Portfolio: Exo-arm*

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Element A: Identification and Justification of the Problem

Problem statement

In our modern society, the rapidly-growing industries of construction, manufacturing, and logistics frequently require workers to lift, carry, and pull extreme loads for extended periods as a part of their job duties (Bureau of Labor Statistics, 2020). This idea is corroborated by recent local studies, sampled from 32 respondents: 15.4% have experienced a workplace accident in some form limiting their physical abilities—of this percentage 100% experienced an accident relating to their shoulders; 34.6% answered that they had been frequently (when ranked out of 10, 5 or greater) been asked (or required) to lift loads exceeding that of ~50 lbs; Whilst 45% said that their physical workload was physically taxing. A second, broader study also confirms these results—finding that construction workers are engaged in some form of heavy lifting (>50 lbs) for 93% of their workday, and laborers for 75% (Aristizabal, 2023). The average load is 58.8 lbs for construction workers and 26.3 lbs across other professions (Aristizabal, 2023). Many workers report difficulty meeting these physical requirements, often wishing they were stronger to manage the workload more effectively (Carvajal-Arango et al, 2021). Prolonged exposure to these conditions, combined with extended work hours, leads to musculoskeletal disorders, injuries, and substantial financial losses due to workers' compensation claims (Kaur et al, 2021). This issue has persisted for decades and continues to grow with the increasing demand in labor-intensive industries like construction and manufacturing (Goppireddy et al, 2016). Without intervention, this problem is likely to be a continuous problem with no solution.

Problem background/statistics

From our research on our problem, we have been able to find background information/studies from multiple sources.

Background article #1:

Title: Investigating the impact of physical fatigue on construction workers' situational awareness

Article summary: Those under physical fatigue experienced a significant reduction in situational awareness. Both hazard recognition and safety risk assessment were significantly reduced as well. It was found there was a strong correlation between heart rate and physical fatigue score. It was shown physical fatigue played a critical role in the job of construction workers.

Background article #2:

Title: Costs of Occupational Injuries in Construction in the United States

Article summary: In 2002, the cost of non-fatal and fatal injuries in the construction industry was $11.55 billion dollars. The average cost per case (whether fatal or non-fatal) was $27,000 dollars. These numbers were compared to the rest of the industry as a whole, with the numbers being significantly higher.

Background article #3:

Title: Workers' Compensation Claim Rates and Costs for Musculoskeletal Disorders Related to Overexertion Among Construction Workers - Ohio, 2007-2017

Article summary: The physical overexertion of construction workers is the main cause of work related musculoskeletal disorders. Overexertion from lifting and lowering caused 30% of WMSDs while pulling, holding, carrying, and catching materials caused an additional 37% of WMSDs. Workers could make compensation claims due to this. Workers aged 35-44 years old experienced the highest claim rate: 63 per 10,000 full time employees.

Validation of problem

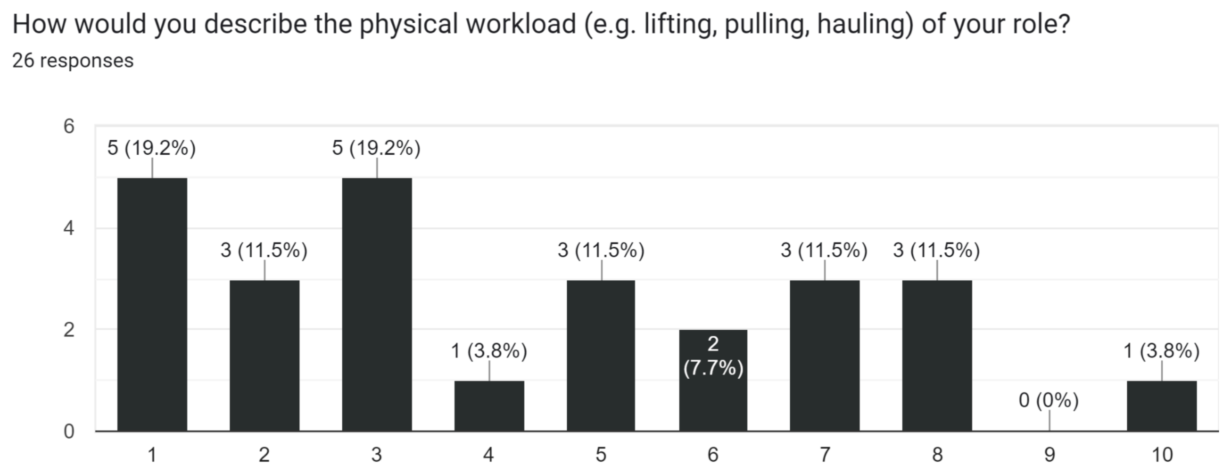
Survey:

Survey and Evaluations (Gathered from the Consumers / Stakeholders)
Method of distribution: The team created the survey using Google Forms to help establish constraints and better define the problem. We used email, social media, and personal contact to distribute the survey.

SURVEY QUESTION #1

PURPOSE: This question determined if the respondent experienced heavy workloads within their daily role(s). Participants answering values greater than five (more frequently than not) were more heavily weighted when taking into account the results of the following questions.

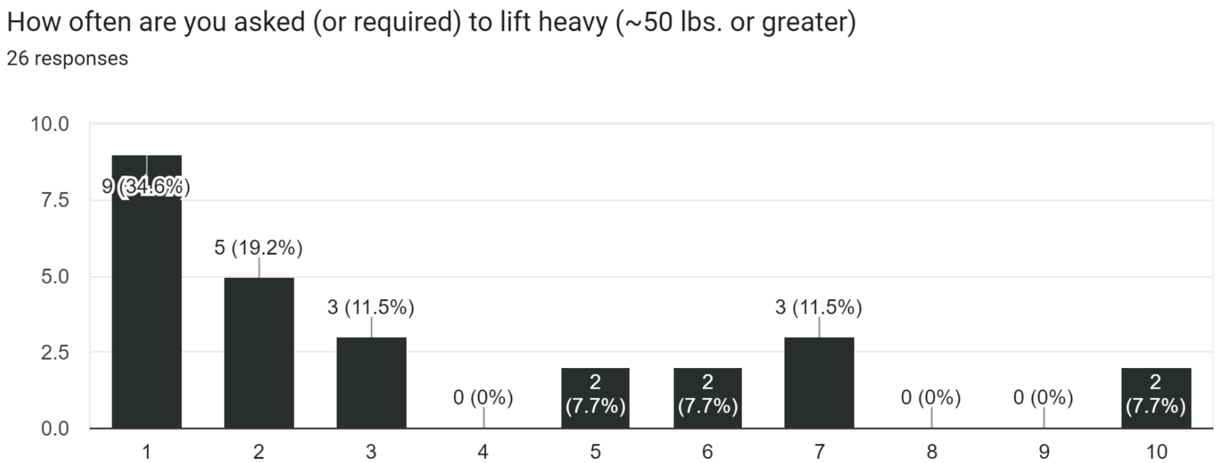
$N = 26$



REFLECTION: This question was used as a filter, we could more heavily weight, or entirely remove respondents when considering the several demographics answering the form. Though it was intriguing to find that a majority of people indicated a high workload, possibly reflective of many individuals over-compensating their workload.

SURVEY QUESTION #2

$N = 26$

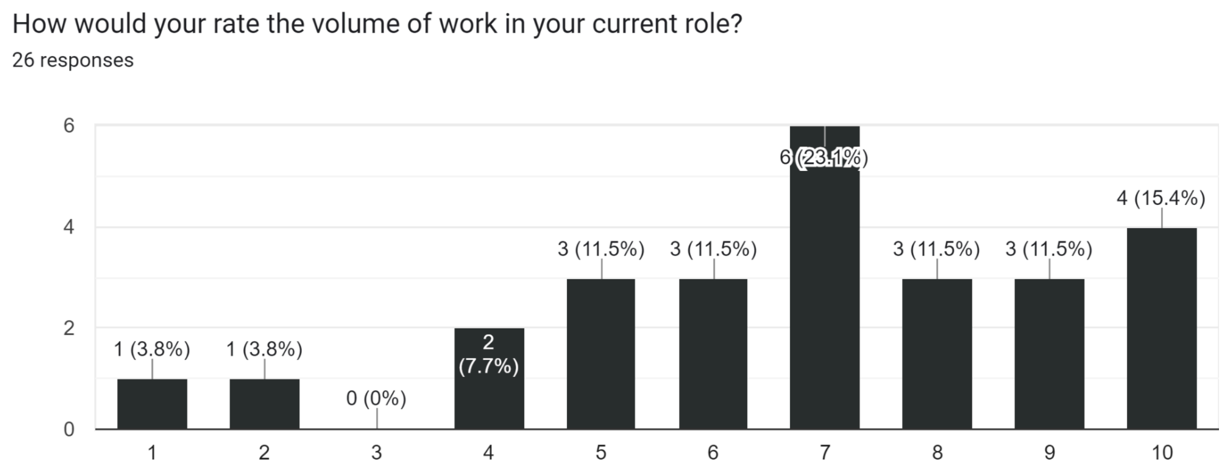


REFLECTION: We asked this question to assess how frequently people lift heavy weights, as it directly relates to our problem statement. Understanding the frequency of heavy weightlifting will help us better address the issue at hand and identify any patterns or factors that could influence the outcomes we're studying.

SURVEY QUESTION #3

PURPOSE: This question determined how much work a given respondent received frequently, and could be used to determine the frequency of the workloads experienced by those who lifted heavy loads.

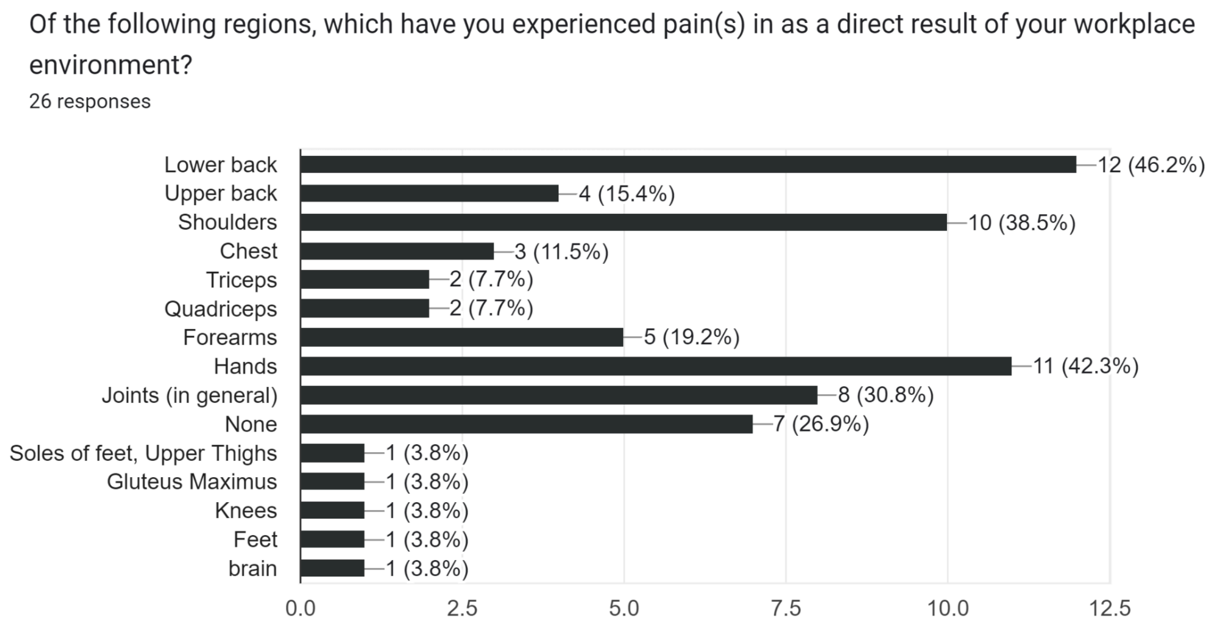
$N = 26$



REFLECTION: This question was a great application of our filter, respondents who heavily weighted their physical workload may or may not have *frequently* experienced such loads, and allowed us to estimate the number of individuals.

SURVEY QUESTION #4

$N = 26$

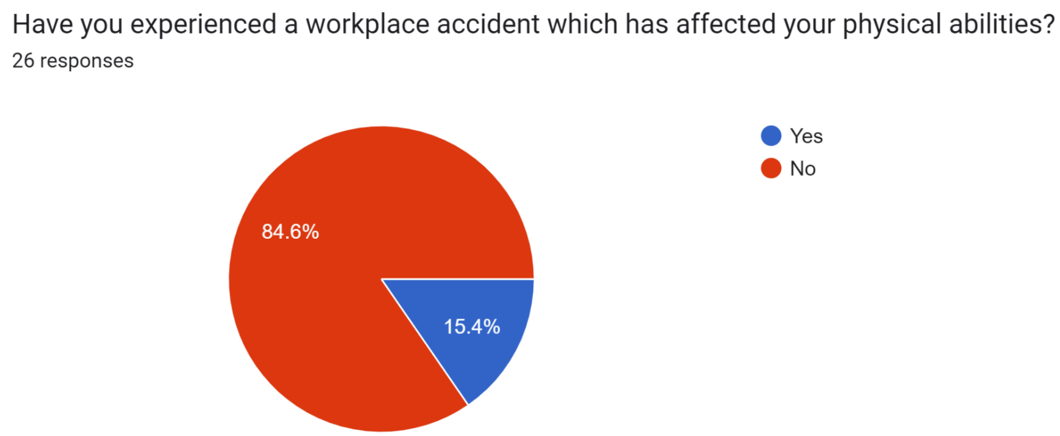


<u>REFLECTION:</u> We asked this question to identify where people experience pain, as this insight helps us refine our problem statement. By understanding the specific areas of pain, we can more effectively target the underlying causes and develop solutions to address them.

SURVEY QUESTION #5

<u>PURPOSE:</u> This question, rather simply, determined which (if any) respondents were affected by workplace accidents; respondents who answered 'yes' could receive an additional question; aimed at determining *where* the accident had affected them physically.

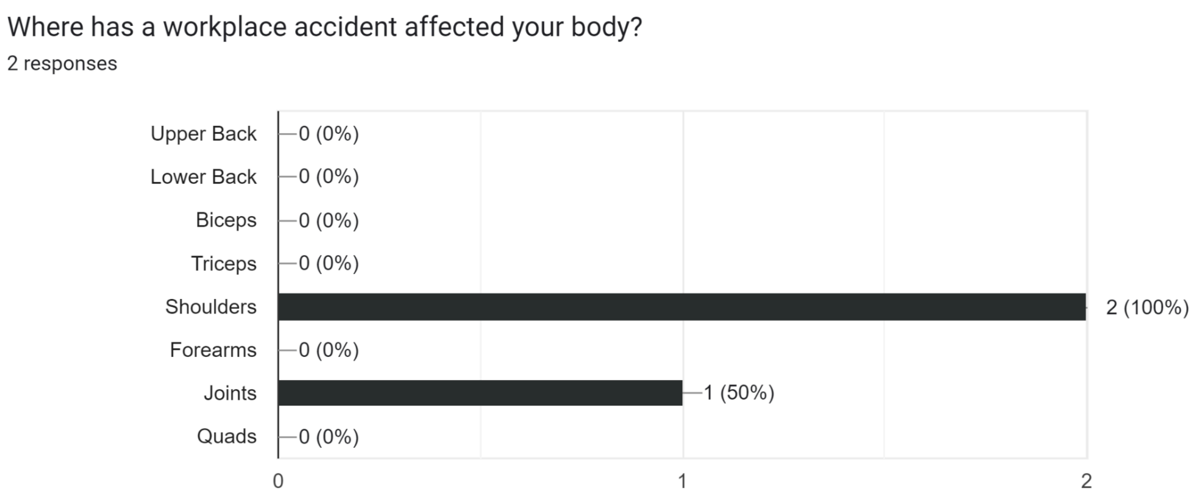
$N = 26$



<u>REFLECTION:</u> This question was another filtering question, and allowed us to see *who* was affected by workplace accident(s). We were surprised to see the sheer number of applicants answering yes to this question: a staggering 15.4%. This meant that of the wide demographic, spanning from school children to construction workers, many had experienced an accident.

SURVEY QUESTION #6

$N = 26$



REFLECTION: This question aimed to determine if anyone has experienced a workplace injury and, if so, to identify its location. We asked this to gain a clearer understanding of the specific issue and to pinpoint potential solutions for addressing and resolving it.

Consumers and users:

Consumers & Users - (People and companies that would purchase and use the product.)
Who/ What Examples

Construction Workers

- Men and women who work on construction sites, often lifting heavy materials and performing physically demanding tasks.

Manufacturing Workers

- Employees in manufacturing plants who frequently lift heavy items during production processes.

Warehouse & Logistics Workers

- Laborers and logistics personnel who are tasked with lifting, carrying, and stacking heavy goods in warehouses, loading docks, and distribution centers.

Laborers & Tradespeople

- Individuals working in trades such as plumbing, electrical work, and carpentry, where heavy lifting is often required.

Companies

- Bechtel Corporation
- General Motors (GM)
- Amazon
- UPS
- Honeywell International
- Ergodyne

- The Hartford
- PepsiCo

Article Title

The Impact of Exoskeleton Technology on Reducing Physical Strain and Injuries in Labor-Intensive Industries

Article Introduction

"Exoskeleton technology has become a key focus in industries requiring high levels of manual labor, where workers face the constant risk of musculoskeletal injuries from repetitive, physically demanding tasks. The development and deployment of wearable exoskeletons have been evaluated in a series of field studies, examining their effectiveness in reducing the physical strain of lifting, carrying, and handling heavy objects. Studies show that these devices, which offer external support to the body, can significantly decrease fatigue, prevent injury, and enhance productivity. While many of the workers involved in the studies were skilled professionals with experience in manual labor, the introduction of exoskeletons helped them manage more substantial loads without the typical physical toll. Exoskeletons were found to reduce lower back and shoulder strain by up to 50%, providing workers with better ergonomic support during high-intensity tasks. Moreover, the devices were effective in preventing common workplace injuries like muscle sprains, strains, and tendonitis. However, challenges remain regarding the adaptability and comfort of these devices for long-duration wear. The article discusses both the practical benefits and limitations of exoskeletons, suggesting that further development and refinement are necessary to fully integrate this technology into industries such as manufacturing, logistics, and construction."

Evaluation of Article

This article highlights the potential of exoskeleton technology, specifically the Hybrid Assistive Limb (HAL®) from Cyberdyne, to reduce the physical strain experienced by workers in labor-intensive industries. Similar to how hunting accidents are often self-inflicted due to improper handling or inadequate safety measures, physical strain and injuries in industries like construction and manufacturing are often caused by repetitive, strenuous movements that lead to musculoskeletal disorders. The introduction of wearable exoskeletons, as discussed in this article, offers a promising solution by supporting the body during lifting and movement, reducing the risk of injury. This parallels the concept of improving safety and efficiency during manual tasks by using technology to alleviate the burden on the worker's body, much like addressing firearm safety issues in hunting by using proper handling techniques.

Article Title

How Many People Are Killed or Injured in Hunting Accidents

Article Introduction

"...In reality, most of the greatest dangers to hunters are not related to firearms but occur for other reasons, such as car accidents traveling to and from hunting sites or heart attacks while hiking woods and hills. Particularly dangerous are falls from tree stands. Recent estimates say that there are almost 6,000 hunting accidents to hunters each year involving falls from tree stands—six times as many as are wounded by firearms. A recent survey in the state of Indiana found that 55% of all hunting-related accidents in that state were related to tree stands. The vast majority of fatal accidental shootings while hunting involve the use of shotguns or rifles while hunting deer. This is also perhaps no surprise, since deer hunting is one of the most popular forms of hunting where high-powered firearms are used. The Committee to Abolish Sport Hunting maintains the Hunting Accidents Center, which collects news stories about hunting accidents throughout the world. Although the list is long, it's not comprehensive, and not every hunting accident is reported in the news."

Evaluation of Article

This article was beneficial because the team saw that there are problems while hunting and there is still a need for innovation. There is a need for safer methods and the team has a chance to help reduce hunting accidents.

Article Title

Tree Stands Account for majority of Hunting Accidents

Article Introduction

"...Of the 600,000 deer hunters expected to participate in the nine-day gun-deer season starting at first light Saturday, four out of five will use a tree stand. Statistics are even higher for bow hunters…. Every year in Wisconsin, and throughout the country, hunters are hurt and killed in tree stand accidents. In fact, accidents involving tree stands have replaced firearms accidents as the leading cause of hunting-related injuries and deaths in the U.S., according to a 2015 Marshfield Clinic and Wisconsin Department of Natural Resources study… Though tree stand safety has always been a part of the state's hunter safety courses, it became mandatory in 2015. Tree stands are used by 84% of firearms hunters and 97% of bow hunters, according to the DNR ...In 2015, a hunter was shot and killed when he handed a loaded rifle to a companion sitting in the same tree stand and the other hunter, who was wearing mittens, accidentally grabbed the trigger."

Evaluation of Article

In this scholarly article, the team saw that we are dealing with the leading cause of hunting-related injuries so we know that we have a problem to be fixed. There is a need for safer ways of getting the weapon up and down and there is a great market for our potential product.

Existing products:

- Honda Walking Assist Device

Honda's Walking Assist Device helps people with weakened leg muscles regain mobility. It uses a lightweight, frame-based system to provide support and guidance during walking. It's designed to track and adjust the user's gait for smooth walking.

- LED Technologies

The LED pads and wraps use light therapy to relieve achy and sore joints. It is drug free, easy to use, and of moderate cost all while acting fast with relief. The product also relaxes muscles and increases blood circulation. It projects different wavelengths of light to achieve this.

- Wearable Muscles

Developed by researchers at ETH is a wearable textile exomuscle. It is made to increase upper body strength and endurance of people with limited mobility. It works with sensors in the fabric and a smart algorithm that detects the user's intentional movements. With this it uses cables to provide artificial tendons. Nothing is out of control for the user.

- HAL-FL 05

The HAL-FL (HAL for Well-Being Lower Limb Type Pro) is a robust wearable robotic device designed to aid individuals with chronic mobility impairments, enhancing lower-limb function. It builds upon the technology of its predecessors, with various upgrades to functionality, comfort, and mobility—offering more advanced support and rehabilitation for the wearer's lower limbs. The device can be customized to the needs of the user, offering several variations aimed at different purposes or mobility impairments.

- EksoNR

The Ekso exoskeleton is a robotic rehabilitation device designed to improve gait, posture, and balance for patients with lingering effects: stroke, spinal cord injury, ABI, and MS. The device promotes natural walking posture by supporting postural alignment and assisting patients in bearing their own weight. The EksoNR provides gait training, guiding therapists to adjust assistance levels and optimize patient recovery. It also includes pre-gait activities, real-time data capture, and patient engagement features; EskoNR is a great alternative compared to conventional therapy which is more flexible.

Experts interview justification:

Expert Interview #1
Name: Albert Angarita **Position:** Project Lead **Company:** MTR Contractors **Email:** albert@mtrcontractors.com **Occupation:** Construction Management **Interview Location:** Zoom **Interview Date & Time:** 10/12/24 6:00-6:25 **Interview Duration:** 25 mins
Questions Answers Reflections
Understanding the Scope and Impact

- **What are the most common types of injuries you see in workers who engage in heavy lifting, and what are the primary contributing factors?**

  Though workers do typically lift some heavy loads, like construction materials, workers also have a variety of equipment available to aid in these loads, like wheelbarrows, that really reduce or relocate the load on the worker—reducing the chance of injury in many cases. But of course injuries still do happen, most commonly I would answer that injuries are caused by the inability to maintain a safe work environment; slips, trips, and falls are just as, if not more dangerous than the long-term effects of heavy loads in my own opinion.

- **In your experience, are there particular demographics (age, gender, experience level) more prone to workplace injuries due to heavy lifting?**

  Well, a vast majority of our contractors range from twenty to forty, and are mostly male—making this demographic vastly more prone to injury.

- **What are the most frequent types of injuries that occur in construction, manufacturing, and logistics due to lifting, and are there specific body parts that are affected more than others?**

  Again, I would answer that the most frequent injuries occur as a byproduct of an unsafe workplace—slip, trips, and falls can be incredibly dangerous with or without a heavy load.

- **How do the physical demands of heavy lifting change over time for workers, and what long-term health risks should be taken into account?**

  The demands are mostly dependent on the stage of the project—I would consider the exposure to certain materials, like the byproducts of welding, to be far more wide-reaching and dangerous.

Training and Preventive Measures

- **What are the current best practices for lifting techniques in these industries, and how effective are they in preventing injury?**

  We've tried to move away from having workers directly lift heavy loads—but when they do, the advice is probably more simple than you think, always trying to distribute the load across as much surface area, and lift with the legs.

- **How do employers currently address the issue of physical workload and musculoskeletal risk for workers, and do you think these approaches are sufficient?**

  —

- **What role do ergonomics play in preventing injuries, and how can ergonomic interventions be integrated into workplaces that require heavy lifting?**

  Well, ergonomics is a big part of our choice in equipment—but so is cost—we aim to create as efficient of a workplace as possible, choosing ergonomic, comfortable equipment is important to preventing some of the most common, preventable injuries.

- **How do you evaluate whether lifting tasks are within a worker's physical capability, and what tools or technologies are available to help make this determination?**

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Technological Solutions

- **Do you see wearable technology (such as exoskeletons or sensors) as a viable solution for reducing injuries in physically demanding jobs?**

  Certainly, wearables, like your project have great potential, especially if they can be made flexible, ergonomic solutions; they don't even necessarily need to be powered, but reducing the load, especially in some of those more awkward positions, would go a long way towards creating a less physically demanding work environment for some of our contractors. However, I don't think these solutions are *currently* viable, there is still plenty of development that needs to go into making these solutions less bulky, expensive, and robust enough to be better suited for our contractors.

- **What innovations or technologies do you believe have the most potential to help reduce the physical strain of lifting in these industries?**

  Though I would love to see exoskeletons in the field, especially with the potential efficiency improvements—devices that reduce the possibility for again: slips, trips, and falls will likely be more important to reducing injuries. As far as physical strain, we don't necessarily need powered solutions like you may suggest, though great, but simple devices which help in better distributing the load across the body.

- **How do you see the future of assistive technology in helping workers with heavy lifting tasks, and what barriers do you anticipate in implementing these solutions at scale?**

  I think the future is going to be unpowered solutions which maximize safety features, again for slip, trips, and falls, while also providing support for lifting by shifting the weight during lifting activities. I think the most important barrier may be making such solutions widely available, i.e. reducing the cost, and making them applicable to the physical environment of construction.

Organizational and Cultural Factors

- **How do workers perceive the physical demands of their roles, and do they feel adequately supported in terms of injury prevention, recovery, and overall wellness?**

  —

Long-term Solutions and Sustainability

- **Given the high frequency of physical strain in labor-intensive industries, what long-term strategies or policy changes do you think could help mitigate the risk of injury?**

  Especially in upper management, we need to be better informed of the more minute of injuries—we are chronically uninformed of the long-standing injuries, many minute, because they go unreported to management; ultimately preventing the ability for solutions to be made (and mitigate risk by extension).

Expert Interview #2

Name: Derek Kloer

Position: Fort Worth Division Manager

Company: Crossland Construction

Email: linkedin.com/in/derek-kloer-424805162

Occupation: Construction Management

Interview Location: Zoom

Interview Date & Time: 10/12/24 6:40-6:55

Interview Duration: 15 mins

Questions Answers Reflections

Understanding the Scope and Impact

1. **Most common injuries and contributing factors**

   The most common injuries are back, shoulder, and knee issues, often caused by improper lifting techniques, heavy loads, and repetitive movements. Fatigue and tight deadlines also increase the risk.

2. **Demographics more prone to injury**

   Older workers tend to be more prone to injury due to wear and tear, while younger workers may not have developed proper lifting techniques, making them more susceptible to acute injuries.

3. **Frequent injuries and affected body parts**

   In construction, lower back, shoulders, and knees are most affected. In manufacturing and logistics, lower backs and wrists are common due to repetitive lifting and awkward postures.

4. **Long-term changes and health risks**

   Over time, workers develop chronic issues like herniated discs and arthritis, especially if lifting is not done correctly. Continuous strain can lead to permanent musculoskeletal disorders.

Training and Preventive Measures

5. **Best lifting practices and effectiveness**

   Proper training on lifting techniques, such as using legs instead of the back, is essential. These practices help but are often ineffective if workers aren't consistently reminded or incentivized to follow them.

6. **Employer approaches to workload and risk**

   Employers often provide basic training and ergonomic equipment, but these measures aren't always enough. More proactive safety programs and rest periods are needed to reduce physical strain.

7. **Role of ergonomics in injury prevention**

   Ergonomics, like using lifting aids or adjusting workstations, can significantly reduce injury risks. However, integrating them fully in industries requiring heavy lifting is often challenging.

8. **Evaluating worker capability and tools**

   Employers typically rely on physical assessments and self-reporting to gauge worker capability. Tools like lifting monitors or wearable devices could improve this process by providing real-time feedback.

Technological Solutions

9. **Wearable technology for injury reduction**

   Wearable technologies like exoskeletons and sensors show promise, but they're still in the early stages. Cost and worker acceptance are barriers to widespread adoption.

10. **Innovations to reduce physical strain**

    Technologies like automated lifting equipment or smart wearables that monitor strain could reduce physical demands. However, high upfront costs and integration challenges remain.

11. **Future of assistive technology and barriers**

    Assistive technology like robotic exoskeletons could revolutionize lifting tasks. The main barriers include cost, scalability, and ensuring the technology is robust enough for the demands of construction sites.

Organizational and Cultural Factors

12. **Worker perception of physical demands**

    Many workers feel they're not adequately supported in terms of injury prevention and recovery. Cultural changes, such as fostering open communication about physical strain, could improve support.

Long-term Solutions and Sustainability

13. **Long-term strategies and policy changes**

    To reduce injury risk, long-term strategies should include better ergonomic training, more rest periods, and stricter regulations on load limits. Policy changes should incentivize healthier work environments and prioritize worker wellness.

Reflection questions

Many construction workers indeed report difficulty with the physical requirements needed of them, wishing they were stronger to handle their workload more sufficiently (Carvajal-Arango et al, 2021). It is obvious that the requirements for the job have construction workers facing frequent carrying, pushing, and pulling of heavy loads (Bureau of Labor Statistics, 2020), which stems the subsequent consequences due to condition exposure. The prolonged exposure can add up over time, leading to musculoskeletal disorders, injuries, and substantial financial losses due to workers' compensation claims (Kaur et al, 2021). Not only do we feel this problem is worth solving, but also Sentient Energy's head electrical engineer: Nagi, who shares a vast pool of experience in solving problems through his mentors and company work he has done. His credibility is very trustworthy and i

Element B: Documentation and Analysis of Prior Solution Attempts

Introduction

Our team's journey began in the archives of *Google Patents*, where we set out to find as many patents related to exoskeletons—both powered and unpowered—as possible. Our goal was to explore any solution that could enhance the wearer's physical capabilities. After extensive searching, we identified eighteen patents that varied significantly in design, focus, and limitations.

While the implementation of each patent differed, they primarily addressed the mechanical specifications required for their respective designs. This diversity of concepts provided us with valuable insights into the complexity, cost, and efficiency of the mechanisms we intended to implement and those we initially overlooked.

We highlighted several critical critiques: mobility, technical complexity, static functionality, and cost-effectiveness. This analysis was part of our multi-step patent evaluation process, further informed by the expertise we gathered from professionals in Element A.

Patent Analysis

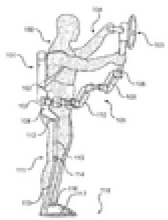
Patent [1]

Exoskeleton and method of providing an assistive torque to an arm of a wearer
US10569413B2
Russ Angold, James Lubin, Mario Solano, Chris Paretich, Tom Mastaler, Claire CUNNINGHAM, Kevin Dacey
February 2, 2020
This patent focuses on an exoskeleton designed to help with limb movement. It has a back-supporting spine that connects to the user’s waist and chest, making it stable. There’s a motor on the shoulder that assists in lifting the arm when using power tools. The design braces against the user’s tricep, which allows for better lifting of heavy tools. The exoskeleton is a great solution for the physical strain that comes with using heavy tools. It helps reduce fatigue and supports the user’s movements, which is a big plus for productivity and safety. Its ergonomic design is definitely a strong point, as it makes tool operation easier over long periods. On the downside, it might be a bit bulky, which could limit mobility and comfort for some users. Overall, this patent contributes useful insights into assistive technologies for labor-intensive tasks. We can use this idea to use as arm support for our product. **Pros** ● Provides significant support, reducing fatigue

• Promotes posture and productivity • Enhances handling of power tools **Cons** • Bulky, potentially limiting mobility • Requires adjustments/training • Motor limitations in battery and weight capacity

Patent [2]

Exoskeleton and Method of Providing an Assistive Torque To an Arm of a Wearer
US10569413B2
Russ Angold, Nicholas Fleming, Emily ROGERS, Brett JAEGER, Chris Paretich
February 25, 2020



This patent describes an exoskeleton system designed to support the user's back while holding heavy tools. It features a spine that runs along the back and extends down the sides of the legs, providing solid support. There's a gimbal-like addition at the hip, which allows for greater flexibility. This setup lets users easily handle various tools, such as angle grinders, that are suited for high-tensile steel.we can use this to add onto or device that will allow us to attach heavy tool and hold it easily.

This exoskeleton offers a smart solution for managing heavy tools, which can reduce strain on the body during use. The adaptive control and feedback features are particularly beneficial, as they enhance the user's comfort and efficiency. However, the complexity of the system might be a bit of a hurdle for some users in terms of maintenance and learning curve. Overall, this patent brings valuable advancements to assistive technology for tough manual tasks.

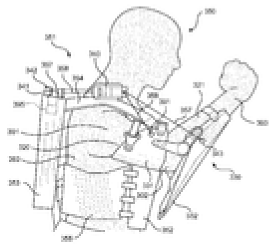
Pros

- Provides significant support, reducing fatigue
- Promotes posture and productivity

- Enhances handling of power tools **Cons** - Bulky, potentially limiting mobility - Requires adjustments/training - Motor limitations in battery and weight capacity

Patent [3]

Device and Method for Strengthening the Arms of Human Exoskeletons
US10596059B2
Russ Angold, Nicholas Fleming, Emily ROGERS, Brett JAEGER, Chris Paretich
March 24, 2020



The 2020 patent for the "Exoskeleton system with enhanced power supply and ergonomic design" outlines a back-supported exoskeleton that helps users carry heavy tools more efficiently. It has a spine that runs along the back and legs, plus a gimbal mechanism at the hip, which allows for better mobility. This design is particularly well-suited for tools like angle grinders, significantly improving user comfort and efficiency during tough tasks.

This exoskeleton offers a solid solution for carrying heavy tools, effectively reducing physical strain. The ergonomic design and enhanced power supply are big advantages, making it easier for users to perform demanding tasks without feeling overwhelmed. However, the complexity of the system could pose challenges for some users when it comes to setup and maintenance. Overall, this patent contributes valuable insights into improving assistive technology in demanding work environments. We can use this for better arm mechanism allowing us to lift heavy weight and hold it in a certain position.

Pros

- Enhanced power supply supports extended use without frequent recharging

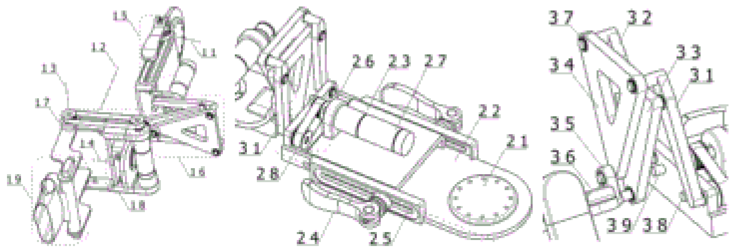
- Ergonomic design improves comfort and ease of operation
- Damping structure minimizes impact, enhancing the user experience

Cons

- Sophisticated design could increase manufacturing costs
- System complexity may make it challenging for users to learn
- Heavy reliance on advanced technology could lead to potential failures

Patent [4]

4-degree-of-freedom Forearm of Upper Limb Exoskeleton Robot
CN107648013B
周呈科, 邱静程, 洪李展, 王露刘, 薆恒吴, 家海薛, 泽文赵, 恩盛郑晓, 娟陈晔
July 14, 2020



The 2020 patent CN107648013 B describes a 4-movement exoskeleton for the forearm, specifically designed to aid in upper limb rehabilitation. This device allows for movement at the elbow, rotation of the forearm, and wrist movement both up/down and side to side. These features make therapy sessions more flexible and effective for users.

This exoskeleton provides a valuable tool for upper limb rehabilitation by enabling a range of movements that mimic natural arm actions. Its flexibility can significantly enhance the effectiveness of therapy, helping users regain mobility. However, the complexity of the device may require specialized training for both therapists and patients, which could be a barrier to widespread use. Overall, this patent adds important advancements to rehabilitation technologies, focusing on user adaptability and recovery. We can use this kind of part to allow for more flexibility in our design allowing our device to be more versatile.

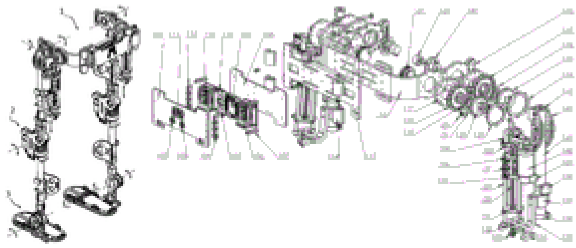
Pros

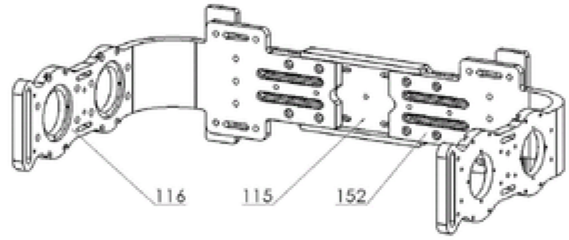
- Enables a full range of arm movements, improving rehabilitation outcomes
- Enhances flexibility in therapy sessions

• Specifically designed for upper limb rehabilitation, addressing a critical therapeutic need **Cons** • May require professional guidance for optimal use in therapy • Complex adjustments may pose challenges for some users • Durability concerns due to frequent use in rehabilitation settings

Patent [5]

Power-assisted Exoskeleton Robot
CN109262596B
朱爱斌, 宋纪元, 屠尧, 沈皇, 申志涛,郑威豪
October 27, 2020





The 2020 patent CN109262596 B details a power-assisted exoskeleton designed to enhance mobility and comfort. It features a comprehensive mechanism that includes the waist, hip, knee, and foot, all working together to support move

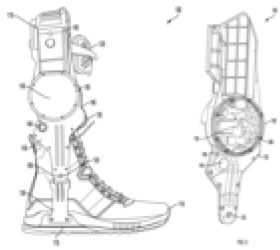
ment. A spring cam system allows for flexible hip joint movement and ensures it returns to its original position. Additionally, the exoskeleton incorporates a damping structure to minimize impact when the foot strikes the ground, along with an elastic torsion block to provide extra flexibility in leg movements. It also offers dynamic protection to make walking more comfortable and reduce strain when carrying heavy objects.

This exoskeleton suit offers significant benefits for improving mobility and comfort, especially for those who struggle with movement. Its design allows for natural leg motion while providing support, which can reduce fatigue and strain. The damping structure and elastic features enhance user experience by minimizing impact and allowing for a smoother walking motion. However, the complexity of the system might require adjustment and training for effective use. Overall, this patent represents a meaningful step forward in assistive technologies for mobility enhancement.We can use

this design as a hip attachment that will allow us to transfer the device between the users arms and legs. **Pros** ● Supports a full range of leg movements, enhancing overall mobility ● Damping structure reduces impact, making walking more comfortable ● Dynamic protection helps reduce strain when carrying heavy loads **Cons** ● May be heavy or cumbersome, potentially affecting comfort over extended use ● Requires precise fitting for effectiveness, adding complexity to setup ● Could necessitate ongoing maintenance and adjustments

Patent [6]

Real-time Feedback-based Optimization of an Exoskeleton
US11918536
Luke Mooney, Jean-François, DUVAL, Rachel Harris, Jonathan Kaplan
March 5, 2024



The 2022 patent U.S. Patent No. 11,918,536 B2 introduces a system designed to measure the collaboration level between a user and an exoskeleton boot. This innovative device applies force to assist with limb movement while simultaneously tracking various parameters related to both the exoskeleton and the user's biometrics during motion. Based on these measurements, the system calculates a metric that reflects how effectively the user and the exoskeleton are working together.

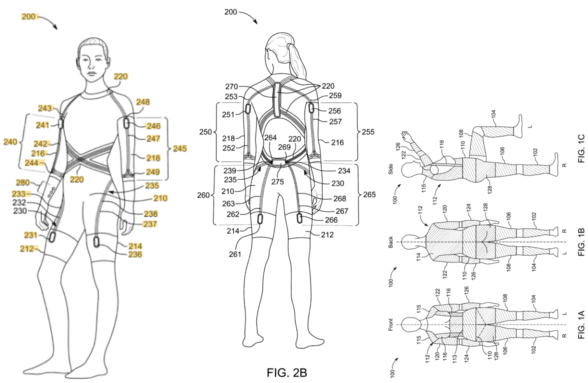
This exoskeleton system provides a valuable approach to improving user-exoskeleton interaction by measuring and analyzing collaboration levels. By actively assisting limb movement and tracking biometric data, it can enhance the effectiveness of rehabilitation and mobility support. The ability to determine a collaboration metric could lead to more personalized adjustments in assistance, improving user experience. However, the complexity of the system may require training and could present challenges in real-world applications. Overall, this patent contributes important advancements to the field of assistive technology, focusing on optimizing user experience and interaction. We can use this idea to add a feet attachment making walking easier as an attachment to our previous design.

Pros

• Measures collaboration between the user and exoskeleton, allowing for tailored assistance • Tracks biometrics, enhancing personalized support • Potentially improves the effectiveness of rehabilitation and mobility tasks **Cons** • Complexity in tracking and interpreting biometric data may require advanced training • High-tech components could lead to increased costs • Dependency on technology may present issues in less controlled environments

Patent [7]

Exosuit System Systems and Methods for Assisting, Resisting and Aligning Core Biomechanical Functions
US10828527B2
Richard Mahoney, Melinda Cromie Lear
November 10, 2020



The exosuit can be worn either outside the body or underneath the clothes of the user. The exosuit is to be assistive both physically in certain tasks and in communication through physical expressions. Other activities it can assist with is interacting with the environment or capturing information from the user. It may also resist the wearer's movements as an exercise.

This patented item attempts to solve a similar problem to ours. It has assistance in physical activity as a secondary objective, put to the side by its main objective of being a specifically exercise assistance device. The sensors it has allows it to adjust to the user, gain data, and adjust itself specifically to the user. These are all good attributes however the more negative attributes would be that the device is not capable of providing relief from lifting very heavy objects, and would most likely tire out the user more due to being an exercise device that provides resistance against movements. The unique aspect would be that due to our problem being its secondary objective, it would approach it from a different angle than most would trying to solve the problem directly. This angle could let us think about possible ways to utilize sensors that would customize how any future system works for a user.

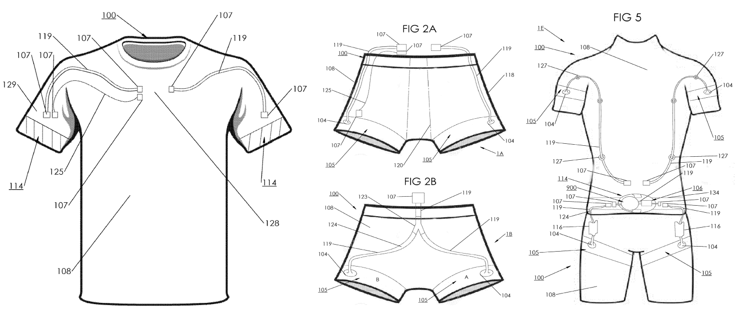
Patent [8]

Pneumatic training device and garment for increasing strength

US20220218047A1

Sean Tremaine Whalen

July 14, 2022



A device that performs blood flow restriction during the day and is integrated with a garment. It must be controllable with applying desired compression levels to muscle sets with the intention to increase both the health and fitness of the user in their everyday activities. In its whole it's an integrated garment and blood flow restriction training system.

Another exercise device, it attempts to solve the problem of making one stronger in a different type of context. This device is a compression system that is meant to increase health while one exercises with it on. This means that there is no actual increase in strength that would be needed to provide relief during lifting. The upside for it however is that it is a comfortable system for the user, not quite so burdening as robotic systems. It is another product that gives us insight in how to make a more

comfortable and discrete product, but it also gives us the knowledge on different ways to increase someone's strength. We could apply all of this to our future product by acknowledging the different systems that could mix.

Patent [9]

Wearable Device for Preventing Musculoskeletal Injuries and Enhancing Performance
CN112004511B
基 鉉 ベ, 賢 燮 林, 範 洙 金, 主 榮 尹, 奎 正 金, 東 眞 玄
March 5, 2024
It is a wearable device that prevents musculoskeletal injuries and enhances one's performance. The assistance with a person's actions is to be provided during physical activity. Integration with any kind of garment is available and the device utilizes sensors to provide customized assistance. The product patented is intended to solve our same problem via a wearable flexible system. This system allows for comfort in everyday activities and uses sensors to detect the movement of the user. The product aims to provide a broader relief in every aspect of life however, and so its overall effectiveness may be lower due to this. This product focuses on the comfort of the user and so what was down to provide comfort can be added to our overall research. One of the most important aspects of a solution is how comfortable it is to use.

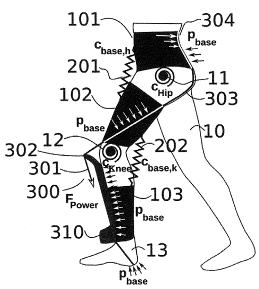
Patent [10]

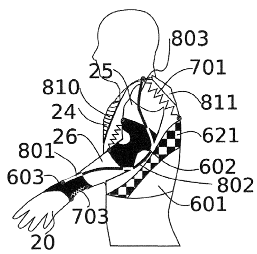
Flexible Wearable Muscle Assist Device

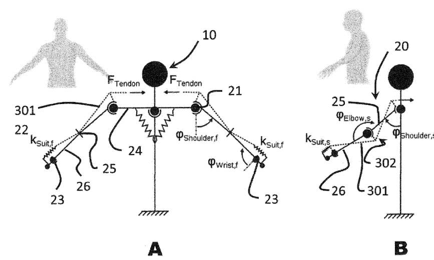
JP7362159B2

リーナー ローベアトドゥアルテ ハイメシュミット カイ

October 17, 2023







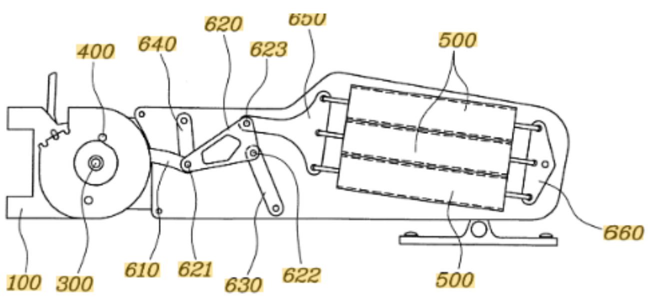
It is a flexible wearable muscle assistance device that has both passive and active components. It supports where the body has weakened ligaments and has direct contact with human skin. The system has been made with the intent of reduced mass and can be concealed when worn under clothing.

The patent attempts to solve a similar problem to ours by providing a passive and non intrusive system that corrects the body to move how it should while also slightly assisting it. It is a more discrete system and does not demand an uncomfortable approach to how it is worn, however it is made more for helping those who already have musculoskeletal disorders and for a normal person,

would be less effective. Overall the patent is able to add the elements of how it's passive to our research.

Patent [11]

Upper Arm Module of Wearable Muscle Strength Assist Device and Wearable Muscle Strength Assist Device Including the Same
JP7443029B2
基 鉉 べ, 賢 燮 林, 範 洙 金, 主 榮 尹, 奎 正 金, 東 眞 玄
March 5, 2024



An upper arm module of a strength assist device, it is meant to assist the users arms with robotic muscle assistant arms. The objective was to make this device more durable than its counterparts in the medical, military, and work fields. It is connected to the hip and is meant to provide all round assistance.

The patent is trying to solve a specific variation of ours, and it succeeds in such that it increases the arm strength of the user with robotic arms. It is simple and bases itself off of other products already in the field, however the distribution of its assistance is questionable since it is limited only to the arms. It being only limited to the arms gives us insight into a specific part of the body and what assistance it could use.

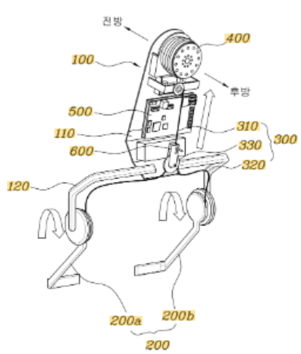
Patent [12]

Wearable Apparatus for Assisting Muscular Strength

KR101988078B!

고훈건

June 12, 2019



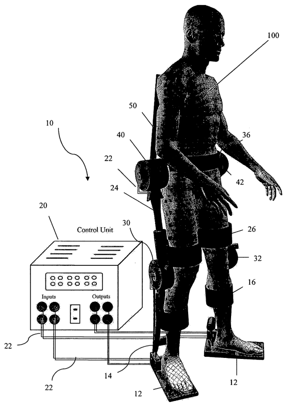
A wearable apparatus that lays on the back of the user and connects to the legs. It is meant to support back and lumbar strength. It has the intent to both be simple and non burdening with the process of lifting and assisting one's strength. It targets the legs as well, with it being a simple robotic system

equipped with sensors. The device solves our same problem to a degree, by targeting a part of the body it assumed would be best in assisting with the users lifting. It keeps it simple, and from that it is non-burdening when put in use by the user. As with other patents seen however it only targets a specific part of the body which can be problematic if assistance with other parts is ever needed.

Patent [13]

Exoskeletal Device for Rehabilitation
US7190141B1
Hashem Ashrafiuon, Mehdi Nikkhah
March 13, 2007

FIG. 1



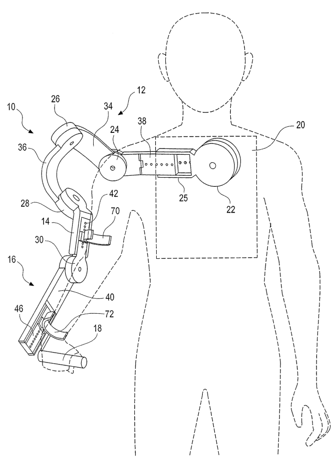
Describes an exoskeletal device designed to adapt to the patient, fitting to the lower extremities with modular extensions for each stage of the rehabilitation process. The modular device uses just two actuators by default, and includes a supporting back brace, and through the use of two additional 'modules' may support walking. The actuators, while affixed directly to the patient's chassis, are controlled by an external stationary control unit separated from the patient. The control unit communicates directly with the actuators, using dynamic full-state feedback algorithms to adjust actuator forces in response to the patient (*U.S. Patent No. 7190141B1, 2007).*

Advantages	***Drawbacks***
Supporting Brace	*Separated Control Unit*
Modular Actuation	*Cumbersome*

This text discusses a solution for retraining mobility in patients who have suffered strokes. Although the systems described in this patent are not designed for heavy workloads, they offer the potential for modular actuators that can be attached to provide additional support as needed. For instance, if a user

requires more strength, more actuation units can be added. However, a drawback of this system is that it is tethered to a stationary control unit, which limits the wearer's flexibility in accessing specific locations within their work environment.

Patent [14]

Robotic Upper Limb Rehabilitation Device
US20190201273A1
Rana Soltani-Zarrin, Amin Zeiaee, Reza Langari, Reza Tafreshi
July 4, 2019
 FIG. 1 Generally defines a rehabilitative device for the upper limb extremities, with the goal of aiding patients in recovering from strokes or other traumatic injuries. The design consists of five degrees of freedom; two of which are designed to mimic human natural inner-shoulder movement. An upper arm member is attached through a pivot mechanism to the forearm assembly, control signals are

received from a separate, external, stationary control unit.

Advantages	***Drawbacks***
Inflatable Handgrip	*Separated Control Unit*
Conforms To Normal Movement	*Bulky*

This device offers a solution for patients who experience chronic mobility impairments due to stroke or bodily trauma. The patent describes several innovative mechanical mechanisms that, while technically complex, allow users to reach various positions and align with the natural movement of the human arm and hand. However, these mechanisms contribute to the device's bulkiness, making it difficult to wear under everyday clothing. Additionally, there is potential for exploring more sophisticated mechanisms beyond a direct drive.

Patent [15]

Support Frame for an Upper Limb Exoskeleton
EP3903755A2
Andrea Baldoni, Matteo Moise, Simona Crea, Emilio Trigili, Mario Cortese, Nicola Vitiello, Francesco Giovacchini
August 16, 2023

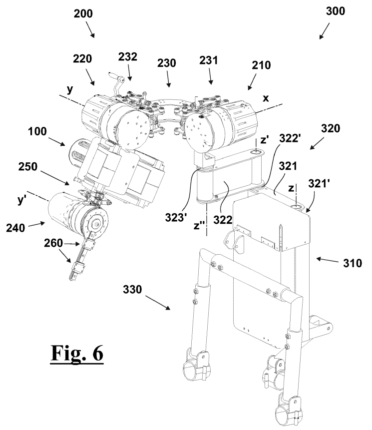


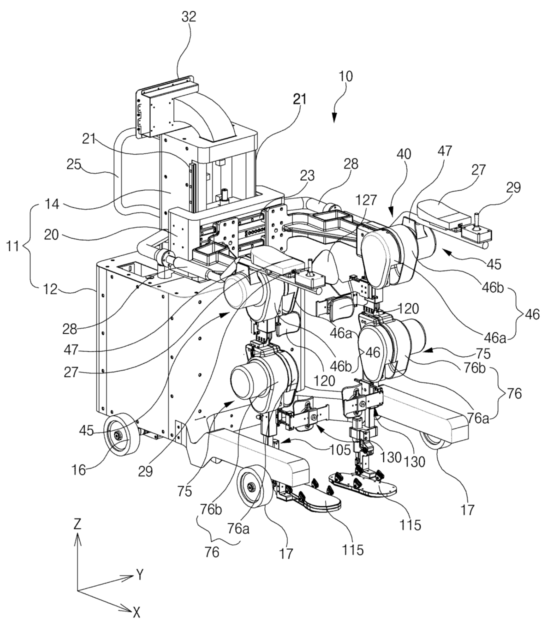
Fig. 6

Expresses a design for the support system of a general-purpose robotic exoskeleton device, designed for both adaptability and modularity to the patient's body type and physique. Uses a variety of sliding mechanisms to support the patient through a large plurality of positions. The structure supports translations and rotations in the upper limb about all axes.

Advantages	***Drawbacks***
Inflatable Handgrip	*Cumbersome*
Natural Movement	

This solution is designed for upper-limb exoskeletons and features less mechanical complexity than other options, maximizing the wearer's mobility. The support frame is straightforward in its design, yet the mechanisms allow for various positions, enabling workers to maintain their regular working postures even while wearing bulky suits. This approach offers a less technically complex and more cost-effective alternative for providing workers with the ability to adopt different positions.

Patent [16]

Robot for Assisting User to Walk With Lower Body Exoskeleton
KR101869968B1
Kim Ho-yeon, Jinwon Lee
March 25, 2016
 Describes a walking-assist robot equipped with a foot exoskeleton designed to aid users in walking by providing external force. The robot consists of a main body that adjusts its movement based on the user's walking speed and direction, and lower extremity exoskeletons that attach to the user's legs. These exoskeletons feature joints at the hips and knees that rotate with the help of electric motors, allowing natural leg movement. The joints have stoppers to control rotation angles, ensuring safe and controlled mobility.

Advantages	*Drawbacks*
Enhanced mobility	*Limited Rotation Range*
Natural movement	*Complexity*
Adjustable support	*Stationary*

This device is designed for individuals who have experienced traumatic injuries that have resulted in mobility challenges. Although it is primarily intended to be stationary, it offers the potential for enhanced natural leg movement while providing support and comfort to the user. Additionally, it has the capability to facilitate strong exoskeletal actions, assisting workers more effectively while remaining mechanically limited and stationary. This patented device is unlikely to be used, because the device is stationary and likely would not aid workers in their movement with carrying and or hauling large objects.

Patent [17]

Upper-body Robotic Exoskeleton
US11911330B2
Ashish Warren Deshpande, Bongsu Kim
June 14, 2021

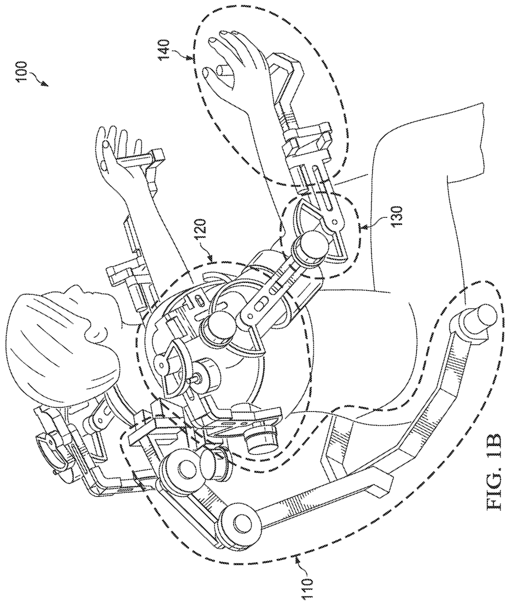


FIG. 1B

The patent describes a support frame for an upper limb exoskeleton that can be positioned in various spatial orientations relative to an outer support. The support frame includes a containment shell, a weight-balancing system, and a kinematic chain. The chain has several rotational joints and links, allowing for flexible movement along multiple parallel rotation axes. This design enables the exoskeleton to be adjusted and placed in different relative positions with respect to the containment shell for better adaptability and comfort during use.

Advantages	***Drawbacks***
Large mobility range	*Limited forearm and elbow mobility*
Upper body support	*Potential complexity*
Precision control	*Energy Consumption*

Another general-purpose solution aims to provide the wearer with as much natural motion as possible. This is achieved through a variety of independently simple yet technically complex mechanical devices, resulting in a wide range of natural positions for the wearer across all axes. Additionally, the upper body support device counterbalances weight in multiple directions. Although these devices are exceptionally complex and costly, they offer an incredibly natural feeling of mobility and support for the wearer. It is likely that the mechanical implementations described by this patent will be useful, as they give the wearer almost complete motion in their arms.

Patent [18]

Exoskeleton vehicle upper body structure
US10745055B2
Richard Daniel Pastrick, Stephen William Gallagher
August 30, 2018

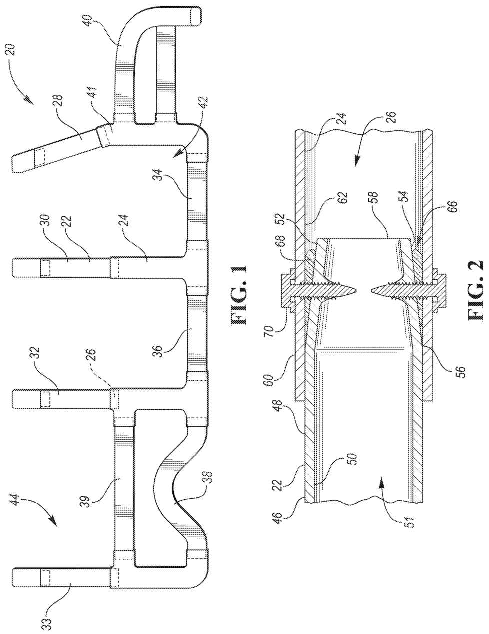


FIG. 1

FIG. 2

The patent describes a vehicle body exoskeleton composed of multiple nodes, each with a receptacle, and tubes with tapered end portions that fit into these receptacles. The tapered ends are bonded to the nodes using adhesive, filling gaps between the end portions and the receptacles to ensure a secure connection. This structure forms the skeleton of a vehicle body by linking nodes and tubes with adhesive, creating a stable and reinforced framework.

Advantages	***Drawbacks***
Simple construction	*Potential Complexity*
Upper body support	
Precision control	
Weight Balance	

This general-purpose solution is designed to be a simple, reliable, and cost-effective way to construct exoskeleton mechanisms. It includes several features, such as weight balancing and connectivity between modular nodes. The simplicity of the design is its greatest strength, although it may lead to future complexities that could create design challenges for exoskeletons built from this framework. This approach allows developers to bypass the lengthy processes of designing, testing, and prototyping a complete frame, enabling them to start building the exoskeleton immediately, effectively fractionalizing the development time.

Reflection

We found that whilst many of the designs we reviewed highlighted, improved upon, or innovated upon existing weak points of the exoskeleton concept—*many failed for a variety of reasons.* Patent 1, an assistive device for lifting heavy power-tools: limited by hardware capacity, bulky, and required extensive training. Patent 2, a sub-patent of the aforementioned suffers the same pitfalls. Patent 3, a clear improvement that also aims to assist in lifting power-tools: overly-sophisticated, and reliant on complex hardware components that create additional points of failure. Patent 4, aimed at physical therapy, proves useful—mimicking natural human movement: complex adjustable system overly-tailored to specific users. Patent 5, a full-lower extremity support system, minimizes the impact on the foot through a system of springs: overly-tailored and cumbersome (subsequently affecting long-term use). Patent 6, a system for quantifying the 'collaboration level' between a human and an attached mechanism: complex tracking mechanism and expensive technical features. Patent 7, a slim upper-body skeleton worn above or below the clothes: prioritizes data collection over functionality.

Patent 8, fabric garments that perform blood-flow analysis, gives insight into creating a product both comfortable and discreet: provides no relief or physical strength increase. Patent 9, prevents musculoskeletal disorders through tracking of everyday activity: but fails to effectively increase strength by any significant measure Patent 10, a system created with the intent of reducing volume and mass, allowing it to be worn comfortably under clothing: under-powered solution. Patent 11, an upper-arm module aimed at assisting users in medical, military, and labour: only limited to the upper-arm region, and provides no support elsewhere. Patent 12, a back apparatus, extending to the lower body, supporting both lumbar and lower body extremities: targets only the lumbar regions. Patent 13, a modular back-supported exoskeleton: limited by an external control and power supply. Patent 14, a rehabilitative device for the upper extremities with several degrees of freedom that mimic human movement: limited to one arm, and—like the aforementioned—limited by an external power supply. Patent 15, a general purpose exoskeleton solution, supports all axes about translation and rotation: cumbersome and bulky. Patent 16, a rehabilitative exoskeleton which responds to the user's impulses: limited movement range, technically complex, and entirely stationary. Patent 17, possibly the most applicable—an upper-back supported dual-arm system that involves several mechanisms to achieve near-natural levels of movement: potential mechanism complexity, energy consumption. Patent 18, a general purpose robotic and exoskeleton frame, low cost and reliable: limits future developments as increasingly specialized modifications become necessary. In short, no device perfectly achieved the goals we had laid out—constraints set by our mentor from Sentient Energy, Nagi San. Nagi San is a lead electrical engineer working with extensive engineering experience, thus why his judgement was used to support our constraints and criticisms of patents.

The design specifications focus on enhancing performance through increased strength and mobility while ensuring safety, durability, and comfort for long-term use. Materials like PLA, ABS, aluminum, and steel were chosen for their balance of strength, cost, and heat resistance, with ergonomic features like a back brace and gas shocks addressing health risks. The compact, lightweight, and modular design ensures seamless integration into work environments, even under extreme conditions. A long-lasting battery supports at least 12 hours of operation, making the device practical, adaptable, and cost-effective for various industries.

Element C: Presentation and Justification of Solution Design Requirements

The design specifications focus on enhancing performance through increased strength and mobility while ensuring safety, durability, and comfort for long-term use. Materials like PLA, ABS, aluminum, and steel were chosen for their balance of strength, cost, and heat resistance, with ergonomic features like a back brace and gas shocks addressing health risks. The compact, lightweight, and modular design ensures seamless integration into work environments, even under extreme conditions. A long-lasting battery supports at least 12 hours of operation, making the device practical, adaptable, and cost-effective for various industries

Reflective Questions

The exoskeleton must support lifting 20 kg consistently to meet industrial standards, ensuring users can handle significant loads without strain (Simms & Callahan, 2022). Efficiency should reduce user energy expenditure by at least 20%, aligning with advancements in wearable assistive technologies (Sanchez & Miller, 2023). Its weight must not exceed 4.5 kg to prioritize comfort and usability (Sanchez & Miller, 2023). Additionally, production costs should remain under $500 for market accessibility (Lee & Huang, 2021). Durability requires reliable operation for over five years or 10,000 usage hours (Lee & Huang, 2021).

Stakeholders

- Construction workers
- Sentient Energy
- Laborers
- People with physical disabilities

Input

- Sentient Energy was able to give us input on material by telling us to use SuperCaps for our batteries because they are sturdy batteries that don't catch on fire and are resistant to cold and heat. They also informed us it would be beneficial to use gas shocks to brace the arm. We got this information by going into their headquarters and talking to one of the employees.
- The construction workers and laborers gave us data on pain that they deal with so that we could more accurately make our problem statement. This also allowed me to have a

design in mind to solve a problem faced by lots of people. We got our information from a survey we did where we went out and interviewed them.

Benchmarks for Success

1. Safety tests confirm the device can handle forces of 100 lbs without failure.
2. Operates continuously for 12 hours with the included battery.
3. At least 90% of surveyed users report reduced strain and improved mobility compared to manual labor.
4. Device passes durability tests for extreme conditions (temperature, load).

Design Specification

- This list is in a list by highest priority

Criteria	
Customer Need(s)	● Consistently improved employee performance: should through powered or unpowered means provide employees with increased strength, mobility, or power such that their work efficiency is increased.

	• Meets safety standards: employees are not indirectly or directly put at risk for using our product long-term. • Straightforward solution: should be implemented such that usage of the product is clean and simple. • Withstands wide-variety of extreme conditions: should withstand sleet, rain, snow, heat—all possible working conditions, but must work most optimally in factory/logistics environments. • Long-lasting: the product should have a lifespan of at least five years, without needing large repairs with maintenance being performed.
Performance	• Accurate: retains a complete plurality of positions in all three-dimensions, translation and rotation that does not limit work in the optimal environment. • Strong: handles a large variety of weight and forces in the ideal environment,

	boosting the user's effective load capacity. ● Mobile: does not inhibit the user's ability to quickly respond to changes within the environment.
Target Cost	● Optimally within the range of $100 - $500; must retain a relatively cheap cost compared to other solutions within the industry to increase the breadth of available purchasers.
Ergonomics	● Wearable over/under clothes ● Easily worn, removed, and adjusted ● Comfortable: can be worn for hours on end without long-term health effects to the user. ● Practical: the device should be cumbersome, without adding overbearing mass or mechanisms which inhibit the ability of the wearer to perform in work environments. ● Modular: possible to add or remove the upper and lower extremity modules of

	the device.
Durability & Maintenance	● Durable: shouldn't require frequent repairs to usage-essential mechanisms or safety-features or maintenance whilst still lasting for extended periods of at least five years, should only need to replace power source. ● Long-lasting battery: the device should be made extremely power-efficient such that the device can boost a user's power for an extended period of at least twelve hours, the power source itself should be sufficient for these periods without extreme efficiency improving sacrifices to be made to device performance.
Size & Weight	● Needs to be as compact and lightweight as possible to reduce payload weight, fuel consumption, and space constraints. ● modularity can help keep the solution adaptable without increasing weight. ● Compact: the internal chassis

	mechanisms must be make as small width as possible such that it can comfortably be worn under a large sweater without being immediately noticeable. ● Lightweight internal chassis mechanisms must be constructed such that it does not degrade user performance significantly when unpowered. ● Thin & Sleek: outer casing should not be made overly cumbersome such that it degrades performance by not disallowing certain positions that may be necessary for specific work environments.
Operating Environment	● Construction environment(s) may be very dirty, hot, humid, etc. ● Product may withstand environmental conditions for extended periods. ● The Ideal operating temperature would be -10 to 60 degree celsius

Product Life	- Long-lasting: should last at least five years without needing to be replaced. - Repairable: Variety of at-home or on-site solutions to replace chassis and mechanically faulty components will make it unlikely that an entire unit is rendered completely unusable.
Material(s)	- Casing (Printed) - PLA: cost-effective material which, while not incredibly strong, is durable enough to withstand frequent usage. - Joints (Machined) - Aluminum: Joints will be the point of connection between modules, and should not break or come undone during repeated usage, which could have significant safety repercussions - Steel: (above) - Chassis (Printed) - PLA: makes up much of the

	skeleton, cost-effective ○ ABS: strong heat resistant properties that may be useful in insulating powered components. ○ Aluminum: rigid, inflexible material which will provide a back-bone structure to the PLA skeleton and chassis. ● Battery ○ Super-capacitors (powerful batteries operable @ high-temperature) ● Shoulder Pads ○ Base to build atop ● Gas Shocks ○ Prevents dropping of arm when
Safety, Legal, and Ethical Issue(s)	● Possibility for workers and or industries job security to be disrupted

	by the availability of low-cost tools that increase worker productivity. ● Safety concerns with the device causing long-term chronic health issues, like back-pain ● To solve back pain we will have a brace that is attached to the back so that it reduces back problems..
Environmental Impact and Sustainability	N/A
Aesthetics	● Fits seamlessly under a sweatshirt or other clothing item without noticeably sticking out, poking, or making the user feel especially constricted ● Casing is sleek, without jagged edges, and appears as a single, monochromatic or single color solid piece.
Additional Criteria	N/A

Target Consumer

Target Consumer(s)	Construction, Labor, Logistics
Age(s)	18 - 65
Demographic(s)	N/A
Income	Mid-range, Employer-funded

Ethical Considerations
Safety: The device must have good safety mechanisms to prevent injuries from overexertion, improper use, or equipment failure. It's crucial to ensure that users cannot unintentionally push their bodies beyond its safe limits, as this could lead to strain, muscle damage, or joint injuries. For example, the exo-arm could include weight limit indicators, automatic shutdowns when nearing unsafe loads, and training requirements for users. **Well-being**: Another ethical aspect is to prevent user dependency. Relying heavily on the exo-arm over time could reduce a person's natural muscle strength, so the design should encourage safe, balanced use to maintain physical health rather than replacing it entirely.

Constraints

1. **Money**

   The design must remain cost-effective to ensure accessibility for the intended users, such as construction workers and laborers. Material selection and manufacturing processes are optimized to keep production costs low while maintaining quality and performance. For example, lightweight plastics like PLA and ABS are used where possible, reducing overall expenses compared to heavier or more expensive alternatives like titanium.

2. **Weight**

   The total weight of the exo-arm must not exceed 15 lbs to ensure portability and ease of use. This constraint ensures the device does not hinder movement or cause additional strain. Lightweight materials and a modular design are incorporated to maintain this balance while allowing for strength and durability.

3. **Temperature**

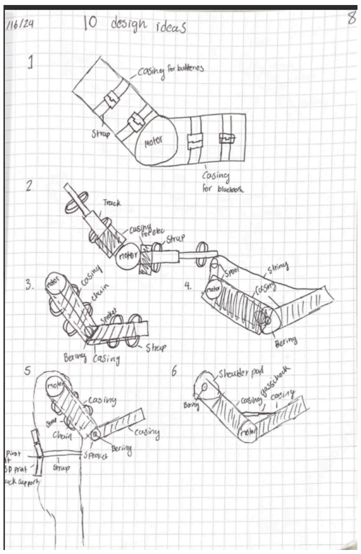
   The exo-arm must function reliably in extreme conditions, with an operating temperature range of -20°C to 50°C. This ensures usability in outdoor environments such as construction sites or warehouses. Materials like aluminum and ABS are selected for their resistance to heat and cold, and the electronic components are designed to avoid overheating or freezing.

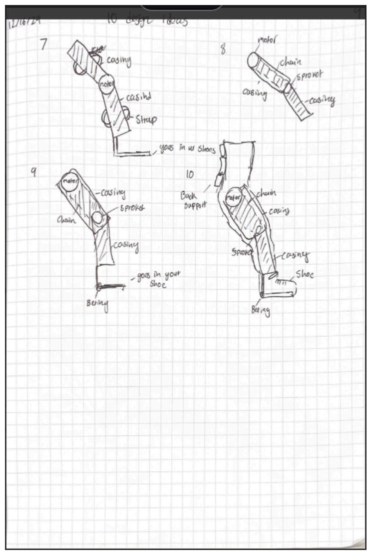
4. **Material**

   Materials must provide a balance of strength, durability, and cost-effectiveness. PLA and ABS plastics offer lightweight properties for non-load-bearing components, while aluminum and steel provide the strength necessary for load-bearing parts. SuperCaps are selected for batteries due to their resistance to extreme temperatures and reduced fire risk, as recommended by Sentient Energy.

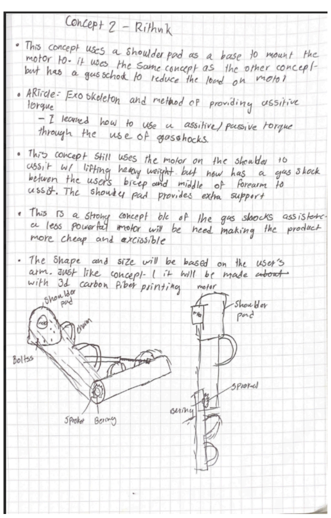
Element D: Design Concept Generation, Analysis, and

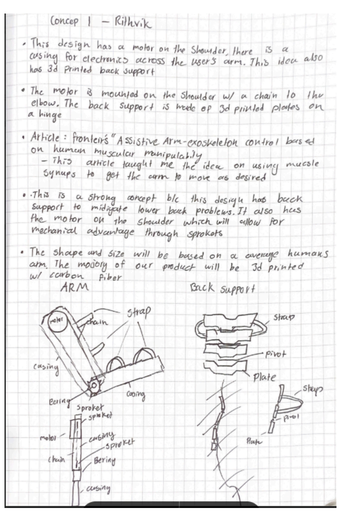
Multiple design solutions

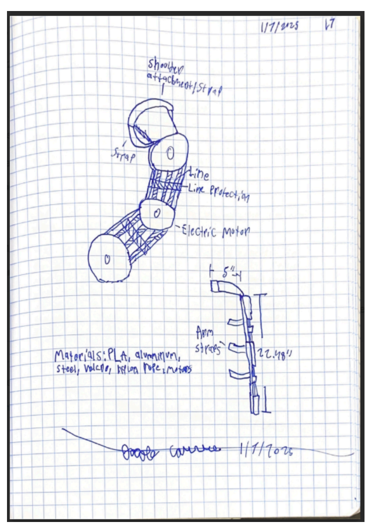




Detailed concept sketches and annotated drawings







List of all design goals

1. Functionality (Highest Priority)

- **Torque and Load Capacity:** Ensure the device provides sufficient torque to assist the wearer in lifting heavy loads, mimicking the strength of multiple workers.

2. Safety (High Priority)

- **Separation of Electrical and Mechanical Components:** Isolate the electrical and mechanical parts to prevent safety hazards from component interference.

3. Durability and Reliability (High Priority)

- **Material Selection:** Use durable, lightweight materials (e.g., aluminum, PLA, carbon fiber) to ensure longevity and resistance to wear.

4. Cost (High Priority)

- **Affordable Manufacturing:** Design the device using cost-effective materials and off-the-shelf components to keep the production cost low.

5. Environmental Impact (Medium Priority)

- **Non-Polluting Operation:** Ensure the device operates without harmful emissions and is made from recyclable materials to reduce environmental harm.

6. Standardization (Medium Priority)

- **Off-the-Shelf Components:** Utilize standardized parts like motors and connectors for easy replacement and minimal complexity.

7. Aesthetics (Medium Priority)

- **Functional Appearance:** Design the device to be visually professional with bright, reflective safety features for better visibility in industrial settings.

8. Ease of Maintenance (Medium Priority)

- **Accessible Components:** Ensure key components like wiring and connectors are easy to access for maintenance and repair, minimizing downtime.

9. Quality Control (Medium Priority)

- **Consistency in Manufacturing:** Establish standardized manufacturing processes to maintain uniform product quality across all units.

Desired Features in Final Design:

- ➢ **Specifications:**
  - High torque output for heavy lifting.
  - Lightweight and ergonomic design for ease of use.
  - Clear, accessible maintenance areas.
- ➢ **Parameters:**
  - Torque and load capacity.
  - Power source longevity and efficiency.
  - Ergonomically comfortable fit for various users.
- ➢ **Constraints:**
  - Cost limitation (under $200).
  - Limited customization of components to maintain affordability.
  - Must meet safety and durability standards for industrial environments.

Reflection and Analysis of Design Goals

1. Functionality (Highest Priority)

- **Reflection:** The device's core function is to assist in lifting heavy loads through torque, making it essential for the design to provide sufficient power while remaining ergonomic.
- **Analysis:** Balancing power with user comfort is crucial, requiring testing to ensure effective performance without sacrificing ease of use.

2. Safety (High Priority)

- **Reflection:** Safety features like separating electrical and mechanical parts and using reflective colors ensure safe operation in industrial environments.
- **Analysis:** Isolating components improves safety but must not complicate the design or reduce performance. Bright colors enhance visibility and reduce accidents.

3. Durability and Reliability (High Priority)

- **Reflection:** The device must be durable, using materials like aluminum and carbon fiber to withstand tough conditions.

- **Analysis:** Materials need to balance strength and weight, and regular maintenance for power source replacement should be factored into the design.

4. Cost (High Priority)

- **Reflection:** Keeping the device affordable while maintaining quality is essential for broad adoption.
- **Analysis:** Off-the-shelf parts help manage costs, but the electrical components, particularly the actuator, may still drive up the price.

5. Environmental Impact (Medium Priority)

- **Reflection:** The device should be eco-friendly, with recyclable materials and low environmental impact during operation.
- **Analysis:** Sustainable materials and safe disposal mechanisms must be considered to reduce ecological harm.

6. Standardization (Medium Priority)

- **Reflection:** Using standardized parts ensures cost-effective production and easy repairs.
- **Analysis:** Custom parts are limited to the casing, which helps control costs but may limit design flexibility for specific use cases.

7. Aesthetics (Medium Priority)

- **Reflection:** Visual appeal with safety features like reflective tape enhances user adoption without compromising function.
- **Analysis:** Safety and visibility should remain the focus, with aesthetics being secondary but still important for user interaction.

8. Ease of Maintenance (Medium Priority)

- **Reflection:** Easy maintenance ensures long-term use, with accessible components for repairs.
- **Analysis:** Organizing components for accessibility will reduce downtime, but care must be taken to maintain production efficiency.

9. Quality Control (Medium Priority)

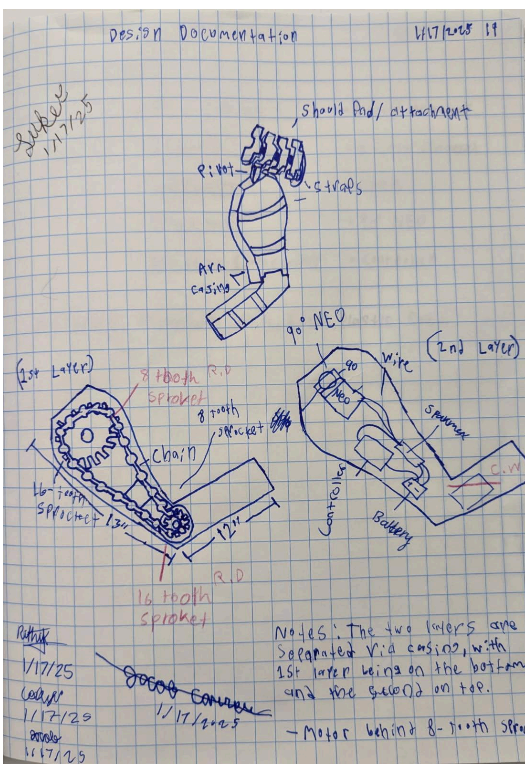
- **Reflection:** Consistent manufacturing ensures reliable performance and safety across units.
- **Analysis:** Regular quality checks are necessary to identify issues early, given the device’s complexity.

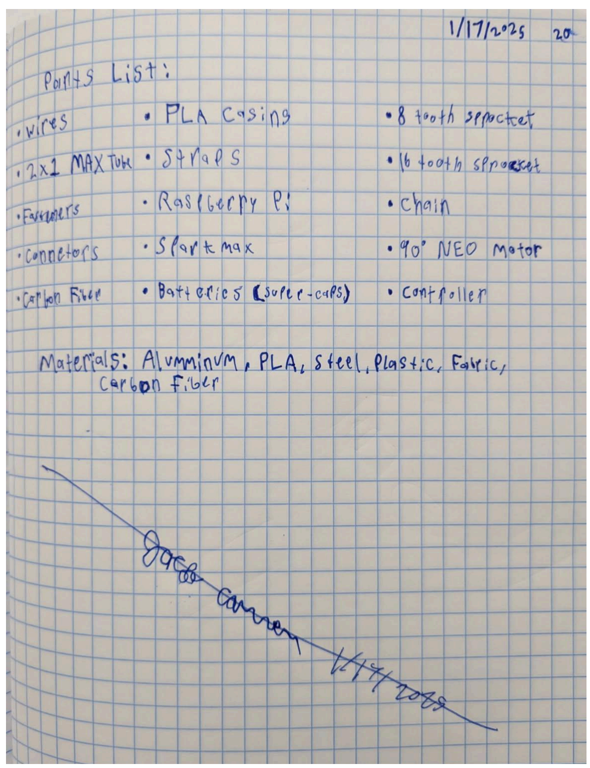
Decision Matrix

Criteria	Weight	Rithvik Idea 1	Rithvik Idea 2	Jacob Idea 1	Jacob Idea 2	Cody Idea 1	Cody Idea 2
Functionality (F)	15	9	7	8	7	6	5
Comfort (C)	10	8	6	7	8	6	5
Durability (D)	12	8.00	7.00	6.00	6.00	9.00	7.00
Weight (W)	10	7.00	8.00	9.00	8.00	6.00	7.00
Cost (Co)	8	6.00	7	6.00	7.00	5.00	6.00
Ease of Use (E)	1	9.00	8	5.00	7.00	8.00	6.00
Adjustability (A)	8	8.00	7	7.00	6.00	7	8.00
Battery Life (B)	8	7	6	8	7	8	6
Materials (M)	7	9.00	8	7	6	7	8
Safety (S)	15	9	8	7	6	8	7

Idea	Final Score
Rithvik Idea 1	759
Rithvik Idea 2	685
Jacob Idea 1	729
Jacob Idea 2	692
Cody Idea 1	711
Cody Idea 2	598

Final design





Justification

The reason we selected this design to continue onward is because this design utilizes material that we have such as 2x1 max tube pattern bars and sprockets with chain so by doing this we will be able to further reduce costs. The design is also simple and because of this we can design and create it without any clear issues to overcome.

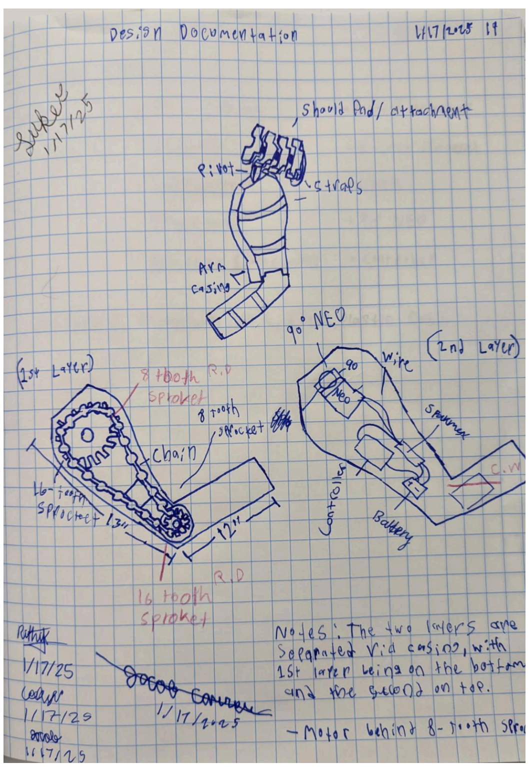
Reflective Questions

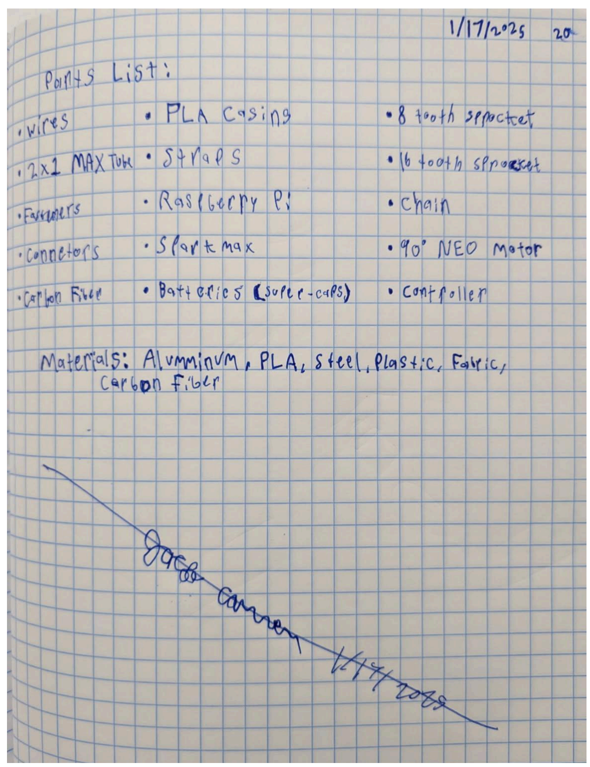
- We used Morphological Analysis to generate ideas by focusing on user needs and explored component combinations by each subsystem. To ensure we met design requirements, we utilized a matrix to track and validate each solution against key functional and ergonomic goals.
- The best solution to try was a modular exoskeleton arm with a neo motor and a carbon fiber frame. This design provides a balance of strength, lightweight, and flexibility, addressing both user mobility and comfort needs.
- The choice is defended based on weighted decision matrices, where carbon fiber scored highest for strength-to-weight ratio, and neo motor is very easy to use. Additionally, stakeholder feedback emphasized the importance of comfort and adjustability, which this design delivers.

Element E: Application of STEM Principles and Practices

This section is the culmination of our prior research efforts—patents, past solutions, safety, improvements—to create the most objectively-optimal solution to the problem: ‘I want to be stronger.’ We have brainstormed the following solution, which we believe is the most optimal solution given both the problem, and the resources at our disposal.

Our conceptualizations have birthed the following solution, a central ‘stationary arm:’ a long, flat piece with at one end a rotational actuator (motor) which supplies torque to the entire assembly, and at the other an expandable joint cuff (linking hardware) connecting to the wearer’s body. Connected to the powered (torqued) end of the actuator is the dynamic (moving, rotating) arm: a similarly shaped arm outfitted with the same linking hardware, providing two points of contact.





This is supported by the following equations:

$F_{Target} = 30\ lbs \qquad l = 16\ in = 1\frac{1}{3}\ ft \qquad G_{ratio} = \frac{21}{1}$

$N_{stall} = 3.36\ Nm = 2.48\ ft \cdot lbs \qquad N_{speed} = 5,750\ RPM$

$\tau_{required} = F_{Target} \cdot l = 39.9\ ft \cdot lbs$

$\tau_{output,\,50\%} = N_{stall} \cdot G_{ratio} = 52.08\ ft \cdot lbs$

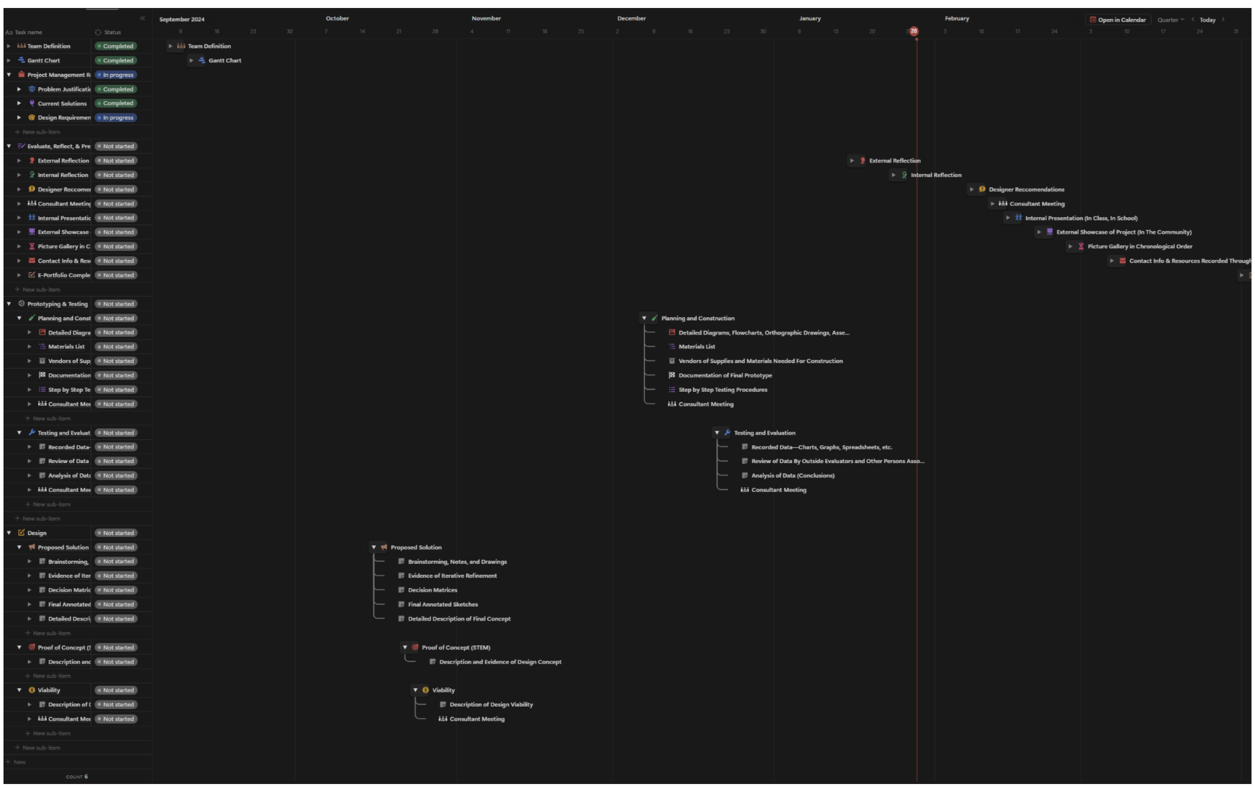
$$\tau_{excess} = \tau_{output} - \tau_{required} = 12.9\, ft \cdot lbs$$

In other words, the assembly will be capable of more than the required 30 lbs at 50% of the motor's maximum current.

As for production, we expect to only use the following tools:

- Horizontal Band Saw
- Vertical Band Saw
- Sander
- Integrated Development Environment (IDE)

The development of our project is on a tight, but reasonable schedule:

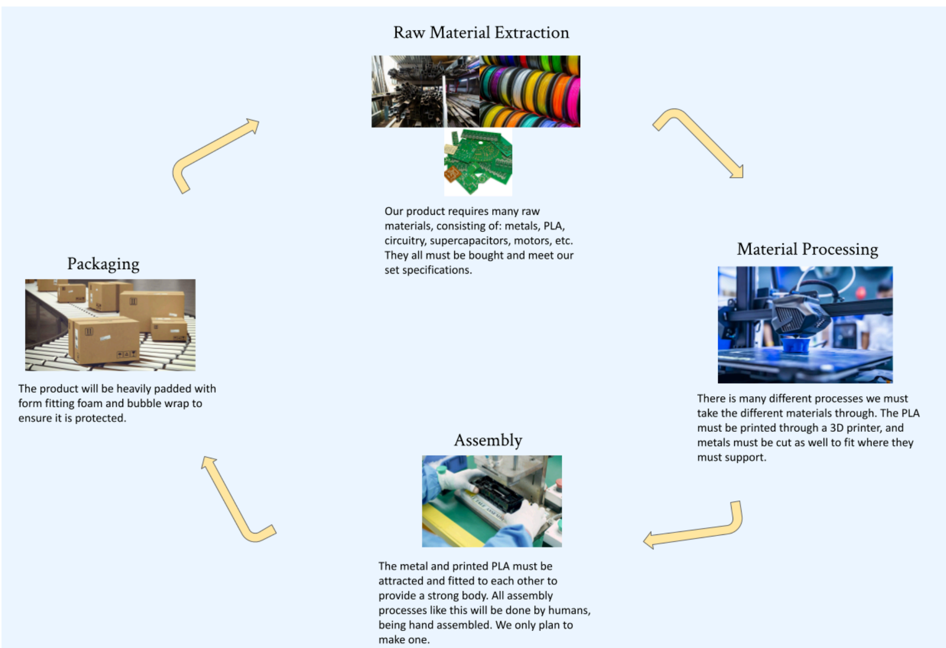


The development of the mechanical design was primarily relegated to Rithvik and Jacob, while Cody handled the conceptual Programming and Electrical responsibilities with Rithvik.

Element F: Consideration of Design Viability

Our group has taken great lengths to review and discuss both the design of our product and the extent of which it should perform. In our meetings we discussed the performance needs of our product, specifically the lifting of weight, which when decided affected how the design of our product looked. The culmination of our final judgement has given our design viability the capacity to address our problem as a proper solution.

Life Cycle Assessment:



Looking at the graphic above, it can be said that the life cycle of our product is considerably reasonable. The materials needed are mostly inexpensive, especially when compared to the material costs seen in the projects of bigger companies. The processing, assembly, packaging, and even the utilization which is not shown on the graphic has no outlying flaws that would render the life cycle unreasonable. The cycle is also sustainable in that it does not rely on a finite resource and can be made by those who have tools generally available to them. The product has neither waste that critically hurts the environment nor is made of materials that are specifically biodegradable, promoting only a small degree of sustainability when it comes to environmental impact.

Reflective Questions:

- How do we show evidence that the proposed design has merit beyond the classroom or lab as a real solution?

By showing our own and even other products that are similar to ours in the intended workplace would give merit to the effectiveness shown outside of the lab. In the wild, there is no control over variables and so recording product use in this situation is the best way to show the merit of our product.

- How can we show evidence that the design could realistically get into the hands of the people the design is trying to help in a sustainable way?

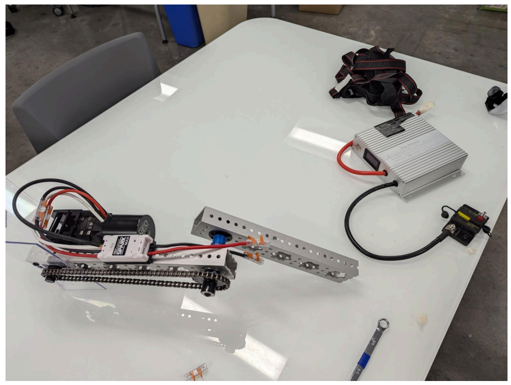
Producing a clean and readable bill of materials will enable us to garner the evidence needed, as it will produce an estimated cost for us. Calculating and showing a low estimated cost will be the proof on how we may sell the product for a cheaper price, therefore enabling sustainability in getting the product to the hands of the people that need it.

- What evidence would I/we have to offer to honestly ask a family to invest their life savings in this idea?

Based on a multitude of credible studies, we would have our deep and vast research done on our problem to establish a basis for our evidence. To then construct from there, we would build a working prototype to showcase that the product does indeed solve the problem it was created for. Adding furthermore on that we also have the numbers on the projected growth in the demand for products like ours, adding a combination of evidence that will be ample.

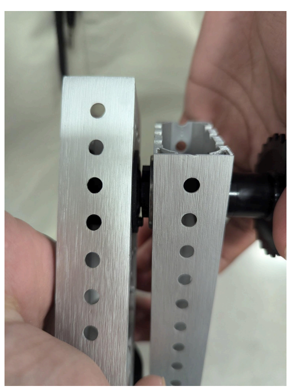
Element G: Construction of a Testable Prototype

Mock Up:



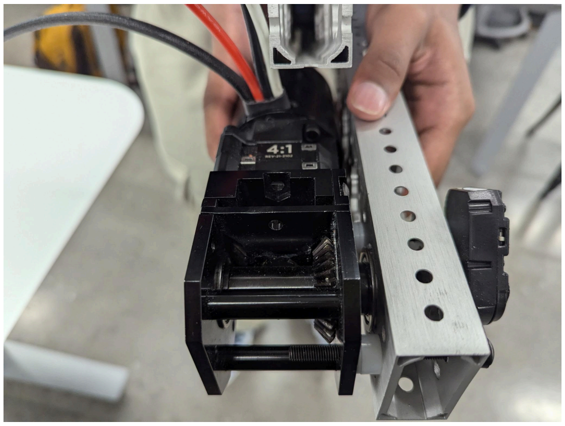
Build procedure overview:

- Make the following cuts (Complete by 3/14):
    - Cut both arm shafts to 15”
    - Cut the drive shaft to 5”
    - Cut 4 standoff holes onto the left or right side of the frame for the Raspberry Pi 3B+, using documentation to determine the correct placement of holes.

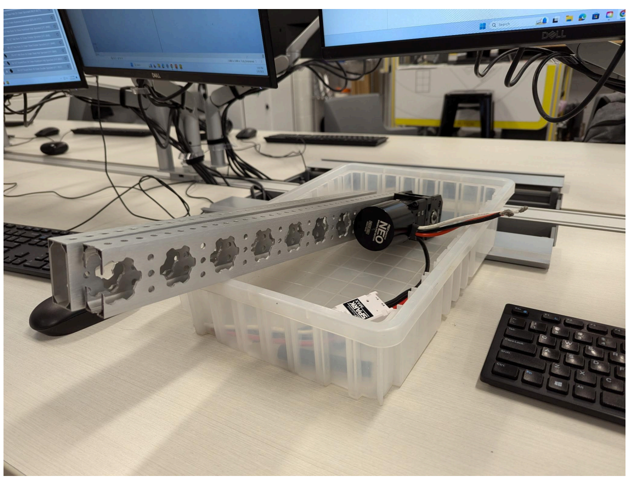


- On the upper and lower arms respectively, using a hammer, affix the shaft-end-caps by hammering them into place--this will house the shaft that is driven later. (Complete by 3/14)
- Assemble the motor gearbox (Complete by 3/14):
    - For the correct, 20:1 reduction--both a 5:1 and 4:1 reduction gearboxes are placed onto the motor gearbox, then screwed in place using the correct hardware.

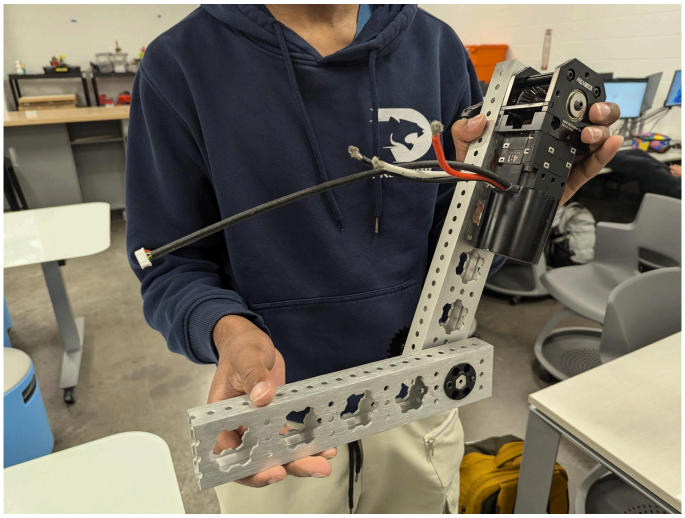
- ○ Screw the correct gearboxes into the motor gearbox, stacked vertically to save space



- Affix the assembled motor gearbox to the end of the upper arm opposite of the end-cap using the correct hardware. (Complete by 3/14)
- Attach the motor controller to the other face (left or right) of the upper arm assembly with the correct hardware. (Complete by 3/14)



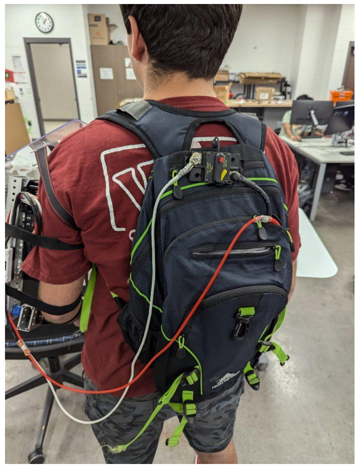
- Drive shaft, cut to size, into the end-caps. (Complete by 3/14)
- On the opposite side of the upper arm assembly, place the correct sprockets for the chain onto the end of the motor shaft, and the shaft driven between the end-caps. (Complete by 3/28)



- Placing the correct amount of chain using the distance between the two sprockets, connect the sprockets. (Complete by 3/28)

IMG_0274.MOV

- Using a supporting backpack, which carries the power supply (a nanocrystalline battery); from which the hot wires are fed into the breaker, to prevent constant power supply to the electrical components.



- Using a custom-printed casing, mounted the supercapacitors onto the upper arm frame while leaving accessible leads for powering both the motors and the Raspberry Pi 3B+. (Complete by 4/7)
- Connected the necessary leads from the supercapacitors to both the Raspberry Pi 3B+ and the motor system to establish a stable power connection. (Complete by 4/7)
- Affixed the Raspberry Pi 3B+ onto the same surface as the motor controller using standoff hardware, ensuring a secure and vibration-resistant placement. (Complete by 4/7)
- Affix the Raspberry Pi 3B+ to the same surface as the motor controller, screwing standoff hardware into screw holes cut into frame. (Complete by 4/11)
- Using mounting hardware, screw larger 3D printed casing to the upper arm. (Complete by 4/11)
- After affixing the backplate using mounting hardware, affix a second casing to the lower arm. (Complete by 4/11)

Summing Material and Labor Costs:

- Material Cost: $193.00
- Labor Cost: $175.00
- Total Production Cost = $193 + $175 = $368.00

Incremental testing:

For the incremental testing, the process would follow several steps.

1. The device is worn, turned on, and connected to the laptop.
2. Equal weights are held in both hands, and varied with each additional trial.
3. For each trial, the wearer will attempt to lift both amounts of weight for three reps:

    - A fail is recorded (for either side) if the weight cannot be lifted at least 90 degrees (perpendicular) to the angle to the forearm.
    - A pass is recorded (for either side) if the weight can be lifted at least 90 degrees (perpendicular) to the angle to the forearm.
- Repeat trials until both sides cannot be lifted, determining the maximum weight of the control and with the device equipped.

Following these testing procedures it can be determined how effective the aid provided is. The control group of the unassisted arm proved effective especially as the weights got higher.

Modifications during build:

A variety of changes were made to the build of our product throughout its lifespan. These changes spanned from regions such as power source to the attachment system.

Changes made -

- Power source changed to large supercap battery
- Power source location was changed from being on the arm to being separated in a backpack
- Casing was not added
- Shoulder attachment added
- Strap placement
- Added spacers for alignment issues

Element H: Prototype Testing and Data Collection Plan

1. Objectives of Testing

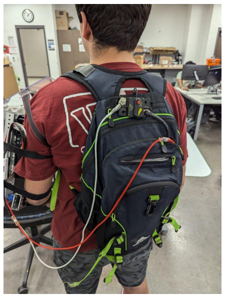
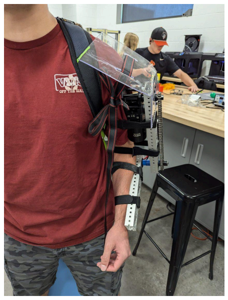
Goal:
To evaluate how effectively the exo arm supports construction workers in reducing strain and increasing lifting capacity, while meeting safety, usability, and durability standards.

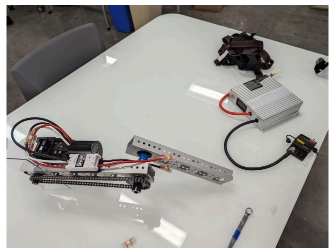
High-Priority Requirements to Test:

- ☐ Load-bearing capacity (80lbs) at 35% power
- ☐ Comfort during extended wear (1 hours)
- ☐ Range of motion (degrees: 100)
- ☐ Battery life / power system performance (200 hours)

3. Documentation of Testing

Link to the videosTest at gym

4. Expert Validation and Review

To ensure the exo arm is safe, effective, and truly beneficial for labor-intensive environments, we will seek validation from experts who understand both human movement and the physical demands of construction work. Their insights will help confirm that our design reduces strain without compromising performance on the job site.

Who Can Help Validate:

- Occupational therapist with a focus on injury prevention and ergonomics for manual laborers
- Mechanical or biomedical engineer experienced in designing or testing wearable assistive devices for physical labor
- Construction safety specialist with knowledge of OSHA standards and job site risks
- Vocational rehabilitation expert who works with injured construction workers returning to physical jobs
- Experienced construction foreman or site supervisor who can offer practical, real-world evaluation from the field

Required Training or Credentials:

- A degree in mechanical engineering, biomechanics, or occupational health
- OSHA certification or other safety training relevant to high-risk physical labor
- Field experience working with or evaluating tools, gear, or technology used in construction and heavy industry
- Familiarity with ergonomic assessments for manual material handling and repetitive strain injury prevention
- Practical knowledge of how workers interact with tools, scaffolding, and heavy materials in unpredictable environments

Special Computer Programs, Technology, or Equipment You Might Use

To design, build, and test the exo arm for construction workers, we require a combination of software tools, hardware components, and equipment suited for high-performance robotics and wearable technology. These tools support precise control, reliable power delivery, and efficient data analysis.

Computer Programs and Software:

- REV Hardware Client
- Fusion 360
- VS Code
- Python
- Sensor software
- CAD/CAM tools

Technology and Hardware:

- High-performance laptop or desktop computer
- Neo Motors

- Motor Controllers SPARK MAX, REV
- Rechargeable Battery Packs (12V–24V)
- Circuit Breakers
- Smooth Motion Controllers or PID systems
- Sensors
- 3D Printer

Element I: Testing, Data Collection, and Analysis

Throughout the development of our prototype, we followed the Iterative Engineering Design process--specifically we made use of important empirical tests which would determine the viability of our prototype.

We identified three critical elements of our prototype which would necessitate testing:

- Lifting

  At minimum, any user, with minimal effort, should be made capable of lifting an additional ~30 lbs when performing a curl motion.

- Power

  The onboard electronics, control unit, motor controllers, and wiring must all work in tandem to provide a fully functional range of motion without issue.

- Comfort

  A wearer, of any body type, should be able to comfortably fit into the device and keep it equipped for an extended period of time; at least 1 hour or greater.

This was further broken down into the following tests which were performed:

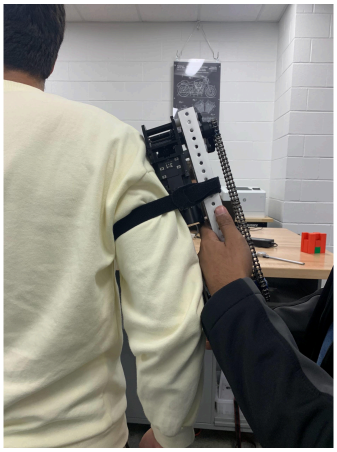
Strap Testing

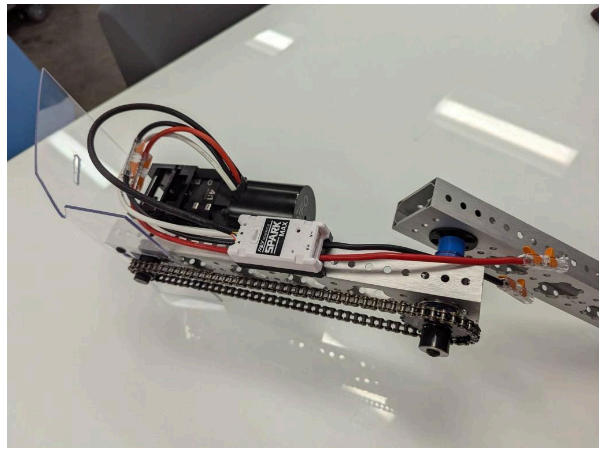



[IMG_0285.MOV](IMG_0285.MOV)

Qualitatively, we tested differing strap configurations at several different angles to find out what best prevents slipping on the frame--eventually settling with a cross-body strap supported by an under-arm pit strap with the new lexan in combination with the existing frame to arm straps that transfer power to the arm.

From this result, we observed that the device tends to slip when the main shaft is angled exactly downwards, in-line with the upper-arm region--this could lead to complications with the device staying up if not fixed, resulting in the change being made to add an upper lexan-plate which rests on the shoulder, secured to the body by an additional under-the-armpit strap.

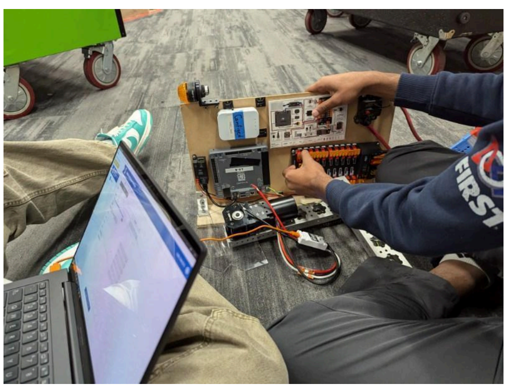




Before, with support required to prevent slipping

After, (not worn), no longer requiring added support

Drivetrain Testing

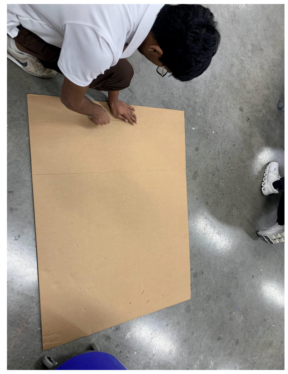


[video000002.3gp]

Qualitatively, we tested the full functionality of the device, testing if all electrical components could work in tandem to produce torque on a wearer when worn. This test was successful, and we moved on to improving the device.

Cardboard Strap Test

Considering a suggestion from our mentor, mentioned in Build Update #3, we tested a design where the force of our straps would be more evenly distributed across the skin--using cardboard strips we tested looping arm bands which would perform this function:



Ultimately, we decided not to pursue this option--as a result of the cardboard straps still slipping off of the arm, and our straps not being long enough to fully fit around the arm and the band.

Weight Lifting Test

We tested the total weight that could be lifted (unsupported, without a wearer), by the arm using a table, straps, and a set of weights:

IMG_0326.MOV IMG_0325.MOV IMG_0321.MOV
IMG_0327.MOVIMG_0322.MOV

Ultimately, we tested up a range of weights--we found that static friction F_s, could be overcome with a percentile output of 2%, and the following values for succeeding weight ranges using 5 pound increments:

Output Range	Weight Range (lbs)
2-3%	0-5
3-5%	5-10
5-6%	10-15

Unfortunately, due to a limitation in the amount of weights we could procure, and our setup--more weight ranges could not be tested; but it does present the potential for our device to lift our desired weight, and optimistically at less than 50 amps, our target.

Functionality Test

Our implementation revolves around allowing people to lift greater amounts of weight without requiring greater musculoskeletal stress and muscle effort to be applied; in short, increasing the maximum amount of weight that can be lifted by a single individual.

Our test will determine the total amount of weight that can be lifted in addition by a single user--the added maximum that someone can lift--and at what amperage and voltages does our implement maximum.

The device will be equipped by our wearer (Rithvik), using straps and his other warm will remain unsupported entirely--acting as a control for the experiment. Power will be turned on, and a control unit (laptop) connected over a USB-C connection to control the output of the device.

We made slight modifications to our testing procedure, gathering data on whether three (3) reps could be performed (on either arm) by the wearer rather than a single rep.

Materials:

- Laptop
- USB-C Cable
- Weights (Varying)
- Weight Straps
- Implement Straps
- Prototype

Procedure:

- The device is worn, turned on, and connected to the laptop.
- Equal weights are held in both hands, and varied with each additional trial.
- For each trial, the wearer will attempt to lift both amounts of weight for three reps:
    - A fail is recorded (for either side) if the weight cannot be lifted at least 90 degrees (perpendicular) to the angle to the forearm.

  - A pass is recorded (for either side) if the weight can be lifted at least 90 degrees (perpendicular) to the angle to the forearm.
- Repeat trials until both sides cannot be lifted, determining the maximum weight of the control and with the device equipped.

After conducting the experiment at our local gym, where a range of weights could be found, the following experimental results were found:

Weight (lbs.)	Minimum Output (%)	Experiment Lifted? (Y/N)	Control Lifted? (Y/N)
20	5	Yes	Yes
30	7	Yes	Yes
40	10	Yes	Yes
50	15	Yes	No
60	20	Yes	No
70	35	Yes	No

This test data, despite challenges during the testing process (laptop failure, power failure, etc), shows promising results for the prototype device--with great evidence that loads exceeding our target weight (30 lbs.) can be lifted with a greater degree of ease by the wearer.

This test data was made more accurate by our choice to perform multiple reps instead of a single one, as the target consumer of the device would likely not be limited to a single rep of their load. This is made more accurate by our rigorous testing to find the minimum percentile output of our motor where the weight would aid the user, and the fact that the weather could, at a threshold between (50-60 lbs) exceed their control (non-device) arm maximum weight.

Our test results, while showing promise, are not without their issues. During the test we noted that the key point of connection between the wearer and the device was our main constraint, forcing the arm into awkward positions that could make the weight harder to lift--this was noted by our expert contact based on video footage. To fix the issue, we were recommended to increase the overall surface area of these connection points and not allow them to freely twist and move about the axis of the arm.

Feedback

After conducting several of our tests, and meeting with our mentor, we received the following feedback during our mentor meeting with Mr. Nagi, we compiled a number of comments, advice, and concerns that have impacted our design:

- Stray away from using a buck converter to lower the voltage to power the Raspberry PI, this will significantly lower the amperage--the main advantage of utilizing this type of battery.
- Given that the battery will provide constant output (i.e. there is no ‘off’ button), we must place a breaker on the connection between battery and any electrical components.
- Rather than directly strapping components to the arm, design something with more surface area; this will prevent additional tension ‘cutting’ into the skin--making it more uncomfortable for long periods of time.

Reflection

End-users would likely view the prototype positively due to its ability to increase performance by 30 lbs in curl reps, which represents a significant improvement in strength for many. The affordability of under $100 and the quick build time are also major advantages, making it accessible to a wide range of users, from fitness enthusiasts to those in rehabilitation. As long as the device is comfortable and does not impede movement, end-users would appreciate the practicality and cost-effectiveness of the solution, especially if it can be easily integrated into their existing workout routines.

Experts, however, based on advice from our mentor would likely be cautious but intrigued by the results. While the increase in performance is promising--experts would likely require more rigorous and frequent testing of the device in different (less than ideal) environment conditions. Safety and long-term wearability would be key concerns, as experts would want to ensure the device does not cause strain or injury over time. They would also look for further refinement to improve customization, durability, and overall safety, ensuring the device is effective in the long term across various users and exercise environments.

Element J: Documentation of External Evaluation

Design Review by Qualified Stakeholders

The EXO arm was reviewed by Mr. Nagi a Electrical engineer at Sentient Energy Mr. Preston, a Mechanical Engineer from Sentient Energy both of whom have significant experience in mechanical design and robotics. Their feedback was necessary in order to refine the design and to ensure it met the intended goals of assisting weight lifting heavy weights to help hard working laborers.

Key Suggestions:

- Supercapacitors for Temperature Resistance: Mr. Nagi and Mr. Preston recommended using supercapacitors due to their higher temperature resistance compared to traditional batteries, allowing the EXO arm to perform reliably in extreme temperatures, ranging from -40°C to 80°C.

- Velcro for Adjustability: They suggested replacing the clips with Velcro, making the system more adjustable to accommodate different users, ensuring better flexibility in its application.

- Protective Casing for Shoulder Support Contact: To optimize the arm's performance, they advised adding a protective casing to better improve the contact between the arm and the drive's shoulder support. This would ensure a more efficient and secure connection, enhancing overall performance.

Meeting Design Goals

The primary goal of the EXO arm was to assist with lifting weights. It has successfully met this goal by enabling users to lift weights safely and efficiently. Not only has the arm achieved its intended purpose, but it has exceeded expectations by being capable of lifting up to 80 pounds with only 35% of its full power. This performance surpasses the original design goals and showcases the arm's potential for handling heavier loads than initially imagined

Technical Components and Rationale

The EXO arm incorporates high-performance components, including Neo motors, REV Max tubes, SparkMax motor controllers, AndyMark breaker, and supercapacitors for batteries. These components were chosen for their reliability, power efficiency, and ability to support the arm's lifting capacity. The Neo motors provide the torque needed for lifting heavy weights, while the SparkMax controllers allow for precise control over the motors. The supercapacitors and batteries ensure the arm has enough power to lift weights effectively while also being protected from extreme temperatures ranging from -40 degrees Celsius to 80 degrees Celsius.

Element K: Reflection on the Design Project

Ultimately, the project, and resulting prototype created present a bright future for powered musculoskeletal implements in aiding a number of identified target groups (namely, those with musculoskeletal disabilities and injuries, heavy industry, and logistics). At a low-cost the team was able to produce a prototype, in an efficient time manner, that, when tested, enabled a were to substantially increase the maximum force that could be exerted without significant outside intervention or effort required to achieve such a result.

Looking back at the individual sections of this journey, broken down by element:

Element A:

Our problem identification was relatively simple, with just a single goal in mind: 'I want to be stronger,' which was expanded into a more thorough and nuanced justification of our issue, and how it affected several target groups, which was then verified by multiple of our mentors as a real, nuanced issue that required solving.

Element B:

This procedure was the most rigorous; over the course of a month, we documented, verified, and researched numerous existing solutions within the space of our solution; this process gave us the necessary knowledge to better define, understand, and develop our own solution. We took inspiration from various solutions that we found during this step, helping us during our prototyping phase to make a fully-developed final product.

Element C:

Our presentation of our solution acted as a collection of both Elements A and B into a final, finished product that presented both the problem at hand, and why it was an issue. However, we could have achieved a better grade on this section by focusing on our presentation's cohesiveness and argumentation as a whole: if a judge isn't willing to identify it as a problem based on what we present, why would our consumer?

Element D:

This was by far the most important step in our process, and absolutely essential to the following steps of our individual process. This was majorly successful in more than just what was apparent, besides providing us an idea of the mechanics and implementations behind our solution, it also allowed us to explore a large breadth of options beyond the general concept we had already brainstormed. Future groups should try to explore as many different options as possible, this is the last point during the project where solutions can be explored freely without a significant upfront material cost.

Element E:

Applying STEM principles was the second most important element, the engineering design process allowed us to iterate and improve over our design as we tested, encountering different challenges and conflicts within our original design that created a better product. Future teams must be able to properly apply this principle to create a finished and thorough product.

Element F:

This step allows us to identify the most viable of several designs, ranking based on elements we considered essential beyond just core functionality. Future teams will need this step to be successful, as it also allows us to identify how each solution numerically compares against others when compared.

Element G:

This step was the least straightforward, but also one of the most important--the first real feel and testing of our product that provided us with real, tangible, qualitative and quantifiable data on the performance of our prototype. This step was important because

Element H:

This step allotted us valuable physical quantitative and qualitative data that allowed us to make revisions on our prototype that improved the overall functionality. To future builders, this step should be completed with careful coordination such that the tests made reveal valuable information about the prototype.

Element I:

This step allotted us valuable physical quantitative and qualitative data that allowed us to make revisions on our prototype that improved the overall functionality. To future builders, this step should be completed with careful coordination such that the tests made reveal valuable information about the prototype.

Within the scope of this project, we found several areas where overall functionality of the core elements could be improved. One, in the attachment to the wearer's body, which was proven to cause more strain over time by cutting into the skin, this could be improved by increasing the overall surface area that the straps' force is spread over--stopping it from cutting into the skin. Two, in the control of the device--we planned to add a controller (raspberry pi) and encoder which would 'boost' the user in their desired direction of travel by detecting the change in velocity.

Element L: Presentation of Designer's Recommendations

For the exoskeleton arm prototype project, here are some detailed recommendations and improvement plans for future iterations:

1. Increasing Surface Area on Straps for Comfort

One important improvement would be to increase the surface area of the straps used in the exoskeleton. The current design has straps that may cut into the skin during use, leading to discomfort for the wearer. This can be addressed by utilizing wider straps or padding them with a soft, breathable material like memory foam or neoprene. The aim is to distribute the pressure more evenly across the arm and reduce localized discomfort, which will improve the overall user experience.
For implementation, the straps could be redesigned in CAD software to be wider, and prototyping could involve testing different types of padding to find the most comfortable combination. The team could also work with ergonomic specialists to ensure optimal strap placement and size.

2. Integration of the Control Unit and Encoder

A significant upgrade would be to incorporate the control unit and encoder into the device itself, rather than relying on an external laptop. This would make the exoskeleton more autonomous, streamlined, and portable, enabling users to use it without additional external devices.

The control unit and encoder should be miniaturized to fit within the exoskeleton's frame. Future iterations of the design could consider integrating these components into a single compact unit, possibly using flexible PCBs or custom enclosures to house the electronics. Testing the performance of the miniaturized unit would be necessary to ensure it does not overheat or cause malfunctions during prolonged use.

3. Streamlining the Wiring and Electronics

The current design uses a backpack to house the wiring and electronics, which can be cumbersome and aesthetically unpleasing. A more efficient solution would be to clean up the wiring by mounting all components onto a single, cohesive frame. This approach would make the device lighter, more comfortable, and visually cleaner, reducing the risk of wires tangling or being exposed to wear and tear.
The design can be modified to integrate the wiring into the main exoskeleton frame using cable

management systems such as clips, channels, or tubing. Careful attention should be paid to the placement of sensitive components to avoid strain or overheating. A more refined aesthetic can be achieved by 3D printing the frame to ensure both functionality and visual appeal.

4. Refining the Metal Bars with a Smooth 3D Printed Chassis

One of the key issues with the current prototype is the metal bars that could potentially cause discomfort or injury to the wearer. These bars should be shortened and replaced with a smooth 3D printed chassis that would be both safer and more comfortable for the user.

The metal bars can be cut down to a smaller, more ergonomic size, and a custom 3D printed casing could be developed to cover these bars. The 3D printed chassis could be designed with contoured shapes to prevent sharp edges, and it would also allow for more personalization and aesthetic flexibility. Furthermore, lightweight materials like carbon fiber or reinforced plastic could be used in the chassis to minimize weight while maintaining durability.

Conclusion:

In order to improve the exoskeleton arm prototype for future use, the project team should focus on enhancing user comfort, reducing the need for external devices and replacing them with internal control devices, and creating a more streamlined and aesthetically appealing design. These recommendations offer clear pathways for refining the prototype, ensuring that it is more user-friendly, functional, and commercially viable. The implementation plans are based on real-world solutions such as material selection, component miniaturization, and ergonomic design improvements, all of which can be tested and optimized in future iterations.

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Weight and Usability

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Appendix

Although we did not have time to implement, test, or add the Control Unit to our device--we created the following pseudo run on the Control Unit:

```
# Setup the CAN interface
Initialize CAN bus (e.g., "can0") for communication

# Define device IDs
motor_id = 1        # Motor ID for Spark Max
encoder_id = 2      # Encoder ID for feedback

# Function to send PWM signal to motor
Function send_PWM_to_motor(pwm_value):
    # Scale PWM from -1.0 to 1.0 into a valid range for CAN
(e.g., 0 to 255)
    pwm_scaled = Scale pwm_value from range -1.0 to 1.0 to 0 to
255

    # Create CAN message with PWM value
    Create CAN message with arbitration ID motor_id and data as
pwm_scaled

    # Send the message over CAN bus
    Send CAN message to bus

# Function to read encoder feedback from CAN
Function read_encoder_feedback():
    # Wait for incoming CAN messages
    Wait for CAN message

    # If message ID matches encoder_id
```

```
    If received message ID equals encoder_id:
        # Extract encoder data from the message
        encoder_value = Extract data from CAN message (e.g.,
position or velocity)
        Return encoder_value

    # If no feedback, return error or None
    Return None

# Main control loop
Loop:
    # Read encoder feedback
    encoder_position = read_encoder_feedback()

    If encoder_position is not None:
        # Print the current encoder position for debugging
        Print "Encoder Position: " + encoder_position

        # Control logic based on encoder position
        If encoder_position < -1000:
            # Move motor forward (e.g., set PWM to 0.5)
            send_PWM_to_motor(0.5)

        Else If encoder_position > 1000:
            # Move motor backward (e.g., set PWM to -0.5)
            send_PWM_to_motor(-0.5)

        Else:
            # Stop motor if within a target range
            send_PWM_to_motor(0)

    Else:
        # Handle case if no encoder feedback is received
        Print "No encoder feedback received"
```

```
    # Wait for a short period before next loop iteration (e.g.,
0.1 seconds)
    Wait for 0.1 seconds
```

This pseudocode outlines a basic control system for a motor using a CAN (Controller Area Network) bus interface. It initializes communication with two devices identified by unique IDs: a motor controller (motor_id = 1) and an encoder (encoder_id = 2). The system defines a function to send Pulse Width Modulation (PWM) signals to the motor, scaling values from a normalized range of -1.0 to 1.0 into a byte-compatible range (0 to 255) for CAN transmission. It then constructs a CAN message using this scaled value and sends it using the motor's device ID. Another function is dedicated to receiving and interpreting messages from the encoder, checking for matching message IDs and extracting position or velocity feedback from the message data.

The main loop of the program continuously reads encoder data to monitor the motor's position. Based on this feedback, it decides whether to drive the motor forward, backward, or stop it entirely. If the encoder reports a position less than -1000, the motor moves forward with a moderate PWM value. If the position exceeds 1000, the motor moves backward. When the position is within the acceptable range, the motor stops. This loop includes a short wait interval (e.g., 0.1 seconds) to pace the execution. The program also handles the absence of encoder data gracefully by printing a diagnostic message. Overall, the code exemplifies a simple feedback control loop in an embedded or robotics system using CAN communication.