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EVALUATION OF THE USE OF EXOSKELETONS WHILE PERFORMING DIFFERENT TASKS OF INDUSTRIAL WORKERS

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Abstract

Robotic exoskeleton technologies are one of the most active fields of robotics in recent years. Exoskeleton systems can give essential support for limb motions with enhanced strength and endurance, and they have a wide variety of therapeutic and supportive utility in life. These technologies have been extensively improved to be utilized for human power enhancement, worker injury prevention, human power assistance, and physical interface in augmented reality. Employees in the manufacturing and construction industries perform especially challenging duties, increasing their risk of health problems, disability, and medical leave, resulting in diminished job competitiveness and a shortage of qualified applicants. The usage of an exoskeleton might decrease muscular peak loads and lessen worker injury risks. This study includes a detailed analysis of employees wearing exoskeletons while doing various job-related duties. In this thesis the tests assess the benefits of adopting exoskeletons in lowering human muscular activity and, as a result, weariness, and exhaustion. Unlike industrial robots, robotic exoskeleton technologies must be carefully built since they actually interact with actual users. The study used two widely available exoskeletons named Eksovest, an upper-body exoskeleton, and LegX, a lower-body exoskeleton. The study includes five applications: shoulder height weight-lifting, wall drilling, and roof drilling positions for the upper body Eksovest, and virtual chair and knee position for the lower body LegX. This application evaluated electromyography (EMG) signals which were collected using EMG sensors on the human body as supportive tools. Furthermore, the investigations compare the different volunteer's body muscle data gathered by EMG sensors mounted on biceps, thigh and calf muscles. The work also evaluates the accuracies of the data collecting procedures used in this study. Based on this study, it is discovered that by employing these exoskeletons may reduce muscular activity by up to 60%, hence enhancing the workforce's work life by reducing load and stresses on their body. This research will assist to raise the awareness by the outcomes of SMEs about the use of exoskeleton.

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List of Abbreviations

EMG   Electromyography

ECG   Electrocardiography

ARV   Average Rectified Value

Cha   Channel

Hz   Hertz (unit)

ADC   Analog-to-Digital Converter

EXO   Exoskeleton

sEMG   Surface electromyography

CMR   Common Mode Rejection

EMI   Electromagnetic interference

RLD Amp   Right-Leg Drive Amplifier

PGA   Programmable Gain Amplifier

mV   Millivolt

Tx   Transmitter

Rx   Receiver

Wi-Fi   Wireless Fidelity

1 Introduction

Muscular discomfort and musculoskeletal issues can occur at any age in the human body. Every human body has several major regions that are damaged by working in the industry for an extended period of time in one posture. Wearable robotic exoskeletons are a type of robot that may be employed in industries to decrease muscular strain on workers' bodies. They are physically bonded to humans and execute duties near to them. The analysis of the strength of muscle contraction invarious volunteers while performing an industrial activity in a repeated manner with the assistance of a robotic upper-limb Eksovest and lower-limb LegX is provided [1].

The key advantage of using exoskeletons in the industrial sector is to decrease the number of work-related injuries. The human body cannot take the overloaded weight, stress which makes accidents during working time in the industries. But usingan exoskeleton can reduce work-related injuries in the industries a lot.

1.1   Background

The origins of Exoskeleton studies may be traced all the way back to 1890, with N. Yagn's purely theoretical design of a Robotic Exoskeleton [2]. He received a US allowance for his lower-limb enhancer model that comprises a lengthy bow that operates parallel towards the user's legs. This ideal model may aid persons in their walking, running, and leaping [2].

The exoskeleton, which first appeared in 1956, is a popular choice for persons who are disabled because as it may aid in the rehabilitation of stroke patients or industrialworkers who labor for extended periods of time. Exoskeletons have a robotic operating mechanism that allows humans to move weak or weary parts of the body similar to normal mobility by manipulating the input of the robotic Exoskeleton [3].

General Electric Research (Schenectady, NY) collaborated with Cornell University and received funding from the United States Organization of Naval Research to makea prototype of the full-body powered exoskeleton, in the deceased 1960s. The exoskeleton, dubbed "Hardiman" (from either the "Human Augmentation Research and Development Investigation"), was a massive hydraulically operated machine that included ingredients for amplifying the wearer's arms (along with hands but even without wrists) as well as legs. It envisioned dramatically increasing human power (25:1) [4] [5].

The Hardiman I Exoskeleton was developed like a combined Army-Navy system by General Electric Company throughout 1965. The Hardiman I was a full-body powered exoskeleton with 30 degrees - of - freedom and then a weight of 680 kilograms (1500lbs) [2].

Throughout the year 2004, the University of California, Berkeley's Human Engineering and Robotics Laboratory developed the 1st functioning energetically independent loadbearing human Exoskeleton (BLEEX). This Exoskeleton enhances the wearer's strength and flexibility while moving. The robotic exoskeletonof BLEEX's walking speed (up to 75 kg) is 0.9 m/s with payload and also 1.3 m/s without the load [2] [4].

At the beginning of the 21st-century exoskeletons hit the market and are nowadays itis available to a growing number of consumers. About users, it can be said that gait rehabilitation in stroke and also spinal cord injured patients were the initial users. TheLokomat exoskeleton was first made in 2021 and it was used for gait therapy and nowis utilized in hospitals and rehabilitation facilities throughout the world. Hocoma AG,the company behind the Lokomat, announced the shipping of the 500th unit in 2013 [6] [7].

Exoskeleton technologies could be used to enhance a user by applying external tension to the person's joints. Because the exoskeleton is now assisting the user, this has the ability to diminish the user's own muscular activity. Therefore, exoskeleton technology is being examined in a variety of job environments because it has the potential to minimize physical weariness and the danger of WMSDs by reducing muscular activity. The bulk of exoskeleton research has focused on the usage of backand shoulder supportive exoskeletons. Exoskeletons for both the back and shouldershave been demonstrated in experiments to minimize muscular activity and enhance endurance time when performing simulated job tasks [6] [7].

Active robotic exoskeletons are a much more aggressive technology that includes motors for movement and can assist personnel with lifting. Wearable exoskeletons are intended not only to increase employee performance but also to significantly reduce workplace injuries. However, through reducing professional injury for businesses across the country, we were able to validate our beliefs on the application of passive exoskeletons in the workplace.

The main experiment in this thesis is to evaluate two different kinds of exoskeleton which are eksovest and legX. As like the recent research in 2021 in the university of gavle and this was a thesis work about evaluating the advantages of a passive exoskeleton. Adding some new work with this thesis work, also upgrade some previous research work of this advantages evaluation work of passive exoskeleton. Using new processing and area under curve methods, find the efficiency of different working positions which are usually employees used to work in the industry for a long time, where the shimmer sensor was used with surface electrodes in muscle.

1.2   Purpose of Thesis

The industry demand for using exoskeletons in various working processes is growing, as their usage can ease the strain, minimize the incidence of work-related physical ailments, or increase labor performance and accuracy. Exoskeletons are wearable robotic suites that provide benefits to the entire body or a specific body part such as the arm, back, leg, knee, etc. Exoskeleton technology is now having a favorable impact on people who work in the industry. Wearing exoskeleton employees felt supported and were able to relax more in their bodies while doing job activities in the industry. So, the main purpose of this thesis is to evaluate the exoskeletons with some new working positions and upgrade the previous thesis research work which is done by Md Arifur Rahman at the University of Gavle about evaluation of the advantages of passive Exoskeleton in different working positions and also finds out the efficiency with using newly area under curve methods that can improve that exoskeleton suit is more valuable for workers' health. The previous work has some lacking with measurement system and also using peak value of graph for efficiency calculation of data, where taking the area under the curve is more effective on that research work which is used in this thesis work.

1.3   Sustainable Development Goals

In terms of sustainable development objectives, this project will address one target (9.1) and one significant goal (9) from Agenda 2030. The development of the exoskeleton technology and evaluation of the advantages are the main objectives. This initiative will assist industry, innovation, and infrastructure by providing industrial workers with support approaches. When financial expenditures and logistical issues with residents exacerbate the challenges, this technology solution assists industrial site management. Various working processes are convenient and economical to all types of industries, finally resulting in the development of quality infrastructure [8] [9].

This initiative stimulates another sustainable objective as the primary goal (3) from Agenda 2030, as well as the long-term implications. Various types of work positions in the industry cause a lot of health issues for employees. Wearable exoskeletons are increasingly being employed in physically demanding tasks to promote excellent ergonomics and boost muscular power, and they have the potential to lessen the global health crisis [8].

1.4   Apparatus and instrumentation

In order to set up the proper equipment, the thesis needed the selection of each component of the experimental setup to get the required result. As a result, in this part, a quick analysis of some of the equipment will be expanded. Finally, shall have a strong knowledge of their behavior and will analyze why those specific pieces of equipment were picked for this particular experimental setup. The name of the instruments are given below:

- Wearable lower limb LegX

- Wearable upper limb Eksovest

- Shimmer ConsensysPro Software

- Shimmer3 EMG Sensor

- Shimmer Dock

- Surface ECG Electrodes

- Biological Leads

- Body Straps

- MATLAB Software

1.5 Specific goal and deliverables of thesis

The objective of this study is to assess the benefits of Exoskeletons in industrial factories. This eventually leads to improved performance, particularly if the goals areset at a high level and embraced by staff. Specific goals of this studies are separatelygiven below:

- Evaluation of exoskeleton upper body eksovest for new position of weight lifting withtwo different weights for various spring levels.

- Exoskeleton upper body eksovest, upgrade the evaluation with new methods for roof drilling position with three different weighted drill machines with varied spring levels as previous researched.

- Upgrade the Evaluation of exoskeleton upper body eksovest for wall drilling position withthree different weighted drill machines for various spring levels with new methods.

- Exoskeleton lower body legX upgrade evaluation for chair position drilling with newly added for threedifferent weighted drill machines with the new data processing methods.

- Upgrade Evaluation of exoskeleton lower body legX for knee position drilling with newly added three different weighted drill machines with newly build process methods.

- Finally evaluate the statistical analysis with one volunteer data for five workingdays in a week.

1.6   Thesis Report Structure

This report is organized into six sections. The first chapter provides a brief background and overview of the Exoskeletons. It also examines how exoskeletons will become increasingly desirable for industrial employees on a daily basis. Furthermore, the major purpose, tools, and goal of the report are covered in thischapter, followed by outcomes during the thesis process.

Chapter 2 describes Exoskeletons, Shimmer sensors, and the most significant usable materials like Electrodes, and so on. It will provide more extensive information on how exoskeletons operate in our current industry, as well as some more theory regarding our experimental instruments. Throughout the study, we will also briefly cover EMG signals and their disruptions. Finally, discuss the Filter, which is used toprocess our data.

Chapter 3 describes in detail how this thesis works and how the experiment wascarried out. This Methodology is a precisely defined set of coherent procedures,flowcharts, and processes that establish how to effectively organize, execute, and deliver the thesis throughout the ongoing implementation phase until tasks are done.Also, define the modes and parameters required for Exoskeletons, as well as the internal circuit layout of the shimmer sensor using a block diagram.

Chapter 4 represents the entire thesis's obtained results and analyses. First, the eksovest analysis, in which volunteers engage in three distinct activities like lifting, roof drilling, and wall drilling utilizing various eksovest spring levels. Second, the legX study, in which the volunteer works in two distinct positions, chair and knee. Finally, the efficiency and statistical overview of the exoskeleton are defined in this chapter.

Chapter 5 provides a discussion of the relevance of thesis outcome results with respect to what was previously known about the research, as well as a brief examination of allthe data obtained in Chapter 4 with a comparability of all the settings under which thetests were conducted.

The end of Chapter 6 summarizes the entire thesis, and it discusses every aspect of this work. The future scope of this for improving Exoskeleton benefits for various applications is discussed more in this chapter.

2 Theory

2.1 Exoskeleton

The term exoskeleton refers to the tough, exterior skin of invertebrate creatures (bugs, spiders, crabs, and so on) that permits their bodies to maintain their shape without the need for an internal skeleton. Exoskeletons are generally wearable robots in robotics. They connect to the external of our body like skin and add some extra force to our muscles' typical activity. They range from simple suits that provide some support to our muscles (for example, for rehabilitation, army, and industry) to suits that allow users to lift big weights with relatively little effort [10].

2.1.1 Different Type of Exoskeleton

Nowadays lots of industries use this exoskeleton for their working purpose. Industrial exoskeletons are exoskeletons most of which are utilized in the workplace. They are designed to improve the performance of an employee's body components, mainly the lower back and upper extremities (back, arms, shoulders, leg, and knee). Industrial exoskeletons are mechanically affecting personal assistive devices that are meant to reduce the strain of physical tasks such as heavy lifting while minimizing the risks of musculoskeletal problems [11]. Types of industrial exoskeletons include:

2.1.1.1 Upper limb exoskeletons

The upper body, comprising the arms, shoulders, and torso, is supported by them. Back-assist exoskeletons that help employees maintain proper posture and support the lumbar spine performing lifting or static holding duties. Exoskeletons with shoulder-assist and tool-holding support are used to aid in the gripping of heavy tools or to support the upper extremities during prolonged overhead activity [11].

2.1.1.2 Lower limb exoskeletons

Legs, hips, and the lower torso are all supported by them. Leg-assist devices support the ankle, hip, or knee joint when moving or carrying a weight; or function as a substitute for something like a chair to give comfort from prolonged standing [12].

2.1.1.3 Full body exoskeletons

Full-body exoskeletons are intended to help the complete body with heavy applications. These kinds of exoskeletons are intended to give actuation torque to major joints such as the ankles, knees, hips, spine, shoulder, and elbows. Active full exoskeletons can support more commonly than passive exoskeletons [10].

2.1.2   Exoskeleton in Industry

Exoskeletons help in reducing the risk of musculoskeletal problems in workers, which cost businesses billions of dollars each year. Exoskeleton users experience reduced back and joint pain and are able to be more health-conscious both on and off the job.

While still operating in inefficient contexts, supply chains must deal with the rising volume of commodities required to fulfill orders. Exoskeleton technology allows businesses to avoid installing fully automated systems that take up a lot of space.

2.1.2.1   Vehicles Industry:

The assembly Line Workers of the Ford car company try to make the Exoskeleton as a Tech to Boost Performance. The upper body exoskeleton Eksovest from the supplier of Ekso Bionics helps the Ford companies workers with the position of overhead tasks. The working people who construct those trucks in Ford's factories are real beings with flaws. They may have lots of health issues like back and shoulder discomfort as a result of doing repeated duties in their occupations, especially if they operate on chassis hung above them. Some assembly workers, according to Ford, elevate their arms 4,600 times each day, or 1 million times each year [13].

2.1.2.2   Construction Industry:

The most important reason that why construction laborers utilize exoskeletons is to avoid injuries of body parts.

With the phrase "power without agony," this was Ekso's first product for industrial workers. While exoskeleton suits have often been a part of everyday life owing to their appeal in science fiction, this became one of the first items to make them a reality in customers' thoughts. This robotic system type was first employed on factory floors by industry heavyweights like Ford [14].

Workers may modify the grip and force delivered to each finger using the backpack, as the glove replicates natural human activity to increase strength and dexterity. Construction Laborers and architects in the building business may use gloves in virtually any situation to increase occupational safety since they are incredibly lightweight and portable [14].

2.1.3   Using Exoskeletons of this Thesis

The Eksovest is a kind of passive upper-body exoskeleton that is made from Ekso Bionics, and it is designed to elevate and support the user's arms while conducting chores from chest height to above position. Some commercial exoskeleton designs use lighter materials and also have a lower number of components [15].

Figure 2.1: Upper body exoskeleton-Eksovest

This transformation is clearly seen in exoskeletons meant to minimize the stresses placed on a user's shoulders. The Eksovest positions the power actuators in line onlywith the shoulder and elbow joint and transfers the arms force through into the pelvisusing a single bar aligned with both the user's spine and a crossbeam structure of pivot joints. In this study, a reduction in the maximum shoulder abduction range of motionhas been found in a different position, however, it concluded that the use of this exoskeleton can be beneficial for this type of task [15].

LegX is a brand name for two commercially marketed leg-supporting exoskeletons. In our thesis, the SuitX has been used for leg experiments. SuitX, which was foundedin 2012 and is based in California, creates robotic exoskeletons for the medical and industrial markets. Phoenix, the world's lightest and most sophisticated medical exoskeleton, was created by the business to assist patients with mobility issues. The legX has two operating modes: (dynamic) spring assistance and locked. The exoskeleton absorbs energy throughout knee contraction to cradle the person when descending to a crouched posture and distributes that energy during knee flexion to help supplements the muscles when rising to a standing posture in spring supportmode [16].

Figure 2.2: Lower body exoskeleton-LegX

In the mode of spring assist, the legX exoskeleton also includes two separate degreesof support, with varying amounts of supporting force delivered to the user. The degree of spring help may be changed to match personal desire or the worker's load. In the locked mode, whenever the user achieves a specified angle (110° of knee flexion), the user can successfully be seated, and the exoskeleton supports the upper body weight. The supporting force is delivered along the buttocks and shins of the users and transmitted towards the ground in both the mode of spring assist and locking. The locking mode is useful for static jobs, whereas the spring assistance mode is useful for dynamic tasks with varying work heights [16].

2.2 Using sensor of this thesis

A shimmer sensor is used in this thesis which is a kinematic sensor with integrated storage and a low-powerstandards-based transmission system that enables developing applications in motion capture, lengthy data collecting, and real-time monitoring. It contains a five-wire EMG Unit that can be set up to capture the electrical activity connected with skeletalmuscular activity and may be used to evaluate and monitor the kinematics of human or animal activity. Anyone who wants to utilize Shimmer gear to capture ECG (Electrocardiograph) data from their skin should do so [17].

2.2.1 Components overview and description

Shimmer3, the newest edition of the Shimmer technology, offers upgrades to theinitial model based on years of experimental studies and deployments that gather datathrough Bluetooth along with data on the Shimmer's SD card. In the below Shimmer3 sensor figure and some important components, a description is given.
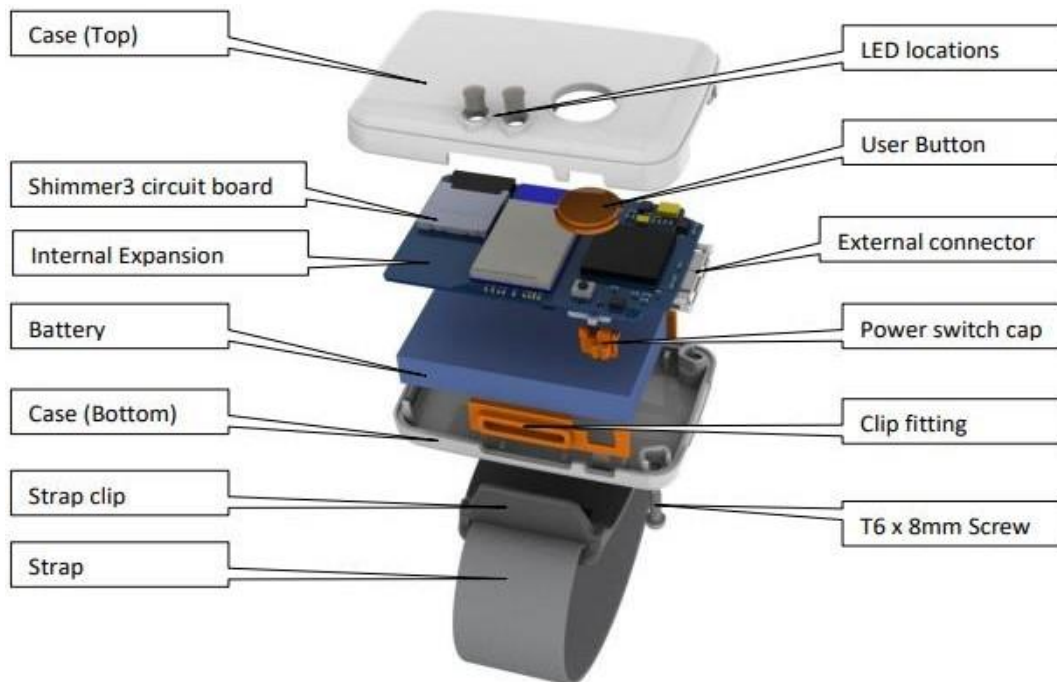

Figure 2.3: Exploded view of Shimmer3 [1].

Power switch: Shimmer devices are supplied from the factory pre-programmedwith LogAndStream programming although with the power turned off. Use the sliding switch to turn on the device [17].

Battery: The special battery bank named Lithium Polymer is used for charging Shimmer. This battery of Shimmer has a capacity of 450 mAh and it has a safe circuitboard that can protect the overflow of current [17].

User button: The Shimmer3 has an orange-colored user button whose purpose is determined by settings. It should be noted that this button doesn't always offer tactile input to users [17].

Shimmer LED Indicators: This Shimmer sensor has a total of two LED indicators which are controlled by the software. The lower indicator is tri-colored which is meant to reflect operating status (green, yellow, and red). The upper indicator is bi- colored (blue/green) and displays the data transmission mode [17].

MicroSD Card Socket: The Shimmer motherboard includes a microSD card slot for adding extra memory space with capabilities of up to 32GB. This enables extra data storage whereas the Shimmer is not able to stream and guarantees that data is not lost while mobile, throughout network disruptions, or while changing batteries.

When the device is in a USB dock or multi-charger, the EMG leads should not be put on the subject's body as a precaution [17].

2.3   Electrical activity Measurement- EMG Electrode

In living organisms, electrodes are now used to transform ionic currents into electrical currents. Surface electromyography (sEMG) signals are typically related to muscular activity and may be collected easily employing electrodes on the surface of the skin, just above muscles of significance. Traditional Ag/AgCl electrodes produce high sEMG signals [19]. The electrodes transform the ionic currents produced in the human body's basic units into electrical currents. They essentially serve as converters between ionic and electronic currents. A numerical method of the electrode and body might aid in our knowledge of how electrodes capture biological information. We must learn the processes that produce the propagation processes in between electrodes and also the physical figure while electrodes operate as receivers [20].

Surface electrodes composed of silver-silver chloride (Ag/AgCl) are used. That is surrounded by an electrolyte or body electrode gel with a resistance of 100 Ohm. This gel is known as a non-irritating gel with such a rear surround made of pre-gelled sticky components. The entire dimension of such electrode is 25 mm, on an inside electrode gel measuring 15 mm as well as the circular silver measuring roughly 10 mm. Those electrodes are latex-free therefore simple to make and withdraw out from the body [18] [20].

Each EMG board is linked to five working electrodes one of them is positive and another one is a negative electrode for every one of the two channels, as well as aneutral electrolyte. Everysingle electrode picks up interference from the surroundings as well as the electrical service signal from tissues at the point of contact with skin. The disturbance out fromsurroundings is shared by all electrodes, whereas the local electrical signal is dependent upon the location of the electrode. Therefore, when one signal is deductedfrom another, the general portion is deleted, and also the neighborhood signals (the desired EMG component) remain during reduction and may be enhanced to enable processing simpler [20].

For our thesis, some important recommendations must be needed while using electrodes.

a) The material of the electrode must be Ag/AgCl, and the optimal center-to- center inter-electrode spacing also is 20mm for both positive and negative electrodes. The size of the electrode should not be more than 10mm [18] [20].
b) When we start to measure, electrodes should not be put on a muscular tendon. When muscles approach their tendon position, the fibers becomenarrower and generate a lower-amplitude EMG signal [18] [20].
c) When we need to locate the electrodes, they should not be positioned on the muscle's sensory center. This produces erroneous data because the sound generated would be a sum of both nerve and musculoskeletal energy andhence does not always reflect muscle activity [18] [20].
d) The last recommendation is that electrodes should not be put on the body's outer borders. This raises the likelihood of going to pick up crossover signalsfrom muscles that aren't being monitored [18] [20].

2.4   Area Under the curve

The area circumscribed by the variable we're dealing with, vertical lines denoting the substring boundaries, and the x-axis is known as the area under the curve. The area under the curve of a constant random variable is shown in the graph above, and the interval denotes the method's vertical boundaries [21].
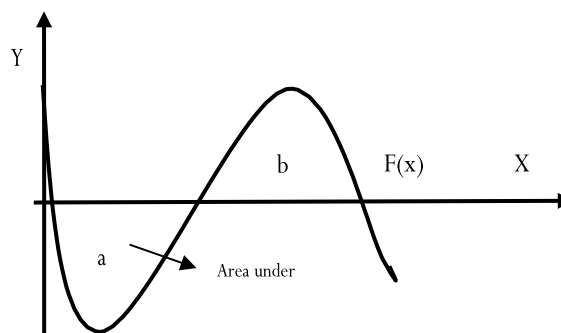
Figure 2.4: Area under the curve. [2]

The area under the curve of the constant variable, f(x), as depicted in the figure above. The function's vertical boundaries are represented by the range [a,b]. The zone must always be circumscribed by the x-axis [21].

Use the procedures below as a reference for computing the area under the curve of f(x):

Step 1: Draw the constrained rectangle on the diagram of f(x). When you're satisfied in your abilities, you may skip this stage.

Step 2: Draw the region's borders at x=a and x=b.

Step 3: Bring up the derivative in third step. Split the definitive integrals on the x-axis from those on the y-axis [21].

Step 4: Calculate the absolute value of the numerical method. If the area is discovered underneath the x-axis, use the absolute number value.

It will give the necessary instances that cover all of the area's conceivable stances: 1) the area under the curve above the x-axis, 2) the area below the x-axis, and 3) the area in both areas [21].

The limit for the provided curve, the area of the curve may be determined in regard to the various axes. The area under the curve may be computed in two ways: with regard to the x-axis and with relative to the y-axis. The line is under the axes in some situations, and partially under the axes in others [21].

Type of different area under the curve:

- Area with respect to the x-axis.

- Area with respect to the y-axis.

- Area below the axis.

- Area above and below the axis.

- Area of a circle.

2.5   Averaging the data

The term "average" is a basic one that has a variety of connotations. Either adding, multiplying, grouping, or dividing tasks between the elements in the collection determines the sort of averaging to employ.

The average is the amount which may be used to substitute each object while producing the very same results. If I can just discard my results and substitute this with a single "average" result [22].

There are several types of average for averaging the data. They are:

Name & Meaning	Formula / Example	Used for
Arithmetic Mean [average]	$\dfrac{sum}{size} = \dfrac{a+b+c}{3}$	Most situations ("average item")
Median [middle value]	Middle of sorted list (2 middles? Average 'em)	Wildly varying samples (houses, incomes)
Mode [most popular]	Most popular value	No compromises (winner takes all)
Geometric Mean [average factor]	$\sqrt[3]{abc}$	Investments, growth, area, volume
Harmonic Mean [average rate]	$\dfrac{3}{\dfrac{1}{a}+\dfrac{1}{b}+\dfrac{1}{c}}$	Speed, production, cost

Figure 2.5: Different type of averaging methods. [3]

One of the average's objectives is really to comprehend an information gathering by obtaining a random group. However, the computation is dependent on how the components in the group communicate with one another [22].

For averaging the data there are some advantages and disadvantages. Which are-

Advantages:

- It functions so efficiently for simple list like combinations or additions.

- It's simple to compute, simply add and divide [22].

- This is intuitive — this is the quantity "inside the center," driven up by high quantities and pushed lower by simpler pieces [22].

Disadvantages:

- Anomalies will affect the average, and it struggles with very disparate samples. The mean of 100, 200, and -300 equals zero, that is deceptive [22].

2.6   Data refining

Electromyography impulses are impacted by a variety of elements, including muscle structure and physiological processes, as well as a variety of external stimuli. As a result, EMG signals are vulnerable to a variety of disturbances. Interfering voltages produce damage in the measured signal. There are certain intrinsic sounds in thesystem that hinder its performance. When the signal-to-noise ratio is exceedingly low, it is problematic, if not difficult, to extract valuable information from the EMG signal. To minimize noises in EMG signals, numerous noise reduction techniques areapplied [23].

The most significant aspect of data refining processing is filtering. A filter is a device or method of processing that eliminates the majority of undesired signal disturbance or component features from an original signal or device. Filtering most usually entails removing any unneeded noise frequency or frequency bands from an original signal in order to identify exclusive true measurements data signal.To eliminate phase drifts, the filtering was designed to be applied to digital signals twice, in forwarding and reverse sequence of samples. It was created by combining eight in sequence filters, including a high-pass, a low-pass, and six stopband filters, and for main power inherent noise (60 Hz) and its first five harmonics [23] [24].

The Butterworth filter provides a much flatter frequency distribution in the passband,which is ideal for most analog pathways. The frequency response of such a higher- level Butterworth filter is smoother, and the signal attenuation further than the passband rises [23].

2.7   Risky Interaction

Interference is a basic characteristic of wireless communication systems; inside where numerous transmissions frequently occur concurrently across a single communicationlink. When we are going to collect the data, we can be found some unwanted interference and some of them are discussed below:

2.7.1   Motion Artefacts

The change in comparative location of electrodes towards the body is the most prominent phenomenon that leads here to motion artifact. It modifies the region of the contact area, induces muscle deformation, and produces effects in the interface surface produced by variations in the structural stiffness of the conductive gel orindeed the amount of sweat, resulting in electrical coupling. As a result, there is a lotof electrical signal disturbance. Motion artifacts produced during normal activities, notably movement, can even have amplitudes that are an order of magnitude higher than brain function signals. When dry electrodes are used in place of conductive gel electrodes, these abnormalities become much more prominent [25] [26].

2.7.2   Baseline Wander

Baseline wander is known as a low-frequency extraneous activity within ECG that can interfere affect signal processing, making clinical interpretation erroneous and incorrect. The addition of collecting rate increase, where baseline wander filtering is performed on a signal acquired at a considerably different frequency than the source ECG, can significantly decrease filter complexity. Altering the sampling rate entails two stages.

Because decimation eliminates the sensor's high-frequency information, a low pass filter that gives an approximation of something like the baseline wander substitution must be used to replace the baseline wander removal. After a baseline forecast has now been adjusted to the real sampling rate it may be removed from the actual signal, effectively high pass filtering it [27] [28].

2.7.3   Power line Interference

These interferences might be caused by stray switching current fields caused by holes in the patient's wires. Powerline interference seems to be a typical cause of disturbance and other biologic signals monitored from the muscle's surface. Based on the nation, such interference is distinguished by 50 or 60 Hz continuous interference, which may be followed by harmonics. This type of noise is characterized as narrowband noise, and it impedes visual examination of and automated segmentation operations.

Several strategies and approaches for eliminating such noise have been devised and reviewed, including band-stop FIR as well as IIR filtering, adaptive filters, estimated element subtraction, wavelet transform, and sophisticated algorithms that manage fluctuations in power line frequency [28].

2.7.4   Inherent Noise in Electronics Equipment

This is a kind of noise that is present in all kinds of electrical devices and this noise cannot be eliminated. This must be reduced by using higher-quality elements and sophisticated circuit designs. Electrical noise is commonly seen as an unwelcome disruption in which power intensity should be maintained as low as feasible in relation to signal power. Because of the broadband distortion component of presenting a quite lower power range, precision measurement is quite difficult. Erroneous signals within receivers at measurable frequencies must also be examined for and deleted on a regular basis, however, must electromagnetic disturbances in the research laboratory: PCs should be safeguarded, WiFi hotspots should always be disabled, and mobile phones should be turned off, and etc. Because of a similar reason, insulated cables with thoroughly cleaned, threaded connections should be preferable [29] [30].

2.7.5   Ambient Noise

This type of noise can be caused by electromagnetic radiation. The magnitude of this interference will be several times that of the perfect EMG signal. The participant's awareness is constantly linked to electromagnetic radiation from the outside. This is not that simple or quick to remove this blemish from the world's surface. If indeed the amplitude is large, a high pass filter is frequently used to lower it. [30].

2.7.6   Amplifier Saturation

The op-amp will saturate if the input voltage is increased too much or if the gain is increased too much. Although higher frequency interference from voltage converters or radio transmission does not directly damage the EMG signal, it might create other detrimental consequences like amplifier saturation. Improving the measuring equipment may help to reduce mistakes caused by flaws. However, reducing artifacts induced by the method of measurement itself can be accomplished by the application of methods that filters out all the artifacts while potentially leaving useful signal unaltered. This can be done through the use of hardware filters signal processing [30].

3 Process and Methods

This chapter provided a brief explanation of the experimental system. This chapter also discusses how the measurements were acquired from the various positions and setups. These approaches demonstrate the developing EMG system for evaluating the benefits of exoskeletons.

3.1 Volunteer description

Three healthy volunteers (Male) between the age of 27 and 33 (mean 30 ± 3) participated in this thesis data measurement. The weight of the subjects between (68-80), and their length was (160-173) cm. Before participating in the tests, all volunteers provided informed consent and said that they had no signs of orthopedic or neurological issues. Volunteers were chosen based on length, weight, and body size that the exoskeleton can fit all the volunteers' bodies and they can work as industrial workers. Volunteers were asked to drill on a board in a different position for different weighted drill machines by wearing LegX and Eksovest [31].

3.2 Measurement Task

The experiment entails the completion of a variety of activities meant to evaluate theimpact of utilizing exoskeletons in various job positions, as well as the versatility of the exoskeleton. Each participant performed the same task without the use of anexoskeleton. They are discussed in further detail below:

- Volunteer sits in chair position by wearing LegX and drills a wooden boardfor different weighted drill machines.

- Volunteer sits in knee position by wearing LegX and drills a wooden boardfor different weighted drill machines.

- Volunteer stands in one place and lifts the different weighted boxes by wearingEksovest.

- Volunteer stands in one place and holds the drill machine by wearing Eksovestand drill in the roof for different weighted drill machines.

- Volunteer stands in one place and holds the drill machine by wearing Eksovest and drill in the wall for different weighted drill machines.

- Finally take the data total of 5 days with both LegX and Eksovest in the samecondition for statistical analysis.

The major purpose of the task was to assess the possible benefits of the exoskeleton, which include reduced muscular strain, a greater comfort rating, and the ability tooperate for an extended period of time in one position while working in the industry.

3.3 Working Steps Flow chart

In below there is a flow chart that depicts the whole operation of the thesis study. Ourflow chart starts with the devices of the thesis and then Bluetooth was used to connect the sensor towards the device. Login to that same device and configure the sensor forinsertion in the user's body. In the following sequence, set up the ConsensysPro application for extra analysis. Following the installation of the exoskeletons, data collecting will begin, with sensor devices pre-processing the data. Shimmer outputs raw data, which is then processed using MATLAB. In the final phases, a data graph will be displayed to the user for an explanation [31].
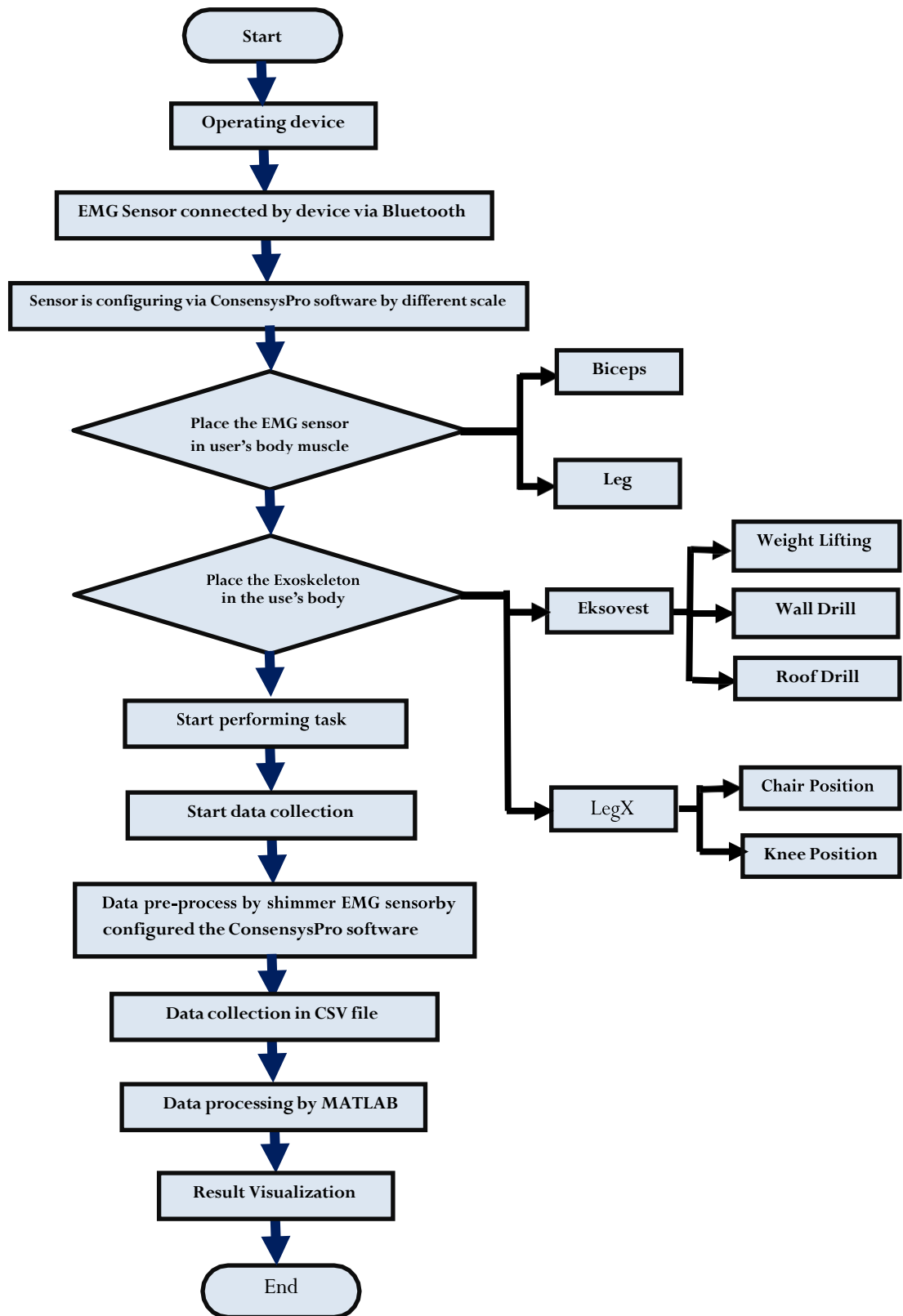
Figure 3.1: Flowchart of the working process.

3.4 Internal mechanism and component description of sensor

From the below internal circuit diagram of the shimmer sensor, we can see that each EMG board is linked with five electrodes by biological lead. There are two different kinds of ports in channel 1, where one is negative (Ch1N) and another one is positive(ch1P). Similarly, channel 2 also has two different ports, same as one is positive(Ch2P) and other one is negative (ch2N), as well as in middle there is a neutral reference electrode (Ref). The reason for employing three electrodes in this manner is because the amplitude of the EMG signal is often relatively tiny in comparison to noise. The signal collected from every single electrode comprises environmental noise as well as a local electrical signal from the muscles at the point of skin contact [17].

Electrodes: Every EMG board point connects to Ch2N (white), Ch2P (black), Ref (green), Ch1N (red) and Ch1P (brown) electrodes with biological leads [17].

Defibrillation protection: It merely survives and does not replicate itself. To allow Respiration demodulation, there is no defibrillation safety is included for inputs Ch2P and Ch2N [17].

EMI Filter: This filter works to reduce the electromagnetic interference and the 3dB filter bandwidth is approximately 3MHz [17].

Right-Leg Drive Amplifier (RLD Amp): Counteracts common-mode interference. The right-leg drive (RLD) options specify the voltage which must be utilized at the right-leg drive amplifier's inputs for common-mode disturbance reduction and maybe tuned separately for every chip. [17].

Programmable Gain Amplifier (PGA): This amplifier is used to increase input signal amplitude and here seven gain settings available are available. The default gain can be changed in software [17].

Analog to Digital Converters ($\Delta\Sigma$ ADC): These converts use for input analog signals to a digital representation of this signal by a 24-bit signed integer value to each sample. These values are supplied into the Shimmer3 processor, which either saves them to an SD card or sends them through Bluetooth [17].

3.5 Pre-Procedure of Collecting Data

Sensor setup has been done for two positions in our volunteer body. One is in the shoulder position and another one is in the leg, and for measurement, we use a surface electrode.

For the shoulder setup, the reference port of the shimmer sensor was placed in the solid bone of the hand. Two-port of channel 1 was placed on one side of the muscle and two-port of channel 2 was placed on another side of the hand muscle. For adjusting the sensor with hand body straps (small one) was used according to volunteers' hand width. This setup was used for eksovest.

For the leg setup, the reference port of the shimmer sensor was also placed in the solid bone of the leg which was a knee. Two-port of channel 1 was placed on the one side of muscle in leg and two-port of the channel 2 was placed on another side of leg muscle. For adjusting the sensor with hand body straps (bigger one) was used according to volunteer's leg width. This setup was used for LegX.

There are two versions in the shimmer sensor for use one of them is ConsensysBasic and another one is ConsensysPro software. In this thesis experiment, shimmer ConsensysPro software was used to collect the data. And for software applications some steps have been followed, which are given below:

Initially launch the software of 'ConsensysPro'. Then dock the shimmer sensor by using wire. Select the 'Manage device' and set up the program "FIRMWARE". After that select the settings of 'LogAndStream' firmware for collecting the data. Also, select the Shimmer that is used to experiment. Then need to select the tools of 'Configure' and select the section of 'EMG'. After selecting the name of Shimmer and sampling rate, select the gain and other preferred value from the toolbar for collecting EMG data. Click the button of 'WRITE CONFIG' for finishing the configuration. Press the NEXT button and undock the shimmer sensor from the dock of shimmer and connect with the laptop by using Bluetooth. Again, go to the settings of 'Live DATA' and need to click the live Wi-Fi symbol to connect and start steaming by using the button of 'steam'. Data then start to record directly in PC or shimmer SD card by the button of 'record'. Finally, 'Export' the data required place for experimental further processing [32].

3.6 Analysis the used Exoskeleton

The Exoskeleton has intended to provide a complete augmentation of strength at the joint level. A modular approach is used for the Embodiment tendon to make the system functional, versatile, and dependable. Exoskeletons for the upper body Eksovest and lower body LegX are already introduced in Chapter two. Each component can function individually and give help as required. Furthermore, each subsystem contains a number of elements that allow for joint-level support.

When employing an EMG sensor to determine the contractions level for executing an industrial work with an exoskeleton, the lower level the amplitudes have the better outcomes. Since when our body's contraction or energy is minimal, it indicates that we consume less power to execute tasks when using exoskeletons. However, when a similar task is performed without the exoskeleton, the amplitude is greater than the same job is performed while wearing the exoskeleton. Both exoskeleton components were compared in various scenarios using distinct data gathering methods. These methodologies analysis for subsystems is outlined below:

3.6.1   Eksovest

The upper body exoskeleton for our thesis is Eksovest, which is considered for using the biceps muscle to collect the data of EMG signal. In an analysis of Eksovest, it was considered two cases which are with using Exoskeleton and, without using Exoskeletons. The initial 1st case was also considered four levels of spring depending on use. Consider three more scenarios for each spring level: wall drilling positions, roof drilling positions, and weight-lifting positions.

In every scenario, these three places are taken into consideration for each spring level. Also, consider these three postures in the absence of an Exoskeleton. In these circumstances, the drilling position was altered into two points at the same time. The average width among these two places is 10 cm. Here, level-1 is the lowest level and level-4 is the highest level respectively. The second scenario does not partition any parts since no Exoskeleton is used to obtain data from the body. These standard data are used as a baseline against which the other instances are compared.
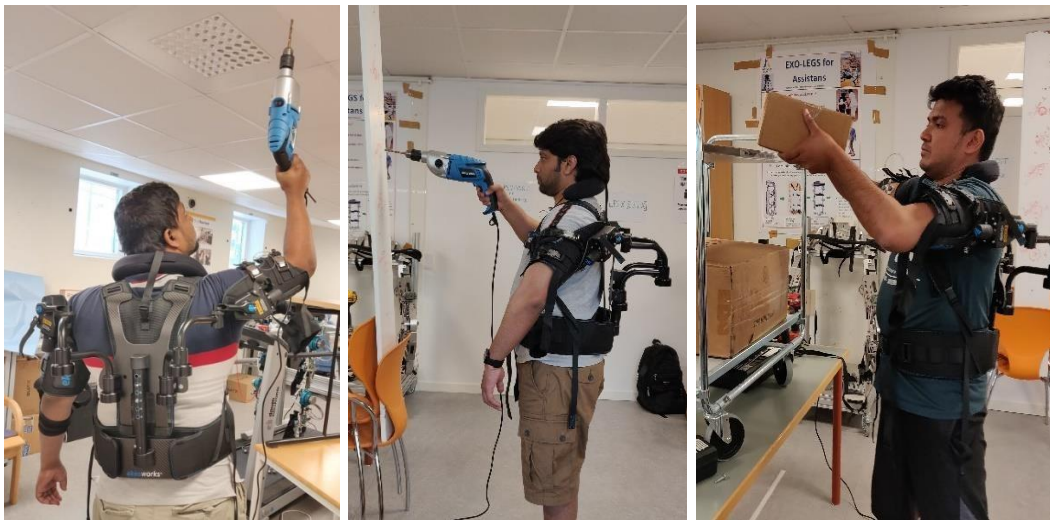
Figure 3.2: Roof drill, wall drill and lifting position for Eksovest.

In this case, three volunteer data were combined and analyzed in MATLAB, as well as the maximum and average value of the resulting graph to readily examine with oneanother. Each volunteer of these three situations EMG data was represented by its amplitude as well as indicated how and why the signals were modified by wearing the upper body - Eksovest which is evaluating with its amplitude value, and thus how in the future, exoskeletons will also benefit industrial employees and w

3.6.2   LegX

In this lower-body exoskeleton-LegX, also consider two different cases which are with using the Exoskeleton and, without using Exoskeletons. The first case considersbattery support with exoskeleton the second scenario does not partition any partssince no Exoskeleton is used to obtain data from the body. To acquire typical body data, it merely used the Shimmer EMG sensor module. These standard data are usedas a baseline against which the other instances are compared. Consider the chairposition and the knee position for both with and without an exoskeleton. Consider just wall drilling methods in these two positions, not others just like Eksovest. Because we want to analyze leg position using the exoskeleton lower body LegX.

Figure 3.3: Knee and chair position for LegX.

In this section, we will consider the battery support for the Exoskeleton LegX. Also,consider these two postures in the absence of an Exoskeleton. In these circumstances,the drilling position was altered into two points at the same time. The average width among these two places is 10 cm. In this case, three volunteer data were combined and analyzed in MATLAB, as well as the maximum and average value of the resulting graph to readily examine with one another. EMG data collecting from all of these twosituations were displayed by amplitude, which shows that the signal is modified by wearing the lower body- LegX with analyzing the amplitude value where try to provethat how in the future, exoskeletons will be suited for industrial workers in the future.

3.7   Area under work

Considering the equation of the curve, the boundary of the curve, and the axis containing the curve allows us to calculate the area under a curve. In general, we haveformulae for calculating the areas of conventional structures such as squares, rectangles, quadrilaterals, polygons, and circles, but there is no formula for calculating the area under a curve. The integration procedure aids in solving the problem and determining the needed area [21].

We will study how to obtain the area under the curve with respect to the axis, as wellas the area between a curve and a line, in this part. There are three simple proceduresthat may be used to compute the area under the curve. Initially, we must know thecurve's equation (y = f(x)), the bounds across which the area is to be determined, andthe axis encompassing the area. Second, we must determine the curve's integration. Finally, we must add the upper and lower limits to the integral solution and subtract the results to find the area under the curve [21].

$$\text{Area} = \int_a^b y.\,dx$$

$$= \int_a^b f(x).\,dx$$

$$= [g(x)]_a^b$$

$$= g(b) - g(a)$$

Collecting signal data for this experiment gives both relaxation and working data. Forevaluating the original muscle contraction only working are under every signal has been calculated for this thesis. This working area gives the efficiency of exoskeletonsvarious tasks [21].

3.8 Averaging the data

Obtaining an averaging or conventional input value might help you comprehend the information's key characteristics. Data averaging allows users to even see the schemes based of an information source by looking beyond stochastic fluctuations. There are numerous forms of averages, which should be noted right away. Every average does have its own purpose and provides a somewhat unique interpretation of a data set's primary pattern [22] [33].

In the data averaging, collecting all three volunteers' data and add them together. Then this data is called addition of all volunteer data. After that this data was divided by there because we need three volunteers' average data in one data line where one x-axis and one y axis. These data averaging is needed because we need analysis this data by area under curve where every point of data will be considered. Here, used the authentic mean analysis for better results of combination of every volunteers [33].

The arithmetic mean is an of the best frequent dataset averaging methods used during the computational and scientific sciences. The arithmetic mean is also known as the mean. Other means exist, however for the purposes of this essay, mean will relate to an arithmetic mean. A mean is computed by summing all of the database format's items and divide the total by the number of elements in the dataset. A mean total everything and distributes it fairly across all parts. Although the mean is simple to grasp and compute but is hardly beyond problems [22][33].

The most frequent form of average is the arithmetic mean:

$$\text{average} = \frac{\text{sum}}{\text{number}}$$

There three main reasons for analysis these averaging methods.

Which are:

- Data averaging could very well be employed to even out erratic results.
- The three main prevalent averages are the mean, median, and mode.
- On averaging scope values, MaxBotix advises using a median or mode.

3.9 Signal processing steps

This block diagram is a framework where the main sections or functions of this workare expressed by blocks connected together to form that demonstrate the blocks'connections.

```
1st    Collect Data
2nd    Amplification
3rd    Analog to Digital Conversion
4th    Filtering
5th    Average Rectification
6th    Result Visualization
```
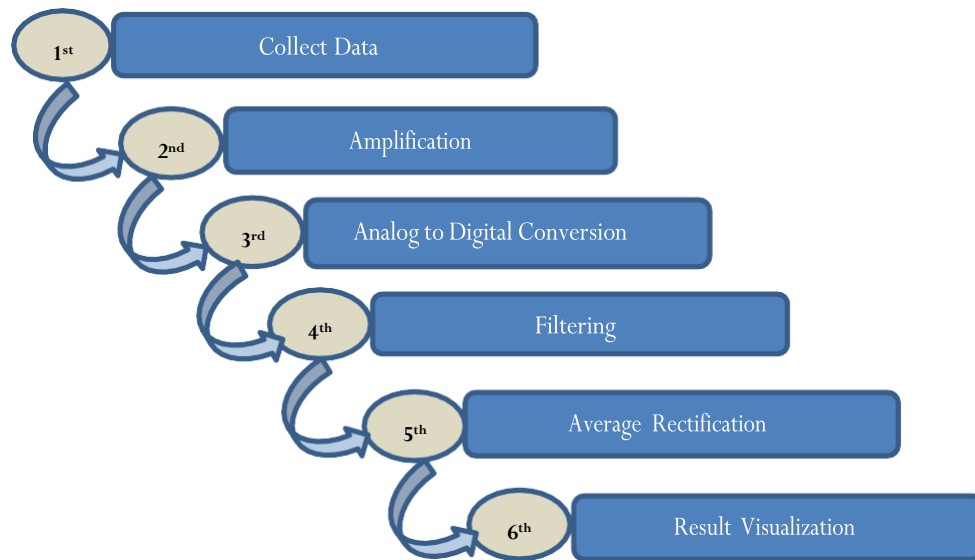
Figure 3.4: Block diagram for data processing

The preceding block diagram represents some of the processes required to complete the processing of our collected signals. We need to set up the sensor device with the participant's body initially. The raw data is then collected from various regions of thebody. The Shimmer EMG device automatically pre-processed data ready for final processing. Signal data was amplified during pre-processing since it was so much tinyto display visually. The amplified analog data is then converted into digital data by adedicated EMG device's Analog-to-Digital converter. The raw data of this device may be seen in the outcome of the Analog-to-Digital converter. These raw data were thenanalyzed again to provide the user with a final visual output. This raw data was filtered in order to remove artifacts and noise from the EMG signal. These data than average adjusted after filtering to produce the absolute value. At this final stage, the data wasdisplayed on the screen for such users to view the completed diagram for the EMG system.

3.10 Data Processing Analysis

The procedure of assessing data through quantitative or statistical methods to identify meaningful information is known as data analysis. After collecting the raw data, we also need some processing to analyze.

Step-1

For amplification, we know that it is a group of procedures used to increase the intensity of a signal. Whenever the normal signal output level of a sensor is judged to be much low, that time signal amplification is performed.

The amplifier is a kind of electronic device which can boost the amplitude of the signal. This electronic device has two-port, where the input port uses to deliver the signal from a power source to enhance the amplitude of a signal, the result of this signal with proportionately larger amplitude is shown at its output port. It can provide an amplifier's gain, output voltage ratio, current or power to input, and determines the degree of amplification [34].
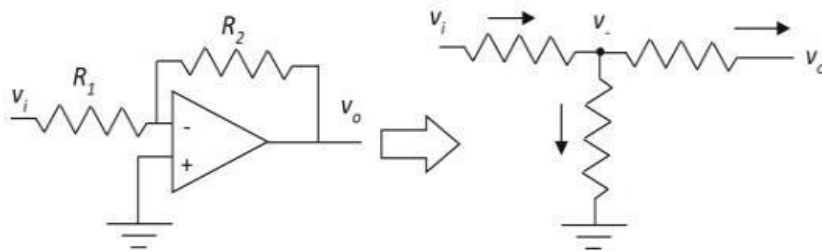

Figure 3.5: Circuit diagram of a basic amplifier. [4]

In our thesis, the collected electrical EMG signal is too low for a voltage potential in the system of EMG biofeedback, which is such a small as the range of microvolt. For this reason, our collected EMG signals data must need to be amplified appropriately that the data can be figured in an ordered manner [34]. For the amplification, we used the Shimmer3 EMG device, where we set the default gain of 12 by software tools. By using this amplification gain, our signal data represent the larger quantity signal, and signals which are measured after amplification are visually displayed perfectly to the user [34].

Step-2

An analog-to-digital converter (ADC) is one kind of electronic device which convertsthe analog signal into the digital format which can be read and analyzed by amicrocontroller. ADC converters are currently incorporated into the majority of microcontrollers. An external ADC converter may also be connected to any sort of microcontroller [35].

The process of ADC conversion must be initiated mostly by user software, and conversions might take multiple microseconds to perform. Once the conversion is finished. As most sensors in real life provide analog output voltages, ADC converters are extremely helpful in real-time applications [35].

For this thesis, the output of two amplifiers was routed to a delta-sigma analog-to- digital (ADC) converter, that must need to convert the analog input data into digital signal data, which can allow the raw data graph to be shown on a computer screen.

Step-3

EMG signals are vulnerable to interference, for this reason, high-quality filtering forthe signals from nearby muscles is necessary, which can be supplied by the Butterworth filter, and it has a smoother nature [29].

A second-order high-pass Butterworth digitized filter with such a cutoff frequency using 10 Hz as well as an eighth-order low-pass Butterworth digitized filter with sucha cutoff frequency using 400 Hz were created to attenuate movement artifacts and inherent measurement noise. The above cutoff frequencies are being used because thegastrocnemius in calm standing produces a very low magnitude and also the power EMG within these parameters [30].

In our thesis because of the sampling frequency is 1024 Hz, we used 20 Hz for the high-pass butter worth filters to reduce low frequency and for the lowpass filter, used400 Hz to eliminate the high frequency from the gathered EMG raw data signal, which is much better to exhibit the final visualization graph for this thesis.

Step-4

The rectified amplitude of an external dc represents the quantity of charge conveyedby the same Dc supply as averaging over time, a rectified alternating current.

The alternating current (AC) is changed into a dc power from any kind of electrical energy by develop of the full-wave rectification in our data processing part. Even during the full-wave rectification process, both positively and negatively parts of thealternating current would be converted into a single positive dc electrical signal [36].

In addition, in the field of engineering, the average rectified value (ARV) is a numberderived from the signal's average actual values. The ARV is primarily also used to differentiate and certify Ac / Dc voltage. This process of ARV is quantified by averaging the exact value of the waveforms throughout a whole wave period. [36].

A Full-wave rectification and as well as average rectifier value are both employed inthis thesis work for the rectification of our EMG filtered data. After using the high- pass butter worth filtered for the data value of this work is corrected, which is also shown as a feedback result on the visible screen.

Step-5

To show the result, there are many ways to represent the results like audio and visual. This work used the visual way as a envelop graph. The most important fact is thatresults must have contained necessary information which is understandable and readable to users.

Recently, average linear envelopes have been employed in gait analysis to represent and analyze EMG signal data. This graph effectively illustrates profile-level work that has been standardized in terms of both time and amplitude. We are thought to besignificantly effective for eliminating many of the random features of the visual depiction of EMG patterns since we operate with real-time data [37].

The envelop data graph for results is depicted in the image above. It considers one channel for gathering this data graph, and this graph depicts our volunteer's muscular contraction during the time of training and the muscle has been relaxing after completing the one training period. In this case, the x-axis represents time in secondsand the Y-axis represents amplitude in millivolts. The envelop graphs shown above depict the final step graph, which is utilized in other sections of the analysis for EMGdata signal to evaluate the effectiveness of exoskeletons [37].

4 Results and Analysis

This chapter will provide a rapid summary of the key findings, which are separated into three sections based on the kind of study, qualitative and quantitative. Experiments were performed in order to assess the efficiency of the exoskeleton.Three strong young volunteer individuals performed identical upper-limb and lower-limb actions with the help of an exoskeleton robot in the studies.

4.1 Eksovest Analysis

In this section, we discussed upper body eksovest and analyzed the different workingpositions of industrial workers with EMG data graphs and tables. We consider three types of working positions for analyzing the eksovest properly. These positions are weight lifting, roof, and wall drilling positions respectively. In this analysis, we consider three volunteers as one by one for every position. We describe every position details more briefly below:

4.1.1 Weight Lifting

For analysis of the weight lifting position, we consider two types of weight which are5kg and 10kg. Here, we use four different springs from Level-1 to Level-4 and also took one data signal without wearing eksovest. Level-4 is the highest spring level which gives the highest amount of support and Level-1 is the lowest spring level which gives the lowest amount of support.
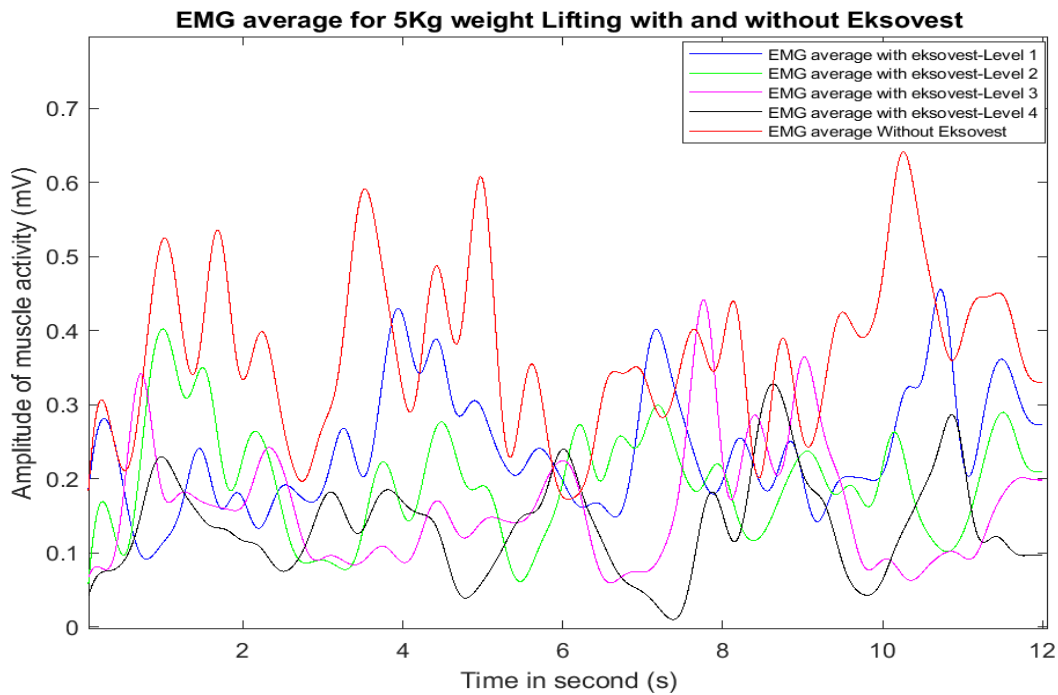

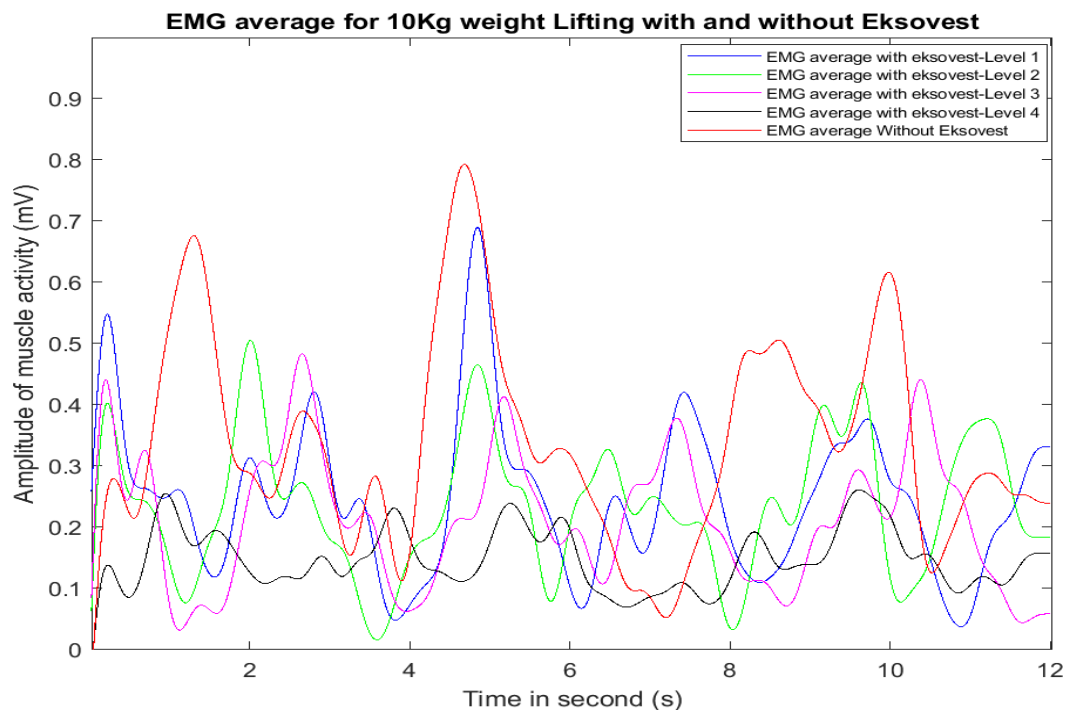*Figure 4.1: 5kg weight lifting graph for Eksovest.*

Figure 4.2: 10kg weight lifting graph for Eksovest.

Figures 4.1 and 4.2 represent the EMG average signal graph for eksovest Weight lifting positions. In both, the graphs have five types of line graphs. These line graphsare representing the EMG average line data graph for all three volunteers together. Inthese graphs, X-axis illustrates the time in second and Y-axis represents the amplitude of muscle activity in mV. As like, the black line graph shows the average data line graph for all three volunteers using spring level-4 for weight lifting position for 5kg and 10 kg respectively inside both graphs.

Similarly, Level-1 blue line graph, Level-2 green line graph, Level-3 yellow line graph are also showing EMG average signal for three volunteers weight lifting positions for5kg and 10kg respectively. In our analysis, which line graph has the lowest average amplitude, it has the highest efficiency because it saves a high amount of energy, andwhose has the highest amplitude, it has the lowest efficiency because it saves less amount of energy.

On the graph, all the signals show the muscle contraction for a working time as well as the relaxation time. For calculating the efficiency here use only the working area of the graph that can know how much of the efficiency conform to the average. For more deeply evaluation we consider a table that considers weight lifting positions fortwo different weights with four spring levels.

	Lifting			
	5 kg Weight		10 kg Weight	
Spring Level	Average Area(mV)	Efficiency (%)	Average Area(mV)	Efficiency (%)
Level 1	0.8990	36.2%	1.0366	30.9%
Level 2	0.7801	44.6%	0.8622	42.5%
Level 3	0.6784	51.8%	0.7456	50.3%
Level 4	0.5316	62.2%	0.5990	60.1%
Without Exo	1.4100		1.5015	

Table 4.1: Efficiency calculation of Eksovest - weight lifting

The above table 4.1, shows three columns where 1st column illustrates the spring levels with or without exoskeleton and 2nd and 3rd column shows two different weights respectively. In 2nd and 3rd columns are also divided into two sub-columns which are represented the Average value of the working area and the efficiency of this average working area for different spring levels where without exoskeleton value as our reference value. A more clear analysis is given in the next chapter which has a discussion with the efficiency bar graph. For calculating this efficiency, we use an equation which is given below:

$$Efficiency = \frac{Average\ value\ of\ Without\ ekso - Average\ value\ of\ with\ ekso}{Average\ value\ of\ Without\ ekso} \times 100$$

4.1.2   Roof Drilling

In this section, we analyze the roof drilling position using three different weight drilling machines: 2kg, 3kg, and 4kg. In this case, we also used four different springs ranging from Level 1 to Level 4, as well as one data signal without the use of aneksovest. Level-4 is the highest spring level with the most support, while Level-1 is the lowest spring level with the least amount of support, as in the prior example.
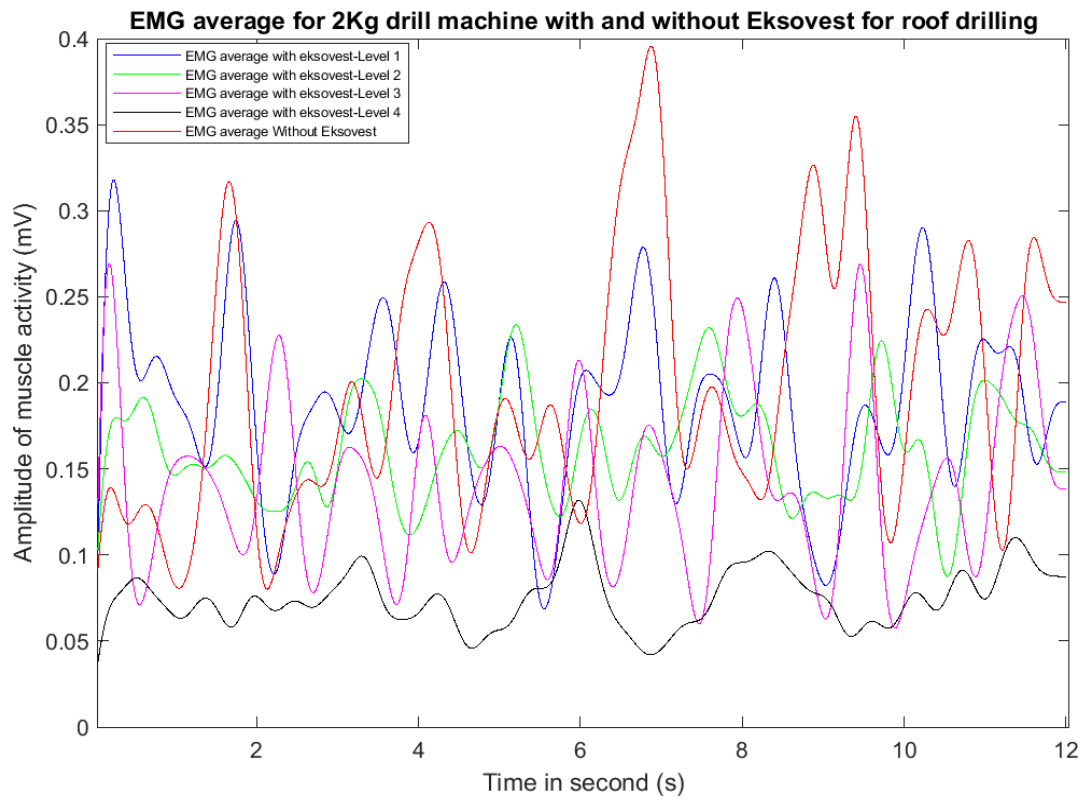
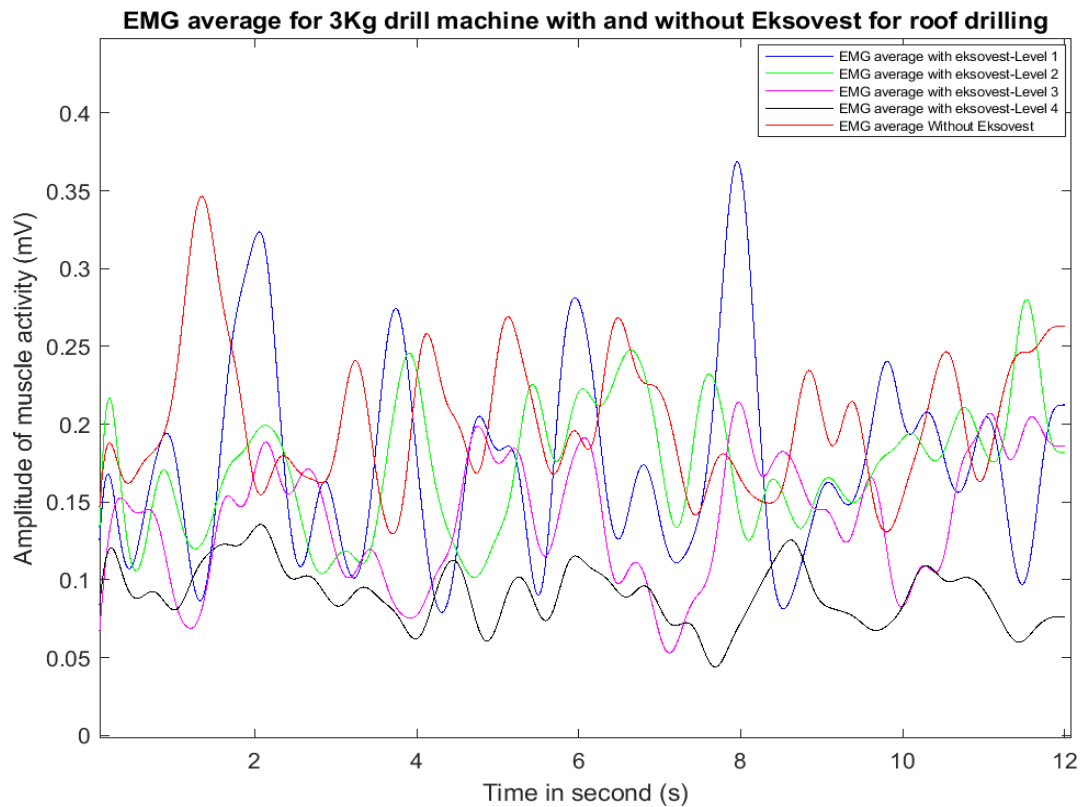*Figure 4.3: Roof drilling graph of Eksovest for 2 kg drill machine.*

Figure 4.4: Roof drilling graph of Eksovest for 3 kg drill machine.

EMG average for 4Kg drill machine with and without Eksovest for roof drilling
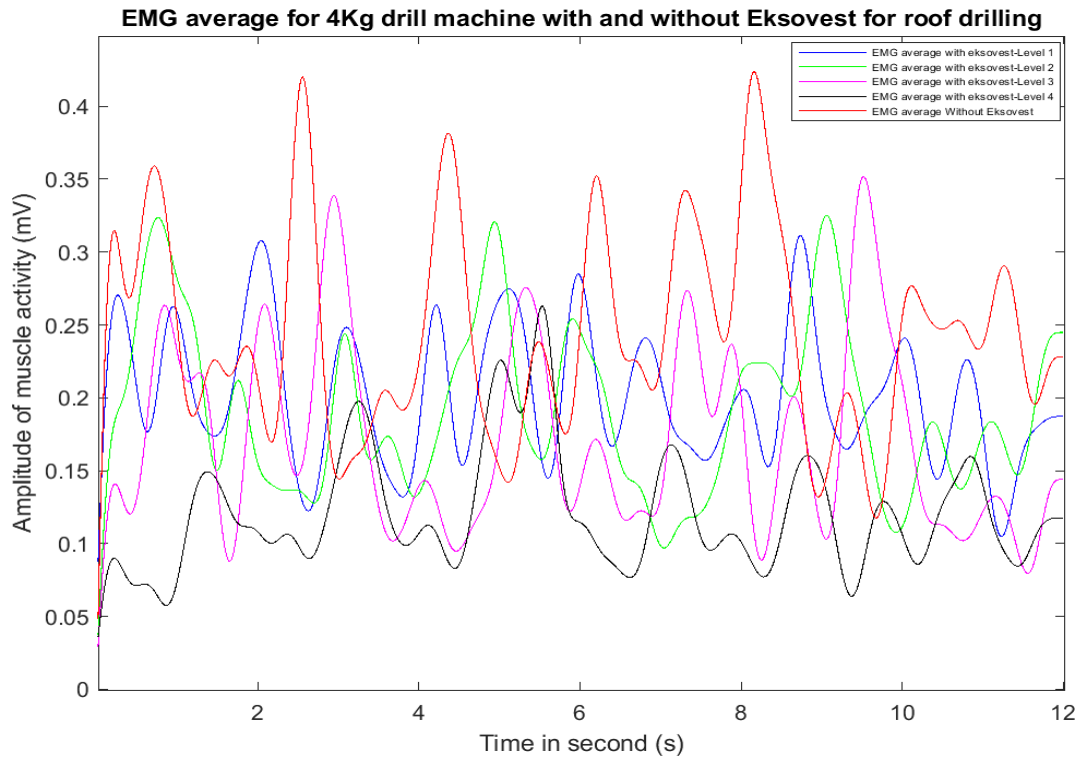
Figure 4.5: Roof drilling graph of Eksovest for 4 kg drill machine.

The EMG signal graph for Eksovest roof drilling positions is depicted in Figures 4.3,4.4, and 4.5. There are five different types of line graphs in all of the graphs. These line graphs provide the EMG average line data graph for all three volunteers combined. The X-axis in these graphs indicates the time in seconds, while the Y-axisshows the amplitude of muscle activity in millivolts.

As explained previously, the blue line graph illustrates the average data line graph forall three volunteers using level-1 springs at roof drilling positions of 2kg, 3kg, and 4kg, respectively. Level-2 green line graph, Level-3 yellow line graph, and Level-4 black line graph all exhibit EMG average signal for three volunteers' roof drilling positions for all weight drill machines. In our analysis, the line graph with the lowest average amplitude has the best efficiency because it saves the most energy, while theline graph with the highest amplitude has the lowest efficiency because it saves the least amount of energy.

All of the signals on the graph represent muscular contraction for a working time as well as relaxation time. Here, just the working region of the graph is used to calculateefficiency so that we can see how much of the efficiency conforms to the average. Fora more thorough examination, consider the following table, which considers roof drilling sites for three distinct weight drill machines with four spring levels.

35

Spring Level	Roof Drill					
	2 kg Weight		3 kg Weight		4 kg Weight	
	Average Area (mV)	Efficiency (%)	Average Area (mV)	Efficiency (%)	Average Area (mV)	Efficiency (%)
Level 1	0.7732	32.3%	0.8210	31.4%	0.9964	30.6%
Level 2	0.5715	49.9%	0.6401	46.5%	0.7706	46.3%
Level 3	0.4896	57.1%	0.5701	52.3%	0.7002	51.3%
Level4	0.3982	65.1%	0.4328	63.8%	0.5736	60.1%
Without Exo	1.1425		1.1961		1.4353	

Table 4.2: Efficiency calculation of Eksovest - Roof drill.

In above table 4.2, the first column depicts the spring levels with or without exoskeleton, while the second, third, and fourth columns indicate three different weights, respectively. The second, third, and fourth columns are further separated into two sub-columns that indicate the average value of the working area and the efficiency of this average working area for different spring levels where we use the value of the exoskeleton as our reference value. The next chapter provides a more detailed study, which includes a discussion of the efficiency bar graph. We apply the same equation as in our prior scenario of weight lifting to calculate this efficiency.

4.1.3 Wall Drilling

In this section, we illustrate and analyze the wall drilling position, and in this instance, we examine three different types of weight drilling machines, which are 2kg, 3kg, and 4kg, respectively. In this case, we also used four different springs ranging from Level 1 to Level 4, as well as one data signal without the use of an eksovest. Level-4 is the highest spring level with the most support, while Level-1 is the lowest spring level with the least amount of support, like in the roof drilling scenario.
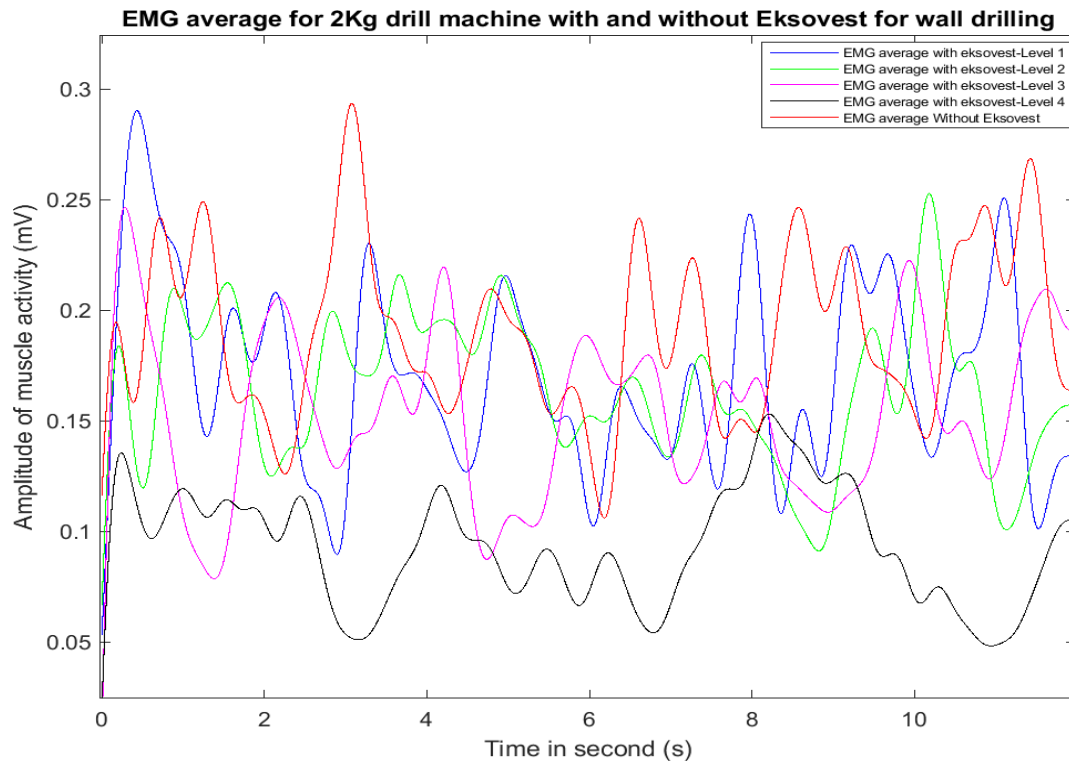
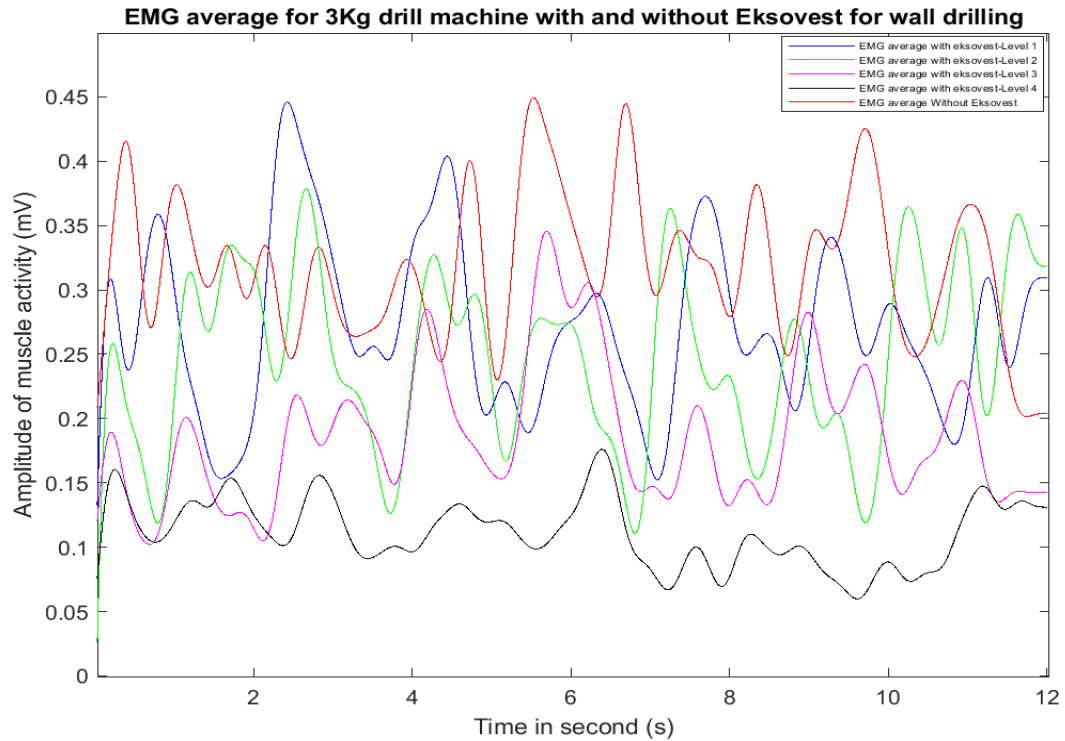*Figure 4.6: Wall drilling graph of Eksovest for 2 kg drill machine.*

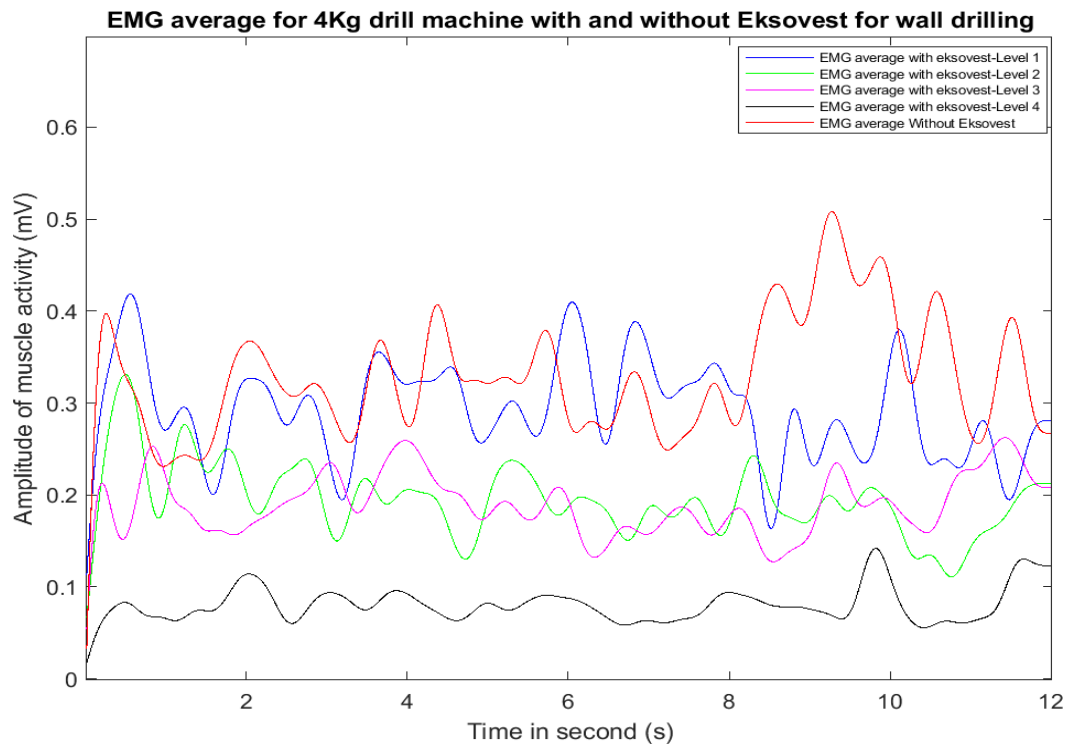*Figure 4.7: Wall drilling graph of Eksovest for 3 kg drill machine.*

Figure 4.8: Wall drilling graph of Eksovest for 4 kg drill machine.

Figures 4.6, 4.7, and 4.8 show the EMG signal graph for eksovest wall drilling locations. All of the graphs have five distinct types of line graphs. The EMG averageline data graph for all three participants is provided by these line graphs. The X-axis in these graphs represents time in seconds, while the Y-axis represents muscle activity amplitude in millivolts. The green line graph, as previously indicated, displays the average data line graph for all three volunteers using level-2 springs for wall drillinglocations of 2kg, 3kg, and 4kg, respectively.

All the different colored line graphs mention EMG average signal for four volunteers as the same as before the roof drill using all weight drill machines. According to our findings, the line graph with the lowest average amplitudehas the most efficient because it saves the most energy, while the line graph with thehighest amplitude has the lowest efficiency since it saves the least amount of energy.

All of the signals on the graph show muscle contraction during both working and relaxing times. In this case, only the working zone of the graph is utilized to measureefficiency, allowing us to observe how much of it conforms to the average. Considerthe following table, which analyzes wall drilling locations for three different weight drill machines with four spring levels.

| Spring Level | Wall Drill | | | | | |
| | 2 kg Weight | | 3 kg Weight | | 4 kg Weight | |
	Average Area (mV)	Efficiency (%)	Average Area (mV)	Efficiency (%)	Average Area (mV)	Efficiency (%)
Level 1	0.7597	34.5%	0.8129	32.6%	0.8737	31.5%
Level 2	0.6290	45.8%	0.6630	45.08%	0.7137	44.03%
Level 3	0.5219	54.9%	0.5531	54.1%	0.6023	52.7%
Level4	0.4079	64.8%	0.4379	63.7%	0.4934	61.3%
Without Exo	1.1597		1.2074		1.2751	

Table 4.3: Efficiency calculation of Eksovest - Wall drill.

The first column in Table 4.3 displays the spring levels with or without an exoskeleton, whereas the second, third, and fourth columns represent three various weights, respectively. The second, third, and fourth columns are also subdivided into two sub-columns that represent the average quantity of working area and the efficiency of this average working area for various spring levels, with the value of the exoskeleton serving as our reference value. The following chapter goes into further detail, including a description of the efficiency bar graph. To determine this efficiency, we use the same equation as in our previous instance of weight lifting.

4.2 LegX analysis

In this section, we examined lower body LegX and analyzed diverse manufacturing industry worker working positions using EMG data graphs and their efficiency table. To thoroughly analyze the LegX, we considered two sorts of working positions. These are the chair drilling position and the knee drilling position, respectively. In this analysis, three volunteers are considered one after one for each position. We briefly outline each position in further depth.

4.2.1   Chair Position

The volunteers' exoskeleton suit was assessed at the start of each research, and they were permitted to operate the exoskeleton for several seconds while selecting a battery support level. After that, the subjects were fitted using electrodes to guarantee that the exoskeleton straps and hardware did not interact with the electrodes throughout testing. Once this setting was confirmed, the exoskeleton parameters were collected, and thus the exoskeleton was donned to acquire a reference for every muscle group.

In this part of the analysis, for the chair position, we consider three types of weight drilling machines which are 2kg, 3kg, and 4kg. In this case, we additionally consider the volunteers' only wall drilling for the chair position. LegX lacks any form of spring level. It includes a long-lasting battery that allows it to function in various positions. We collected one data signal while wearing the LegX and one data signal while not wearing the LegX.
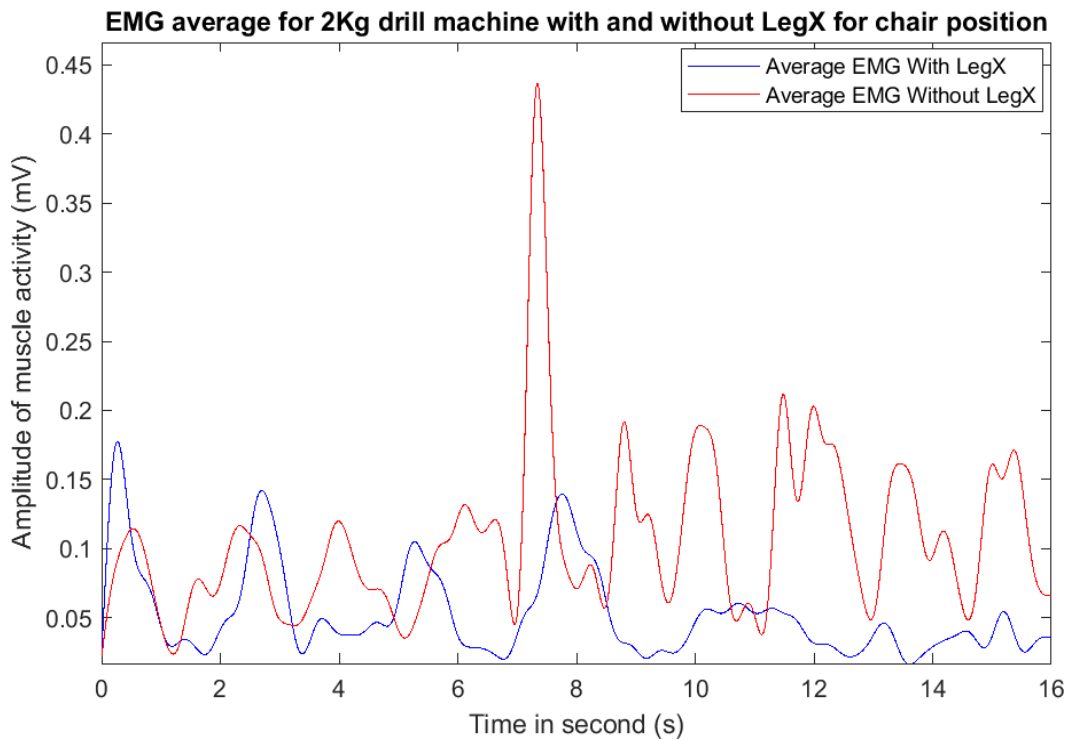

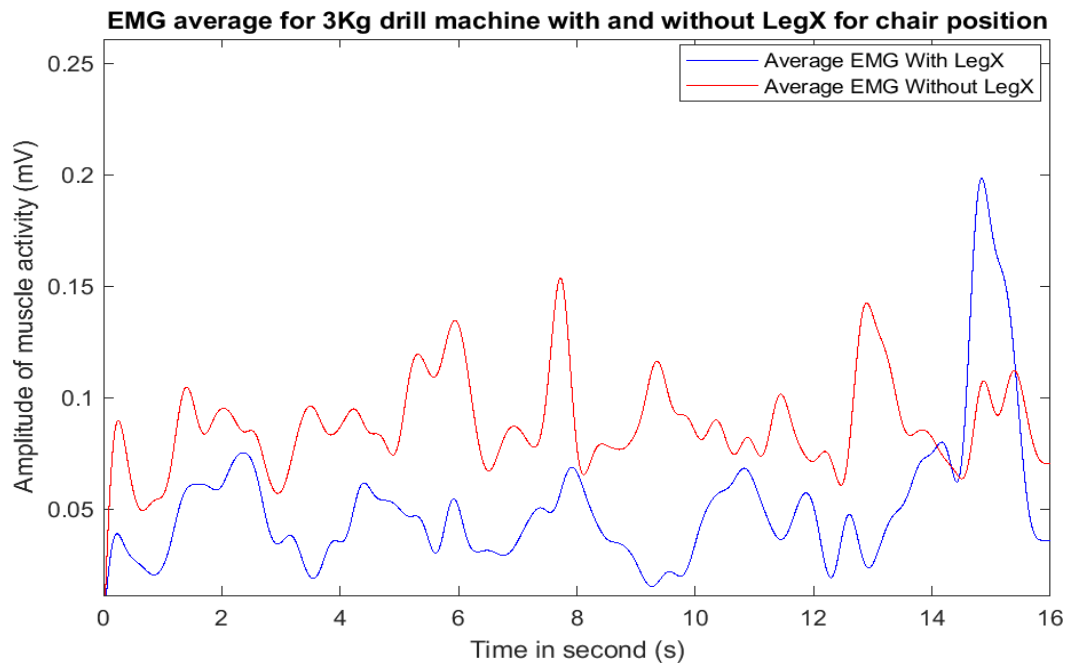*Figure 4.9: Chair position graph of legX for 2 kg drill machine.*

Figure 4.10: Chair position graph of legX for 3 kg drill machine.
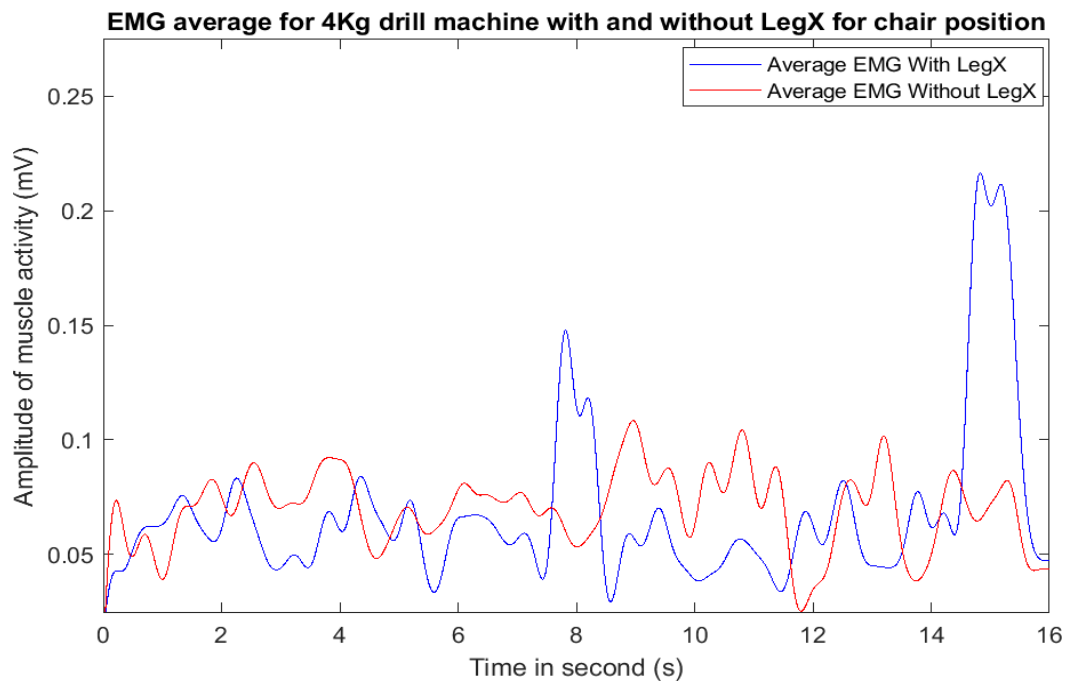
Figure 4.11: Chair position graph of legX for 4 kg drill machine.

Figures 4.9, 4.10, and 4.11 show the EMG signal graph for LegX in the sitting position during wall drilling. All of the graphs have two types of line curves. These line graphs provide the average EMG line data graph for all three participants, with and without LegX. The X-axis in these graphs represents time in seconds, while the Y-axis represents muscle activity amplitude in millivolts.

Furthermore, the blue line graph shows the average data line graph for all three volunteers who used LegX for chair position at 2kg, 3kg, and 4kg, respectively. Similarly, the red line graph represents the EMG average signal for all three volunteers when drilling in the chair position for each weight drill machine.

In our evaluation, using LegX has the lowest average amplitude but the highest efficiency because it saves the most energy from our leg, whereas not using LegX has the highest amplitude but the lowest efficiency since it saves the least amount of energy.

For a more detailed study, we look at a table that takes into consideration chair position drilling for three distinct weight drill machines.

Weight of drill machine	LegX-Chair Position		
	With LegX (mV)	Without LegX (mV)	Efficiency (%)
2 kg	0.4527	0.9144	50.5%
3 kg	0.4077	0.7744	47.4%
4 kg	0.4169	0.7564	44.8%

Table 4.4: Efficiency calculation of LegX - chair position

Above table 4.4 shows four columns: the first column shows the weight of the drill machine, the second and third columns show with and without LegX, and the fourth column shows the efficiency. The average value of the working area is represented in the second and third columns, and the fourth column shows the efficiency of this average working area for different chair positions with and without wearing LegX, and this without LegX value is used as our reference value for calculating efficiency in the fourth column. The following chapter goes into further detail, including a description of the efficiency bar graph. We utilize the same equation as in our prior scenario in eksovest to calculate this efficiency which is given below:

$$Efficiency = \frac{Average\ value\ of\ Without\ LegX - Average\ value\ of\ with\ LegX}{Average\ value\ of\ Without\ LegX} \times 100$$

Exoskeletons that provide supporting force somewhere at the knee may also be able to minimize muscular activity in the muscles all over the joint of the lower leg throughout squatting positions. Reduced muscular efforts should minimize compressive strain at the knee joint as well. It is thus predicted that the usage of legX may decrease squatting pain as well as suffering, and also the chance of acquiring knee illnesses such as knee arthritic or meniscal damage.

4.2.2   Knee Position

The exoskeleton manufactured for the leg is meant to be aligned with the user's knee unit. A comfortable seat is placed on the user's posterior and exactly when the legX delivers a supportive force towards the user while the user is squatting. Every activity and scenario combination offered in the experiment has been done for each participant member. This would lead to a more accurate representation of working in genuine situations.

In this section of the result, for the knee position, we also consider three types of weight drilling machines as like chair position, which is 2kg, 3kg, and 4kg respectively. In this case, also we additionally consider the volunteers only wall drilling for knee position. LegX has no use of any form of spring level. It includes a long-lasting battery that allows it to function in various positions. We also collected one data signal while wearing the LegX and one data signal while not wearing the LegX as like chair position.
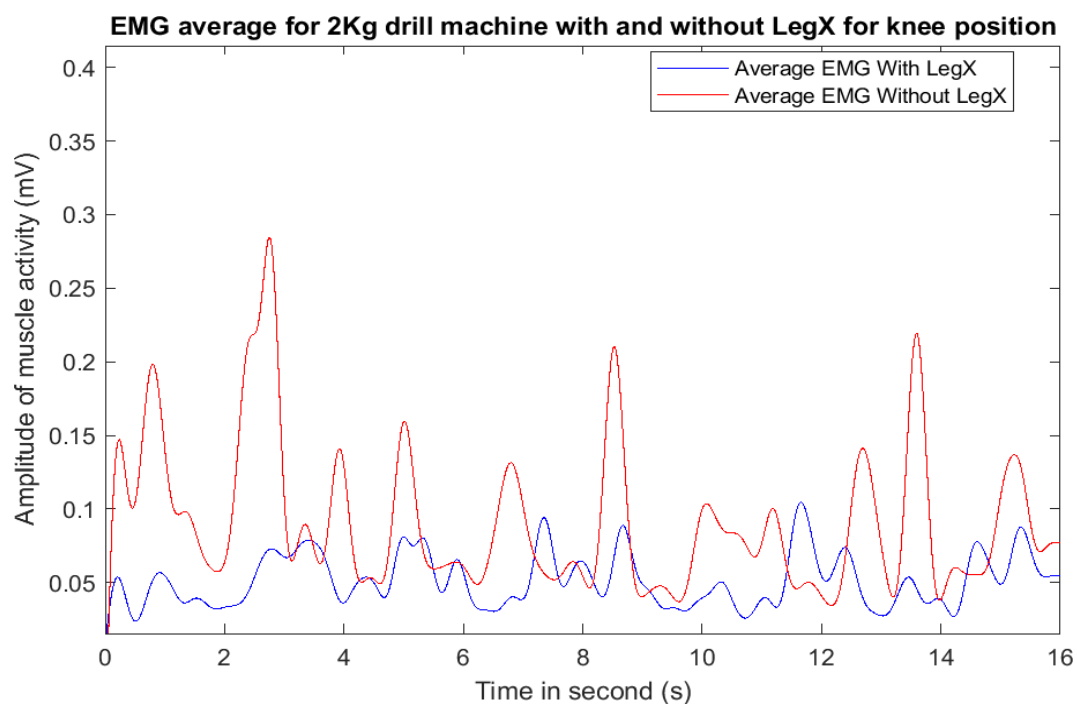

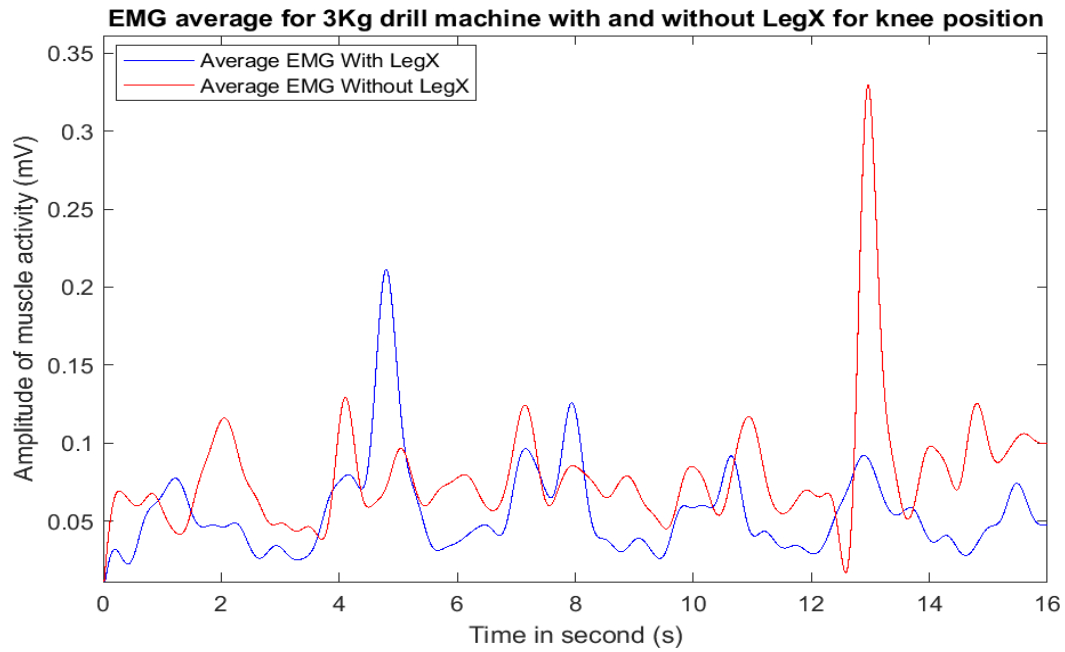*Figure 4.12: Knee position graph of legX for 2 kg drill machine.*

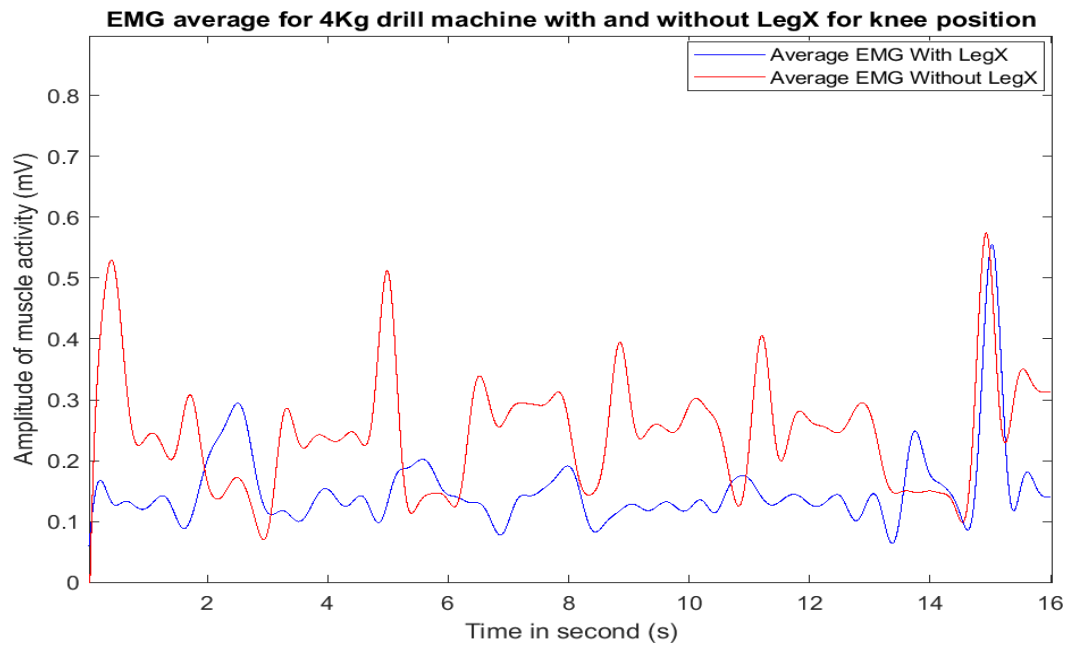*Figure 4.13: Knee position graph of legX for 3 kg drill machine.*

Figure 4.14: Knee position graph of legX for 4 kg drill machine.

The EMG signal graph for LegX in the sitting position during wall drilling is shown in Figures 4.12, 4.13, and 4.14. There are two sorts of line curves in all of the graphs. The average EMG line data graph for all three subjects, with and without LegX, is shown in these line graphs. The X-axis in these graphs indicates the time in seconds,while the Y-axis shows the amplitude of muscle activity in millivolts.

The blue line graph also depicts the average data line graph for all three volunteers who utilized LegX for knee position at 2kg, 3kg, and 4kg, respectively. Similarly, thered line graph depicts the average EMG signal for all three volunteers when drilling in chair position for each weight drill machine.

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Using LegX has the lowest average amplitude but the best efficiency because it saves the most energy from our leg, whereas not using LegX has the highest amplitude but the lowest efficiency because it saves the least amount of energy. For a more in-depth examination, we look at a table that takes chair position drilling for three different weight drill machines into account.

Weight of drill machine	LegX-Knee Position		
	With LegX (mV)	Without LegX (mV)	Efficiency (%)
2 kg	0.4058	0.8120	50.01%
3 kg	0.3915	0.7661	48.9%
4 kg	1.1720	2.2181	47.2%

Table 4.5: Efficiency calculation of LegX - knee position

The first column in Table 4.5 displays the weight of the drill machine, the second and third columns show with and without LegX, and the fourth column shows the efficiency. The second and third columns show the average value of the working area, and the fourth column shows the efficiency of this average working area for different chair positions with and without wearing LegX, and this without LegX value is used as our reference value for calculating efficiency in the fourth column. The chapter that follows goes into further detail, including an explanation of the efficiency bar graph.

The effect of employing the battery support modes of the legX on muscular activation in the users' thighs, quadriceps, and leg muscles was studied. The exoskeleton, it was thought, would minimize strain on the quadriceps, the major knee extensor, while having little to no effect on the other muscle fibers.

4.3 Statistical Analysis

In this section, we discussed the statistical analysis of the exoskeleton. We divided this analysis into two parts, the first one is eksovest analysis and the second one is LegX analysis. With this analysis, we try to evaluate the working average area under the curve (mm^2) consistency of the exoskeleton. Here, we took one industrial volunteer data for five working days in a week. These data were taken for all positions of activityof eksovest and LegX. We want to prove that exoskeleton will give the same amountof working area in everyday work for the industrial worker.

4.3.1 Statistical analysis of Eksovest

In the Eksovest statistical analysis, we consider three position which are weight lifting, Roof drilling and Wall drilling positions. In below bar chart, x-axis represents the time as five working day and y-axis represents the average working area. Here, blue bar indicates the weight lifting positions and similarly red bar and yellow bar indicates the roof drilling and wall drilling position respectively.

Figure 4.15: Statistical bar graph for Eksovest.
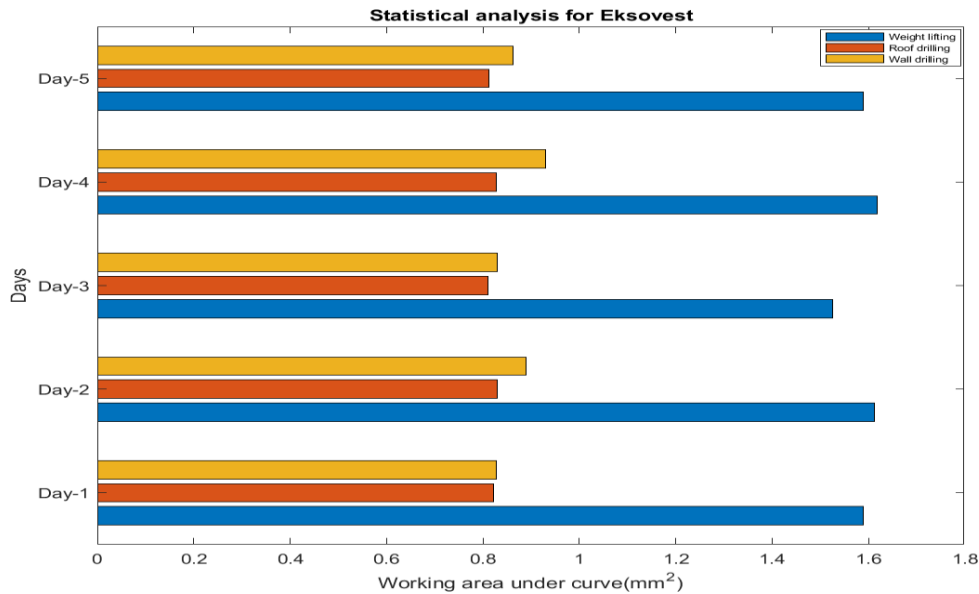
The blue bar for the weight lifting position in the graph analysis displays the generally equal working area value for five working days. However, it has a somewhat different value in everyday work, with a range of 1.55 to 1.63. The difference between different days' values is negotiable for evaluation analysis, and this little discrepancyoccurs due to some minor inaccuracy.

On the other hand, the red bar for the roof drilling position shows a nearly comparable amount of working area value for the same five working days. It also has a slightly different value that ranges from 0.80 to 0.82. This minor variation in value is equally significant for our evaluation job. The third bar is a yellow bar that represents the location of the wall drilling position which is also shown a mostly equal amount of average value for the same five working days. It is also having some slightly different values from others which are between 0.83 to 0.89. This difference is also because of some minor errors of data collection interference. We consider this difference in our statistical analysis.

Eksovest working area for all three positions is about identical. As a result, we may conclude that the Eksovest saves approximately the same number of energies in industrial activities on a daily basis.

4.3.2   Statistical analysis of LegX

In the legs statistical analysis, we consider two positions which are chair position and knee position. In the below bar chart, the x-axis represents the time as five working days and the y-axis represents the average working area. Here, the blue bar indicates the chair position average signal bar, and the red bar indicates the knee position average signal bar.
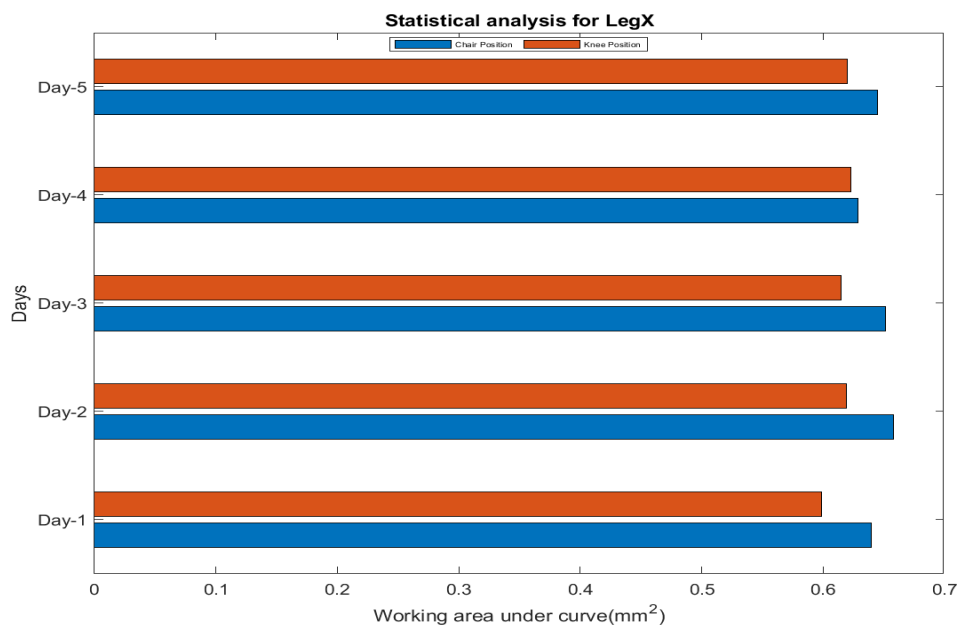

Figure 4.16: Statistical bar graph for LegX.

From the graph analysis, the blue bar for chair position shows the mostly equal average value for five working days. But it is having some slightly different values and its range is between considering from 0.60 to 0.65 which is negotiable for evaluation, and it happens for some errors.

On another side, the red bar for knee position also illustrates the mostly equal amount of average value for the same five working days. It is also having some slightly different value which is between 0.60 to 0.67. This slight change value is also considerable for our evaluation work.

The average value for both the position for LegX is mostly equal. So, we can say that the LegX saves mostly the same amount of energy for every day in industrial work.

5 Discussion

This chapter provides a brief summary of the overall outcomes. After we have computed all measurements, we will display our approach based on all subsequent outcomes for every experimental scenario. This report is also going to discuss various objectives (arm supporting exoskeletons, leg supporting exoskeleton) as well as the study's limitations. The discussion for each is delivered in the order listed below.

In chapter 4, figures 4.1 and 4.2 represent the results graph of simultaneously 5 kg and 10 kg weight lifting for the analysis of arm supporting exoskeleton-eksovest. In both graphs, the amplitude of every signal decrease by increasing the spring from level 1 to level 4. There without eksovest signal is compared with all the spring levelssignals in table 4.1. In spring level 4 it gives full support to the user's arm for thisreason the muscle contraction is very low. And when the user doesn't wear eksovestthey didn't feel any support and for this reason, the muscle contraction is so high in the signal of without eksovest.
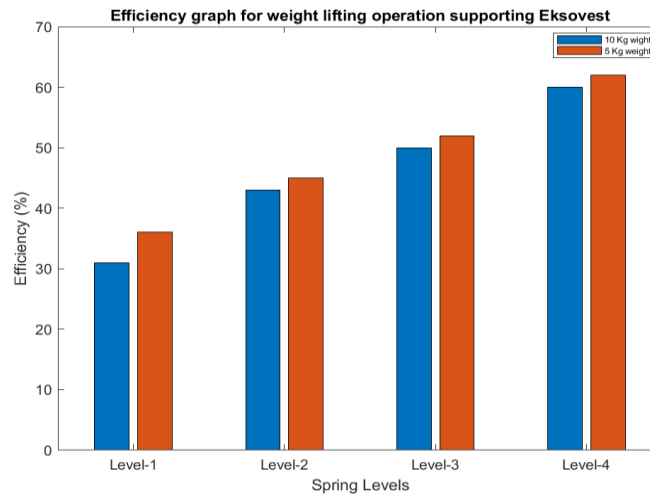

Figure 5.1: Efficiency graph for weight lifting of Eksovest.

This bar graph illustrates the efficiency of weight lifting. Here x-axis represents spring levels, and the y-axis represents efficiency. The red bar is for 5 kg weight and the blue bar is for 10 kg weight. From the bar graph, we can discuss level 4, here 10 kg weightgives the efficiency 59% whether 5 kg weight gives the efficiency of 61% so we cansay that when we increase the weight the efficiency is a little bit decrease. Similarly for level 1, 2, 3 shows the same analysis about efficiency. The energy expenditure while working with the upper body eksovest is generally higher than for the normal working process.

Figures 4.3, 4.4, and 4.5 in Chapter 4 show the results graph for the position of the roof drilling, and figures 4.6, 4.7, and 4.8 show the results graph for the position of the wall drilling with a 2 kg, 3 kg, and 4 kg weighted drill machine for the analysis of the arm supporting exoskeleton-eksovest. In all of the graphs, raising the spring from level 1 to level 4 reduces the amplitude of each signal which is shown in tables 4.2 and 4.3. There, the absence of an eksovest signal is compared to all of the spring level signals. Because spring level 4 provides complete support to the user's arm, muscular contraction is quite minimal. And when the user does not wear the eksovest, they do not feel any support, which explains why the muscular contraction is so high in the signal without the eksovest.
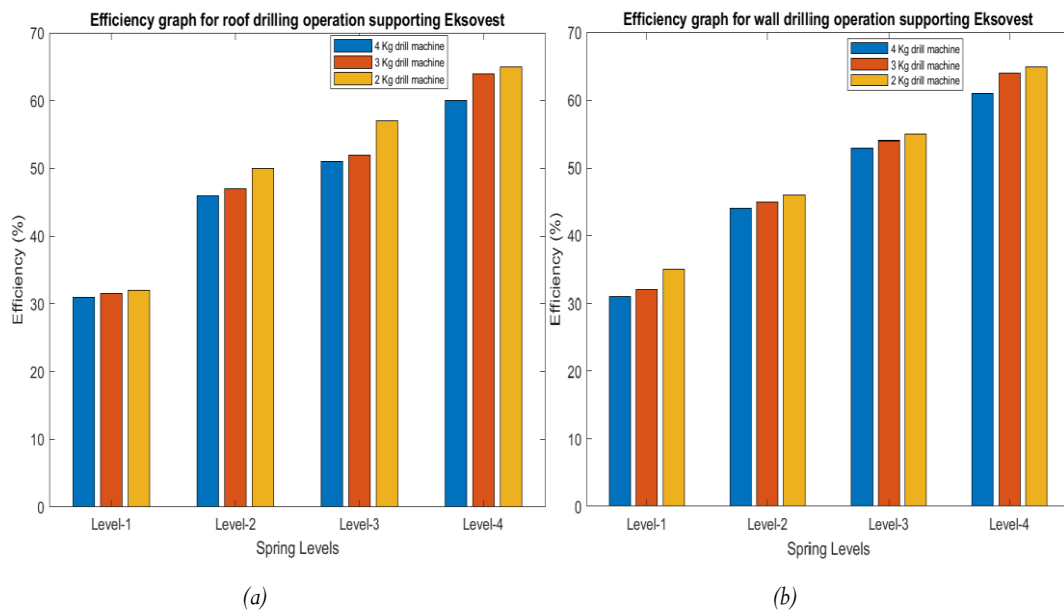

Figure 5.2: Efficiency graph for (a) roof drill and (b) wall drill of Eksovest.

The effectiveness of roof drilling and wall drilling is depicted in both bar graphs above. The x-axis in those graphs reflects spring levels, and the y-axis represents efficiency. The blue bar represents a 4 kg weighted drill machine, the red bar represents a 3 kg weighted drill machine, and the yellow bar represents a 2 kg weighted drill machine. We may explain level 4 using the bar graph, where 4 kg weight offers an efficiency of 60.1%, 3 kg weight gives an efficiency of 63.8%, and 2 kg weight gives an efficiency of 65.2% for roof drill of the graph (a) and the efficiency of 64.8%, 63.7%, 61.3% are for 4 kg, 3 kg, 2 kg level 4 wall drill of the graph (b). As a result, when we reduce the weight, the efficiency increases. Working with the upper body exoskeleton -Eksovest consumes more energy than conventional working processes. Similarly, levels 1, 2, 3 display the same efficiency explanation for both figures above. Finally, it can be said that exoskeletons allow workers to maintain flexibility and ease of movement while improving quality, stability, and consistency for industrial work.

Figures 4.9, 4.10, and 4.11 in Chapter 4 show the chair position results graph, while figures 4.12, 4.13, and 4.14 show the knee position results graph using a 2 kg, 3 kg, and 4 kg weighted drill machine for the examination of the leg supporting exoskeleton-legX. Raising the weight of the drill machine, the amplitude increase of each signal in all of the graphs, as shown in table 4.4. There, the absence of a legX signal is contrasted to battery-powered legX signals. Because battery support offers entire support to the user's leg, muscle contraction is quite low. Furthermore, when the user does not wear the legX, they do not feel any support.
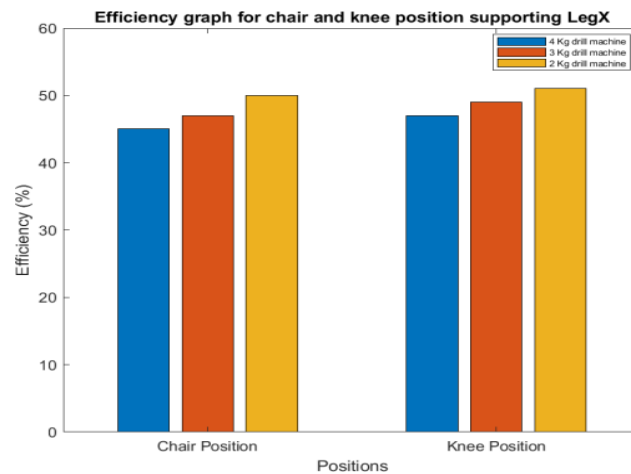

Figure 5.3: Efficiency graph for chair and knee position of legX.

The bar graph above shows the efficiency of chair and knee positions. In those graphs, the x-axis indicates two various working positions, while the y-axis represents efficiency. The blue bar represents a weighted drill machine weighing 4 kg, the red bar a drill machine weighing 3 kg, and the yellow bar a drill machine weighing 2 kg. We can explain chair position using a bar graph, in which 4 kg weight provides the efficiency of 44.8 percent, 3 kg weight provides the efficiency of 47.3 percent, and 2kg weight provides the efficiency of 50.4%, and the efficiency of 47.2%, 48.8%, and 50.01% are for simultaneous 4 kg, 3 kg, and 2 kg knee position. As a result, when we reduce the weight, the efficiency increases. These finding results indicate that the legX can be useful for different tasks of industrial work because the exoskeleton's construction transmits the load from the flexible seat to the ground, eliminating the user's knee joint.

There is another part in the result section which is a statistical analysis of the exoskeleton. In the industry generally, each employee works five days a week. And every day the employee cannot perform the same physical support for their work. Sometimes workers need to effort more physical pressure, which make injuries to their health and body muscles. They need to spend lots of energy. In our research, we collect data five days for all experiments. And compare the working area of muscle each day with another day. From the bar graph (4.15 and 4.16) it was shown that the muscle attraction is almost the same for every day which can prove that if the exoskeleton uses in the industry for work purposes, it can save the same amount of energy every day.

6 Conclusions

This research study proposed a wearable robotic device that uses a passive exoskeleton to impose behavior controls on industrial workers, keeping them in safer positions. In the developed framework, the exoskeleton actually inhibits workers from adoptingharmful positions, causing them to develop better and more pleasant body positions. Workers' positional problems must be corrected since muscle and leg knee discomfort and injuries are caused not only by a single incident but also by accumulating musculoskeletal injury from risky body strain tasks such as drilling. This wearable exoskeleton provides the finest assistance in the workplace for all sorts of workers, such as increasing muscle strength, regaining movement, reducing load, and preventing significant muscle disorders. The results of the experiments demonstratedthat the exoskeleton technology has the capacity to be implemented as a safety technique for industrial users.

It is possible to indicate that the exoskeleton technology has been assessed in a variety of approaches utilizing an EMG sensor. The muscular activity of three volunteers was measured using EMG signal analysis, and the benefit of the exoskeleton system for industrial workers was validated. In this case, an EMG sensor is deployed to captureEMG signal data from a volunteer's body muscle. As a result, this sensor is vital in this study project to analyze the exoskeleton. The real-time EMG signal data acquired while utilizing the exoskeleton is displayed together with all elements of the system for different operating positions for different loaded drill machines.

This investigation is necessary to understand muscular endurance power after working in various industrial working positions while using an exoskeleton. The device intends to reduce industrial workers' disabilities and muscular disorders, making their jobs simpler and better. Analyze the benefits of two exoskeleton systems as a safer alternative for industrial workers who are on the job for an extended amountof time.

6.1   Future study:

The research should be expanded in future studies that will be focused on a variety oftopics. Initially, the technology must be able to manage more readily and get a specific perspective into a user's body's many parts. In the suggested method, the exoskeletonmust do more diverse positions of working that are connected to industrial activity, such as shifting weights, walking up with weight, shoulder twisted drilling position, and so on. We need to concentrate mostly on evaluating the benefits of exoskeletons by gathering data as thoroughly and removing as many noises and artifacts as feasible. Finally, this developed exoskeleton technology serves as a valuable example for illustrating the concept of monitoring and assessing the benefits of industrial workers who use exoskeletons in various working positions. The technology is focusing on all areas, and preferably, the EMG approach will be improved as well in order to build up a stronger response for the exoskeleton's biological function. Robotic exoskeletons have been around for millennia, empowering individuals for stronger safeguards, power, and assistance.

References

[1] Yan, Z., Han, B., Du, Z., Huang, T., Bai, O., & Peng, A. (2021). Development and testing of a wearable passive lower-limb support exoskeleton to support industrial workers. *Biocybernetics and Biomedical Engineering*, *41*(1), 221–238.https://doi.org/10.1016/j.bbe.2020.12.010

[2] Kumar, V., Hote, Y. V., & Jain, S. (2019, October 1). Review of Exoskeleton: History, Design and Control. https://doi.org/10.1109/RDCAPE47089.2019.8979099

[3] Ying, G. L. (2014, May 1). Development of Arm Exo-skeleton for Bicep Brachii Muscle. Retrieved January 4, 2022, from utpedia.utp.edu.my website: http://utpedia.utp.edu.my/id/eprint/14237

[4] Gopura, R. A. R. C., Kiguchi, K., & Bandara, D. S. V. (2011). A brief review on upperextremity robotic exoskeleton systems. *2011 6th International Conference on Industrial and Information Systems*. https://doi.org/10.1109/iciinfs.2011.6038092

[5] Ali, H. (2014). Bionic exoskeleton: history, development and the future. In *IOSR Journal ofMechanical and Civil Engineering (IOSR-JMCE), International Conference on Advances in Engineering & Technology*.

[6] Rodriguez, H. (2019). Realistic Computer aided design : model of an exoskeleton. Retrieved January 8, 2022, from DIVA website: https://www.diva-portal.org/smash/record.jsf?pid=diva2:1344565

[7] Bao, G., Pan, L., Fang, H., Wu, X., Yu, H., Cai, S., … Wan, Y. (2019). Academic Review and Perspectives on Robotic Exoskeletons. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *27*(11), 2294–2304. https://doi.org/10.1109/tnsre.2019.2944655

[8] Martin. (n.d.). The Sustainable Development Agenda. Retrieved from United Nations Sustainable Development website: https://www.un.org/sustainabledevelopment/development-agenda

[9] Martin. (n.d.). Infrastructure and Industrialization. Retrieved from United Nations Sustainable Development website: https://www.un.org/sustainabledevelopment/infrastructure-industrialization

[10] Christensen, S., Bai, S., Rafique, S., Isaksson, M., O'Sullivan, L., Power, V., & Virk, G. S. (2018). AXO-SUIT - A Modular Full-Body Exoskeleton for Physical Assistance. *Mechanism Design for Robotics*, 443–450. https://doi.org/10.1007/978-3-030-00365-4_52

[11] Grazi, L., Trigili, E., Proface, G., Giovacchini, F., Crea, S., & Vitiello, N. (2020). Design and Experimental Evaluation of a Semi-Passive Upper-Limb Exoskeleton for Workers With Motorized Tuning of Assistance. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *28*(10), 2276–2285. https://doi.org/10.1109/tnsre.2020.3014408

[12] Masud, N., Sajid, R., Smith, C., & Isaksson, M. (2021). Design, control, and actuator selection of a lower-body assistive exoskeleton with 3-D passive compliant supports. Retrieved January 4, 2022, from Mechatronics (Oxford) website: https://www.diva-portal.org/smash/record.jsf?pid=diva2:1600424

[13] Voilque, A., Masood, J., Fauroux, JC., Sabourin, L., & Guezet, O. (2019). Industrial Exoskeleton Technology: Classification, Structural Analysis, and Structural Complexity Indicator. *2019 Wearable Robotics Association Conference (WearRAcon)*. https://doi.org/10.1109/wearracon.2019.8719395

[14] Zhu, Z., Dutta, A., & Dai, F. (2021). Exoskeletons for manual material handling – A review and implication for construction applications. *Automation in Construction*, *122*, 103493. https://doi.org/10.1016/j.autcon.2020.103493

[15] Hodson, A. D. (2021, May 1). Arm supporting exoskeletons efficacy changes due to exoskeleton, size, and sex. Retrieved January 4, 2022, from soar.wichita.edu website: https://soar.wichita.edu/handle/10057/21592

[16] Pillai, M. V., Van Engelhoven, L., & Kazerooni, H. (2020). Evaluation of a Lower Leg Support Exoskeleton on Floor and Below Hip Height Panel Work. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *62*(3), 489–500. https://doi.org/10.1177/0018720820907752

[17] Welcome to the BMS lab. (n.d.). Retrieved from BMS LAB — Where Technology Meets Life website: https://bmslab.utwente.nl

[18] EMG User Guide Revision 1.12. (n.d.). Retrieved from https://bmslab.utwente.nl/wp-content/uploads/2019/12/Shimmer-EMG-muscle-contraction.pdf

[19] Laferriere, P., Lemaire, E. D., & Chan, A. D. C. (2011). Surface Electromyographic Signals Using Dry Electrodes. *IEEE Transactions on Instrumentation and Measurement*, *60*(10), 3259–3268. https://doi.org/10.1109/tim.2011.2164279

[20] Nasrollaholhosseini, S. H., Mercier, J., Fischer, G., & Besio, W. G. (2019). Electrode–Electrolyte Interface Modeling and Impedance Characterizing of Tripolar Concentric Ring Electrode. *IEEE Transactions on Biomedical Engineering*, *66*(10), 2897–2905. https://doi.org/10.1109/tbme.2019.2897935

[21] Atapattu, S., Tellambura, C., & Jiang, H. (2010). Analysis of area under the ROC curve of energy detection. *IEEE Transactions on Wireless Communications*, *9*(3), 1216–1225. https://doi.org/10.1109/twc.2010.03.091085

[22] Betterexplained.com. (2019). *How To Analyze Data Using the Average – BetterExplained*. [online] Available at: https://betterexplained.com/articles/how-to-analyze-data-using-the-average/.

[23] Kularatna, N., Ross, A. S., Fernando, J., & James, S. (2019). Background to Surge Protection. *Design of Transient Protection Systems; Elsevier: Amsterdam, The Netherlands*, 1-15. https://www.sciencedirect.com/topics/engineering/motion-artifact

[24] Ghibaudo, G., & Boutchacha, T. (2002). Electrical noise and RTS fluctuations in advanced CMOS devices. *Microelectronics Reliability*, *42*(4-5), 573–582. https://doi.org/10.1016/s0026-2714(02)00025-2

[25] Motion Artifact - an overview | ScienceDirect Topics. (n.d.). Retrieved from www.sciencedirect.com website:

[26] Bertrand, A., Mihajlovic, V., Grundlehner, B., Van Hoof, C., & Moonen, M. (2013). Motion artifact reduction in EEG recordings using multi-channel contact impedance measurements. *2013 IEEE Biomedical Circuits and Systems Conference (BioCAS)*. https://doi.org/10.1109/biocas.2013.6679688

[27] Donghui Zhang. (2005). Wavelet Approach for ECG Baseline Wander Correction and Noise Reduction. *2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*. https://doi.org/10.1109/iembs.2005.1616642

[28] Sörnmo, L., & Laguna, P. (2005). The electrocardiogram—A brief background. *Bioelectrical signal processing in cardiac and neurological applications*, 411-452.

[29] Kabanov, A. A., & Nikonova, G. V. (2019). Development of Analog Filtering Circuit for Electromyography Signals. *2019 Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT)*. https://doi.org/10.1109/usbereit.2019.8736559

[30] Mello, R. G. T., Oliveira, L. F., & Nadal, J. (2007). Digital Butterworth filter for subtracting noise from low magnitude surface electromyogram. *Computer Methods and Programs in Biomedicine*, *87*(1), 28–35. https://doi.org/10.1016/j.cmpb.2007.04.004

[31] Rahman, M. A. (2021). A comparative study to explore the advantages of passive exoskeletons by monitoring the muscle activity of workers. Retrieved January 8, 2022, from DIVA website: https://www.diva-portal.org/smash/record.jsf?pid=diva2:1524075

[32] Welcome to the BMS lab. (n.d.). Retrieved from BMS LAB — Where Technology Meets Life website: https://bmslab.utwente.nl

[33] Hof, A. L., Elzinga, H., Grimmius, W., & Halbertsma, J. P. K. (2002). Speed dependence of averaged EMG profiles in walking. *Gait & Posture*, *16*(1), 78–86. https://doi.org/10.1016/s0966-6362(01)00206-5

[34] Wang, J., Tang, L. and E Bronlund, J. (2013). Surface EMG Signal Amplification and Filtering. *International Journal of Computer Applications*, [online] 82(1), pp.15–22. doi:10.5120/14079-2073.

[35] Jaewook Kim, & Seonghwan Cho. (n.d.). A Time-Based Analog-to-Digital Converter Using a Multi-Phase Voltage-Controlled Oscillator. *2006 IEEE International Symposium on Circuits and Systems*. https://doi.org/10.1109/iscas.2006.1693489

[36] Mandrile, F., Farina, D., Pozzo, M., & Merletti, R. (2003). Stimulation artifact in surface emg signal: effect of the stimulation waveform, detection system, and current amplitude using hybrid stimulation technique. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *11*(4), 407–415. https://doi.org/10.1109/tnsre.2003.819791

[37] Chu, J.-U., Moon, I., Lee, Y.-J., Kim, S.-K., & Mun, M.-S. (2007). A Supervised Feature- Projection-Based Real-Time EMG Pattern Recognition for Multifunction Myoelectric Hand Control. *IEEE/ASME Transactions on Mechatronics*, *12*(3), 282–290. https://doi.org/10.1109/tmech.2007.897262

Figure References

[1] Welcome to the BMS lab. (n.d.). Retrieved from BMS LAB — Where Technology Meets Life website: https://bmslab.utwente.nl

[2] Area Under the Curve - Method, Formula, Solved Examples, FAQs. (n.d.). Retrieved fromCuemath website: https://www.cuemath.com/calculus/area-under-the-curve/

[3] Betterexplained.com. (2019). *How To Analyze Data Using the Average – BetterExplained*. [online] Available at: https://betterexplained.com/articles/how-to-analyze-data-using-the-average/.

[4] Cheng-Chung Hsu, & Jieh-Tsorng Wu. (2003). A highly linear 125-mhz cmos switched- resistor programmable-gain amplifier. *IEEE Journal of Solid-State Circuits*, *38*(10), 1663– 1670. https://doi.org/10.1109/jssc.2003.817665