iPhone Holder for Use in Motor Vehicles

BME 300/200

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Table of Contents

Abstract

Multiple Sclerosis (MS) is a degenerative condition caused by the destruction of the myelin sheath of neuronal axons. It is usually caused by an auto-immune response and is characterized by decreased signal propagation, resulting in patients losing motor function, memory, and sensation. Our client has MS and copes while driving by using his iPhone for navigation and reminders. Currently his iPhone is attached to the center of the steering wheel, which is the optimal position for him due to his condition, but this causes problems because the iPhone turns as the wheel is rotated, sometimes completely upside-down. The client requires a new iPhone holder that will keep his iPhone upright at all times, regardless of steering wheel rotation. This holder needs to be at the optimal position for him, safe, and aesthetically pleasing.

Background

The human body has approximately 100 billion neurons that are innervated through multiple systems. These neurons propagate electrical signals, whose effects range from voluntary movement of the limbs to pacemaker neurons that regulate heart rate. The length of any given neuron can range from 4 microns to 1.5 meters in length[1]. If these neurons cannot properly propagate electrical signals, which is the situation in Multiple Sclerosis, various debilitating symptoms may occur.

Multiple Sclerosis is an inflammatory disease affecting the central nervous system (CNS), which consists of the brain and the spinal cord and contains a specific type of neuron that is only found in the CNS, called an interneuron[2, 3, 4.] These interneurons, like other neurons, contain dendrites that receive electrical signals, cell bodies that maintain the integrity of the cell, and axons that propagate electrical signals. In the CNS, interneurons form large networks that are pivotal in consciousness, memory, and cognition. The brain and the spinal cord both contain white and grey matter; grey matter that corresponds to the cell body of the interneuron while white matter corresponds to the axons of interneurons[5]. Multiple Sclerosis affects larger portions of white matter of the CNS than it does gray matter; thus, the interneurons of an individual affected by Multiple Sclerosis may be able to receive a signal, but it may either be damped or staunched out completely when it reaches the white matter or an affected axon. More specifically, Multiple Sclerosis degrades myelin, the fatty insulation around axons that helps propagate electrical signals along faster.

Little is known about the causes of Multiple Sclerosis. However, it is clear that the immune systems of individuals afflicted with MS attack the myelin sheath and cells responsible for maintaining it (see figure 1), instead of protecting the body against foreign agents. The myelin sheath is a fatty insulation created and maintained by oligodendrites, a type of glial cell[2]. The insulation provided by the myelin reduces signal loss and helps propagate action potentials down axons. When the glial cells are attacked, the myelin no longer has as many cells to maintain the myelin surrounding the axons. Without maintenance, the myelin sheath undergoes the process of demyelination, where the myelin sheath degrades and builds up scar tissue. In some cases the nerve may be destroyed, or other symptoms may develop.

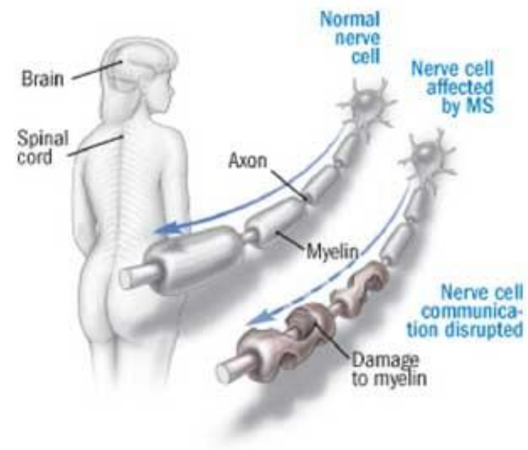

Figure 1: MS degrades the myelin sheath of axons[6]

Individuals with MS may experience a myriad of symptoms that range from paralysis of body parts to memory impairment. The National Multiple Sclerosis Society has established four degrees of Multiple Sclerosis progression: relapsing remitting, secondary progressive, primary progressive, and progressive relapsing. Relapsing remitting is defined as unpredictable attacks of with a very low frequency; these attacks can vary from dizziness to loss of motor control. Most individual classified with relapsing remitting may move into secondary progressive, which is characterized by a decline in cognitive ability. Primary progressive individuals are characterized by an immediate onset of symptoms, like cognitive degradation or muscle motility loss, but may eventually show some improvements. Progressive relapsing individuals have a very sharp decline in cognitive ability (Lublin FD et al, 1996).

Motivation

MS limits the client's memory and range of motion, and causes hypersensitive vision. As a result, he relies heavily on his iPhone while driving for navigation, his calendar and for calling people. Any device that is off-center and requires rapid movement of the eyes disorients him due to his hypersensitive vision. Currently, the client has the iPhone taped to the center of the steering wheel, which is at the ideal elevation, horizontal position, and focal distance for him. These are important factors to be considered during the design process and should be maintained as much as possible.

Problem Statement

Our client, Mr. Jonathan Rubin, is an individual affected by Multiple Sclerosis and is a regular commuter by his car, a 1995 Ford Taurus GL 4-door sedan. Because of his disorder, he requires his iPhone 3GS in front of him while driving for navigation and reminders. The iPhone is currently taped to the center of the steering wheel (see Figure 2) which maintains it at an optimal elevation and focal distance for him, minimizing the disorientation experienced due to hypersensitivity in his eyes. However, as the wheel is turned, the iPhone rotates with it, posing a problem especially while navigating. A device is required to securely mount the iPhone in front of him while he drives and maintain its upright position regardless of steering wheel movement. It should be stable and not cause any obstruction of the air bag or other safety concerns while driving.

Figure 2: Current position of iPhone in client's car

Client Requirements

The device has to allow convenient attachment and removal of the iPhone prior to and after usage. It has to securely maintain the iPhone at its initial position and configuration as determined by the driver, independent of the steering wheel movement. During operation, it should not deviate from its equilibrium position by more than 45°. It should allow the driver to choose between vertical or horizontal iPhone orientations, depending on his preference. It has to be within the elevation and distance constraints (depicted in Figures 3 and 4). Specifically, the iPhone cannot be more than 10cm above the top of the steering wheel nor below the bottom of the front panel of the wheel. It cannot be further than 5cm behind the wheel as well.

Figure 3: Client's height requirements (depicted in red)

Figure 4: Client's depth requirements depicted in red

It has to allow complete access to the iPhone and steering wheel while mounted and cannot obstruct the driver in any way. It cannot obstruct the deployment of the airbag and should not endanger the driver or any passengers in the event of an accident or airbag deployment. It should allow charging of the iPhone if required by the driver. It should be aesthetically pleasing and accommodate different phone models and be able to utilized in differnt car models. The device should not cause any permanent damage or alteration to the car interior. It should not exceed dimensions of 15cm x 10cm x 1.5cm and should weigh below 150g. It should be storable under normal car conditions of temperatures between 0°C and 30°C, and humidity between 50% and 75%. Finally, it has to below the $300 budget.

Existing Devices

There are currently no products on the market that fit all of our client's requirements. IPhone holders currently on the market are stationary and clip on the dashboard. There are no iPhone holders that are mounted on the steering wheel, possibly due to the safety concerns related to airbag deployment. There are a few products that have long adjustable necks that can be manipulated to move in different positions and have the ability to stick on a dashboard or windshield, such as the NAJA King Form by the Thought-Out company[7] (see Figure 5). These products range between $5 and $60.

Figure 5: The NAJA King Form is a portable media holder for cars.

Ethics

Due to the sensitive nature of MS symptoms, the disclosure of specifics about our client's condition has to be handled carefully. It is unclear as to how much information he wishes to divulge about his disease, and therefore his privacy should be respected. However, there is no need to release any information about the client should the product be released on the market. Safety concerns should also be considered when examining the ethical issues of the design and may have an impact on the marketability of the product. It has been shown that many distractions already exist while driving, such as text-messaging, calling and using other applications, which poses serious dangers while driving[8]. It raises concern that allowing the driver greater access to a mobile device while driving could further exacerbate the problem, especially if the driver has to stare at a map on an iPhone for extended periods of time. This device must not present itself as risk to the driver or others around them. There may also be legal repercussions that could arise from accidents caused by distracted drivers using the product, and the product must have adequate warning labels to inform the user of the risks taken while using it.

Safety concerns pertaining to the placement of the product over the steering wheel air bag should also be considered. The final device must be able to withstand the possible deployment of the airbag without becoming dangerous. Thus, rigorous testing must be done to create a safety mechanism that works to keep the driver safe in the event of a crash. Lastly, to inform the user about the risks that accompany the use of the device, a warning label and user guide have to be created to inform and protect the user through proper installation of the device.

Ergonomics

The user of this device will be operating a motor vehicle. Therefore, a key ergonomic issue is to minimize the amount of distraction caused by both the iPhone and the device. This is most easily achieved by limiting the amount of user input required in the device and the iPhone. The device should not hinder the driver’s ability to manipulate the steering wheel or any controls in the car. It should not interfere with the rotation of the steering wheel in any way or cause any alteration to the driver’s driving style. The device should not interfere with the driver’s view in any way (i.e. no reflective surfaces). It should not move or shift while driving, except for those parts intended to move during normal function of the iPhone holder. It should allow for easy access and manipulation of the iPhone at all times. The device should be relatively easy to mount when the car is not in motion and should not detach itself during driving. Overall, the device should not distract the driver or cause the iPhone to be any more of a distraction than it already may be. It also should not be a distraction to other drivers on the road or interfere with any other drivers/vehicles during regular usage. The holder should not pose a safety threat to the driver while driving, especially in the event of a vehicle collision, and should not interfere with proper airbag deployment.

Design Proposal Overview

The device functions as an iPhone holder for our client, who has MS, for use in his car. Therefore, it has to be customized to fit his disability, specifically the hypersensitivity in his vision and his limited range of motion. As previously mentioned, the device has to operate within fixed elevation and distance constraints. It has to allow maximum access to the iPhone and cause minimal obstruction to the steering wheel and other important driving and safety features in the car, especially the airbag. The client aims to eventually market the device, so it should accommodate different phone models and be adaptable in various car models to fit different people's preferences. The three designs proposed below are all possible iPhone holders for use in motor vehicles and can be adapted to fit different phone or car models. All the designs are distinguished by unique features and provide solutions to the problem.

Design 1: Solid Arm Support

The first design is the solid arm support, characterized by a rigid arm attached to the steering column behind the wheel (see Figure 6). The steering column extends behind the steering wheel and attaches to the interior of the car, and therefore does not rotate with the steering wheel. The arm will be attached to the column by Velcro straps, which allow the device to be easily attached and removed from the car, and will extend under the steering wheel to reach the center of the steering wheel. An arm reaching over the top of the steering wheel was considered as well, but determined to be impracticable because it would interfere with steering if the driver were to perform an over arm turn.

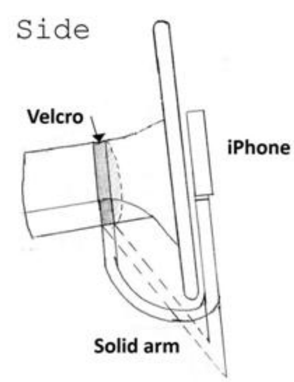

Figure 6: Side view of Solid Arm Support Design

This design allows the iPhone to be in front of the driver in the client's preferred location without the issue of the iPhone turning with the steering wheel, simplifying the design considerably. Also, the simplicity of the components of this design significantly lowers its production and maintenance costs, which is a factor to be considered if the device is to be marketed eventually.

Because the iPhone is located at the center of the steering wheel, there remains the safety issue pertaining to airbag deployment in the case of a collision. This can be resolved by attaching a hinge mechanism to allow the iPhone to swing out of the way of the airbag in the case of deployment. The mechanism would be designed to ensure that it does not endanger the driver.

Design 2: Tripod Support System

This design features an iPhone holder attached to the steering column of the car via a Velcro strap and a rigid stand (see Figures 7 and 8).

The iPhone holder is secured by tripod supports on either side, which are anchored on the steering column. Placing the iPhone holder directly above and behind the steering wheel prevents the iPhone from rotating as the steering wheel is turned, while ensuring the airbag is not obstructed in any way. Furthermore, it is within the elevation and distance constraints set, and therefore is comfortable for the client to use.

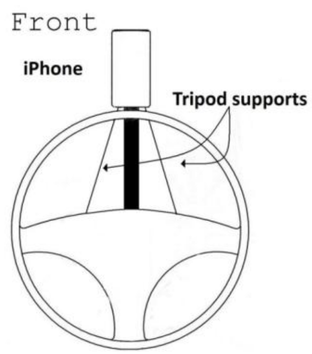

Figure 7: Front (Driver's) View of Tripod Support Design

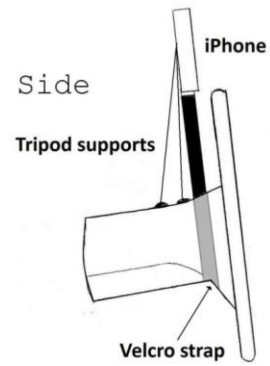

Figure 8: Side View of Tripod Support Design

The iPhone holder can be attached and removed easily on any car model, provided it has a steering column. The device can be strapped easily to the steering column using the adjustable Velcro straps, and the height of the iPhone can be adjusted by varying the distance of the tripod supports, similar to a camera tripod. The tripod supports are fitted using rubber bottoms to ensure sufficient friction against the steering column, preventing slipping of the iPhone while the car is in motion. The position of the iPhone (vertical or horizontal) can be changed by detaching the holder and reattaching it in the desired position.

One of the greatest advantages of the design is its safety. Because the iPhone holder and all the other components of the design are located behind the steering wheel, there is no chance of the airbag deployment endangering the driver or passengers by ejecting any material in their direction. The versatility of the design and its adaptability to various phone and car models is a bonus too. However, there is a possibility of the device tilting as the car makes a sharp turn due to the centripetal force causing a moment about one of the tripod supports. The device may block the driver's hands while turning the steering wheel as well. However, these issues are specific to different drivers and may be solved by adjusting the position of the Velcro strap or tripod supports on the steering column.

Design 3: Gravity Dependent Spinner

This design uses gravity as a passive response system to keep the iPhone held upright. It consists of a free-spinning stepping motor from a CD-ROM drive as a bearing attached to a solid flat base (see Figures 9 and 10). This base has Velcro straps attached to it that keep it fixed in the center of the steering wheel. A CD is fixed to the top of the stepping motor and is weighted at the bottom for added stability. It has Velcro attached to the face of the CD facing the driver. Finally, there is a plastic iPhone holder with Velcro on its back that can attach to the top side of the weighted CD. As the steering wheel turns, the stepping motor axle turns, but since the CD is free-spinning, the weighted CD remains upright and the iPhone remains in the position it is attached in.

Figure 9: Front (Driver's) View of Design 3

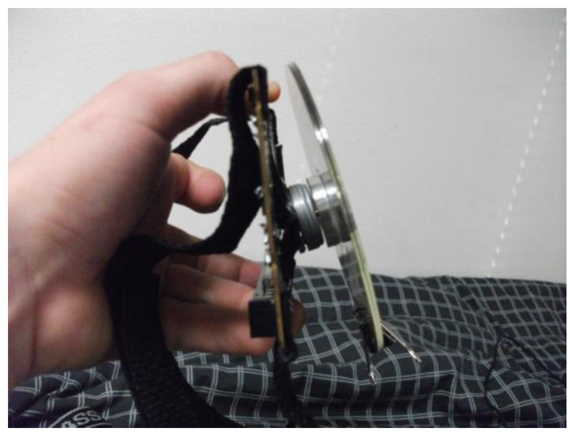

Figure 10: Side View of Design 3

This design is very similar to the client's initial concept and therefore really interests him. Since the device is held in the center of the steering wheel, it is in the optimal position for him. It is easily accessible, within arm's length, and at just the right focal point for him. This is crucial because he will use this device repeatedly while driving, and as his MS progresses, he will become more dependent on it. This device will allow him to still be able to drive safely even as his MS progresses.

It is also a very versatile design. The Velcro straps on the base allow for it to be adjusted and fit almost any steering wheel. In addition, any object can potentially be attached to the rotating CD with Velcro, so the design can actually accommodate other smart phones or mobile devices.

The main drawback of this design is safety. Since the design requires it to be mounted to the center of the steering wheel, proper airbag inflation in the event of a collision is an issue. The device has to be designed carefully to ensure it does not interfere with the airbag in any way, nor hampers its life-saving abilities. The device itself should also be securely attached to the car so it does not become a projectile in the case of airbag deployment.

Design Evaluation

Various factors were taken into consideration in evaluating and choosing the final design. The criteria chosen were (in order of importance): client satisfaction, safety, feasibility, cost effectiveness, marketing potential, and versatility. Weights were assigned to each criterion based on importance, and each design was evaluated based on these weights. Table 1 (below) shows the final design matrix with the scores awarded to each design. Each design could receive a maximum of 100 points.

Criteria	**Weight**	**Solid Arm Support**	**Tripod Support**	**Spinner**
Client Satisfaction	**30**	15	18	29
Safety	**30**	15	25	17
Feasibility	**15**	7	13	14
Cost Effectiveness	**10**	5	7	5
Marketing Potential	**10**	4	5	8
Versatility	**5**	1	4	4
Total	**100**	47	72	77

Table 1: Design Selection Matrix showing the criteria chosen, assigned weights, and scores of each design in each category with the final total shown at the bottom. The Spinner design scored the highest overall.

Client satisfaction was one of the most important factors to take into consideration, and was thus given a weight of 30. The solid arm support did not stand out as a satisfactory design because the positioning of the arm may be awkward and uncomfortable for the driver. It was therefore given a score of 15. The client expressed interest in the tripod support, but the position of the device was not ideal and would require the client to reach over the wheel while driving, giving the device a score of 18. The spinner was by far the most accurate design based on our client's design requirements. When it was tested, it managed to keep the iPhone stable and upright while the wheel turned, meeting the client's request. This gave the spinner a score of 29.

Safety was also given a weight of 30 because it is an important consideration in any device to be used in moving vehicles. The scenario of a collision and possibly airbag deployment had to be carefully considered and examined. The solid arm support was given a low score of 15 for various reasons. Depending on the rigidity of the arm, the support may partially obstruct the airbag. Also, the driver might be subject to a collision with the device itself. The tripod support is the safest design of the three because its position does not interfere with the wheel or the airbag, giving it a score of 25. The spinner presented similar safety issues to that of the solid arm support. Because it is strapped on the wheel, the spinner might prevent the airbag from deploying properly. However, the problem can be resolved by including a hinge mechanism to allow it to be pushed aside, giving it a slightly higher score of 17.

Given our time constraint, the feasibility of constructing the prototype within the given time frame was important, and was given weight of 15. The solid arm support requires a material capable of resisting motion, yet flexible enough to be adjustable. This, coupled with the difficulty in constructing the mechanical components of the design, gave the solid arm support a score of 7. The tripod support is relatively simple because it does not have any specific material requirements, and is mechanistically simple, giving it a score of 13. The spinner was awarded the highest score of 14 because the components of the device are readily available, such as a CD-ROM drive.

Cost effectiveness was given a weight of 10. All the designs are currently significantly under the budget of $300, but the solid arm support would be the most expensive design because it requires a rigid material to be fashioned in the desired shape for the device. Therefore, it was given a score of 5. The tripod support utilizes relatively inexpensive components such as rods and straps, giving it a score of 7. The spinner was a slightly more expensive design due to the CD-ROM motor and CD, giving it a score of 5.

The client wishes to eventually market the product, therefore marketing potential had to be taken into consideration and was assigned a weight of 10. The solid arm support is not aesthetically pleasing and did not appear to be a marketable product; therefore it received a score of 4. The tripod support is potentially marketable because it provides a similar function as GPS systems, but for mobile devices. However, it might obstruct the driver's view of the speedometers, giving it a score of 5. The spinner is the closest design to the client's original concept for a marketable product, scoring it at 8.

Versatility is a subset of marketing potential, but was evaluated separately because it was a specific client requirement, so it was given a weight 5. As the client's MS progresses, he will need to change to another car model better suited to his abilities, and possibly another phone model as well. Therefore, the device has to be adaptable to fit different models. The solid arm support was the least versatile design because it is rather specific to steering wheel sizes and dimensions, so it received a score of 1. The tripod support and the spinner are better able to accommodate different vehicles and phone models due to their detachable components, giving them both 4 as their score.

The final design was chosen based on the total scores for each design. As shown in Table 1, the spinner design received the highest score, and is therefore the final design. The tripod support was a close second and may be taken into consideration as a backup design.

Preliminary Prototype Construction

The preliminary prototype was constructed based on Design 3 (see above). The first step in building the preliminary prototype was acquiring a CD-ROM drive. A CD-Rom drive was donated by the Mechanical Engineering department at the University of Wisconsin-Madison. The stepping motor and one of the circuit boards were extracted from the drive, forming the spinning and rigid backing of the prototype (see Figure 11). Next, a CD was glued to the stepping motor to which weights were attached on the bottom (see Figure 12). Velcro straps were glued to the CD in a 'T' shape, as well as to the back of a plastic iPhone holder, allowing the iPhone holder to be easily attached and removed.

Figure 11: Driver's View of preliminary prototype

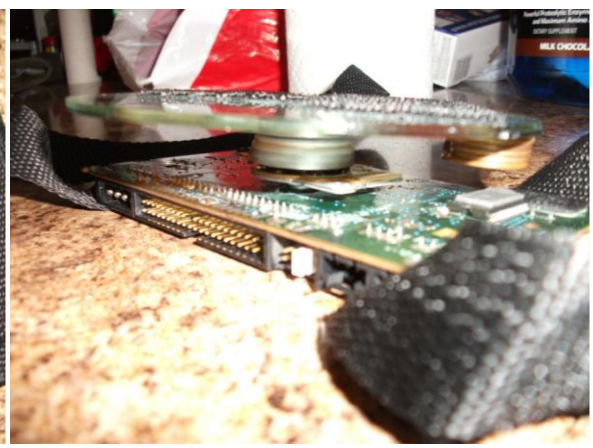

Figure 12: Side View of preliminary prototype

A method of attaching the device to the steering wheel without endangering the driver in the event of an airbag deployment was necessary to ensure the safety of the device. Nylon straps were glued to the top of the underside of the rigid backing and secured at the bottom with patches of Velcro. The device could then be secured on the steering wheel via the nylon straps, which would loop around the steering wheel and be tightened by Velcro straps (see Figure 13).

The concept behind this safety feature is to reduce the chance of injury in the case of an airbag deployment. During normal usage, the device is vertical and firmly attached to the steering wheel by the nylon straps looped around the wheel. However, during an airbag deployment, the front panel of the steering wheel, which the device is placed over, usually flips opens or breaks to allow the airbag to emerge through the center of the wheel. The force of the airbag will break the Velcro at the bottom of the rigid backing, but the device will still be attached to the wheel by the straps glued to the top of the rigid backing. This causes the device to flip upwards using the top connections as fixed pivot points, and will not injure the driver or any other passengers in the car. The mass of the device itself was approximately 0.3kg.

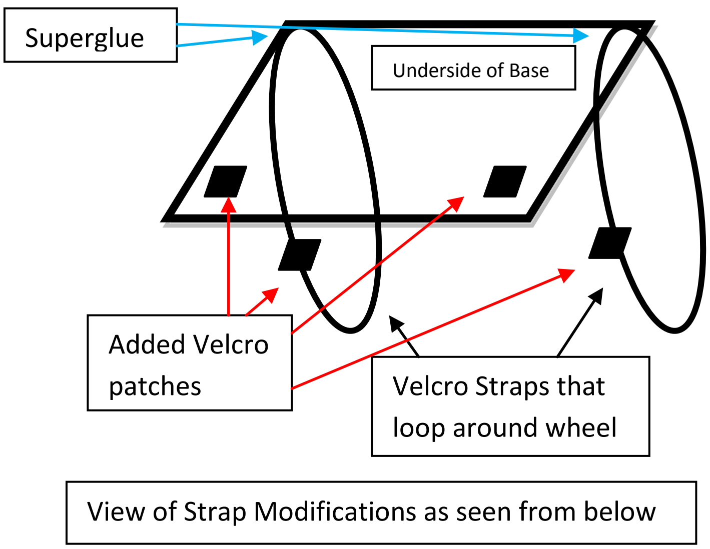

Figure 13: Configuration of preliminary prototype

This preliminary prototype was tested by the client who provided feedback about the convenience and practicality of the device, specifically the angle of tilt of the iPhone and the effectiveness of the weights in keeping the iPhone stationery (see testing section, below). Based on his feedback, the prototype was further modified (see final prototype construction, below).

Final Prototype Construction

The final prototype comprises an iPhone 4 cover, Plexiglas front and back plates, a CD-ROM motor as a bearing, and nylon straps attached to Velcro straps. Figure 14 shows a general sketch of the front and side views of the final prototype. Plexiglas was chosen for the front and back plates because it is cheap, easily obtainable, durable, strong, and aesthetically neutral. It was polished using a grinder before use to prevent any accidental scratches to the user. The back plate was resized from the previous dimensions of 15.2cm x 10.2cm to a smaller size of 10.0cm x 7.0cm, which reduced the size and weight of the device while still retaining its functionality. The Plexiglas front plate replaced the CDs, further reducing space wastage and allowing it to be adjusted to take advantage of the weight of the iPhone as a natural stabilizing force.

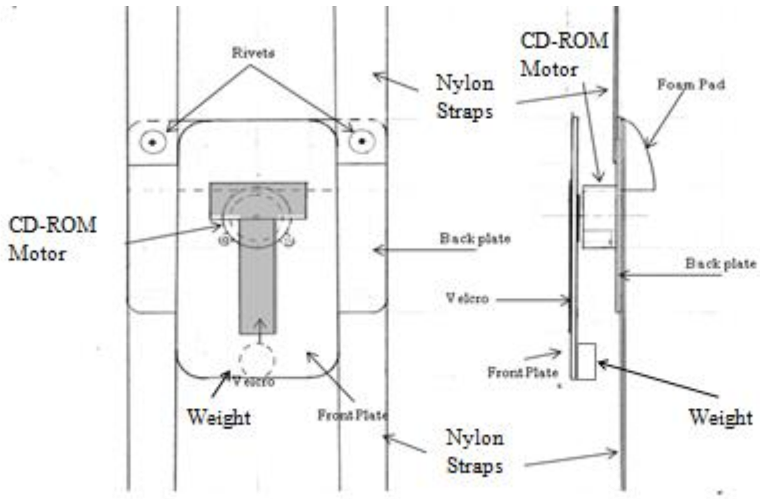

Figure 14: Sketch of final prototype (front and side view)

The iPhone cover is attached to the front plate by Velcro taped on the back of the cover and front of the plate. This allows for convenient attachment and removal of the iPhone from the holder, and allows the user to interchange between vertical and horizontal configurations of the iPhone. The bearing is attached to the front plate by acrylic glue and screwed onto the back plate. This allows the front plate to remain vertical or horizontal regardless of the angle of rotation of the steering wheel. Weights glued to the bottom of the front plate are added to further stabilize the iPhone and minimize swaying. A removable foam pad is also attached on the back plate to allow adaptability to different steering wheel contours and shapes.

The back plate rests on the panel of the steering wheel and is secured at the top by nylon straps riveted using pop rivets (see Figure 15), as well as Velcro connections on the bottom. The nylon straps loop around the middle of the steering wheel and are secured by Velcro at the ends to allow for secure but easily adjustable attachment. As in the preliminary prototype, the design of the straps can reduce the probability of injury to the driver and other passengers in the event of an airbag deployment. The mass of the final prototype was 0.0992kg.

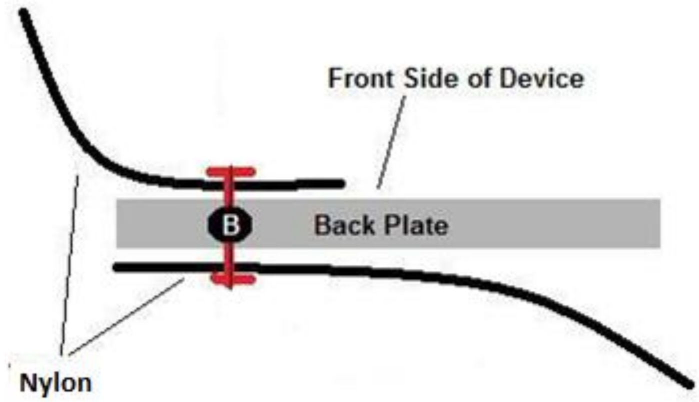

Figure 15: Side view of the rivet attaching nylon straps to the back plate

The final prototype comes complete with a user's manual and safety instructions for the proper attachment and usage of the device. Because the device could be potentially hazardous if attached wrongly or misused, safety warnings are included in the manual and a warning sticker is attached to the device back plate as well.

Testing

A total of 3 tests were performed: testing the stability of the device while driving, mechanical testing of straps and connections, and client evaluation of the prototypes.

Driving testing

Methods and results:

A series of tests were performed using the preliminary prototype in a 2002 Pontiac Grand Am. The device was attached to the steering wheel as designed and a phone (mass 0.53kg) was tied using rubber bands to the plastic case, which was secured to the rotating CD using Velcro.

The first set of experiments was to investigate the angle of deflection experienced by the phone while going around turns. For each test run, the radius of the turn was measured from a pole in the center of the turn's ditch to a point on the road. This point was marked with some black debris which contrasted well with the gray cement, making it easily visible to the driver. The car was driven from a distance before the turn to get to the correct speed and this speed was maintained for the duration of the turn. The driver entered the turn as though following the circle of constant radius. While maintaining this turn radius and speed, the driver monitored the device and approximated the number of degrees that the device rotated from vertical. Most turns were done in both the left and right directions and the resulting degrees rotated were averaged (see Table 2).

Radius of Turn (m)	Speed (m/s)	Average Degrees Rotated
7.3	2.22	2
7.3	4.44	8.5
7.3	6.67	16
6.4	4.44	13.5
5.5	4.44	19
8.2	4.44	9
8.2	6.67	25

Table 2: Rotation of device while turning at various speeds and radii

The second experiment measured the amount of swinging the device experienced during normal operation. The driver parked the car and did some trials of turning the wheel 90^o clockwise and back as fast as possible to simulate sudden swerving to avoid an obstacle on the road, for example. The number of complete swing cycles elapsed before the device settled at equilibrium again was determined to be 3.

The third set of experiments measured the angle of rotation of the steering wheel necessary to cause the device to rotate back to its equilibrium position. This was done while parked and with the phone at two different positions: completely vertical, and at a 15^0 angle away from the driver and towards the ground. The angles required were measured (see Table 3).

Position of Device	Angle of steering wheel before device rotated back to vertical (°)
Vertical	5
15^o from vertical away from driver	6.5

Table 3: Angle of steering wheel before device rotated back to vertical

Conclusion:

The maximum angle the device rotated was 25^o, which was at a radius of 8.2m and a speed of 24 km/hr. It is important to note that this was the fastest speed at which the driver felt comfortable driving around a turn this sharp and that this was an excessive speed with which to be driving around a turn this radius. Therefore, it can be concluded that during safe driving the device should not rotate more than 25^o from the vertical in either direction, which within the client's specification of 45°.

Another important observation from testing is that the device did not sway significantly after completion of the turns and stabilized very quickly back to the vertical, as seen in the "swerve" test.

The data also confirms that the device rotation is directly related to the speed and inversely related to the radii of the turns, which is consistent with the centripetal forces acting on it as defined by the equation: $Fc = \frac{v^2}{r}$.

Material tensile testing

In order to determine whether the superglue or rivet connections between the nylon straps and the back plate are strong enough to withstand the force exerted by a deploying airbag, the connections were subject to tensile testing using the MTS Sintech 10GL at the Wisconsin Structures and Materials Testing Laboratory, UW-Madison. The measured forces required to induce failure in the connections were then compared to the calculated force exerted by the airbag during deployment, which was 420N (see Appendix B for detailed calculations).

Methods and results:

The rivet tests were conducted by placing one end of the nylon strap in one grip and the back plate in the other grip (see Figure 16). The superglue test was performed by placing 2 nylon straps, both glued to the rigid backing, in the grips. Due to the geometry of the prototype, the machine was unable to accommodate the thickness of the circuit board backing and therefore the test had to be conducted using two glued connections. The machine was programmed to apply an axial tensile load on the device until failure occurred at the connection, and the force applied at failure was recorded (see Table 4). The initial lengths were measured as well to ensure the stretching of the nylon straps were not a factor in the measurements. Based on the tests, the average force required to break the rivets was 264N and the force to break the superglue connection was 88.5N.

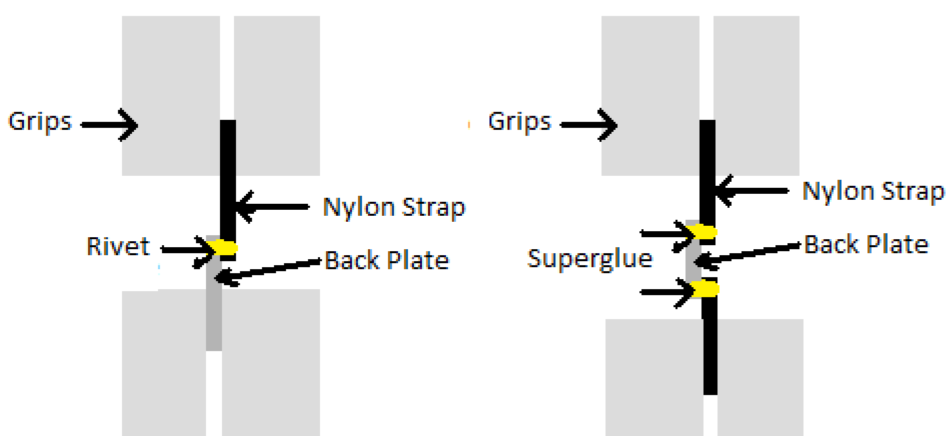

Figure 16: Experimental setup of material tensile testing

Trial	Initial length (m)	Force at failure (N)	Comments
Rivets 1	0.167	280	Hanging by a thread at failure
Rivets 2	0.165	248	Clean tear of the nylon at rivet
Superglue	0.184	88.5 (1st), 102N (2nd)	1st break taken to be failure point

Table 4: Results of material tensile testing

Conclusion:

The material testing results conclusively prove that the rivets are significantly stronger than the superglue (by almost 200%), which was the reason rivets were chosen for the final prototype. Furthermore, the results suggest that the rivets would be strong enough to withstand the force of airbag deployment because two of the rivets can withstand a force of 528N, which is higher than the calculated force exerted by an airbag during deployment (420N). Therefore, the results suggest the method of riveting the nylon straps to the back plate is a suitable method of attachment and will not endanger the driver or any other passengers in the event of airbag deployment.

<u>Client evaluation</u>

To evaluate the client's opinion of the prototypes, both the prototypes were attached to the steering wheel (see Figures 17 and 18) and the client gave his opinion on them (see Appendix D for original surveys). The preliminary prototype scored 9.6 out of 10, while the final prototype scored 10 out of 10. The client very satisfied with the final prototype as it met all his requirements, especially the rotating mechanism, stability and positioning, and provided him a convenient and safe way to access his iPhone while driving.

Figure 17: Client testing out the preliminary prototype

Figure 18: Client testing out the final prototype

Budget Analysis

The client specified a maximum total budget of $300. The total spent over the course of the semester was $47.31 (see Table 5 for breakdown of expenses), which includes the fully functional final product and preliminary prototype, both of which are ready to use in his vehicle according to his requirements. He has been advised that the preliminary prototype is not safe in the event of airbag inflation due to insufficient strength in the strap connections.

Expense	Cost ($)
CDs	2.11
iPhone case	5.00
Nylon straps	10.32
Velcro	7.58
Weights	0.15
Superglue	22.15
Total	47.31

Table 5: Breakdown of expenses

The approximate production cost of the device was analyzed should the client want to mass-produce and sell the device. The bulk costs of the materials were searched on Amazon.com and the quantities were determined based on the final prototype dimensions (see Table 6). It was assumed that the materials would be purchased in bulk for mass production and then divided for individual devices. It was estimated that one worker could assemble the device in a maximum of 3 hours. These assumptions do not factor in economies of scale and streamlining the production process, and are therefore considered overestimates.

Materials	**Unit Price ($)**	**Quantity Needed**	**Cost ($)**
Nylon Straps	0.82 per m	1.128m	0.92
Velcro	8.29 per m	0.533m	4.42
Rivets	0.24 per rivet	2	0.48
Plastic (Polyethylene)	64.53 per m^2	0.044 m^2	2.84
Superglue	1.33 per g	4g	5.30
Used CD-ROM drive	10.00 per drive	1	10.00
		Subtotal	**23.96**

Labor	**Hourly Wages + Fixed Costs ($)**	**Hours**	
One worker	30 per hour	3	90
		Subtotal	**90**
		Total	**$113.96**

Table 6: Breakdown of estimated production cost per device

At $113.96 per device, the product is still relatively competitive in today's market though it is slightly higher in the price range. It offers significant advantages over its competitors. For example, it is the only product that allows drivers access to their electronic devices while driving, since it is placed on the steering wheel. It is also highly customizable as the user only needs to replace the holder with that of their mobile device and attach Velcro to the back of the holder.

As far as in-car navigation is concerned, GPS devices and their holders average around $125 per device. These might also have a monthly subscription fee that the driver would have to pay and a possible installation fee. The market potential for this device rises with the growing prevalence of smart phones, which contain navigation applications that allow them to be used as GPS devices. This product could be a low cost alternative to drivers who have smart phones that also want to use a GPS in their motor vehicles.

Future Work

The client, Mr. Jonathan Rubin, is hoping to eventually place this product on the market for general consumers. Therefore, the device must be extensively tested to ensure it does not pose any significant safety risks. Firstly, all safety issues related to airbag deployment must be adequately addressed. According to the calculations and mechanical testing already performed, the method of attachment is sufficiently strong enough to prevent any injury to the driver. However, to further reduce the probability of injury to the driver, safer methods of attachment should be explored. For example, the nylon straps could be looped through slits made in the back plate and stitched in a style similar to that used in mountaineering straps and parachutes. This would make the force required to cause failure in the connections a function of the material properties of sturdy Plexiglas instead of a singular connection point, and could increase the strength of the attachments. Also, the force required to induce failure in shear in Velcro straps must be tested as well, since they were assumed to be stronger than the rivets.

In order for the device to be proven safe for use, it should be tested in airbag simulation situations, and possibly in actual airbag deployment trials. A trial version of airbag simulation software, the LS-DYNA by the Livermore Software Technology Corporation[9], was acquired this semester but was too complicated to be adequately mastered within the time constraint to be used. Given sufficient time and mastery of the software language, the simulation could prove to be extremely useful in determining the safety of the device.

After simulation testing, the device should be subject to field testing. Such testing is usually extremely costly, and the amount of money and time to arrange for a field test is beyond both the financial budget and the time constraint for this project. However, if the device is to be eventually marketed, it should be tested in car crash experiments to determine its performance in actual airbag deployment situations.

References

1. Enchanted Learning. *"The Brain"* Enchanted Learning, 2001. Web. Retrieved 21 Oct. 2011. <http://www.enchantedlearning.com>
2. Compston A, Coles A (April 2002). *"Multiple sclerosis"* Lancet 359 (9313): 1221–31. doi:10.1016/S0140-6736(02)08220-X. PMID 11955556.
3. Lublin FD, Reingold SC (April 1996). *"Defining the clinical course of multiple sclerosis: results of an international survey."* National Multiple Sclerosis Society (USA) Advisory Committee on Clinical Trials of New Agents in Multiple Sclerosis. Neurology 46 (4): 907–11.
4. Mayo Clinic Staff. *"Multiple Sclerosis"* Mayo Clinic. Mayo Clinic, 11 Dec. 2010. Web. Retrieved 21 Oct. 2011. <http://www.mayoclinic.com>
5. Widmaier, Eric P., Hershel Raff, Kevin T. Strang, and Arthur J. Vander. *Vander's Human Physiology: the Mechanisms of Body Function*. Boston: McGraw-Hill Higher Education, 2008. Print.
6. Reynolds, Chris. Multiple Sclerosis (MS). Digital image. Grass Factor. Dr. Chris Reynolds. Web. 25 Oct. 2011. <http://www.grassfactor.com/mul-case-study.htm>.
7. Naja-King IPhone Holder. Digital image. Thought Out. Gadgetsin. Web. 25 Oct. 2011. <http://www.thoughtout.biz/products/NAJA-King.html>.
8. Distraction.gov "*Statistics and Facts About Distracted Driving*." U.S. Department of Transportation. Web. Retrieved 25 Oct. 2011. <http://www.distraction.gov/stats-and-facts/>.
9. Livermore Software Technology Corporation. LS-DYNA. Web. Retrieved 11 Nov 2011. <http://www.lstc.com/products/ls-dyna>

Appendix A: Product Design Specifications Report

Problem statement/Function:

Our client, Mr. Jonathan Rubin, is an individual affected by multiple sclerosis (MS) who regularly commutes by car. Because of his condition, he has to maintain his focus while driving. This is especially crucial as he has to use his iPhone 3GS for navigation, calling and reminders while driving. Currently, he has the iPhone taped to the center of the steering wheel. However, this creates a problem every time the steering wheel is turned because the iPhone turns with it. A device to securely mount his iPhone to the steering wheel and allow it to remain upright and independent of the steering wheel movement is required. It should be versatile enough to incorporate other phone or car models should he decide to change to a different car or phone model.

Client requirements:

- Securely attach the iPhone to the steering wheel
  - Be at a convenient angle and elevation for him so he does not get disoriented
  - Be at a suitable distance for him to access the iPhone
- Maintain the iPhone at a vertical or horizontal position regardless of the steering wheel position
  - Position of the iPhone chosen by him
- Allow complete access to the iPhone and the steering wheel while mounted
- Allow charging of the iPhone if required
- Aesthetically pleasing
- Can accommodate a variety of iPhone models
- Can be adapted for use in a variety of car models
- Storable under normal car conditions
  - Temperature between 0°C and 30°C
  - Humidity between 50% and 75%
- Dimensions not exceeding 15cm x 10cm x 1.5cm
- Weight under 150g
- Under $300 budget

1. Physical and Operational Characteristics

a. Performance Requirements: The iPhone holder must secure the device in position on the steering wheel and should allow the driver to change its position. While in operation, the device should be able to stay in the desired horizontal/vertical position regardless of steering wheel motion or position. During use, the electronic device being held should not rotate more than 20^o in either direction about the axis coming out of the steering wheel while the steering wheel is being turned.

b. *Safety*: The product should not pose a safety risk to the driver or any passengers. It should not distract the drivers in any way while driving. A warning label should be placed on the device to ensure that drivers focus on the road and do not operate the device while the car is in motion.

c. *Accuracy and Reliability:* The model should securely stay in place and in the right orientation on the steering wheel as the driver turns the wheel. The model should not protrude out from the steering wheel beyond 5cm. The device should be able to maintain true vertical or horizontal position and stay within 20° of it when the steering wheel turns. Any adhesive used to attach the model on the wheel should be strong but removable should the client need to remove it. The model should ultimately be functional for various models of iPhone and other smart phones as well.

d. *Life in Service*: The model should be able to withstand normal usage, and should not fall off the steering wheel if the driver touches it. The model should be able to withstand all temperature conditions in the car, such as extreme cold during the winter (0°C) and heat in the summer (30°C). Any adhesive and components used should not change properties in such conditions. The holder must be able to withstand at least one year's worth of driving or 50,000km of driving distance, with the bearings and rotating mechanism being able to handle hundreds of possible turns during every use.

e. *Shelf Life*: Because there are no biodegradable parts in the model, it should have a shelf life of at least 10 years, excluding any adhesive used. Once installed on the steering wheel, the device should last at least 6 months of driving under normal conditions or until the client decides to remove it.

f. *Operating Environment:* The device will be used on the steering wheel of a car. Therefore, it must be able to handle the range of temperatures found inside a car during any season. However, if the model proves to be more versatile enough, it can work for other motor vehicles such as bikes or scooters provided the operating conditions are similar to inside a car. Adapting the design to external environments is an option that can be explored later.

g. *Ergonomics*: The device holder should allow for easy access to the entire screen of any iPhone model and allow for charging without the cord being an obstruction. The device should be held at an angle that does not block or obstruct access to the screen. The holder must not catch on the user's clothes or other items. Finally, the holder should allow for devices to be held stationary both vertically or horizontally.

h. *Size*: The dimensions of the device should be within 15cm x 10cm x 1.5cm. If the holder is detachable from the base, it should be no more than 1 cm thicker on any side than the iPhone itself. The entire device, including the iPhone, should not extend more than 5 cm from the steering wheel's center.

i. *Weight*: The entire device should weight no more than 500g, including the iPhone itself, which weighs approximately 135g.

j. *Materials*: The device should consist only of lightweight materials. Glass, sharp metals, and toxic substances should not be present in the device. In addition, the materials used should be able to withstand the temperature range of 0°C to 30°C.

k. *Aesthetics, Appearance, and Finish*: The final design should be aesthetically pleasing and have a professional minimalistic finish. It should be smooth and glossy and be as monochromatic as possible.

2. Production Characteristics

a. *Quantity*: At the present time the client only requires one device, but is aiming to market the product in the future, so production ease is a factor to be considered.

b*. Target Product Cost*: The marginal cost of production of the device will be approximately $20-$25. Compared to the average cost of a stationary iPhone holder ($14.97), the device is about $5-$10 more expensive, which will be worth the added advantages it brings.

3. Miscellaneous

a. *Standards and Specifications*: This model will not require any approval by the FDA because it is not a medical device, food-related, or a radiation emitting device. However, the Wisconsin state law prohibits any texting while driving or "being so engaged or occupied as to interfere with the safe driving of that vehicle." Therefore, a warning label or disclaimer is required on the device. Also, there may be safety issues related to the airbag deployment if the device is attached directly in front of the steering wheel in the way of the airbag.

b. *Customer*: Our client has multiple sclerosis (MS) that causes hypersensitivity in his vision and disorientation by excessive head turning. The product must be secured directly in front of him and be able to rotate smoothly without wobbling as the wheel is turned, keeping the iPhone upright.

c. *Patient-related concerns*: This product will not be in contact with any patient or research subjects except the client himself and his family members in the car.

d. *Competition*: There is no present model for a self-correcting iPhone holder in cars. Various stationary iPhone holders range from $5-$30 and may include an adjustable neck to adjust the height of the iPhone as needed.

Appendix B: Calculations of force exerted by airbag on device

Assuming the airbag deploys from rest and reaches v_f = 88.9m/s in t = 0.05s,

mass of iPhone 4 = 137g, mass of device = 99.2g

acceleration of airbag = $\frac{vf}{t}$ = 1780 m/s^2

force exerted by airbag = total mass x acceleration

= 420 N