 45lbs**	Both straps were able to withstand the necessary force. This strap requires more production (having to cut the strap and using two pieces). In addition, it is less safe, if stitching fails, the strap breaks off. This is not the best option.
21	To test the stregth of each strap when bent at a 45 degree angle.	**Procedure:** Fold over a strap so that it forms a 45 degree angle, then sew the straps together while maintaining the angle. Attach one end of the prototype to a force gauge and apply force until the strap fails. **Metrics:** Force withstood before strap deformation or stitching failure.		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing	**Strap easily withstood 45lbs**	Both straps were able to withstand the necessary force. If stitching fails, the strap stays connected but just straightens out, in need of new stitching, but the device is still able to work. This is the best option.
23	To test the strength of 3D printed buckle prototype	**Procedure:** Attach straps to buck and pull until breakage **Metrics:** Force withstood until breakage		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing; polylactic acid clasp	**Force withstood:** The buckle withstoood 20 lbs before unclasping	The buckle did not break. The clasp was just not tight enough. We need to make the divets of arm of the male end larger to ensure a tighter fit into the female end.

24	To evaluate the effectiveness of the device in increasing user CVA while wearing a loaded backpack.	**Procedure:** Have user put on a backpack loaded with 15% of their body weight and stand on a marked spot on the floor, facing parallel to a wall. Have them look straight ahead and stand naturally, and take a picture. Then, have the user engage the prototype device and reposition the backpack until it is comfortable. Again, have the user look straight ahead and take a picture. Determine the CVA of the user in each case user a grid overlay and trigonometry. **Metrics:** Cervical Vertebral Angle (CVA) of user	 	**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing, industrial strength velcro, poolylactic acid clasp	**Average CVA without device:** 60.5 degrees **Average CVA with device:** 63.2 degrees **Average Difference:** 2.7 degrees	The device was able to increase the CVA of the user by an average of 2.7 degrees while the user was supporting a load of 15% of their body weight, satisfying our design metric and indicating that it was successful in improving user posture. User feedback included that the straps of the device were too long and that the width of the part of the device that houses the webbing was too small, combining to make adjusting the device difficult. Additionally, users reported that the device was not prohibitively uncomfortable, and that they felt as if it contributed positively to improving weight distribution.
25	To test the simplicity and intuitiveness of the device	**Procedure:** Have user put on the bacpack loaded with 15% of their body weight and hand them the device without instruction. Then, have the user engage the prototype device and reposition the backpack until it is comfortable. Again, have the user look straight ahead and take a picture. **Metrics:** Number of seconds for user to successfully attach device to backpack		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing, industrial strength velcro, poolylactic acid clasp	**Average time taken**: 45s	The users were able to identify the middle clasp and velcro lock mechanisms quickly, however some users struggled to determine the locations of attachment. Almost all users were able to succesfully attach the device to the backpack without prompts, showing that it was much simpler and intiutive for users.
26	To test the comfort of the device over extended periods of time	**Procedure:** Have user put on a backpack with usual load with device attached. Walk around in backpack for 5 to 10 minutes. Have user report comfort level. **Metrics:** Scale 1 to 10 of comfort.		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing, industrial strength velcro, poolylactic acid clasp	**Average comfort score:** 9/10	The average comfort score of 9/10 exceeds the target metric of a 6/10, demonstrating that users feel that the device is comfortable. This rating is a significant improvement over the previous cross-strap design that included two clasps, indicating that this prototype is more comfortable. This high level of comfort will encourage users to wear the device for extended periods of time, allowing it to have a greater positive effect on their posture.
27	To evaluate the effectiveness of the device in increasing user CVA while wearing a loaded backpack.	**Procedure:** Have user put on a backpack loaded with 15% of their body weight and stand on a marked spot on the floor, facing parallel to a wall. Have them look straight ahead and stand naturally, and take a picture. Then, have the user engage the prototype device and reposition the backpack until it is comfortable. Again, have the user look straight ahead and take a picture. Determine the CVA of the user in each case user a grid overlay and trigonometry. **Metrics:** Cranial Verebral Angle (CVA) of user		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing, industrial strength velcro, poolylactic acid clasp	**Average CVA without device:** 64.4 degrees **Average CVA with device:** 68.4 degrees **Average Difference:** 4.0 degrees	The device was able to increase the CVA of the user by an average of 4.0 degrees while the user was supporting a load of 15% of their body weight, satisfying our design metric and indicating that it was successful in improving user posture. The velcro straps allowed for easy attaching and detaching of the device to the backpack and held the loaded backpack with no signs of failure. The shortened length of the straps allowed the device to be tighter across the chest and improved the performance of the device, while maintaining its ability to be adjusted for variations in user size. Additionally, users reported that the device was not prohibitively uncomfortable, and that they felt as if it contributed positively to improving weight distribution.
28	To test the fashion appeal of the device.	**Procedure:** Allow the user to examine and put on the device. Then, ask them if they would voluntarily wear such a device. **Metrics:** Percentage of users that would voluntarily wear the device.		**Material:** 1 inch wide, 0.048 inches thick polypropylene webbing, industrial strength velcro, poolylactic acid clasp	**Percentage of users that would wear the device:** 70%	Over two-thirds of users surveyed responded that they would voluntarily wear the device, fulfilling our design input and indicating that the appearance of the device does not significantly detract from the willingness of users to use it and therefore its ability to be marketable and positively impact the most amount of users.