Safety First: Assistive Devices for Automotive Independence

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1. Problem Statement and Background

Our client, John, is a high school student with Thrombocytopenia Absent Radius (TAR) syndrome, which is characterized by a bilateral absence of the radial bones [1]. Individuals with TAR syndrome usually exhibit underdevelopment in other bones of the arm and hands, causing the hands to be located near the shoulder [2]. As a result of these symptoms, John experiences difficulty reaching and grasping objects.

John is looking forward to driving after being fitted for adaptive steering equipment consisting of a shoebox-sized steering wheel near his right shoulder and secondary controls by his left hand; however, the barrier between John and driving independently is the ability to buckle his seatbelt. While there have been extensive work in creating modified steering systems to accommodate people with disabilities, often the seatbelt safety mechanism needs to be modified completely—usually a harness or automatic buckling system—which is expensive and sometimes not covered by insurance. Although not a prohibitive barrier to driving, John is also unable to open and close the gas-cap on his car.

The goal of the seat belt project was to develop a method enabling our client to buckle his seat belt and pump gas independently. The seatbelt device should not make modification to the existing seat belt safety system, be removable so the client can use this device in driver and passenger seats of multiple cars, and must not interfere with the adaptive steering equipment. The gas cap opening mechanism should again, not make modifications to the car and be safe to use. One of John’s concerns is how his use of adaptive equipment is perceived, so the products must also be unobtrusive, efficient, and easy to use. The device must adhere to all safety requirements as seat belts are subject to rigorous testing and strict regulations [3].

2. Approach and Solutions Considered

After extensive research into existing products on the market, we found harnesses, buckle extenders and seat belt handles, all of which we considered as possible solutions. Our team considered a harness where the buckles were placed to be within John’s reach, but we could not find a commercially available product that fit our needs, and building our own harness was cost prohibitive since we would have had to perform rigorous safety testing to meet the national highway traffic safety administration standards. Our next idea was to modify the existing seat belt with a seat belt extender, which fit into the existing buckle and have a rigid extension that brings the buckle closer to the driver (available in lengths 3” to 8” [4]). When John was given the device, he was able to buckle himself independently. However, we discovered a problem when consulting with Dr. Roger Nightingale, an expert on vehicle safety at Duke University. The seat belt extender altered the seat belt geometry such that the lap belt rose above John’s pelvic bones, leaving him at risk of internal abdominal injury in the case of an accident. Lastly, we considered seatbelt handles, which attach to the seat belt above the fitting and provide extended reach for those with limited mobility or arthritis [5]. This device alone did not enable our client to buckle his seatbelt and was therefore rejected.

Although there are many devices to assist in buckling seatbelts, we were unable to find a commercial mechanism to maintain slack in the seatbelt so that the user would experience
Minimal resistance from the retraction mechanism and would not need to apply as much force when buckling. The only device we were able to find was a locking clip [6], which is intended for cars that lack a functional locking mechanism to prevent the seatbelt from loosening in situations such as sudden braking. However, locking clips are placed on the seatbelt after buckling is completed to secure it at a certain tightness, so one of them would not assist John in the buckling process. We first attempted to create a ratcheted fitting over the seatbelt that would allow movement in one direction, towards the buckle, and prevent it retracting. This method provided too much friction for John to use comfortably. We then pursued a wedge mounted on a hinge that would wedge into the seatbelt source to prevent retraction. This method was unreliable, so we moved to our current design, which manages to prevent retraction of the seatbelt without introducing unnecessary resistance while drawing out the seatbelt.

While there are commercially available gas cap openers, they all feature a small extension in the plane of the car. Our device features an extended handle perpendicular to the car that accommodates not only a wider range of users with reduced strength, but also users who experience limited reach and grip strength, by allowing the user to bear down on the gas cap using their body weight. We first looked at modifying a gas cap mechanism, but the plastic components were simple enough to be replicated in a cost effective manner.

3. Final Approach and Design

3.1 Multi-tool

The current device is a multi-tool that features two distinct ends: a buckling end, an unbuckling end, and a telescoping pole linking the two. The fitting can be wedged into the buckling end to extend John’s reach, and the unbuckling end fits over the buckle to more easily depress the release button.

3.1.1 Buckling Mechanism

The buckling mechanism is a clip that holds the fitting of the seatbelt while the client buckles himself in as seen in Figure 1. The clip is approximately the width of the fitting, creating strong grip that holds the fitting securely. A hollow, stainless steel rod was flattened at the clip end and attached with two bolts, while the other end was inserted into the end of the telescoping pole and secured with a screw.

3.1.2 Unbuckling Mechanism

The unbuckling mechanism consists of a box without the front and bottom sides, and a protrusion from the top shown in Figure 2. The mechanism fits over the buckle to stabilize the device and can be pressed down to release the seatbelt. There is a cylinder on the top of the device that fits into the telescoping pole and is secured with two screws. The unbuckling mechanism was 3D printed in the strongest of the 3D print plastics available at Duke, acrylonitrile butadiene styrene (ABS), and coated with XTC-3D epoxy to resist the compressive force necessary to unbuckle the seatbelt.

3.1.3 Telescoping Pole

The buckling and unbuckling mechanism are attached on either end of an aluminum telescoping pole, which is adapted from a selfie stick so John can easily extend the device to a length best fits his needs. At its shortest, the multi-tool measures 14 in. long, extends up to 31.5 in., and can be locked at any length in between through a clockwise twist locking mechanism.
shown in Figure 3. The telescoping pole allows John to extend his limited reach in order to buckle and unbuckle his seat belt.

3.2 Slack Maintainer

In addition to the buckling and unbuckling multitool, we also created a device to maintain the slack that John pulls out while buckling. The device consists of a foldable base with a fringed dycem tip as seen in Figure 4a. The slack maintainer sits below the seat belt source on the wall of the car and can be disengaged after buckling. When pulling out the seat belt, the dycem tips fold away and allows for free movement of the seat belt. When the seat belt attempts to retract, the dycem tips are caught and wedged into the seat belt source, which maintains the generated slack (see Figure 4b). After buckling, John can pull on the soft handle to move the slack maintainer out of the way so the seat belt can retract for a snug fit.

3.3 Gas Cap Opener

To give John an added measure of independence when operating his vehicle, we also created a device that would allow John to open and close the gas cap independently. This device consists of a 3D printed plastic head with a cross-shaped cut out that fits over the gas cap, and a T-shaped handle so John can easily turn the device at a comfortable distance (Figure 5). After fitting the head over the gas cap, the user can simply turn the device to open and close the gas cap.

4. Outcome

The multitool and slack maintainer have enabled our client to independently buckle and unbuckle his seatbelt, a feat he was not previously able to accomplish (Figure 6). The multi-tool was evaluated to assess ease of use, compatibility with John’s force generation capabilities, durability, interference with existing seat belt safety system, extent of modification to the vehicle, degree of portability, use in different types of cars, and efficiency of design. This consisted of verification testing by the designers and validation testing by our client while using the devices. To test usability, we gave the device to John for a week to practice with, in addition to observing him use the device extensively during our client meetings. After measuring the forces our client could generate in both tension and compression, we designed the device such that the process of unbuckling and buckling did not exceed 10 lbs of force. Additionally, we ensured the device would be able to withstand use with a minimum safety factor of 2. The device can undergo 16 pounds of compression before sliding when fully extended and can experience 30 pounds when compacted without experiencing any deformation. It can experience 20 pounds of tensile force without sliding when both fully extended and compacted.

Client satisfaction was measured through a questionnaire on the ease of use, independence, and utility (please refer to the Appendix). The results of the survey indicate that our client was overall very satisfied with the design and utility of the devices we created for him. In fact, we received perfect marks across the board, apart from the buckling mechanism, to which John only somewhat disagreed that it takes him a long time to use the buckling mechanism. We believe that with the practice of repeated use, and especially with the use of the slack maintainer, the speed with which our client is able to accomplish this task will rapidly increase.
## 5. Cost

<table>
<thead>
<tr>
<th>Part Description</th>
<th>Place of Purchase</th>
<th>How Part Was Used</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multi-Tool</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OXO Medium Bag Clip</td>
<td>Target</td>
<td>Main component of the buckling mechanism</td>
<td>$11.59 per 7-piece set</td>
</tr>
<tr>
<td>Steel Rod (Half Flattened)</td>
<td>Laboratory Workshop</td>
<td>Two holes were drilled into the flattened half of the rod to attach the clip, and the cylindrical half was inserted into the telescoping pole</td>
<td>$5.00</td>
</tr>
<tr>
<td>CoolReal Selfie Stick</td>
<td>Amazon</td>
<td>The ends were sawed off, leaving just the telescoping pole</td>
<td>$20.99</td>
</tr>
<tr>
<td><strong>Slack Maintainer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Printed ABS Plastic Part</td>
<td>Laboratory Workshop</td>
<td>The unbuckling mechanism is this part</td>
<td>Free service provided by Duke University</td>
</tr>
<tr>
<td>Fringed Dycem</td>
<td>Laboratory Workshop</td>
<td>This is the material on the end of the slack maintainer that wedges in the seatbelt source</td>
<td>$24.48 per 8” x 3 ¼ sheet</td>
</tr>
<tr>
<td>Selfie Stick Phone holder</td>
<td>Amazon</td>
<td>The part on the end of a selfie stick that holds the phone was used to created the foldable base for the slack maintainer</td>
<td>(included in the $ 20.99 above)</td>
</tr>
<tr>
<td><strong>Gas Cap Opener</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless steel rods (x2)</td>
<td>Home Depot</td>
<td>Comprise the t-handle of the device</td>
<td>$8.00</td>
</tr>
<tr>
<td>3D printed base</td>
<td>Laboratory/Workshop</td>
<td>Comprise the grooved base that fits over the gas cap</td>
<td>Free service provided by Duke University</td>
</tr>
</tbody>
</table>

It should be noted that the materials invested in this project went towards the creation of a single product, which generated excess material such extra clips and largely unused sheets of Dycem. In the event that this device were produced on large scale, the cost of production would be driven down by the distribution of materials across multiple devices, as well as the reduced cost of purchasing materials in bulk. 3D printing was utilized for its accessibility and utility in
rapid prototyping, but we recommend using injection molding for large scale production to minimize both cost and production time.

6. Significance

Before this device, our client could not manage to buckle and unbuckle his seatbelt. Using both the telescoping multi-tool and slack maintainer in tandem has allowed our client to complete these tasks, a barrier to him being able to drive independently. The statements from our client and his mother show just how the device will impact his daily life:

“This device has impacted my life by allowing me to avoid the awkward question of asking someone to put my seatbelt. For years I’ve had to ask people to put my seatbelt on, and now thanks to this group, I no longer have to ask that question. Allowing me to independently put on my seatbelt, this device will change the way I interact with cars and the automobile world. I am thankful for this group and everything they’ve done for me. They have been an awesome group to work with, and I’m thankful that I now have independence within the car.” - John

“This project has enabled John to actually independently get in and out of vehicles not only when he’s driving but when he is a passenger in a vehicle as well. He doesn’t have to rely on somebody else to help him with [buckling his seatbelt] or one of us get out of the car and go and do his seatbelt for him, so it’s really made a difference in terms of being independent because that was the one thing that we could not solve and even the experts in the field who do this regularly couldn’t help us solve that. That is an amazing thing for him and will give him great independence. The gas cap piece was a secondary struggle that we had, but that was just a bonus so it will help him be more independent at the gas station. I think [the device] will impact him well, make him independent and really make him proud to be independent ” - John’s Mother

In addition to solving our client’s difficulties with independently buckling his seatbelt, due to the device’s versatility, portability, and cost-effectiveness, we believe this set of products will be useful for people with a wide range of grip-strength, mobility, and reach related physical limitations. The gas cap opener in particular has a number of similar products on the market, although ours is unique in that the handle is perpendicular to the vehicle, making it easier for the consumer to access the handle and requiring less force.

7. Acknowledgements and References

We would like to acknowledge a number of people for their help in completing this project:
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