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Violin Bow-Hand Prosthesis

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SP20 MEMS 500 Independent Study Final Project

Violin Bow-hand Prosthesis

The following report summarizes the ongoing work of designing and engineering a violin bow-hand prosthetic for an 11 year old violinist, Sam. Building off the first two prototypes developed last semester, this project seeks to provide a more comprehensive prosthetic that allows for better control, increased range of motion, comfort, and the possibility of more advanced bowing techniques. With the unfortunate situation of COVID-19, the execution of this project was altered accordingly. Parts of the prosthetic were redesigned and reprinted, while others are still in the design phase. Despite changing circumstances, our goal of providing Sam a proper prosthetic was not lost. The report outlines our research on the biomechanics of violin bowing and how our prosthetic is designed to mitigate long-term health effects on Sam. It also provides information on future work on the prosthetic and testing performance guidelines which can all be completed once a new normal is established.

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1 Introduction

The following project aims to design a violin bow-hand prosthetic for our 11 year old customer, Sam. His current prosthetic is rigidly connected to his arm using a brace and attaches to the bow with two screw clamps. He has limited range of motion because of rigidity of the brace, which ultimately leads to unwanted bouncing of the bow while playing. The screws are cutting into the wood of the bow and slipping which also causes unwanted playing effects. The goal of our design is to solve these current problems and provide Sam with a prosthetic that is more suitable for his needs.

2 Project Motivation

To maximize the outcome and progress of our design, it was important to fully understand the problem and ultimate project motivation. To do this, we carefully outlined our customer's needs based on difficulties with the current prosthetic, and planned a design that would meet all such needs.

2.1 Interpreted User Needs

From the initial interview conducted on September 6^{th}, 2019 with Sam, our customer, we developed a table summarizing our user's needs. The overall design improvements from his current prosthetic are focused on comfort and increased range of motion.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The prosthetic increases the amount of bow used	5
2	The prosthetic is lightweight	5
3	The prosthetic is comfortable	5
4	The prosthetic enables Sam to rotate the bow on the sides of the hair	3
5	The prosthetic is easy to put on	3
6	The prosthetic attachment doesn't destroy the bow	5
7	The prosthetic is not easily destroyed by his dog	3
8	The prosthetic is durable	4

2.2 Design Metrics

To fulfill the needs outlined in Table 1 above, we also need to meet various tangible metrics delineated in the Table 2 below. Some metrics are measurable while others are defined rules or thresholds the prosthetic must adhere to or pass.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,4	Wrist-like flexibility (non-rigid bow attachment)	Binary	Pass	Pass
2	2,3,5	Total weight	kg	< 0.2	< 0.1
3	3	Maximum temperature within prosthetic	Kelvin	$<$ Ambient + 4	$<$ Ambient + 0.1
4	6	Maximum bow clamping force	N	< 5	< 4
5	3,7,8	External limb prostheses and external orthoses: requirements and test methods (ICS 11.040.40)	Binary	Pass	Pass
6	7,8	Minimum number of years until replacement necessary	Integer	> 5	> 7
7	7,8	Standard consumer safety specification for toy safety (ASTM F963-17)	Binary	Pass	Pass

3 Prototypes

We completed two full prototypes and were in the process of designing and printing the third before circumstances changed, making it impossible to move forward with any physical designs. Below are summaries of the first two prototypes and a short report on the progress of the third.

3.1 Mock-up Prototype

The first prototype was a mock-up which served to give us a general understanding of the mechanics of our device. Our main focus was finding a way to securely hold the bow while maintaining natural flexibility of the wrist. We knew ease of use, control and smooth play were important in our design as well. To mimic the natural grip of a violin bow, we used two points of contact between the prosthetic and the bow. After creating the mock-up, we concluded that shortening the distance between brace worn by the user and the bow was greatly needed for maximum control. Below in Fig.1, we have an overview of our mock-up prototype.

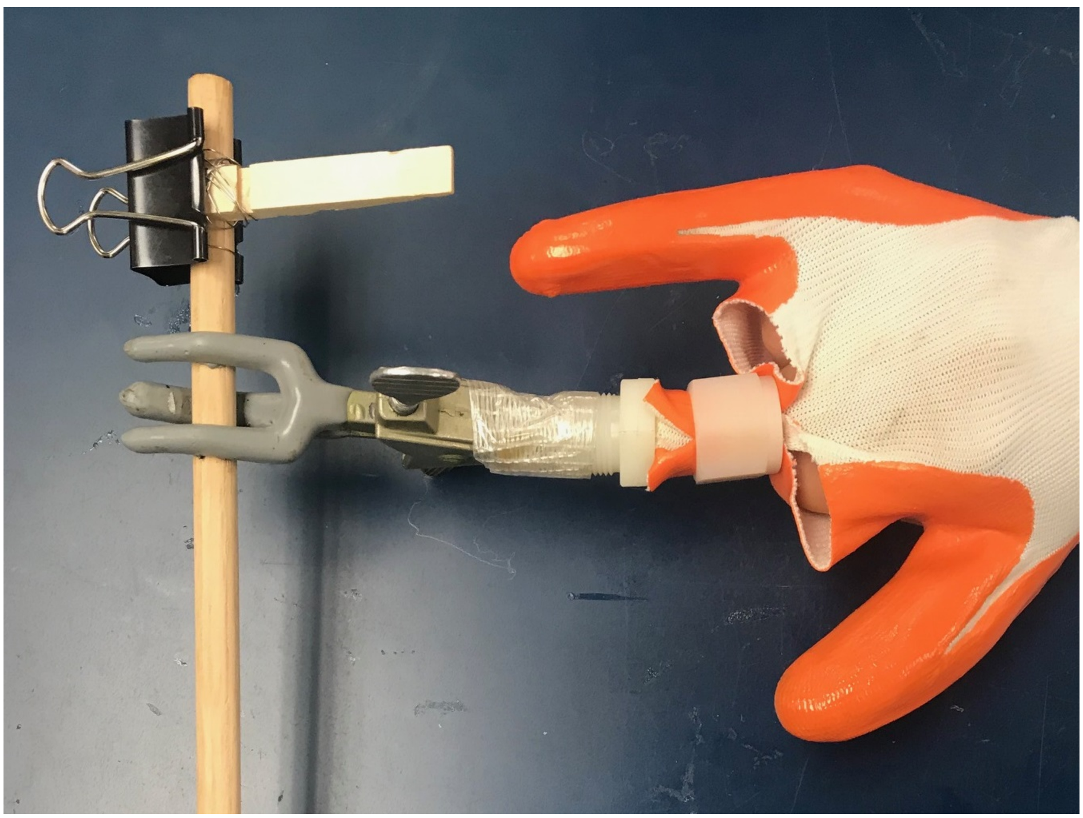


Figure 1: Overview of Mock-up Prototype

3.2 Initial Prototype

After our mock-up design, we used a function tree and morphological chart to create alternate design concepts. As a group, we then developed a matrix table of the six design criteria that were then sorted based on importance. Figure **??** below shows this table which used the Analytic

Hierarchy Process to determine the scoring matrix weights.

	Comfortability	Durability	Ease of Use	Ease of Storage	Difficulty of Fabrication	Safety	Row Total	Weight Value	Weight (%)
Comfortability	**1.00**	0.33	3.00	5.00	5.00	0.11	14.44	0.15	14.64%
Durability	3.00	**1.00**	5.00	7.00	7.00	0.11	23.11	0.23	23.43%
Ease of Use	0.33	0.20	**1.00**	3.00	5.00	0.11	9.64	0.10	9.78%
Ease of Storage	0.20	0.14	0.33	**1.00**	1.00	0.11	2.79	0.03	2.83%
Difficulty of Fabrication	0.20	0.14	0.20	1.00	**1.00**	0.11	2.65	0.03	2.69%
Safety	9.00	9.00	9.00	9.00	9.00	**1.00**	46.00	0.47	46.63%
						Column Total:	**98.64**	**1.00**	**100%**

Figure 2: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

Based on this rubric, we used the Weighted Scoring Matrix shown in Fig.3 below to rank our alternate designs and choose our final concept.

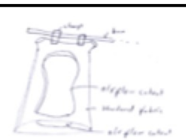
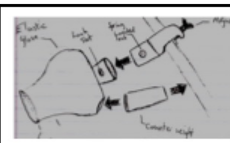
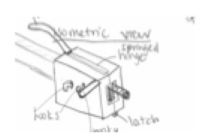
Alternative Deisgn Concepts									
		Violin Bow Holder		**Violin Hand Prosthetic**		**Violin Bow Prosthetic**		**Violin Bow-Hand Prosthetic**	
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Durability	23.43	5	1.17	3	0.70	3	0.70	4	0.94
Safety	46.63	4	1.87	4	1.87	4	1.87	3	1.40
Comfortability	14.64	3	0.44	3	0.44	3	0.44	3	0.44
Ease of use	9.78	2	0.20	4	0.39	4	0.39	2	0.20
Ease of storage	2.83	4	0.11	4	0.11	4	0.11	2	0.06
Difficulty of fabrication	2.69	4	0.11	4	0.11	3	0.08	3	0.08
	Total score	**3.892**		**3.619**		**3.592**		**3.108**	
	Rank	**1**		**2**		**3**		**4**	

Figure 3: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

Once our design concept was selected, we needed to complete a proof of concept and develop CAD models of our prototype. We 3D printed our device since PLA was durable enough to meet all tensile and strength requirements. Using screws, velcro, metal snap fasteners and a brace, we designed the initial prototype shown below in Fig.4

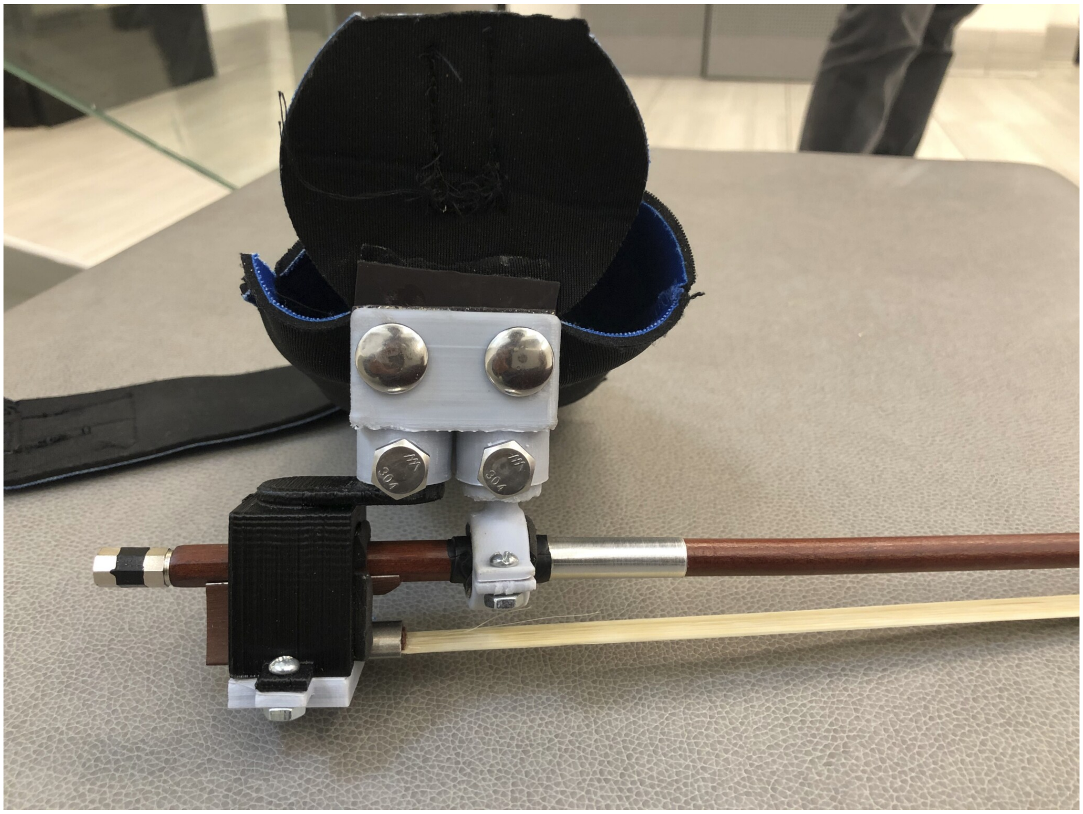


Figure 4: Initial prototype overview

3.3 Current Prototype

Upon completion of our initial prototype which was presented in front of a review board and selected by the customer as the design he wished to move forward with, we started the design of our third prototype. We concluded from the initial prototype that our clamp mechanism could all be one piece instead of two individual clamps which would move the bow closer to the hand, allowing for more control. Additionally, we decided to extend the base plate which attached to the brace so there was more surface area to press down on which would also allow for more control while playing. Because the screws which connected the clamps to the base plate added unnecessary weight, we also decided to redesign the connection. We designed a sliding mechanism that cut down both on weight and distance from the bow. Below in Fig.5 through Fig.7, we have the 3D print of our current prototype.

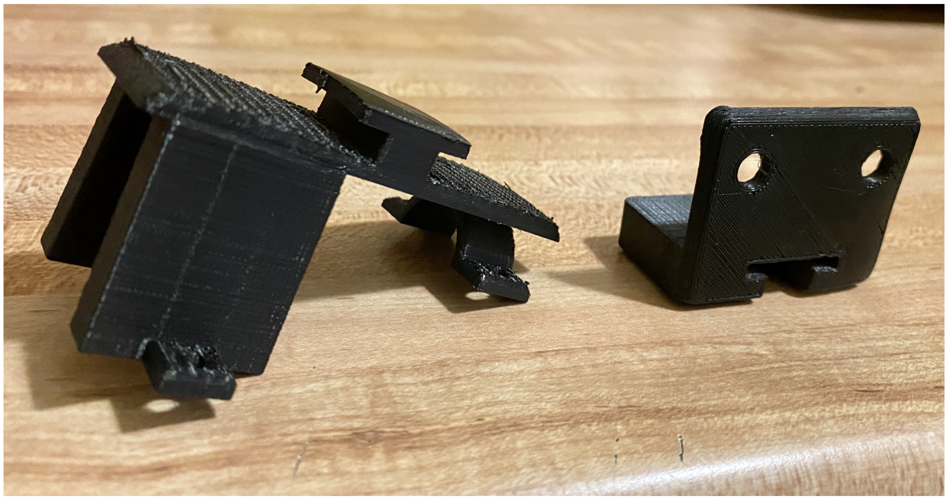


Figure 5: Current print

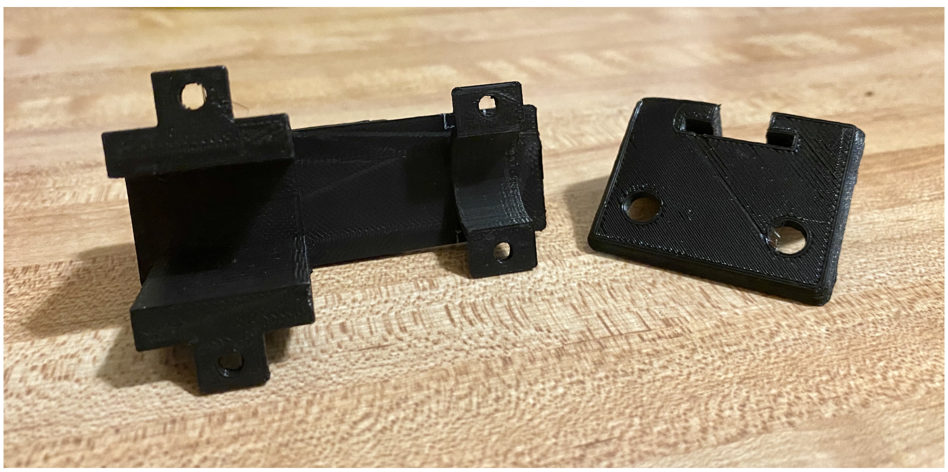


Figure 6: Current print

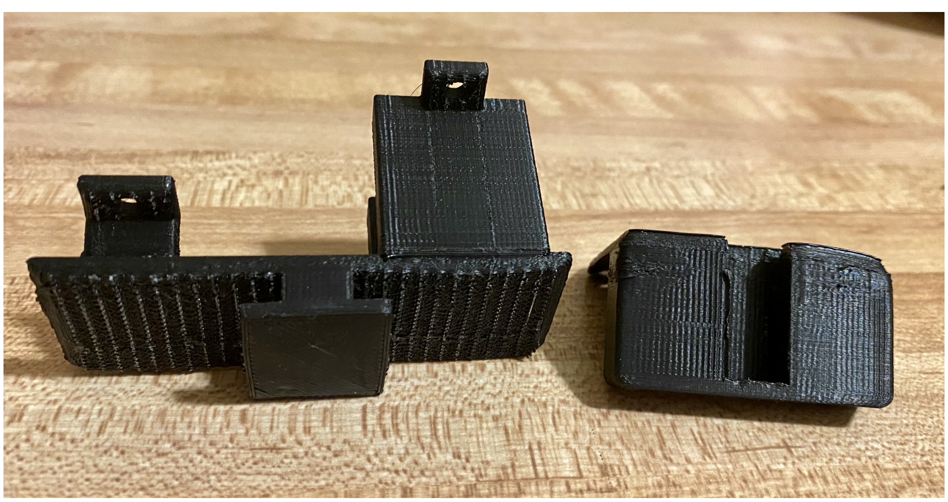


Figure 7: Current print

As can be seen, the clamps are now combined into one piece, the base plate is wider, and the connection mechanism is a sliding T bar. The only missing 3D prints are the bottom pieces of the clamps which would be connected using small screws. Further design of the brace was not completed due to the changing circumstances. With more time a better fastening mechanism for the top and bottom clamps would have been desirable. In terms of the connection of the brace to the base plate, velcro and snap fasteners are functional and lightweight. The magnet between the brace and plate was not necessary and could be removed.

4 Performance and Biomechanics

This section is an analysis of research conducted on the biomechanics of performance art, most specifically, to violin bowing, since that is the most relevant subtopic to our project. We will analyze the performance of our own current prosthetic in terms of its accessibility, strength, and comfort, and then define the biomechanics of violin bowing and describe their relevance to this project and how the information can be used to improve upon our design for a more streamlined product.

4.1 Prosthetic Performance

Due to the changing circumstances, FEM stress and deflection analysis was only completed on the initial prototype. Although modifications were made to the 3D print of the clamps in our current prototype, these changes only decreased maximum stresses acting on the PLA. We analyzed the rectangular clamp because it had an offset with the potential to deform noticeably as can be seen in the following figures. We used an intermediate coarseness mesh for analysis. The boundary conditions for the clamp were fixed in all dimensions on the top. This mimicked the ideal situation of perfectly securing the top of the clamp to the base plate with a set screw. We chose a downward force from the bow onto the clamp as 2.97 pounds. This was determined based on the performance goal that a 0.25 pound force would be exerted at the tip of the bow, furthest from the clamp, to simulate the pressure needed to play at the very tip. The 3D print is made of PLA, however in Solidworks that material is not found in its library. We used ABS for our model since the material properties are very similar. The following figure shows the mesh, boundary conditions, and load described above.

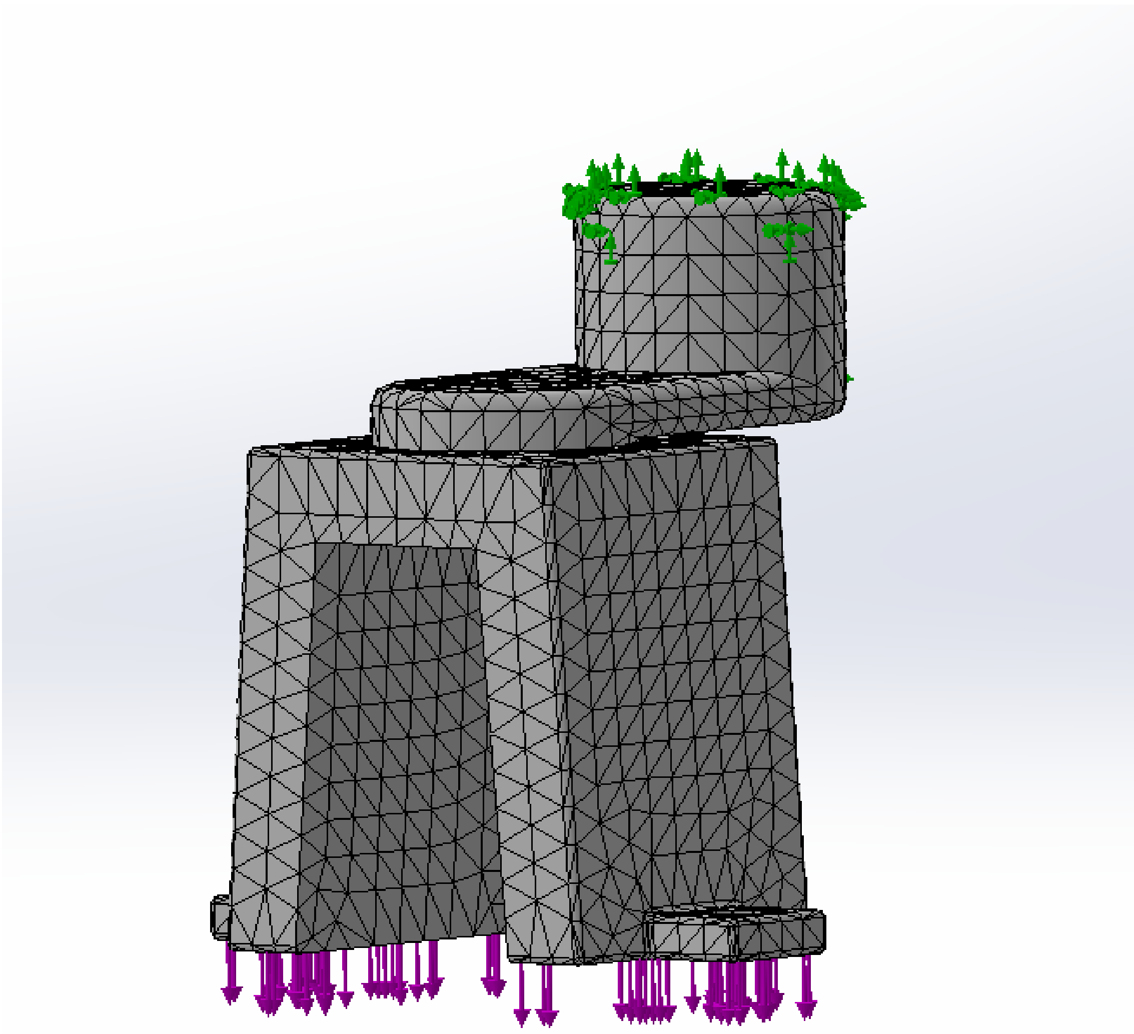


Figure 8: Figure Showing Mesh, Boundary Conditions, and Loads

4.1.1 Stress on Loaded Model

The following figure shows the stresses on the loaded model given the conditions delineated in the above section.

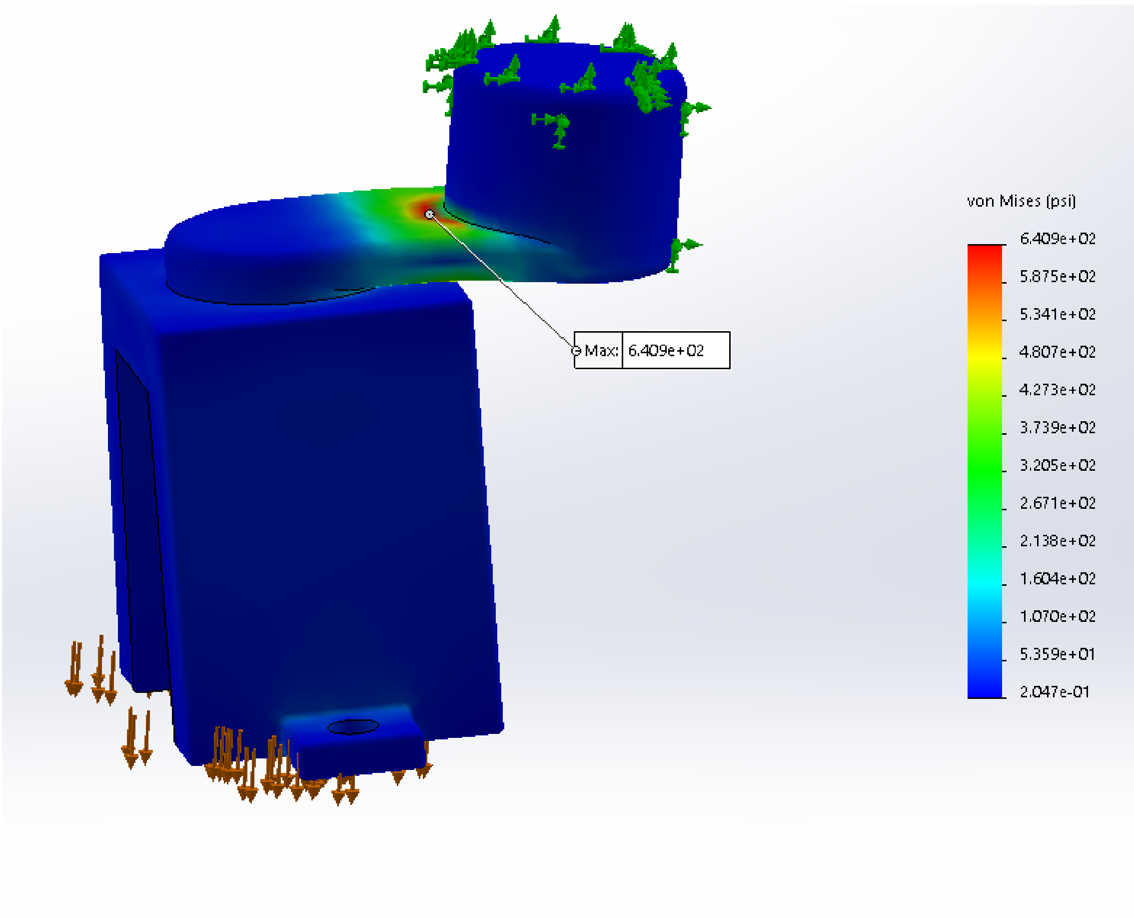


Figure 9: Figure Depicting Von Mises Stress on Loaded Model

Based on the Solidworks simulation, the maximum von Mises stress is 641 psi acting on the offset portion of the clamp support as expected. For PLA, the yield stress is approximately 8840 psi [1]. By dividing this value by 641 psi, we have a factor of safety of 13.8. We used the von Mises static failure theory.

4.1.2 Displacement of Loaded Model

Again using Solidworks, we calculated the maximum deflection expected given our conditions and loads applied. This can be seen in Fig.10 below,

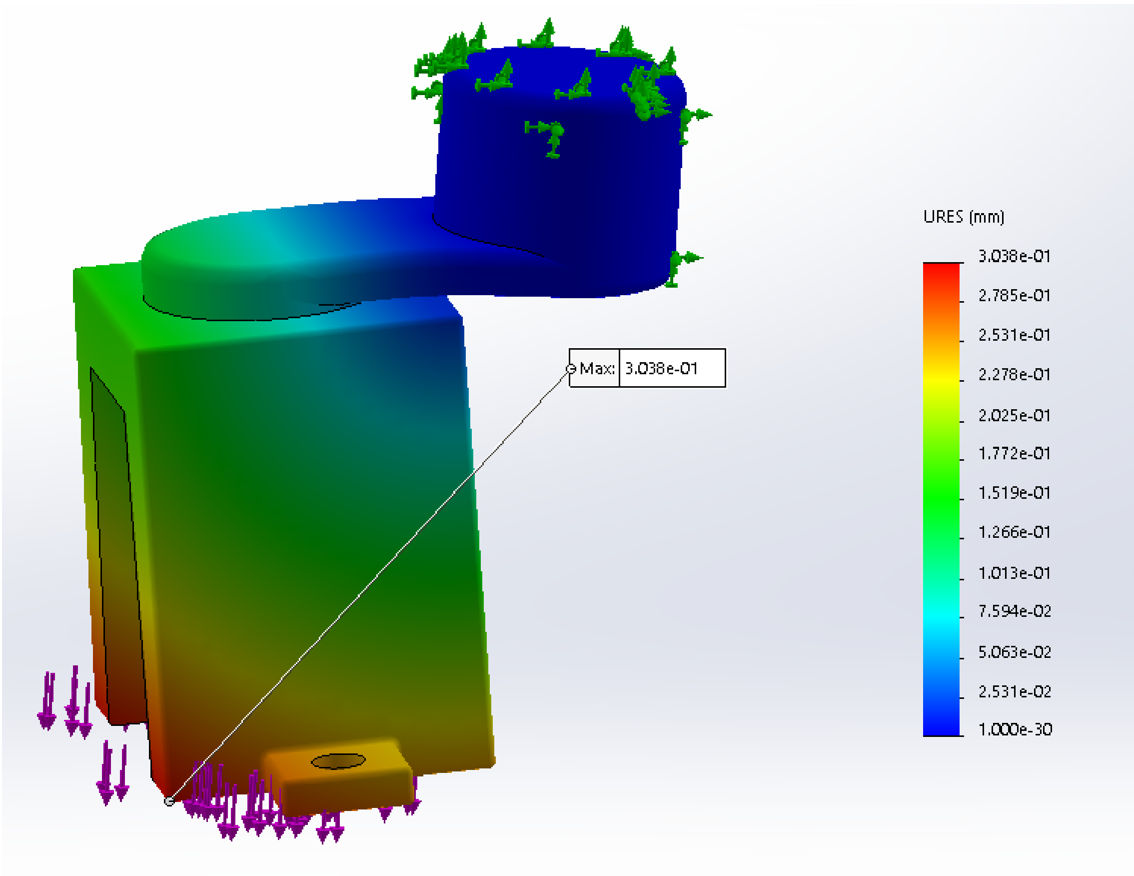


Figure 10: Figure Depicting Displacement of Loaded Model

For the maximum deflection predicted, our simulation gave 0.31 mm occurring at the bottom of the clamp. However, given both clamps have a foam padding on the inside, it would take a much more significant deflection to create alignment issues between bow and clamp. We estimate that anything below a 3 mm maximum displacement is tolerable. Given our maximum predicted displacement is 0.31 mm, we do not expect any issues.

As mentioned before, the current prototype made multiple modifications to the base plate and clamping mechanism. The changes eliminated the offset part of the rectangular clamp, widened the base plate and combined the clamps to one part. By making the clamps one part, with a sliding component to attach to the base plate, the set screws are no longer needed. This decreases the overall weight of the prototype both because of two fewer heavy screws and less PLA material. The widened plate helps put less mean pressure on the skin since it is more evenly distributed. The strength of the PLA material remains the same despite lower maximum stresses and deflections, meaning the FEM analysis should still hold.

4.2 Biomechanics of Violin Bowing

Violin bowing affects several parts of the body including the wrist, hand, arm, shoulder, collarbone, neck, and back (the typical bowing motion on one string requires no shoulder movement, simply hinging at the elbow and wrist flexibility, which were our main focuses for our first prototype), and each of these are affected asymmetrically on the body, due to the right arm performing the bowing action while the left does the fingering and shifting on the strings [2, 3]. This uneven use of the arms leads to asymmetric movement patterns and can affect violinists posture and skeletal growth long term [4, 5, 6]. Repetitive movement, sustained position and taking a muscle beyond its range of motion are the three single causes in muscle disorders that result in chronic pain and dysfunction [7]. For example, playing the violin at a young age (before the skeletal structure is fully formed) and continuing into adulthood can have an impact on the development of young violinists through puberty, causing long-lasting effects in terms of posture, bone structure, alignment, asymmetry, and other skeletal problems including chronic pain [6, 4, 7]. Most violinists learn at a young age, making it imperative to identify and instruct the correct bowing patterns and techniques early on to prevent bad habits from forming inflamed by compensation for the asymmetrical development of certain muscle groups involved in the action of bowing; "prevention is the best treatment" [7].

There are five main bowing styles: (1) *spiccato* (bouncing bow strokes where the bow repeatedly comes off the strings creating small pauses between notes), (2) *sautillé* (aka jumping bow, where the wrist starts a tremelo (shaking) until the tip of the bow bounces along the string), (3) *staccato* (short choppy bow strokes with distinct stops along the string), (4) slur (several notes connected in one long bow stroke), and (5) *detaché* (separate bow strokes corresponding to separate notes) [5, 2]. Each of these styles requires a different technique and therefore a different use of the parts of the arm. For example, sautillé only uses the wrist, slurs require use of the forearm, and spiccato requires the forearm, wrist, and shoulder to lift the bow. Each of these styles therefore affects the body in a different way and traces a different bowing pattern. In his study performed in 1934, Hodgson utilized cyclegraphs to track the bow hand during these various bow strokes. According to Hodgson's study, a cyclegraph is "a photographic record of the track covered by a moving object" (Hodgson 1958) [5]. In addition to the cyclegraphs, he explained his theories of violin bowing with hand drawn diagrams of the hand/bow motion during different strokes. Hodgson determined that in repetitive string crossings from the D to A string, the bow hand moves in an ellipse, as shown in Figure 11. He also tracked the motions of the other bow strokes, including string crossing with a slurred bow (no direction change with different notes), which can be seen in Figure 12.

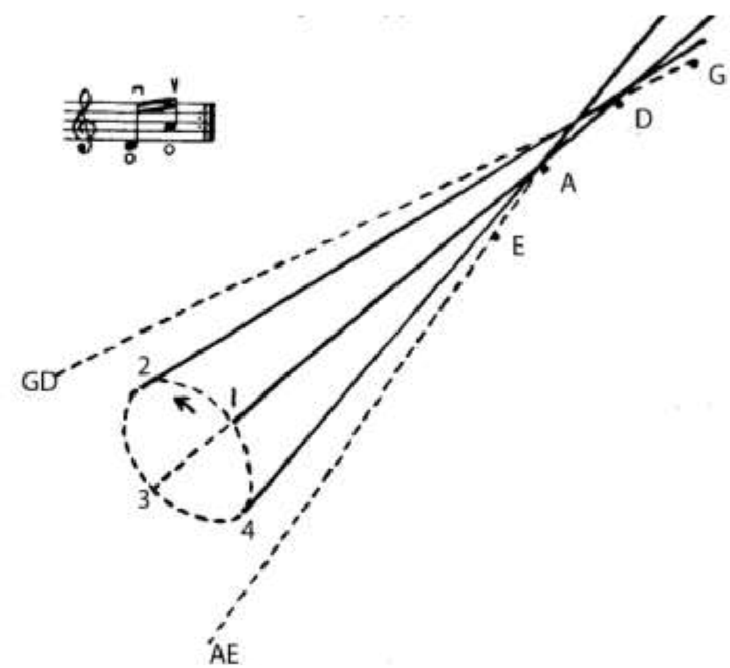


Figure 11: Hodgson's tracked motion of the bow in repetitive string crossings between A and D strings [5]

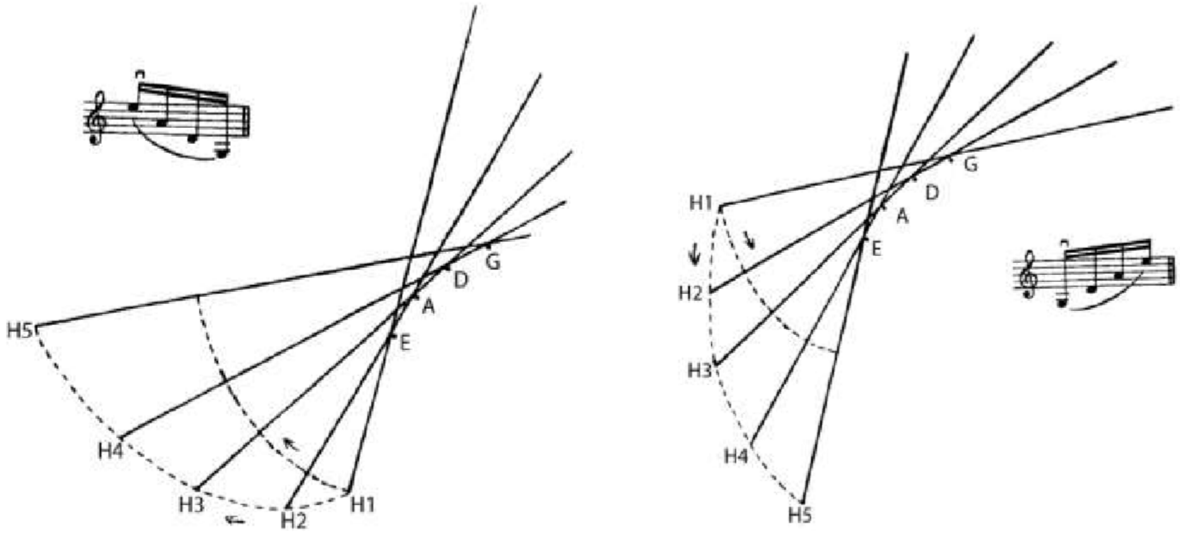


Figure 12: Hodgson's tracked motion of the bow in slurred string crossings [5]

This information can be used to track the bowing habits of our own client in order to better the design of our product and personalize it more effectively, for example, to ensure that our prosthetic is allowing him this full range of motion in as natural an elliptical pattern as possible.

Research in music medicine has reported incidence rates of musculoskeletal disorders of approximately 70% in instrumental musicians, with string players having the highest risk, at rates of performance-related musculoskeletal disorders (PRMDs) of 65% to 88% [8, 9]. Playing the violin requires complex neuromusculoskeletal skills, and the high frequency of repetitive movements, dynamic and static muscle load, awkward postures, poor technique, and practice time are factors causing musculoskeletal strain. In ergonomic terms, these disorders can be categorized based on extrinsic and intrinsic loads. Identification of intrinsic loads, such as muscle utilization and joint motion, is necessary to understand factors influencing musculoskeletal disorders associated with violin playing [8, 9, 10, 11].

Research suggests that an asymmetric playing posture, the associated muscle activity, and joint mobility may contribute to musculoskeletal problems in violinists [8, 9, 7]. Evidence suggests an increased load of intrinsic factors in violin performance. The identification of intrinsic loads and kinematics in violin playing may facilitate the development of prevention strategies and interventions [8, 3].

One 2003 study supplies such information for the arms and violin bow [11, 8]. The motions of eight professional violinists and three advanced university music students were captured in this study using a nine-camera VICON V8i motion capture system. Each performed a fundamental control skill employing all four strings of the violin. The data were analyzed using quantitative model comparison and statistical analysis. The results of this study show parameters such as elbow height normalized by body height and shoulder and elbow joint motion to have highly consistent patterns between the subjects. Wrist control patterns varied widely. Playing on different strings influences right arm patterns significantly, but not left. This was the first study providing quantitative 3-D kinematic data on shoulders, elbows, wrists, and bow. It provides a foundation for further exploration of the kinematic characteristics of violin performance, for the examination of the potential causes of OS, and for an evaluation of practices that might minimize injuries [11, 9, 10].

A 2012 study building off of this research identified the following three patterns of the biomechanics of violin bowing: 1) control pattern changes within single joints, accounting for playing conditions and/or the tools of performance, 2) interactions between joints, including gross to gross motor skills, fine to fine motor skills, and gross to fine control pairs, and 3) control pattern consistencies of some joints that may be linked to the effects of training [10]. The study concluded that these patterns suggest that successful performance on the violin requires flexible motor control strategies that may be understood as compensatory in nature [10].

Other later studies provided insight of the muscle activity variations of the right arm lifting the bow with respect to the string played, the tempo, and bow mass changes with similar results [12] and used audio as well as visual analysis to evaluate the recordings and certain stimuli, extracting movement techniques to compare [13].

Quantitative biomechanical research into bowed string musicians has been performed with increasing frequency but there are voids in the research, particularly in investigating mechanisms of injury and protective strategies. Currently, arts biomechanics research is largely descriptive in nature; there are few studies that investigate protective strategies, although it is expected that the field will progress to incorporate this type of research [14]. Studies with more quantifiable results will be helpful in obtaining a larger picture view of how to remedy the negative effects of the bowing techniques on the body. Since the best way to treat injury is to avoid movements that will cause it [7, 13], more research into this topic will help determine exactly which motions are the most unnatural and compensatory, that is, are the most likely to cause lasting damage with years of repetition.

Due to our client's bow-hand deformity and the somewhat-limited range of motion of the prosthetic, it is inevitable that he will develop some bad habits in bowing technique, in order to compensate for his disability and still play the violin more advanced. In the meantime, however, we can only strive to make our own prosthetic as limitless, natural, and comfortable as possible, mimicking a real arm and hand, and that will meet performance goals but also feel like the wearer's own appendage with practice. By designing our product after the structure of a hand bow-hold, we are minimizing the negative skeletal structural effects on our client's long-term health as a result of repeated unnatural and asymmetrical motions. More work is still needed on the prosthetic itself, which will be described more in depth in the following section.

5 Future Work

Had the unfortunate COVID-19 pandemic not occurred, we would have had the time to complete this project this semester. As such, the remaining work left to do on the prototype will be delegated to future work on the project. The three main goals moving forward with the prototype are: (1) to fit the prosthesis to our client's own arm, (2) to improve upon the fastening point between the prosthesis sleeve and bow attachment feature, and (3) to design a functional ”finger” attachment that can be used for *pizzicato*-style playing (plucking of the strings rather than drawing the bow across them to produce sound). The following sections will detail the planned processes for continuing with the work on this prosthesis.

5.1 Sleeve Adjustments

In order to fit the prosthesis to our client's hand and arm, we had planned to first make a replica of his hand and wrist. Up until this point, we'd been using our own hands as reference to test the usability of the prosthetic, however, our client lacks fingers and therefore has an entirely different hand size and shape, dramatically affecting the fit of the sleeve. To resolve this without needing to excessively meet with our client, we planned to use a molding clay or alginate as a mold; we'd then fill the mold with plaster to have a cast of his hand and wrist. Next, we'd be able to shape and adjust the prosthetic sleeve material to fit the cast hand, rather than one of our own hands, in order to yield a more personalized fit to our client's specifically shaped hand. This way, he'd be able to utilize the prosthetic more efficiently without it sliding, slipping, loosening, or chafing.

In order to fit the sleeve to the cast hand, we'd make adjustments to the sleeve including sewing alterations, addition or removal of certain Velcro straps, in a process of trial-and-error, testing the prosthesis in its application periodically while attached to the cast. We would most likely need a change in overall sleeve material to one that is a bit more stretchy but also more snug around the hand, to fit tighter and prevent slippage, but still allow for flexibility in the wrist. A material we have been considering is one used for compression socks, which are designed to support the ankle but allow its flexion. Compression socks can be knitted from a wide variety of materials such as nylon, cotton, spandex, and natural rubber. These fibers are produced in different combinations and thicknesses depending on the desired elasticity, softness and appearance of the sock or sleeve itself. Most likely, the sleeve we would look for would be a combination between cotton for breathability, nylon and lycra/spandex for stretch and comfort, and neoprene (a synthetic synthetic polymer resembling rubber, resistant to oil, heat, and weathering) for support and compression. For the next prototype, we could most likely use a pre-existing compression sock, which are mostly cylindrical in shape, and just alter it to support the bow-attachment of the prosthetic. However, in the more distant future with additional funding or planning, a custom material can be designed and employed.

5.2 Attachment Point Alterations

In our most recent prototype, we made most of the necessary changes to the fastening point of the sleeve and bow-attachment of the prosthetic. However, with altering the sleeve to a more flexible but compressing material, this would alter the level of support available in the material of the sleeve for the weight of the bow and force on the attachment site.

We had planned to remove the bulky magnet from our initial working prototype (the "final prototype" before this independent study). We found that snap-fasteners were easy to attach and detach with one hand, and would not come loose during play. Velcro provided additional support and flexibility. Because the area of the base plate was increased, it's possible we may not need to make any more significant design changes to the attachment site, since this increased surface area of contact with the sleeve provides more support during lateral bowing motions and alternating pressure application via the bow-arm, which produces alternating torques on the attachment site. However, due to the unfortunate circumstances, we were unable to test this and cannot know for certain at this time.

If we found that more support was required in the sleeve for the bow-attachment, we predict that a twin base plate embedded/sewn into the sleeve material could suffice for support, and embedding this additional plate would be our next step in solidifying the connection point between the sleeve and bow-attachment. This twin plate would lay flat against the hand and be integrated into the sleeve itself (to prevent user discomfort), so the torques on the sleeve would not only be on the snap fasteners at their pinpointed locations. This more even distribution of the forces would cause less uneven pulling of the sleeve, preventing slippage or loosening, and therefore allowing for more consistent control during play.

Finally, in the current prototype, the bow-attachment fastens to the bow by small screws holding the top plates and bottom clamps together around the shaft. This design is a bit user unfriendly, as the screws are very small and difficult to tighten and loosen. We would need more time to determine a better fastening mechanism for these parts, but our preliminary ideas include a small hinge-and-latch configuration so that the bottom clamps would no longer be a separate part, and the whole design would become much simpler to operate with one hand. This type of attachment would need some customization to accommodate the size and application of our prototype, but it would overall simplify the prosthetic and increase its accessibility. Figure 13 shows a drawing of this design concept.

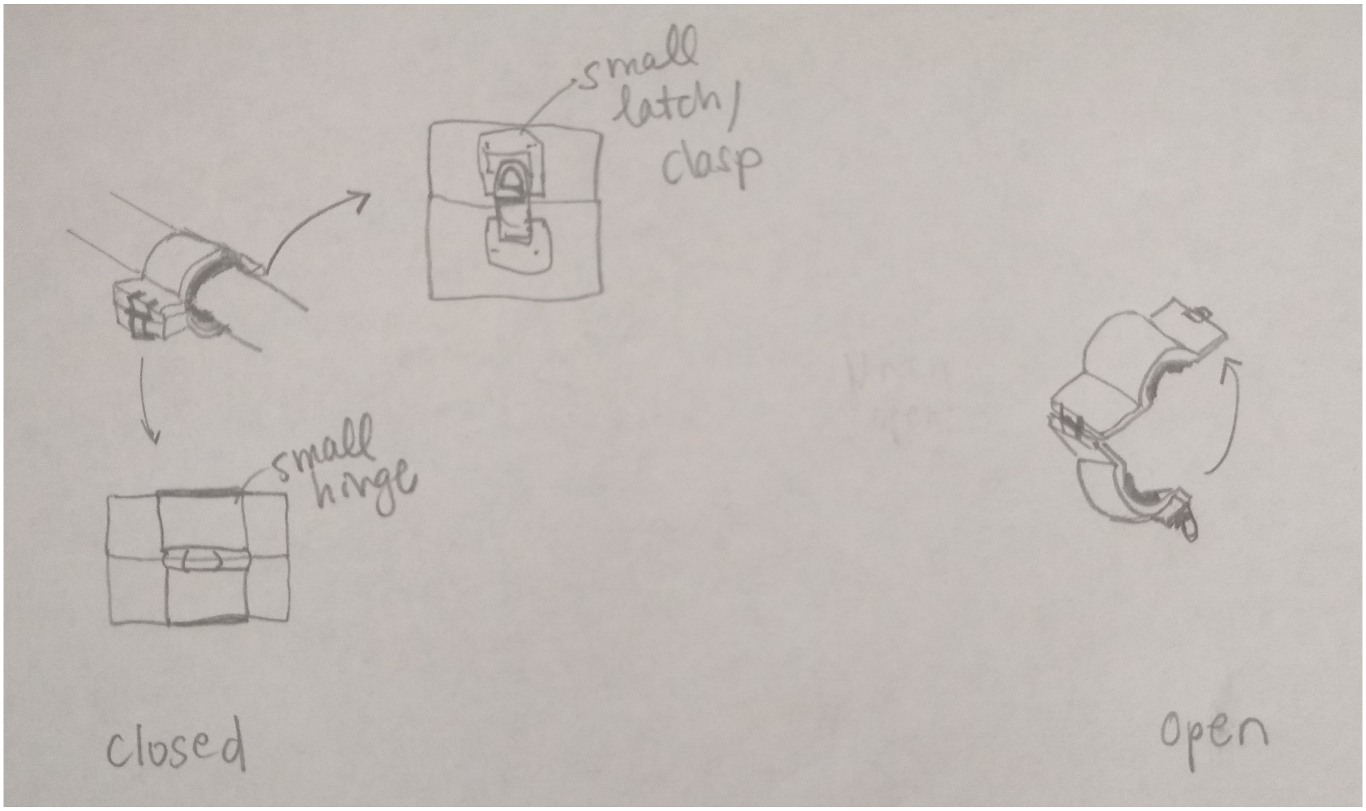


Figure 13: Drawn concept of hinge-and-latch configuration

5.3 Pizzicato Attachment

The most notable addition to our previous design is that of an operational ”finger” attachment that can be added or removed to the bow independent of the rest of the bow-attachment. This component would attach to the bow shaft, further from the frog than the rest of the prosthetic, and be able to be used to pluck the strings of the violin, so that the user can play in the style known as *pizzicato*. This attachment would need to withstand the force necessary to hook onto the string and pull it sufficiently to make it vibrate enough to produce the desired amount of sound. The ”finger” would have to be designed to avoid damage to both the bow and the violin strings, so our goal was to design it as close as possible to a natural finger, complete with padding at the tip where it will come into contact with the delicate violin strings. Figure 14 shows a sketch of the basic ”finger” design concept.

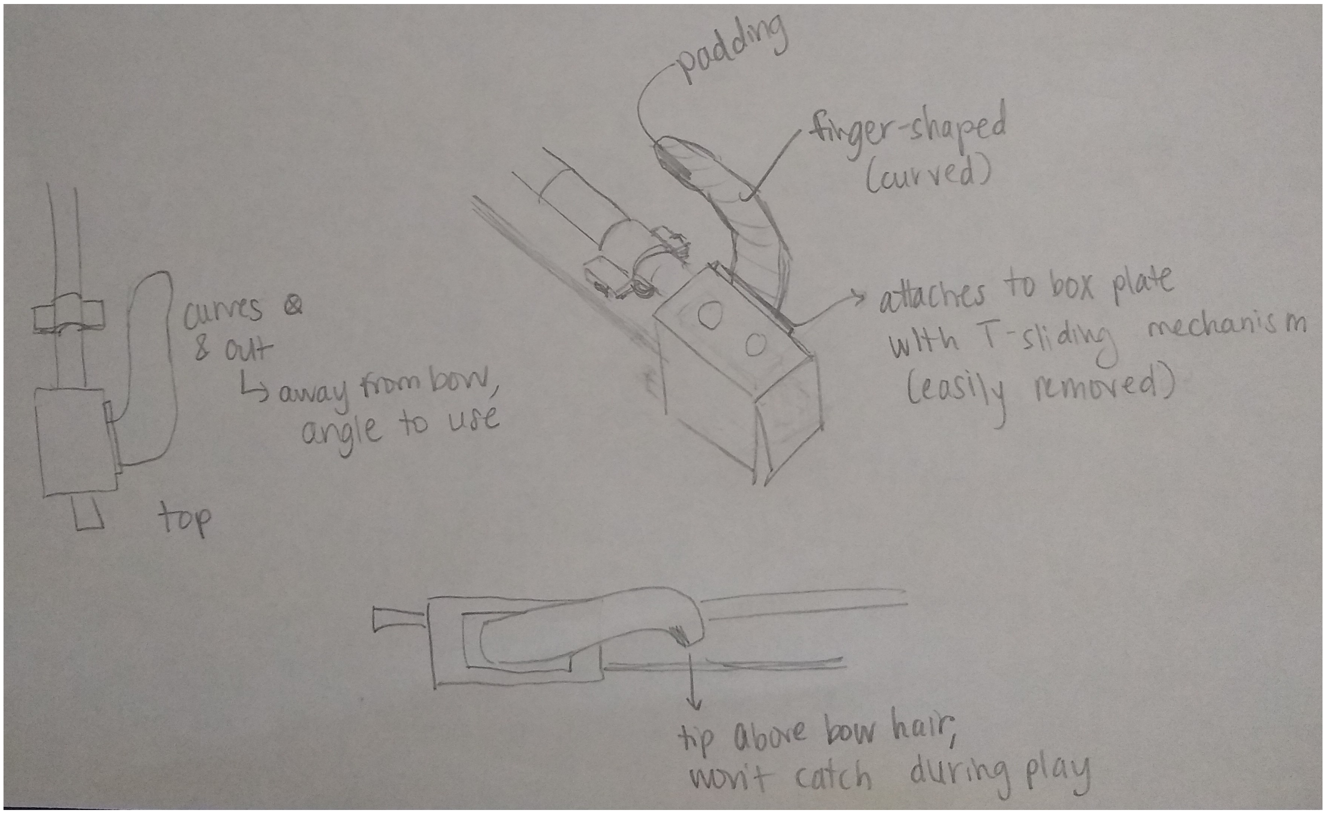


Figure 14: Drawn concept of pizzicato "finger" attachment

Another important design feature of this attachment would be that it cannot be in the way during normal bowing; if its angle of attachment is too large, it will catch on the strings during bowing, but if its angle is too small, the user will not be able to rotate the wrist far enough to use it on the strings for *pizzicato*. In order to perfect the location of the attachment, we will consult our knowledge of proper violin bowing technique and *pizzicato* form, as well as our knowledge of our client's natural limitations, and mimic the natural hand with our design. Figure 15 shows a diagram of the natural hand angle for performing *pizzicato*.

Figure 15: Natural hand angle for pizzicato [15]

As is evident from the diagram, the hand angle for *pizzicato* is more than a 90^o angle from the natural bowing hand position, not to mention, the violinist's hand must be right up by the fingerboard. We did design our product to allow for our client to use the full length of his bow, so luckily the latter point is not an issue. The former depends on the user's natural range of wrist mobility and any limiting factors can then be mitigated by a slightly different attachment angle of the "finger" itself.

Because this part will most likely be designed and printed using SolidWorks, as were the previous parts, we'd be able to use the program to conduct a force analysis on the attachment to ensure it is strong enough to withstand the act of plucking the strings with various intensities. With the SolidWorks analyses confirming the strength of our design, we will then test it in action with the rest of the prosthetic.

This attachment must be securely fastened when attached to the bow, but would also have to be easily removable so it was not a distraction or in the way for the user when playing pieces that do not require *pizzicato*. Therefore, it can be attached similarly to our improved fastening site of the large base plate: with a T-slide system. This will allow easy removal and attachment, as well as a secure fasten to the rest of the prosthetic. This would mean we would have to reprint the box clasp of the bow hold again however, to include the option for this appendage.

5.4 Testing Performance

A factor we will want to consider with the performance of our prosthetic is comfort for the user. Wearing a prosthetic during any activity causes pressures and/or abrasion on contact points with the skin. For example, during bowing, the hand and arm must apply forces to the bow (forces we know from design parameters/performance goals). This weight combined with the weight of prosthetic-and-bow configuration itself, causes more pressure on the contact points within the sleeve, since the entire prosthetic is truly being supported by the wearer's arm. We wish to maximize this possible force and allow for the sleeve to support this force as evenly as possible to avoid pressure points within the sleeve that could cause discomfort. Thus we will utilize the initial prosthetic performance goal of the sleeve needing to be able to support 0.5 lb of force at the tip of the bow for conservative estimate on the resultant force within the sleeve on the wearer's arm.

Since we know that the prosthetic attachment sites and sleeve can both withstand this force (we met the performance goals), the question we must address is whether the internal design of the sleeve prevents any discomfort as a result of these forces over continued use as well as possible. In order to test whether this is the case or not, we can test pressure points with the cast of our client's hand. A simple experiment we could conduct would be to first cover the cast hand with a soft material mimicking skin, such as thin leather, soft fabric, or other similar, easily worn material; next put on the prosthetic; then subject the bow-prosthetic-cast-hand unit to mock-"extensive playing" (for example, heavy vibrations creating enough force for a prolonged amount of time, say the length of a symphony, approximately 45 min-1 hour). We'd conduct this experiment to see where the "fake skin" wears down, as well as perhaps discover any structural problems in the prosthetic itself with prolonged use. Uneven wear on skin can cause itching at best and scratches or abrasions at worst, so we wish to mitigate this as much as possible. After discovering any possible pressure points, we could amend the lining of the sleeve by substituting it with a softer material, adding padding at the pressure points, and/or altering the design of the attachment site in order to disperse the forces more evenly, lessening localized pressures (i.e. wider plate, etc).

Ultimately, our goals are to make the prosthetic not only controllable and capable of drawing sound, but also user-friendly in terms of comfort, accessibility, and other features such as being machine washable and easily portable.

6 Conclusion

Although the trajectory of our project was altered due to unfortunate, changing times, our ultimate objective still remained focused on providing our client, Sam, the best violin bow-hand prosthetic as possible. Using the lessons learned from our first two prototypes, we were able to design a third that allowed for even better control, comfort and range of motion. Despite not being able to physically provide a complete prototype for Sam, we still researched ways to improve the performance of our prosthetic, ways to mitigate potential negative skeletal structural effects on Sam's long-term health, and additions to the prototype that would allow for more advanced bowing techniques. Hopefully in time, we or fellow engineers can see this project come to fruition so that Sam has the prosthetic he needs to play the violin comfortably, with full range of motion. Future needed work on the prototype is already established, as well as performance testing, meaning the project could move forward once normal circumstances are established.

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