Prevention of Weightlifting Injuries by Barbell Modifications

Preliminary Report

October 9, 2024

Biomedical Engineering 200/300

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Table of Contents

Abstract

Every year, thousands of people injure themselves while performing bench press [1]. The more inadequate form is while performing bench press the higher the likelihood of injury is [2]. Competitors have attempted to replicate what the team's design's function will be, but all have succeeded with only creating at most one dimension of what the team's device will do and for a much higher cost per unit than what the team's device will cost. The team's solution to prevent weightlifting injuries is to isolate the root issue of injury for the majority of people and create a device that will help the user fix improper form.

Introduction

Problem Statement

Thousands of weightlifting injuries occur every year. Injuries are often caused by an uneven distribution of load on the barbell, leading to the weight lifter favoring one arm over the other [1]. The team has been tasked with designing a biomedical device that can prevent weight lifting injuries by targeting, identifying, and correcting improper form.

Background

Thousands of weightlifting injuries occur every year according to Nationwide Children's Hospital [1]. There are usually four types of major weightlifting injuries possible that can occur regardless of the lift which are strains, sprains, impingements and tears [1]. For our purposes the lift the team has been tasked with focusing on is bench press. Bench press is performed lying on your back whilst holding the barbell above one's head, you then lower the barbell to below the nipple line and then press the bar back above one's head. The two most common injuries while performing bench press are impingements and tears [2]. The reason for this is due to a space called the subacromial space. The subacromial space lies between the coracoacromial arch above and the humeral head below [3]. It contains the rotator cuff tendons, the long head of the biceps tendon, the shoulder joint capsule, and more important ligaments [3]. When performing bench press with improper form (the angle between the side and the elbow being between 70-90 degrees [2] the acromion bone or the coracoid process impedes upon the subacromial space and can snag onto the tendon causing it to become inflamed. After this occurs any repetitive use of the shoulder can cause the now inflamed tendon to snag further on the bone and with enough repetition can cause a tear in the tendon to occur. The team's solution to this occurrence is to be proactive in preventing injuries instead of reactive by teaching and giving users feedback on proper form so that the possibility of injury while performing bench press is as low as possible.

Considerations & Specifications

The primary objective of this device is to monitor and assess the user's risk of injury during bench press exercises by identifying improper form. Specifically, the system is designed to detect deviations in barbell alignment, such as when the barbell is not parallel to the shoulders or is not level. Additionally, the device must track the path of the barbell and compare it to an ideal trajectory. Based on the analysis, the system will provide feedback to the user in an intelligible format, with guidance on how to correct any identified form issues to reduce the risk of injury. Beyond its functional requirements, the device must be suitable for use in commercial gym environments, allowing for easy transportation and setup by a single individual. Moreover, the product should not interfere with the original functionality of essential workout equipment, such as barbell clips, which must continue to prevent weight slippage, and wrist straps, which must maintain wrist support as intended. This ensures the device integrates seamlessly into existing gym practices while offering enhanced injury prevention capabilities.

Competing Designs

Injuries associated with weightlifting have been a persistent issue for many years. This has led to the development of various devices and applications aimed at tracking the barbell and enhancing the lifting experience. One of the most widely used mobile applications for tracking barbell movement is the WL Analysis - Bar Path Tracker. This app utilizes the phone's camera to monitor the barbell and collect relevant data. Specifically, it tracks metrics such as bar path, velocity, horizontal displacement, and force [4]. While this app is free to use, it has limitations. It only collects data from one side of the barbell, which means it cannot assess whether the barbell is parallel to the shoulders or if it is level. Consequently, it is unable to provide a complete analysis of form that is crucial for injury prevention.

Several competing designs that attach directly to the barbell are available, offering features similar to our proposed design. Two such products are Bar Sensei and Flex by GymAware. Bar Sensei is a sleeve that fits onto the center of the barbell, using an accelerometer to measure bar speed, acceleration, and both vertical and horizontal displacement. However, it does not provide data on the barbell's path or whether it is level. This device is primarily focused on tracking strength and power metrics rather than injury prevention, with a price of $499 [5].

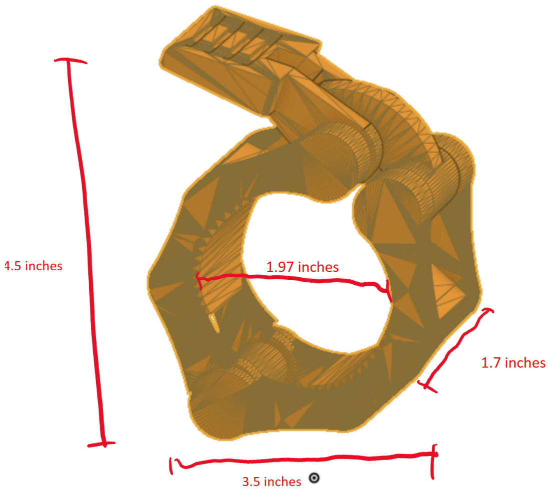
Flex by GymAware operates in a similar manner to Bar Sensei but utilizes a laser optic system instead of an accelerometer for data collection. Additionally, it offers a visual representation of the barbell’s path. Nevertheless, it still lacks the capability to determine whether the barbell is parallel to the shoulders or level [6]. The Flex device is priced at $599.

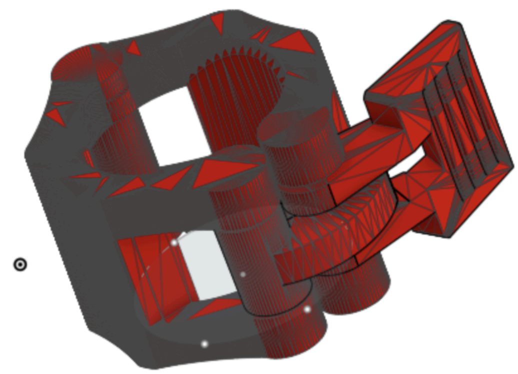
Preliminary Designs and Evaluation

Design 1: Motion System Sensor

Figure 1. Motion System Design. A camera will be set up to track direct movement of the user, and this data will be recorded.

Design 2: Modified Barbell Weightlifting Clip Design





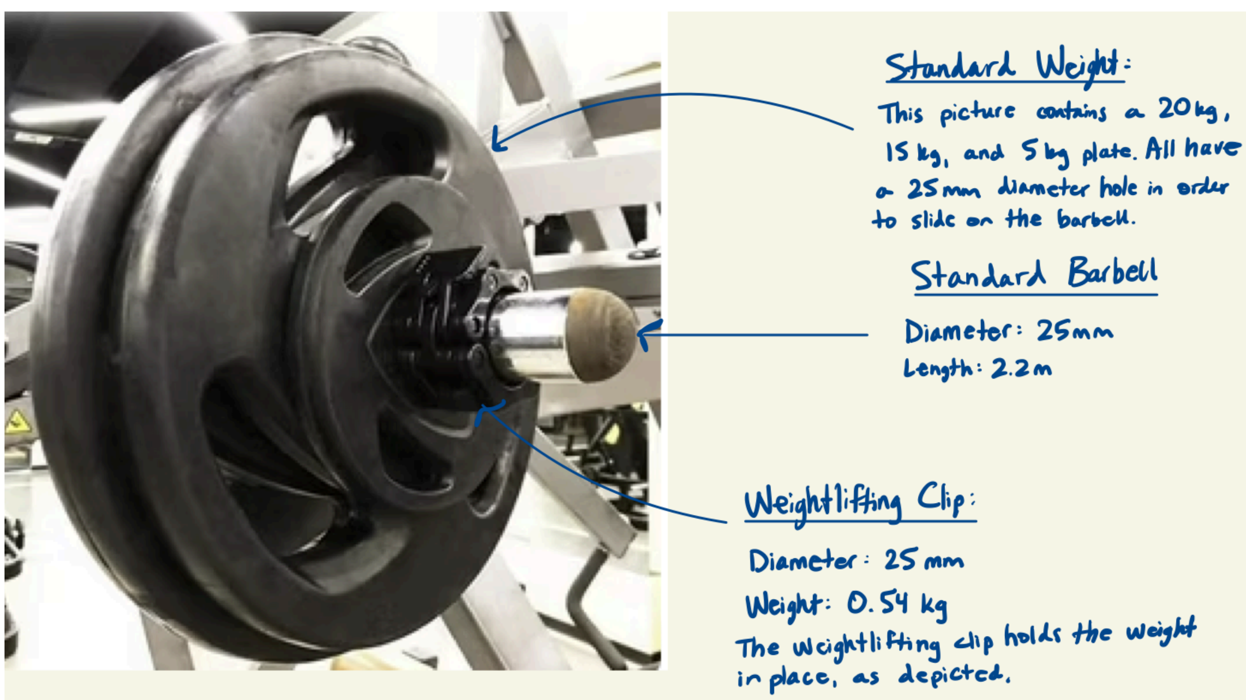


Figure 2. Barbell Weight Clips Design. An accelerometer will be housed within a modified but functional weight lifting clip that is used to clasp weight in place on the barbell.

Design 3: Wrist Strap Design

Figure 3. Wrist Straps Design. An accelerometer will be housed within a modified set of functional wrist straps that are used for wrist support when performing complex lifts such as the barbell bench press.

Design Matrix

Table 1. Design matrix for the Barbell Modifications to prevent injury.

Design Categories (Weight/100)	**Motion System**		**Barbell Weight Clips**		**Wrist Straps**	
Precision (30)	5/5	30	4/5	24	4/5	24
User Comfort (25)	5/5	25	5/5	25	3/5	15
Ease of Use (20)	2/5	8	5/5	20	4/5	16
Maintenance (10)	3/5	6	5/5	10	4/5	8
Ease of Fabrication (10)	2/5	4	4/5	8	3/5	6
Cost (5)	1/5	1	3/5	3	4/5	5
Total Points:	74		90		74	

Criteria Descriptions and Evaluation

Precision:

The precision category depicts how well the device tracks the movement of the barbell. Using existing literature and technical data, an exponential relationship will be expressed as the line of best fit. This line of best fit will represent the path of the barbell that will result in the best form and lowest injury rate when performing a complex lift such as the barbell bench press. Depending on the design model, this data will be collected in different ways. The precision of the injury prevention device will be quantified in inches, with an acceptable range of ±0.5 inch from the determined line of best fit. Precision is the category that holds the most weight due to its crucial impact on the project. A narrow range is required to ensure the success of the product, as well as the wellbeing and safety of the user.

The Motion System was scored a 5/5 and assessed a 30 for its weighted score in the precision category on the design matrix. The Motion system as shown is a proven technology that can diagnose and assess data at the highest level. Quantitatively, this technology would succeed our requirements of precision. Both the barbell weight clips and wrist strap designs are comparable in the precision category of the design matrix. The Barbell weight clips design as well as the wrist strap design would both utilize Arduino microcontroller and accelerometer technology in order to assess and track barbell movement. This technology will be successful and will be tested to be within the acceptable range of ±0.5 inch, thus we scored both designs with a ⅘ and a weighted score of 24. Solely looking from a precision standpoint, the motion system would be the ideal design to move forward with.

User Comfort:

The user comfort category represents the degree to which the device is noticeable to the user while performing the lift. Comfort is a universal necessity when designing a product to be used on or by the human body. This classification is especially important because of the environment in which the device will be used. When undergoing a complex movement such as the barbell bench press, the user will be putting their body under great stress by pushing their physical limits. With the prevention of injury as our primary goal, the comfort of the user while undergoing these actions have been highlighted as a very important class within our design matrix.

The Motion system was scored a 5/5 and assessed a 25 for its weighted score in the user comfort category on the design matrix. The Motion system involves no contact with the user itself, thus giving it no way to discomfort the user in any way from a physical standpoint. The same goes for the barbell weight clips design, which was also scored a 5/5 and assessed a 25 for its weighted score. The weight clips design would be attached to the barbell itself, and would not have any contact with the user while performing a repetition. The wrist straps design was scored a ⅗ and assessed a 15 for its weighted score in this category. This difference stems from the direct contact between the user arm and the wrist strap. Wrist straps, when functional, can make a positive impact on the user's wrist stability when performing a lift such as the barbell bench press. However, it is material dependent in terms of user comfort, and with the addition of the sensor technology being added to the wrist strap, we have assessed the design lower when compared to the motion sensor and barbell weight clips design. Solely looking from a user comfort standpoint, either the barbell weight clamps or the motion system would be the ideal designs to continue forward with.

Ease of Use:

The ease of use category represents how easy it is for the user to both setup and use while lifting. Making our product easy to use is important because we want our product to be readily available for all users. We also want our product to be able to be used in regular commercial gyms, so our product can’t take too much time to set up or use, otherwise it would hinder the users' lifting experience.

The Motion system scored a ⅖ for this category and had an 8 for its weighted score. This is because in order to use the motion system, you would need to set up a camera in the gym and make sure it won’t be disturbed and it can see you at the right angle when you are benching. It would be a struggle to find enough space to put the camera at a suitable distance away from the bench in many commercial gyms. This is not the case for the barbell weight clip design which scored a 5/5 and a 20 weighted score in this category. The barbell weight clip design wouldn’t take any more work to use than using a regular bench clip. All you would have to do is bring the clips into the gym and slide them on the barbell. The one problem with this is many people don’t like benching with clips on without a spotter because it can be more dangerous, however, you can just slide the clips on without clamping them onto the bar which would allow the weight to slide off if needed. The wrist strap design scored a ⅘ and a weighted score of 16. This design would like to be easy to use in any gym as it doesn’t take up any space, you would just need to bring it into your gym. The reason it isn’t a 5/5 is that you need to learn how to put on wrist straps and how to bench with wrist straps. This is not hard to learn or do, but it is one extra thing the user would have to learn before using the design. Looking only from a ease of use perspective, the barbell weight clamps would be the ideal design to continue with.

Maintenance:

The maintenance category represents how hard and how much work the design would be to maintain and keep working. Making sure our product doesn’t require too much maintenance is important because it would deter a lot of people from using it, and if there was a lot of maintenance it would be much harder for our client to use for a long time. While maintenance isn’t the most important category it is still essential to make sure our product isn’t hard to maintain and will not break easily.

The motion system scored a ⅗ in this category. The motion system has some things that would regularly need to be maintained. The camera lenses need to be cleaned if they are ever dirty and it needs to be stored inside where the camera would not be broken. You would also have to check to make sure the camera software is working properly with the camera, and it would be very hard to fix anything if it breaks. The barbell weight clamp scored a 5/5 in this category because there is almost nothing you would need to do to maintain it. The only thing that would need to be replaced is the batteries whenever they run out of charge. The wrist strap design scored a ⅘ because the materials for the strap on the wrist strap need to be replaced whenever there is any damage to them or if there is to much wear and tear on them. The wrist straps would get worn out much quicker because there is tension on the straps whenever they are in use so the material would eventually deteriorate, and would need to be replaced. Solely looking from a maintenance standpoint, the barbell weight clamps would be the ideal design to continue with.

Ease of Fabrication:

The ease of fabrication is a necessary constraint to consider. If there is an easy, realistic, and valid design that does not take any shortcuts or lack taking any variables into consideration which works just as well if not better than an equally valid design, which takes high amounts of time and requires an abundance of trial and error to fabricate, the design to be selected will most assuredly be the former.

The motion system scored a ⅖ in this category. The idea centered around using code referred to us by our client that centered around cameras which was believed to be applicable to this project. Upon further review the code was determined to be beyond the scope of our knowledge and possibly not even able to be applied to our system and situation in a realistic manner. The barbell clamp received a ⅘ in the ease of fabrication category. With limited technology needed to determine a coordinate system with which barbell movement can be tracked and a fabrication process as simple as trying to find a way to attach a little chip in the proper orientation to a barbell clip, this option is a very realistic possibility. The wrist straps received a ⅗ in the ease of fabrication category. This in large part was due to the larger variability in being able to receive accurate measurements due to the possibility of unequal placement of the wrist straps on the wrist. The team would also need to find a way to attach the motion chips needed to track movement into the wrist straps without hindering mobility of the wrist or making them too bulky which is not as much of a concern regarding the barbell clamps. Solely looking from the ease of fabrication perspective the barbell clamps would be the ideal route to take.

Cost:

The cost category represents the expenses that will be incurred in the production of the design. Due to our allotted budget of $300, it is imperative that we do not exceed this amount in order to create a fully functional and thoroughly tested device. While this category may not be a pressing concern for some ideas brought forward in the design matrix, it remains nonetheless important to keep in mind currently in the decision making process, but also throughout the duration of prototyping, fabrication, testing, and final design.

The motion system scored a ⅕ in the cost category. This was in large part due to the costs that would be incurred buying two suitable cameras for the software as well as tripods on which they (the cameras) must stand. The estimated cost for the cameras alone would be somewhere in the range of $600 to $1000 which makes the motion system unrealistic for this aspect of the project. The barbell weight clips scored a ⅗ in the cost category and the wrist straps scored a ⅘ . The decision behind the rankings for these two housing forms was comparative. While neither option is incredibly cheap (hence why no housing form received a 5/5 ranking), purchasing wrist straps is cheaper than the purchase of two barbell clamps. From a solely cost effective perspective this leaves wrist straps as the ideal route to take.

Design Ratings/Final Design Idea

The design team decided to move forward with the Modified Barbell Weightlifting Clip design. This is due primarily to its high scoring in the user comfort, ease of use, maintenance, cost, and ease of fabrication categories. Its precision may have been comparatively less than the Motion Sensor Design, however the cost and ease of use of the motion sensor design deemed the product unusable for the project at hand. The versatility and functionality of the modified barbell weightlifting clip design as shown in the design matrix led the team to move forward with this design.

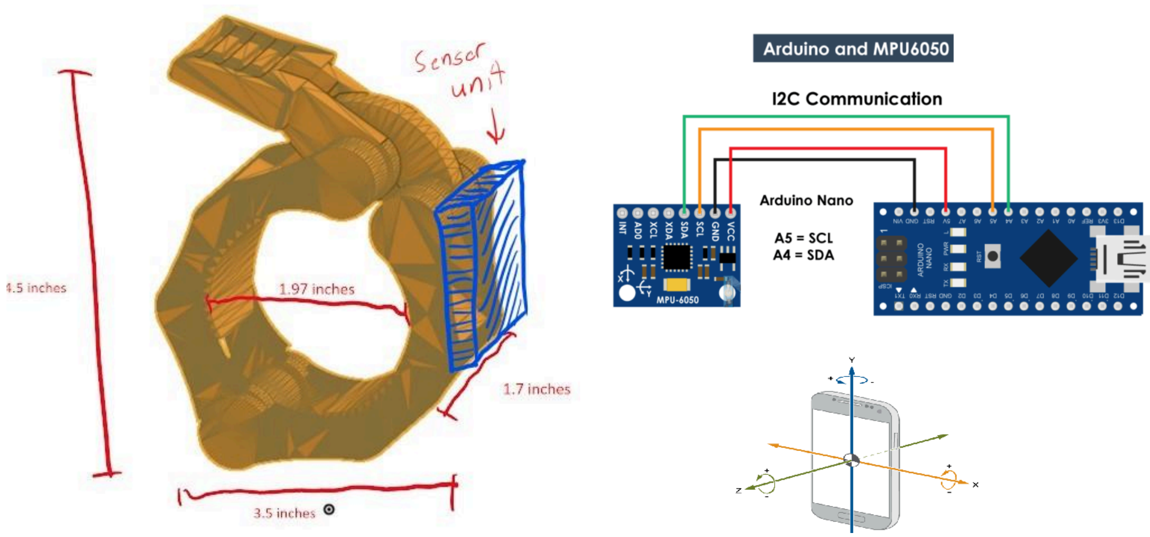


Figure 2,4. These images depict the location of the sensors on the clip and the connection between the Arduino and the MPU6050 IMU.

Materials and Methods

Materials

The weightlifting clip will be 3D printed, and the design team decided that the material used will be tough PLA. When compared to other materials such as PLA, ABS, and PET-G, tough PLA offers better impact resistance, mechanical strength, and thermal resistance [7]. Additionally, this material is available at the UW-Madison makerspace, and is a financially responsible option. The weightlifting clip will be modified to house the sensory technology that the device requires to track the path of the barbell. Two breadboards, Arduino Nano 33 BLEs, MPU6050s, 9V batteries and necessary wires will be required in each modified weightlifting clip.

Methods

The fabrication plan for the final design will be divided into two parts: non-electronic and electronic components. Fabrication of the non-electronic components includes the fabrication of the modified weightlifting clip. Fabrication of the electronic components includes the installation of the Arduino Nano, MPU6050, and 9V on each breadboard, as well as the coding of the bio instrumental devices that will be paired and collect the data from the barbell. This data will be collected and then displayed on a mobile application.

Fabrication of Non-electronic Components

The weightlifting clip will be 3D printed using tough PLA as a material at the UW-Madison Makerspace using the Ultimaker (FDM/FFF) [8]. The modification to the existing weightlifting clip will be minimized to house the necessary technology while maintaining the functionality of the weightlifting clip.

Fabrication of Electronic Components

The Arduino Nano and MPU6050 will be housed on the breadboard and powered by a 9V battery. The MPU6050 will be connected to the Arduino Nano as depicted in Figure 4 in the Final Design section [9]. This connection shown will relay information from the MPU6050 to the Arduino. The Arduino will share data with the other Arduino that is on the other side of the barbell, and this data will be expressed on a mobile application for user interaction.

Proposed Fabrication plan

Following the request of the client, we will primarily focus on the fabrication of the modified weightlifting clip and sensory technology before conveying this information on a mobile application. Due to the ease of use of 3D printing, we will simultaneously fabricate the modified weightlifting clip and the sensory technology. The coding aspect of the housed technology will be the most time-consuming, and we will work with the help of Dr. Christa Wille and the makerspace staff.

Conclusion

In conclusion, our team plans to move forward with the barbell weight clip design. This design will help reduce injuries while people are bench pressing, and it will help them improve their form. To create this design we will fabricate the clip using tough PLA, and it will house the Arduino Nano, MPU6050, 9V battery, breadboard, and connecting wires. We will also code these devices to track the data we want and display it. After fabrication, we will test the functionality of the clip and make sure it stops the weight from sliding off the barbell. We will also be testing our code to make sure it correctly collects and analyzes the data, as well as displays and gives the proper feedback to correct bad form. The final product will be a cost-effective way to track the barbell path and a good tool to improve user's bench form and reduce their risk of injury.

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Appendix

Appendix A: Materials & Expenses

Item	Description	Manufacturer	Part #	QTY	Cost Each	Total	Link
Non-Electronics Components							
Tough PLA	Ultimaker Tough PLA	Makerspace		500g	$0.08 /g	$40.00	https://making.engr.wisc.edu/3d-printers/
Electronics Components							
MPU6050	IMU	Arduino	03-01-0122	2	$3.33	$6.66	https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6050/
Arduino Nano	Arduino Nano	Arduino	A000005	2	$29.33	$58.66	https://store.arduino.cc/products/arduino-nano?srsltid=AfmBOopWjqK-rkYIleqGizCt6IPV-0Kpnh_kMw9wSPioA0jNm1Vpr0mn
Breadboard	Breadboard - Self Adhesive (White)	SparkFun	PRT-12002 RoHS	2	$5.50	$11.00	https://www.sparkfun.com/products/12002

Appendix B: Product Design Specifications

Product Design Specifications: Preventing Weightlifting Injuries by Barbell Modifications

September 19th, 2024

Biomedical Engineering 200/300: Biomedical Engineering Fundamentals & Design

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Function:

Over one million weightlifters experience serious injuries every year. These injuries are often caused by an uneven distribution of load on the barbell, leading to the weight lifter favoring one arm over the other. Incorrect loading while weight training can lead to sprains, strains, fractures and other painful injuries[1]. The team has been tasked with designing a biomedical device that can diagnose this strain on the body in coordination with specific muscles in use.

Client Requirements:

I. Quantify strain on specific muscles when used in complex weightlifting movements such as the barbell bench press

II. Create a sensor system to evaluate activated electronic signals in active muscle fibers

III. Utilize motion technology and camera tracking to develop a service that can track proper weightlifting form

IV. Explore emerging software opportunities while building upon previous years progression

Design Requirements:

1. Physical and Operational Characteristics:

a. Performance Requirements:

I. Modified weightlifting clips will house an Arduino Nano and MPU6050. This technology will be housed within the weightlifting clips, allowing for tracking of the barbell path on every repetition of the bench press.

II. The Arduino Nano on each end of the barbell will be connected via Bluetooth. Both devices will have an MPU6050 to collect data in the form of angular velocity and acceleration. Coding will derive this data into displacement in meters.

III. Collecting this data will provide the user with a barbell path. A line of best fit will be set that correlates with proper bench press form. Derivation from this line of best fit will be recorded and displayed on an application that the user can then analyze.

b. Safety:

I. Any modifications to the barbell must abide by safety regulations put in place by the gym or institution in which the technology is being used

II. If the barbell path is different from the line of best fit in the X axis, the user will be alerted on the application. This would be a result of an uneven distribution of weight on the barbell, or due to the user's body preferences. In both cases, the coordination system will alert the user to alter their form in order to prevent injury.

III. If the barbell path is different from the line of best fit along a combination of the Y and Z axis, the user will be alerted on the application. This would be the result of an improper barbell path. In this case, the coordinate system will be displayed, allowing the user to correct their barbell bench form in order to prevent injury.

IV. Electronic compartments will have no exposed electronic parts to prevent interaction with water or other fluids. Proper cover will ensure no malfunction to injury prevention technology

c. Accuracy and Reliability:

I. The weightlifting clips will be functional as clips, holding the weight on each end of the barbell, preventing sliding or movement of the weights. Functionality will be tested with use of the product with differing weights on the barbell.

II. The MPU6050 will be able to track angular velocity and acceleration of the barbell from the weightlifting clips. This will be derived to create a coordinate system and a line of best fit of the barbell path. Accuracy to this line of best fit will be tested to an acceptable range of 3 cm off of the line of best fit.

III. All barbell modifications will be established on the basis of repeatability, in which actions can be performed upon every lift by the user

d. Life in Service

I. The barbell modifications will have ample power in order to be active for 45-60 minutes, the average time of complete workout [2].

II. The technology will be cased and able to travel via car, airplane, boat, etc.

e. Shelf Life:

I. This device should be stored inside in a climate-controlled environment, around 20-25℃. It should have minimal exposure to, and not be stored in outside conditions such as rain and snow.

II. The device should have a shelf life of at least 10 years while in storage and not being used.

III. If there are any batteries they should be replaced whenever they are dead or every 5 years.

f. Operating Environment:

I. This device will primarily be used inside at a weightlifting gym but can be used outside as long as there is no rain, snow, or extreme conditions (temperatures below 5℃ or above 30℃ or extreme winds)

II. The device should also be dust and dirt-resistant and be strong enough to withstand small impacts like being dropped from 1 meter.

g. Ergonomics:

I. This device should be usable by all people of all heights and weights given that they can use a barbell to do the weightlifting movement.

II. This device should be usable for squatting and benching with a 20kg barbell.

III. This device should be able to be transported by one person easily, and can be brought between different gyms and locations.

h. Size:

I. This product should be able to fit through standard doors and be moved by one person.

i. Weight:

I. This product should be able to be transported by one person so all total components should be less than 10kg.

II. Any barbell attachments should be less than 5 kg, and if the barbell attachment weighs more than 1 kg that weight should be recorded on the outside of the product so the user can accurately see how much weight they have on the bar with the added weight of the attachment.

k. Materials:

I. The materials should be durable enough so they can be dropped from 1 m and light enough to meet the requirements given above.

II. The materials should be safe to touch and should not react with common cleaning chemicals (bleach, alcohol, ammonia), sweat, or water.

l. Aesthetics, Appearance, and Finish:

I. This product shouldn’t have any exposed electronics.
II. The product should not have any excessively sharp edges

2. Product Characteristics:

a. Quantity:

I. Only one of these devices should be needed per barbell.
II. Can be scaled to the amount of barbells that are in the gym .

b. Target Product Cost:

I. The cost of competitors products are in the range of $700-$900. We believe we can undercut this cost by triple and sell it for ideally $150-200. However with a budget of $300 the product will even at maximum cost be well under competition price range.

3. Miscellaneous:

a. Standards and Specifications:

I. Under section 520(o)(1)(B) of the FD&C Act, software that is intended "for maintaining or encouraging a healthy lifestyle and is unrelated to the diagnosis, cure, mitigation, prevention, or treatment of a disease or condition" is not a device under section 201(h) of the FD&C Act. This also indicates that it is generally excluded form CPSC’s authority over consumer products under the Consumer Product Safety Act.[3]
II. If we use EMG technology, the device is considered to be a diagnostic electromygraph (Definition: [A] device intended for medical purposes, such as to monitor and display the bioelectric signals produced by muscles, to stimulate peripheral nerves, and to monitor and display the electrical activity produced by nerves, for the diagnosis and prognosis of neuromuscular disease). This is classified as a Class II device and is exempt from the premarket notification procedures in subpart E of part 807 of this chapter subject to § 890.9. This device is considered noninvasive for testing and therefore does not need premarket approval and is exempt from Section 510(k).[4]
III. If the device does not use EMG technology, it is then classified as a “Low Risk Device” (Class I)and does not need premarket approval, clearance by the FDA, and is exempt from Section 510(k).[5]

b. Customer:

I. There are not many competing designs on the market, but there are many systems that function in a similar fashion. Thus, the intended goal is to combine the technology used in other fields with the knowledge and devices in the fitness industry to make a one of one device that fine-tunes a user's form.

II. Cost effectiveness will be a major concern with this device, as current products with much less capabilities are ranged from $100 and up which is subpar given the population of people who could benefit from this technology.

III. It would be desired to have the device give a digital readout indicating their deviation from what will be considered their optimal range of motion. Other beneficial readouts would be which muscles were under the most strain during the lift and recommendations to improve their performance.

c. Patient-Related Concerns:

I. Since it is classified as a "Low Risk Device" there are minimal concerns for usage of it. There will be no need for sterilization since the device is noninvasive and strictly a biomechanical analysis tool.

II. Accuracy and precision will be crucial for the success of this type of device. The complexity and usability will have to be mitigated as much as possible as well.

III. The device will have a large amount of data to observe, analyze, and compute. This means that it will require robust software and computational resources.

IV. Integrating this technology with EMG tools may increase the complexity of its analysis and must be considered when designing.

d. Competition:

I. "FLEX" , a barbell velocity tracker, provides real-time display, giving immediate feedback on every rep and set, watches velocity and power, and scrutinizes technique and refines movement patterns. Accuracy of these values is unknown.[6]

II. " Bar Sensei" is another barbell velocity tracker that measures your bar speed, displacement, and power output while performing a lift. It is a device that attaches directly to the barbell and takes measurements based on the displacement of the device itself.[7]

III. "InertiaCube® 4" , a 3 DOF sensor, uses MEMS technology to sense angular rate of rotation, gravity and earth magnetic field along three perpendicular axes. The angular rates are integrated to obtain the orientation (yaw, pitch, and roll) of the sensor. Gravitometer and compass measurements are used to prevent the accumulation of gyroscopic drift through advanced sensor fusion algorithms. This technology offers very low latency, unlimited range, precise factory calibration, smooth, jitter-free tracking, in situ static & dynamic magnetic compensation algorithms.[8]

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