UNIVERSITY OF GÄVLE

“FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT”

**“Department of Electrical Engineering, Mathematics, and Science”**

# “PERFORMANCE EVALUATION OF EXOSKELETONS WHILE PERFORMING DIFFERENT TASKS OF WORKERS”

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# Abstract:

Lifting weights, moving large, heavy objects, or maintaining same posture for extended periods of time exposes workers, mostly in the industrial sector, to pressure on their lower backs, which can have a significant negative impact and result in a variety of musculoskeletal problems and discomfort. The use of an exoskeleton can help to protect workers against lower back injuries of this kind.

Past studies have been conducted to study the impact of the exoskeleton on upper body and legs with different exoskeleton, while this study will be an additional study which covers the impact on the most essential and used part of human body i.e., lower back (Thoracolumbar fascia). Workers working in the industrial sectors face more health issues and disabilities because of working on uneven surfaces, under uncomfortable positions like bending, squatting, twisting, and stretching which might impose adverse impact on lower back resulting in a higher number of sick leave. If more people are impacted by disorders caused by lower back pain, the lesser would be the healthy workers available for work leading to shortage of competent workers in the industry. Back discomfort can affect a person's capacity to work; in fact, it's one of the most prevalent causes of temporary or permanent exclusion from the labor force when it comes to sick leave. The total estimated societal costs of low back pain in Sweden in 2001 was €1860 million, which included all medical expenditures as well as lost productivity as a result of the ailment. Estimates place the total economic cost of LBP in Sweden at €740 million, or €78 per person, for all episodes that started in 2011. [1].

This research study used a passive exoskeleton, namely “BackX”, developed by SUITX Inc. and its impact was measured on the body’s lower back in deep squatting and virtual chair position. Electromyography (EMG) sensors were deployed onto the participant's body as a measuring gadget. The investigations also examined the body muscle data of the various volunteers as recorded by the EMG sensors embedded in the thoracic-lumber fascia, a muscle in the lower back with and without exoskeleton.

The 3DSSPP model has also been used in this research to study the impact of force vs angle relation. It showed how much force was exerted on the human's lower back when lifting weights without wearing the exoskeleton.

In addition, using the proper data processing techniques, the signals from the acquired data will be filtered and processed. According to this study, it is possible to minimize skeletal muscle (Thoracolumbar fascia) activity by up to 60% by using these exoskeletons, which will improve the working conditions for the workforce by easing physical strain. The findings of this study will help small and medium enterprises (SMEs) spread the word regarding the advantages of exoskeletons, which will help to increase public awareness.

Keywords: Exoskeleton, Lower-back-muscle, Electromyography, SuitX, BackX

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## List of Abbreviations

| | |
|---|---|
| **EMG** | Electromyography |
| **ECG** | Electrocardiography |
| **ARV** | Average Rectified Value |
| **LBP** | Lower Back Pain |
| **LBM** | Lower Back Muscle |
| **EXO** | Exoskeletons |
| **EMI** | Electro Magnetic Interference |
| **SME's** | Small and Medium Enterprises |
| **AUC** | Area Under Curve |
| **3DSSPP** | 3D Static Strength Prediction Program |
| **SPSS** | Statistical Package for Social Science |
| **ANOVA** | Analysis of Variance Formula |

## Chapter – 1: Introduction:.

Lower back muscular pain is a serious and common illness in real-world practices. Lower back pain (LBP) can take place at any age in the physical body. LBP is one of the major causes of work-related injuries and sicknesses. In the industry, when individuals are continuously working in the same posture, there are a lot of chances of getting a lower back injury or muscle pain [1].

Diverse ailments that affect the bones, joints, muscles, and connective tissues are referred to as musculoskeletal disorders. These ailments are among the most expensive and incapacitating in the United States (USBJI, 2014) and may cause discomfort and a loss of function. Disorders of the musculoskeletal system are problems that can be brought on by inherited, congenital, or acquired pathologic processes, according to the Social Security Administration (SSA). Traumatic or developmental events, infectious, inflammatory, or degenerative processes, as well as neoplastic, vascular, or toxic/metabolic illnesses, can all cause impairments (SSA, 2008) [1].

Musculoskeletal disorders (MSDs) are injuries or discomfort in the musculoskeletal system of the human body, which includes the joints, ligaments, muscles, nerves, tendons, and structures that support the limbs, neck, and back [2]. MSDs can be caused by a quick exertion (e.g., lifting a heavy object), by repeating the same actions under repetitive strain, or by repeated exposure to stress, vibration, or uncomfortable posture [3]. MSDs can affect various regions of the body, including the upper and lower back, neck, shoulders, and extremities (arms, legs, feet, and hands

It has been observed that to lessen the possibility of musculoskeletal disorders (MSDs) or lower back injuries, external assistance devices like an exoskeleton BackX (SuitX) can be used to overcome this problem [4].

From previous research that has conducted at (Hogskolan i Gavle) to study the impact of the exoskeleton on the upper body (bicep's muscle) and legs (thigh's muscle), while this will be an additional study which covers the impact on the most essential and used part of the human body i.e., lower back (thoracic-lumber fascia).

The research being conducted in the past to examine the effectiveness of exoskeletons clearly shows that it helps in improving the workers' effectives, their level of comfort and quality of life. This is so, because exoskeletons have the potential to make the physically challenging tasks easier for the workers and help them to work and manage their tasks in effective ways. Though high-quality exoskeletons can be costly but given the benefits they offer, especially for the employees working in the manufacturing and construction sectors, it is worth the cost.

While individuals do activities like manual handling or weightlifting, lower back exoskeletons are designed to accommodate a perfect trunk extension moment and reduce stress and strain in the lower back. To analyze muscle contraction, volunteers of different ages and heights perform an industrial activity repeatedly with the help of exoskeleton BackX (SuitX) and shimmer EMG sensors [5].

With the aid of the 3DSSPP system, we created models of the participants based on their heights and body weights. Then, using that software, we discovered that when the participants raised the importance of the squat position, it revealed how much force was being applied to the lower back and erector spine (L4/L5, L5/S1). Then, we contrasted the EMG sensor data we had collected with and without exoskeletons.

The findings reveal that the main advantage of an exoskeleton BackX (SuitX) is that, by wearing this gadget, industrial workers or employees can work more feasibly in less time, and the worker is also safe from work-related injuries. The human body is not designed to support an excessive amount of weight or tension, as we all know that each human has different ages and body weights, and because of that, the strength of the muscles in the lower back can only handle weight or stress according to it, which causes mishaps when workers are in the workplace. However, using an exoskeleton can significantly lower the number of workplace accidents in specific industries [5].

### 1.1 Connection with previous research work at HiG:

In the past, two Master thesis studies (Evaluation of the use of exoskeletons while performing different task of industrial workers & Comparative study to explore the advantages of passive exoskeletons by monitoring the muscle activity of workers ) have been conducted at (Hogskolan i Gävle) to analyze the effectiveness of two exoskeletons. The exoskeleton, Eksovest, was used to analyze biceps/triceps muscles of the upper body, whereas, for the lower body's Thigh muscles, LegX by SuitX was used. However, the present study is different and unique in the sense that it analyzes the human back's muscles such as thoracic-lumber fascia. It is important to note that human back-related issues are the most significant musculoskeletal disorders which the majority of the workers are facing nowadays. The present study shows that exoskeletons such as BackX by SuitX, is very efficient in reducing the load on the back muscles. This research also showed that the workers' posture related issues must be resolved timely since risky body strain tasks like weight-lifting cause cumulative musculoskeletal harm. The wearable exoskeleton BackX by SuitX successfully provides the finest assistance for workers, by increasing muscular strength, restoring movement, decreasing load, and avoiding major muscle problems. The outcomes of the experiments clearly demonstrated that exoskeleton technology has the potential to be applied as a safety precaution for industrial users.

## 1.2 Brief Description of this research:

In this research, firstly, a 3D model was created with the help of 3DSSPP software to check how much force is exerted on the lower back when industrial worker lifts bulky object or heavy weight in different angles and positions. By using 3DSSPP software in squat lifting position and in chair position, the amount of force exerted was calculated at various angles. Secondly, in robotics lab at Hogskolan i Gavle, real time data of five participants was collected having different age, height and weight using shimmer sensor without wearing exoskeleton and then the data was collected while wearing the exoskeleton to compare results obtained from both. This study overall helps in analyzing how much relief the exoskeleton is proving to the industrial workers while lifting heavy and bulky objects. Lastly, ANOVA analysis using SPSS software was performed to scientifically prove the results.

## 1.3 Distinct Features of this Research:

The use of 3DSSPP and SPSS software in this study makes it distinct from the previous research conducted in the past at Hogskolan i Gävle involving Eksovest and LegX.

This research is also different from the previous work conducted at Hogskolan i Gävle as it studies the impact of exoskeleton on thoracic-lumber fascia, a muscle near to spinal cord in the lower back which is the largest muscle in the human body. Secondly, it also analyzes the force versus angle relation, and shows that when angle increases, force decreases and vice versa. Thirdly, the study utilizes the technique of 3DSSPP software which has not been used in any past studies yet. In this, a 3D model was created of the participant having same height and weight, to analyze that if the participant without wearing any exoskeleton lifts the weight in any position then how much force will each angle put on his lower back. This test could be done to study the impact of force on lower back in as many angles as possible. Lastly, in this study the ANOVA result analysis has been performed on the results to show the reliability and how much the results are accurate and scientifically proven.

### Similarity and dissimilarity with the past research:

It is evident that the results of this study are unique and different from the other studies conducted. Also, there is no similarity in the procedure used in our research as compared to previous research as the positions used in this study were squat position, lower back bending, chair position etc which is entirely different.

### 1.4 Background:

Hardiman's Exoskeleton, the first exoskeleton, was created for military usage. A full-body exoskeleton is manufactured to analyze the participants' muscle strength or capability to lift the heavy object. Furthermore, the second Exoskeleton was created at the University of Wisconsin-Madison in the U.S. A in the early 1970s [6]. Due to the limitations of the technology at the time and the lack of knowledge and competence needed to operate it, it still took a number of years for the technology to improve and the first exoskeletons to be available for use [7].

The first assembled robotic exoskeletons did not appear until the 20th century. General Electric developed the 1,500-pound Hardiman, also known as the "Human Augmentation Research and Development Investigation" and "Manipulator," in 1960 [. Regrettably, the machine was too big and heavy to function correctly, and the project was abandoned entirely [6].

It has been identified that after Hardiman, BLEEX (Berkeley Lower Extremity Exoskeleton), a set of robotic legs created by engineers at UC Berkeley and supported by DARPA (Defense Advanced Research Project Agency), arrived around 2000. Its goal was to reduce the effort required to move big weights over long distances. Robotic exoskeletons are more common and sophisticated now, with a wide range of purposes. Businesses like SuitX have created exoskeletons for industrial work, neurorehabilitation, and military research [8].

Another work was done for the first exoskeleton devices that entered the market at the start of the twenty-first century and are now available to a growing number of consumers. Gait therapy in patients with spinal cord injuries and strokes was one of the initial applications. The 2001 release of the gait therapy exoskeleton Lokomat, used in hospitals and rehabilitation facilities worldwide, is an early example. Lokomat's manufacturer, Hocoma AG, declared the delivery of the 500th unit in 2013 [8].

When doing activities like manual handling or weightlifting, both lower back exoskeletons are designed to accommodate a perfect trunk extension moment and reduce stress and strain in the lower back. In Sweden (2001), one survey was conducted, about 15 to 30% of the population is going through the lower back (LBP). The occurrence of (LBP) at a specific moment is known as a point prevalence. The prevalence of one month, which refers to the number of people who experience lower back pain within a month, ranges from 19 – 43%. The lifetime prevalence at some point in their life is calculated to be between 60 – 70%. Considering Sweden's short-term sick leave budget, back discomfort expenses comprised 11%. 13% of the early retirement benefits were provided for lower back pain-related issues. In Sweden, lower back discomfort is a vital sign [9].

In the lower back, major risk factors contain repetitive or high forces on lumber tissues (in which we have muscles, ligaments, vertebrae, and intervertebral discs). In another research paper, with a prevalence of around 75% and 84%, low back pain (LBP) is the top cause of disability in the entire world. The pragmatic effect of passive lower back exoskeletons examines peaked aligned lifting conditions at respective three load levels and exposes a significant reduction in lumbar erector spine (LES) and thoracic erector spinae (TES) muscle activities such as 14.4% and 27.6% respectively [10].

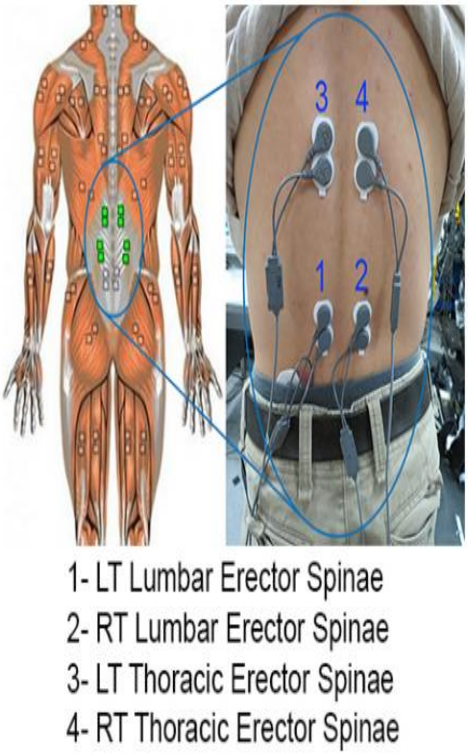



**Figure 1: Description of erector spinae [1]**

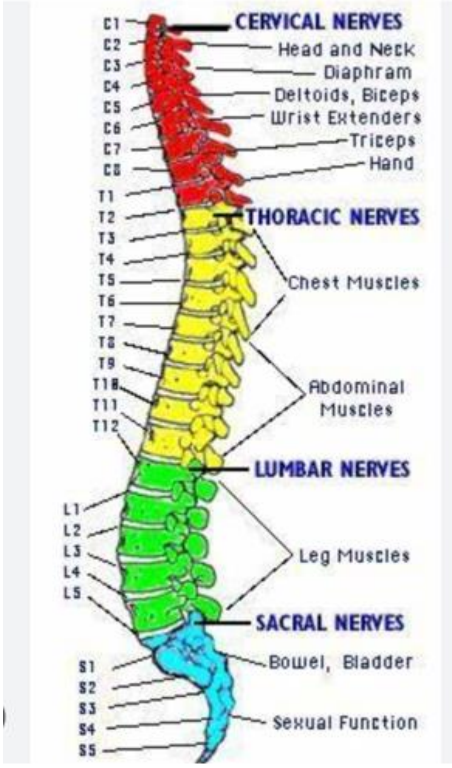



**Figure 2: Human spinal cord [2]**

### 1.5 Research Purpose:

The purpose of this research is to find out the load/stress on the back muscles (Lower Back Muscle) with the help of using Exoskeleton (BackX). This will help individuals abstain from lower back injuries. It has been noted that there is a critical need for an exoskeleton, and its usage can decrease the amount of pain, minimize work-related physical ailments, ease the strain, and further enhance labour accuracy and performance. At the same time, it can be said that exoskeletons are wearable robotic suits that deliver support to the whole body or specific parts

of the body, such as the back, leg, arm, knee, and many more. In addition, employees frequently feel supported, and with that being said, the main aim of the research is to analyze and examine exoskeletons with few new working positions to deliver various advantages of passive methods that might eventually enhance BackX exoskeleton, which will be more valuable for employees' health in the industry [11].

**Table 1: Describing percentage rate of different types of injuries**

| Injuries in Sweden | Percentage |
|---|---|
| Lower Back Pain [11] | 69% |
| Knee Pain [12] | 44% |
| Shoulder Pain [13] | 26% |

### 1.7 Sustainable Development Goals (SDGs):

Our planet is evolving. To achieve the Global Goals, people act, collaborate, and develop new technologies in every nation. The primary goals are the advancement of exoskeleton technology and the analysis of the benefits. This project will create more business, invention, and technology by offering industrial workers assistance strategies. This technological approach aids industrial site management when monetary outlays and logistics challenges with residents compound the problems. Different working methods are practical and cost-effective for all industries, ultimately leading to high-quality infrastructure development [12].

Employees in the sector suffer from several health problems due to their various positions at work. Wearable exoskeletons are being increasingly utilized for physically demanding occupations to improve ergonomics and increase muscular strength, which has the potential to alleviate global health issues [12].

### 1.8 Instruments and Apparatus:

- 3DSSPP
- ANOVA
- Exoskeleton (SuitX)
- Shimmer Emg Sensors
- Shimmer Consensys Pro Software
- “Shimmer3 EMG Sensor”
- “Shimmer Dock”
- “Surface ECG Electrodes”
- “Biological Leads”
- “Body Straps”
- “MATLAB Software”

### 1.9 Research Aim:

My research objective is to determine why the back exoskeleton is significant in industrial tasks. In addition, this study provided a detailed evaluation of the passive BackX exoskeleton, a lightweight upper-limb exoskeleton that provides lower-back muscular support during load-transferring tasks from ground to table height. Also, Lab research was done in which non-expert volunteers completed load-transferring activities from the ground position to the table position, both with and without the help of BackX. Moreover, BackX appears to be a promising approach for reducing back work-related musculoskeletal disorders (WMSDs) among load-transfer employees based on physical, physiological, and psychological evaluations. Furthermore, working with BackX minimizes physical pressure on the back muscles as well as global physiological strain without increasing low back strain or degrading balance. Therefore, wearing passive BackX does not impair work performance; rather, it should aid in boosting productivity during.

Hence, this research aims to evaluate the effectiveness of the available Back-support exoskeleton, namely “BackX”, and to what extent it helps in relieving back muscle pain for these workers [13].

### 1.10 Research Objectives:

- To construct a 3D Model using different individuals with appropriate weight and height and evaluate the data highlighting the pressure of force applied on the lower back (L4/L5, L5/S1).
- To apply sensing and signal processing techniques to collect and process the real-time data of the lower back (L4/L5, L5/S1) with and without Exoskeleton.
- To use one-way ANOVA test result for statistical analysis, which will be used to determine the relationship between different parameters to observe the levels of back pain.

**1.11 Dissertation Structure:**

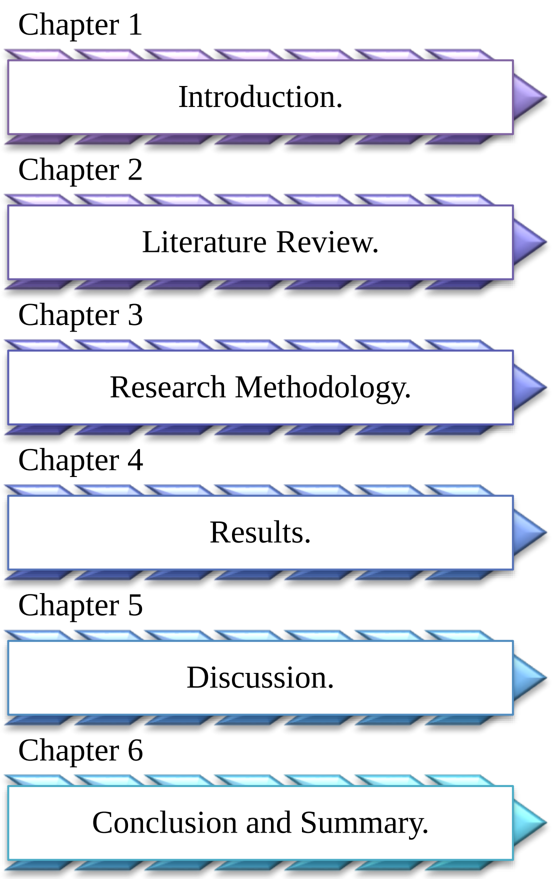



**Figure 2: Dissertation structure**

The structure of the thesis comprises six chapters. The first chapter (Introduction) delivers an overview and background about Exoskeletons. At the same time, it highlights how Exoskeleton helps industrial employees during their working hours. Moreover, the main aim, objectives, and questions are covered in this chapter.

Chapter 2 explains exoskeletons, shimmer sensors, and essential useable materials like electrodes. It will offer more specific details on how exoskeletons function in our contemporary business and different theories related to our experimental tools. The research will also briefly discuss the interruption of EMG signals during the investigation. Discuss the Filter used to process our data to conclude.

Chapter 3 thoroughly explains the experiment and how this thesis works. This methodology establishes how to efficiently organize, execute, and deliver the idea throughout the continuing implementation phase till duties are completed. It is a carefully defined set of procedures, flowcharts, and processes. Using a block diagram, define the modes and settings necessary for Exoskeletons and the shimmer sensor's internal circuitry.

Chapter 4 represents all of the research findings and analysis used in the thesis. In the initial step, the research delivers the 3D model using 3DSSPP, underlining the muscle data. Afterwards, the research uses a Shimmer EMG Sensor to outline the actions with and without using the Exoskeleton. The weight lifted is around 5 – 15 kg. Lastly, the study uses ANOVA for statistical analysis to determine the relationship between different parameters to observe the levels of back pain in the worker's body while performing the different aspects of the job. Chapter 5 presents a discussion of the importance of the thesis outcome outcomes to what was already known about the research and a quick look at all the data from Chapter 4 with a comparison of all the conditions under which the tests were run.

The whole argument is summarized after Chapter 6, which covers all facets of this work. This chapter talks further about the potential for this to improve the benefits of exoskeletons for different uses.

## Chapter – 2: Literature Review:

### 2.1 Exoskeleton:

A tough, rigid shell that surrounds the exterior of some organisms' bodies serves as support and defence. Sometimes, a giant exoskeleton—like the Exoskeleton of a crab—is referred to as a shell. The exoskeleton is short for "external skeleton," which contrasts with the endoskeleton, an internal skeleton. Like a tortoise, a creature may have both an exoskeleton and an endoskeleton [14].

Exoskeletons are mechanical devices that can be worn and cooperate with the wearer. Exoskeletons are frequently used to hold tools or equipment, provide ergonomic support or weightlifting, and prevent repetitive stress injuries. Motorized or active exoskeletons can help move heavy objects while lowering the risk of musculoskeletal injuries [14].


**Figure 3: Lifting weight by using Backx [3]**

**2.2 Classification of Exoskeletons with respect to the human body:**

- **Whole body exoskeleton:** A complete body exoskeleton is a suit used for rehabilitation and military strength enhancement.
- **Upper Body exoskeleton:** An exoskeleton that supports the arms and maybe the torso is called an upper-extremity exoskeleton. It can be divided into the wrist, fingers, shoulders, and elbow joints.
- **Lower Body exoskeleton:** An exoskeleton like this one supports the legs and lower back. Hip, knee, or ankle only, hip-knee, knee-ankle, or hip-knee-ankle are some available combinations [15].

**2.3 Types of Exoskeletons with respect to Functioning:**

**2.3.1 Active Exoskeleton:**

Active exoskeletons can increase human strength or decrease the body's energy usage by using driving systems like motors, hydraulics, or pneumatics. They consist of single or several actuators (such as electrical motors) that increase the body's power. Using the robotic Exoskeleton in active control mode, the limb may move in every required direction [15].


**Figure 4: Active exoskeleton with its components [4]**

To lessen the strain on the waist, an electric motor-assisted device to enhance trunk flexion was created in 2005. The second-generation prototype of this wearable power aid gadget was still 6.5 kg in weight, which is too much for humans to carry while bending down. Later, an intelligent suit created by Takayuki could lessen muscle strain during bending by roughly 14%. A 24V DC motor drives their system. However, integrating the motor into the workplace proved too challenging due to how heavy it was to transport. The HAL, Muscle Suit, and BLEEX active exoskeletons, among other popular models, were also too vast and expensive for employees. The industry does not acknowledge active exoskeletons' affordability, stability, and adaptability. Certain active exoskeletons for commercial use are still being created in the lab [15].


**Figure 5: Active exoskeleton doing lifting weight [5]**

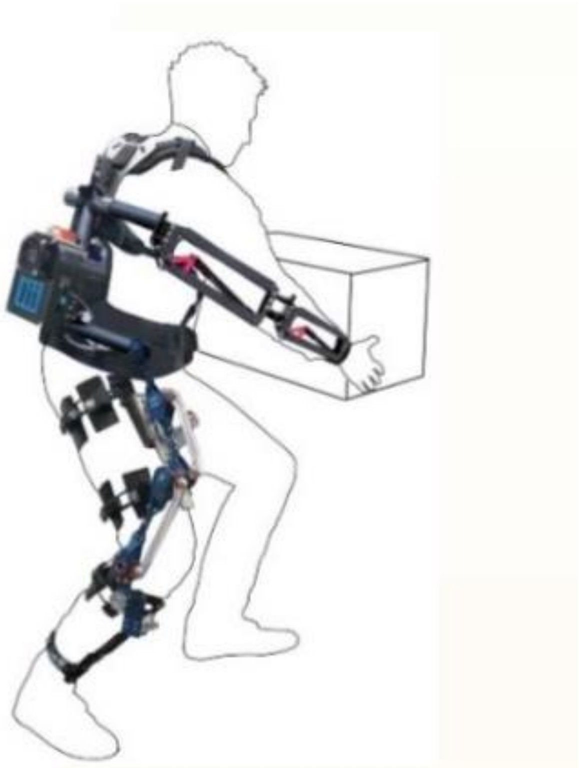


**Figure 6: Occupational exoskeleton in logistics Industry [6]**

### 2.3.2 Passive Exoskeleton:

Passive exoskeletons use elastic materials to store and release energy during lifting tasks. Instead of relying on a power source, they store energy using materials, springs, or dampers, then remove it when needed. A few passive exoskeletons have reached the marketing phase, including Happyback, Personal Lifting Assist Device (PLAD), Laevo, SuitX (BackX & LegX), Ottobock and Bendezy and eksovest. It has been demonstrated that they drastically lessen lower back muscle activation. A chest harness, waist belt, and leg units connect fibreglass rods that make up happy back to one another [16].

**Figure 7: Passive exoskeleton BackX**

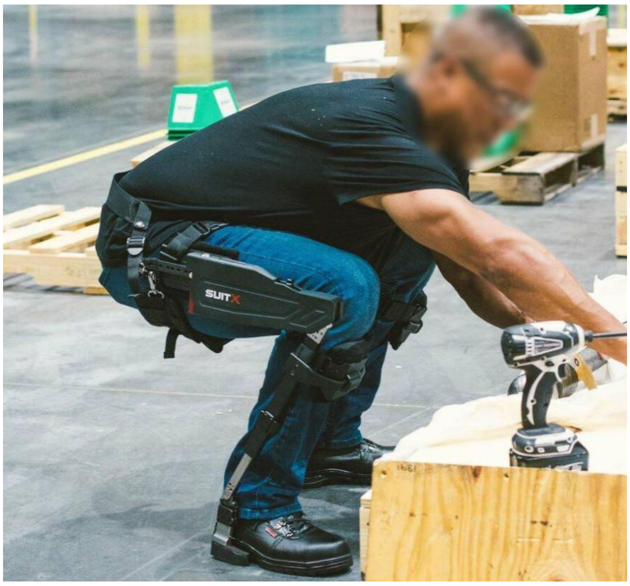



**Figure 8: Passive exoskeleton LegX by SuitX [3]**

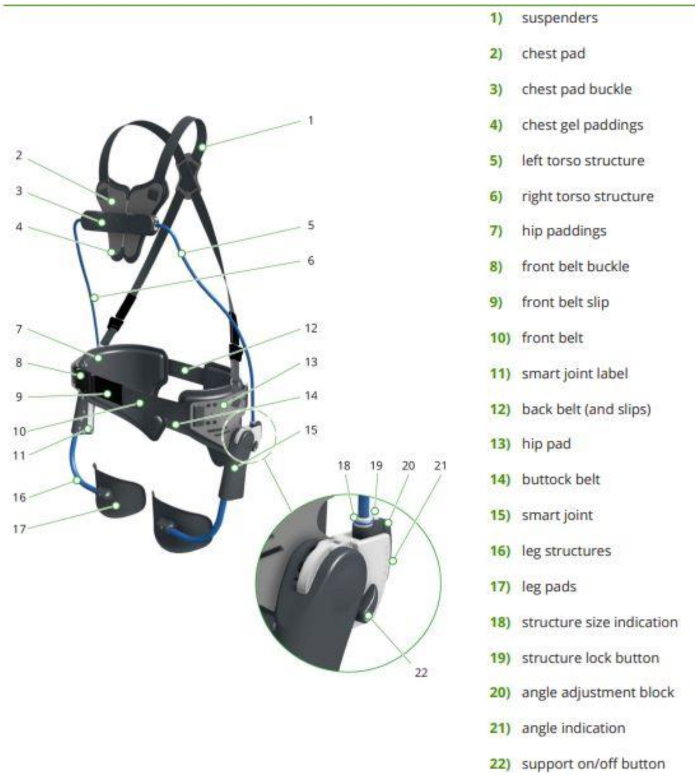



**Figure 9: Leavo passive exoskeleton [7]**

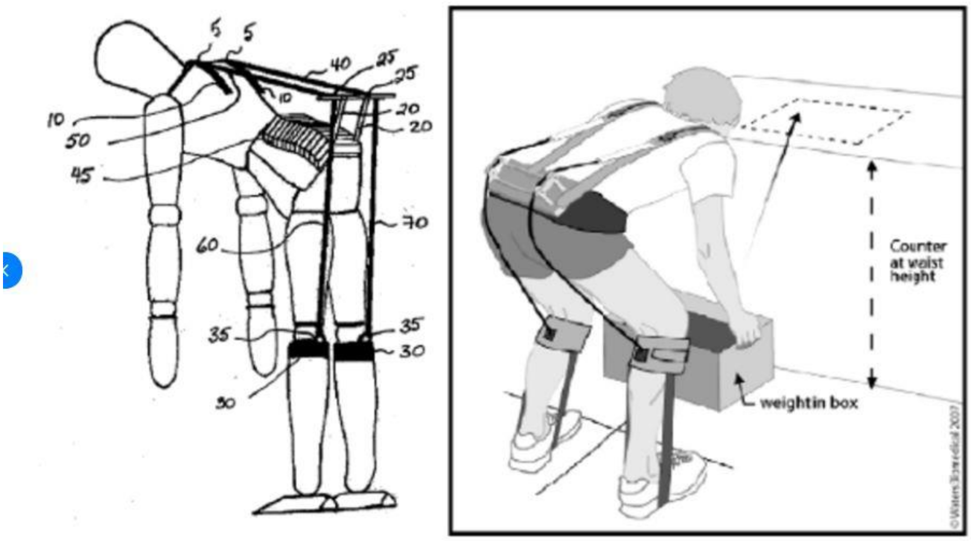



**Figure 10: PLAD exoskeleton for lifting [8]**

The elastic components that make up PLAD support some of the upper body's weight when it bends down. Laevo is a flexible exoskeleton that supports the back and chest while distributing some weight to the legs and chest. Bendezy is composed of a back unit, straps over the shoulders, back, and legs, and a portion of the weight is supported by springs. Most of these passive exoskeletons protect the lower back muscles, omitting to consider how taxing lifting is on the arm muscles. Unfortunately, there is little research on the discomfort the Exoskeleton causes locally [17].

### 2.4 Exoskeleton in Industries:

Exoskeletons are widely used in the logistics and manufacturing sectors. Like in the construction and agricultural sectors, they are used mainly for heavy lifting, prolonged squatting, lifting, bending, and walking around a company's facilities [18].

**Figure 11: Passive exoskeleton using in automotive industry [9]**

Exoskeletons have three key benefits for business and the workplace: fewer workplace accidents, saving billions of dollars in medical costs, sick leave, and litigation. They have enhanced attentiveness, productivity, and job quality due to decreased worker weariness—the capacity to maintain skilled workers past their physical peak in the workforce for longer [18].

**Figure 12: Exoskeleton helping in assembling car [10]**

When bending over to lift something, the lower back exoskeleton can keep the back in the proper position. Additionally, they can lessen the strain while bending down on the back muscles or even the spine. In industrial applications, the Exoskeleton is the most demanding gadget of the military and healthcare sectors and is now reasonably well defined. In contrast, those of business may be more diversified and frequently less defined and met. In our research, the purpose of BackX is to reduce injury in lower back muscles, which is known as “Thoraco-Lumber” [18][19].

These prerequisites are necessary. In response, the Exoskeleton Technical Advisory Group (X-TAG) was founded in March 2018 by Sarcos Robotics and representatives from numerous potential user sectors. The group seeks to establish performance and safety requirements to commercialize powered and quasi-passive, full-body industrial exoskeletons. The X-TAG group includes executives from leading companies in the industrial manufacturing, automotive, aviation and aerospace, construction, oil and gas, and utilities industries. Bechtel, BMW, Caterpillar, Delta Air Lines, GE, Schlumberger, Wurth Industries Service, and other businesses are among them [19].

**Figure 13: BackX helping in industry [3]**

### 2.5 The Use of Exoskeleton in this Research:

In many professional contexts (such as logistics, construction, agriculture, and manufacturing automobiles and aeroplanes), manual material handling (MMH) is a frequent and physically taxing job. MMH is one of the critical risk factors for musculoskeletal injury and involves activities like dynamic lifting and protracted stooping postures. MMH can cause significant compression on the lumbar spine. Workplace accidents have a significant negative influence on employees' quality of life, in addition to raising costs for employers. Guidelines for workplace safety and ergonomics are intended to lessen the workload for employees, which frequently leads to highly severe restrictions on MMH operations regarding item weights and movement frequency. While tools like external manipulators, which unload all or part of the weight to be handled, can lessen the physical stress on employees, these tools may be impractical or impossible to use in particular situations [20].


***Figure 14: BackX used in the Logistics Industry [3]***

Exoskeletons that are intended to unload the lumbar spine have been referred to by many various names, including "back support," "lift assist," "lumbar support," "hip orthosis," and "spinal exoskeleton." To keep things simple, we call them "back-support exoskeletons." We specifically refer to exoskeletons designed around the idea that forces or torques are given in the sagittal plane, between the user's torso and legs, to help with back and hip joint extension [21].

By supplying a part of the torque necessary to complete a physical action (such as lifting or maintaining a stooped position), these gadgets seek to aid the user. The devices achieve this while lowering the para-spinal muscles' work. Inverse dynamic models can be used to determine the necessary torques [21].


**Figure 15: Exoskeleton used in construction industry**

Exoskeletons provide supportive forces and torques using powered actuators, electric motors, or passive elements, such as springs. A passive exoskeleton can store and release energy supplied by the user due to the physical nature of the components employed. Existing passive back support exoskeletons use a variety of elastic parts. The BackX uses incorporated gas springs similarly. Reduced energy usage and less unpleasant actuator dynamics are potential benefits of this system, albeit both would rely on how the clutch is engaged and disengaged. The idea of quasi-passive or semi-active devices, in which the coupling/decoupling or the mechanical characteristics of passive parts (such as springs or dampers) might be automatically modified during operation, can be used in this strategy. No back-supporting exoskeleton has been discovered [22][23].

**Figure 16: Squat position**

**2.6 Shimmer Sensing Package:**

The electrical activity during muscular contractions may be used to analyze and evaluate human or animal movement biomechanics, nerve transmission, muscle response in wounded tissue, activation level, and muscle contractions. As a non-invasive (Surface) EMG sensor, the Shimmer3 EMG sensor captures the activity of the whole muscle. This wireless solution makes access to various strength, gait, and posture data analyses easy. EMG data may be recorded in two channels concurrently with 10-Degree of Freedom (DOF) kinematic data. IMU 10 DOF, this device also can record motion signals, providing additional context if need. Real-time, simultaneous measurement of all movements is possible. With Shimmer sensors, Consensus software enhances the functionality of your managed devices and live data. It is intended for large-scale repeatable trials, generic multi-sensor management, and adaptive human data collecting in the field. Your regulated data, live data, and devices can all benefit from the capabilities of the software that syncs with Shimmer sensors. It is meant for multi-sensor management in general, enormous, repeated trials, and field-based adaptive human data collection [23][24].

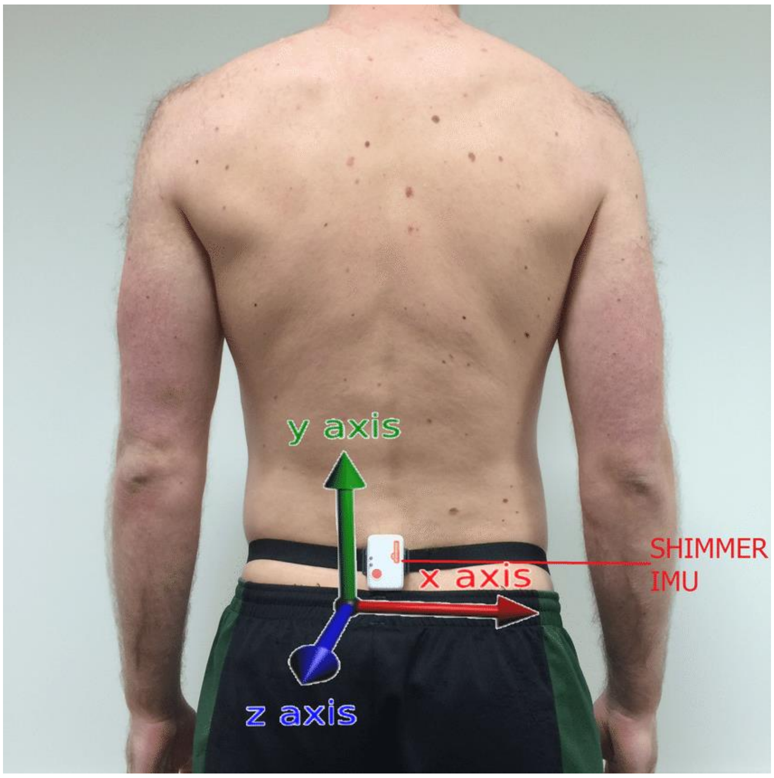



**Figure 17: Shimmer sensor [11]**

### 2.6.1 Benefits:

- "Measure kinematic data from the Shimmer3 IMUs, altimeter, and physiological data like EMG or ECG.
- Using a single reference electrode, measure the EMG data from two channels.
- Integrated altimeter and 9DoF inertial sensing using an accelerometer, gyroscope, and magnetometer, each with a customizable range, provide the highest data quality.
- EMG solution with five wires, four leads, and the user's option of V1 to V6 for measuring bipolar limb leads.
- Right-leg drives with software-configurable interference rejection for common-mode noise.
- Data rate and amplifier strength are software configurable.
- On-chip respiration demodulation capabilities.
- On-chip lead-off detecting capabilities."
- Expander board detection and identification are made possible by EEPROM storage devices, providing the user with 2032 bytes of data storage [25].

## 2.7 Electromyography (EMG):

The electromyograph, a recorded graph of the bioelectrical activity within a human muscle, is created using EMG electrodes. When a stimulus is applied or a signal is recorded during nerve conduction, somatosensory, or muscle twitch recording with human subjects, EMG electrodes are also employed. Different EMG electrode types, such as surface or intramuscular EMG, have been created depending on their intended use [26].

To record the EMG, non-intrusive electrodes are applied to the subject's skin. For recording purposes, it has been discovered that silver/silver chloride electrodes (10 1 mm) have an appropriate signal-to-noise ratio and are electrically very stable. As surface electrodes, they are frequently used. Electromyography (EMG) measures the electrical activity when a neuron activates a muscle. Using the test, the abnormal neuromuscular function is found [26].

## 2.8 BackX:

The primary technology of BackX is concentrated on designing and producing reasonably priced industrial and medical exoskeletons to enhance the lives of employees and those with gait disabilities. Because they are inexpensive, lightweight, passively effective, and durable enough to last at least five years, industrial exoskeletons are highly well-liked by employees. The exoskeletons made by BackX sustain the weight of the wearer's bodily parts rather than picking up or touching the burden. To retain and support the individual body parts of the human, the Exoskeleton works in tandem with the person. When the user is hunching over, the BackX (back-keeping Exoskeleton in suits) supports (i.e. holds) the wearer's trunk. The wearer's back muscles are reduced by around 50% [27].

In the workplace, exoskeletons that support the trunk are being investigated as efficient ergonomic therapies to reduce the frequency of back injuries. BackX has shown that it may reduce by an average of 60% the stress on a user's lower back (L5/S1 disc) when stooping, lifting, bending, or reaching [32]. Lower back strain reduction can lessen the compressive force around the L5-S1 vertebra, lowering the risk of back issues and increasing user endurance [27].

The back is sophisticated enough not to obstruct natural motions even without the use of electronics, enabling the user to carry out the majority of activities—such as walking, ascending and descending stairs, and driving work vehicles—without limitation while receiving assistance when they need it the most [28].

According to this study, wearing BackX while maintaining forward bending postures results in a 75% and 56% reduction in the average muscular activity of the lumbar and thoracic erector spinal muscles in equal populations of male and female individuals. Wearing BackX reduces the incidence of back injuries among employees who often adopt stooping, bending, and crouching positions for various jobs, such as lifting goods, according to the findings of this study and other field tests [29][28].

**Figure 18: Using exoskeleton**

**2.9 Area Under the Curve (AUC):**

When workers perform a task in various postures during work, the lower back muscle gets compressed and contracted, and then the area under the curve provides aid to measure the right area of the muscle to get a value.

The region between the variable, vertical lines designating subdivisions, and the x-axis are referred to as the area under the curve. The graph displays the area under the curve for a constant random variable. The interval represents the vertical limitations of the method.

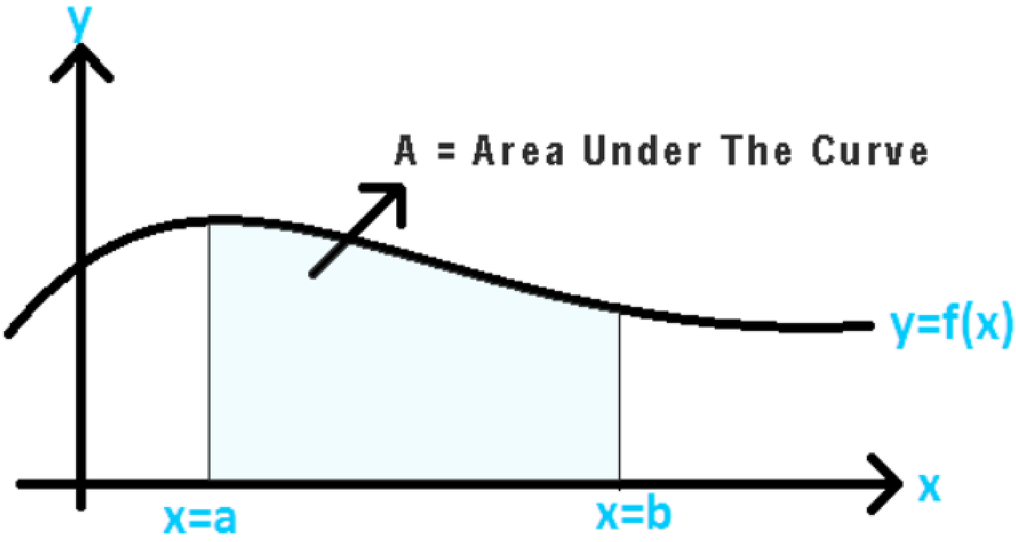



**Figure 19: Area under the curve [11]**

The area under the curve of the constant variable, f(x), is shown in the graphic above. The vertical boundaries of the function are given by the range [a,b]. The x-axis must constantly encircle the zone [30].

The area of the curve, which serves as the curve's limit, can be calculated concerning the several axes. Both the x-axis and the y-axis are valid approaches to compute the area under the angle. In some cases, the line is entirely beneath the axes, whereas in others, it is only partially under them [30].

### 2.11 Averaging the data:

The term "average" has different meanings depending on how the data is combined. The specific type of averaging method used depends on whether the values are added, multiplied, grouped, or divided among the components in the collection. The average represents a value that can replace individual values and yield the same overall results. A single "average" value can simplify and substitute the original findings [31].

**Table 2: Different Types of Averaging Methods:**

| Name & meaning | Formula | Used For |
|---|---|---|
| **Arithmetic Mean** | $\frac{sum}{size} = \frac{a+b+c}{3}$ | Most Situation ("Average item") |

One of the common objectives of the average person is to comprehend data collection through a random sample. However, the calculation process relies on the interaction between the elements within the group.

In this thesis work, arithmetic means are used to calculate the average. With the help of arithmetic mean, we measure the average muscle of all participants. Here, in the formula a,b,c lies the different muscle data of each participant. In our experiment, five participants participated in various real-time postures to use the BackX exoskeleton [31].

## 2.12 Data Refining:

Multiple factors, such as muscle anatomy, physiological processes, and external stimuli, influence electromyography (EMG) impulses. Consequently, EMG signals are vulnerable to various disturbances. Interacting voltages can negatively impact the accuracy of the measured signal. Inherent noises hinder the system's performance. It becomes challenging, if not impossible, to extract meaningful information from the EMG signal when the signal-to-noise ratio is meagre [32].

To mitigate this issue, several techniques are employed to reduce noise in EMG data. Filtering is a crucial step in refining data processing. It involves using a tool or method to eliminate unwanted signal disturbances or component characteristics from the original signal. The goal is to identify unique and genuine data measurements by removing unnecessary noise frequencies or frequency ranges [33].

The filtering process is applied twice to digital signals in the forward and reverse sample order to maintain phase stability. In this case, eight filters were combined in a sequence, including six stopband filters, a low-pass filter, a high-pass filter, and a filter designed to address the primary power inherent noise (60 Hz) and its first five harmonics. The Butterworth filter is preferred for most analogue paths due to its flatter frequency distribution within the passband. This higher-level Butterworth filter offers a smoother frequency response and better attenuation of signals outside the desired passband [33].

## 2.12 About Unwanted Interferences:

Interference is a crucial aspect of wireless communication systems, occurring when multiple transmissions co-occur within a single communication channel. Detecting and addressing unwanted interference is essential during the data collection process [34].

## 2.13 Simulation(3DSSPP):

The 3-Dimensional Strength Statical Prediction Program (3DSSPP) program forecasts the necessary static strength for lifts, presses, pushes and pulls. The programmers a rough job simulation that considers anthropometry for men and women, posture data, and force characteristics. The output contains spinal compression pressures, the proportion of men and women with the strength to execute the indicated work, and data comparisons to NIOSH recommendations. The user may create sophisticated hand force entries and analyze torso twists and bends. An automated posture-generating function and three-dimensional human visual images help with analysis [35].

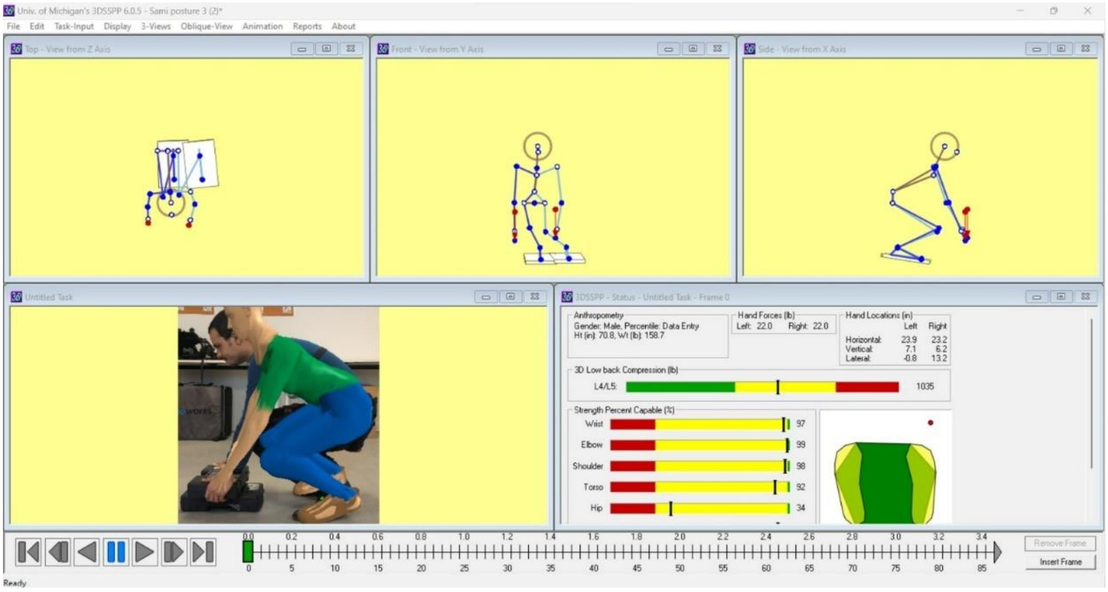


**Figure 20: GUI of 3DSSPP**

The 3DSSPP program is one of the most used digital human models for biomechanical analysis of manual handling tasks. [35] It has been applied, for example, to the motor industry, patient transportation, and people with and without spinal cord injuries' ability to move objects. The input data for 3DSSPP includes characteristics such as sex, height, weight, hand-applied force, body measures, and participant posture when standing, sitting, pausing, squatting, and pulling/pushing activities [35]

The anthropometer and weighing scales were used to measure the height and body weight for the input data. The 3DSSPP program generated the default arm, leg, and other body limb measurements by considering the user's height, weight, and gender. The input data used the size of the workers' shoes, which was 25 mm. It should be mentioned that most solid garbage is collected door to door using plastic bags (30*50 cm, 5–10 kg), and the remainder is collected using two- or four-wheeled carts. In this investigation, the software was used to calculate the force and moment delivered by each of the 20 waste collectors to the L4/L5 intervertebral disc. The L4/L5 disc's spinal forces and moments are compared using 3DSSPP [36].

### 2.14 Efficiency:

The efficiency equation is used to calculate the amount of energy lost as the consequence of inefficiencies, as shown by the formula Losses = Pin - Pout. Another measure of how effectively electrical power is converted into output that may be used in production is the power factor, a value that is likewise expressed as a percentage. Efficiency and power factors can be used to indicate the amount of energy that is lost.

$Efficiency = \frac{Average\ value\ of\ the\ WOE - Averae\ value\ of\ WE}{Average\ value\ of\ the\ WOE} \times 100\% --\rightarrow (1)$ Efficiency, then, is a percentage-based measure of wasted or insufficiently utilized energy. It is calculated by dividing the amount of input power by the output power. The power factor, although it can be used to indicate the proportion of wasted energy, can also be used to express energy efficiency [37].

### 2.15 Butterworth Filter:

A Butterworth filter is a type of signal processing filter that aims to have a frequency response that is as flat (with no ripples) as possible throughout its passband and zero roll-off response within the stopband. The Butterworth filter is one of the most popular digital filters utilized for motion analysis and audio circuits. They are quick and simple to use. Since filtering results are frequency-based, they may be easily understood and predicted [38].

In the spline techniques, choosing the frequency of the cutoff is easier than determining the degree of data imperfection. The main flaw of the Butterworth filter is that it makes tradeoffs.

In order to achieve this pass band flatness, a thin transition band is required when the signal moves through the pass band to that of the stop band. Furthermore, it shows poor phase characteristics. The best frequency response is the “brick wall" frequency response [38].

**These are the properties of Butterworth filters:**

Has a smooth response, dropping monotonically from the set cut-off frequencies at all frequencies. Optimal flatness, comprising an absolute responsiveness of 1 in the passband and 0 in the stopband at a frequency that is 3 dB down from the cut-off frequencies, also known as the half-power frequency. A virtue of Butterworth filters is their smooth, monotonically diminishing frequency response [39].

**$4^{th}$ Order of Butterworth:**

A fourth-order Butterworth filter is produced by cascading into two second-order low-pass Butterworth filters.

If the gains of both filters are set to 1.586, the increase in voltage will be 6 dB lower at the cutoff frequency. We may achieve an even more flat response by choosing various voltage gain levels for each step. Modern research indicates that the flattest response can be achieved with voltage increases around 1.152 for the starting stage and 2.235 for the second phase [40].

The image below shows the fourth-order lowpass Butterworth filter's frequency response.

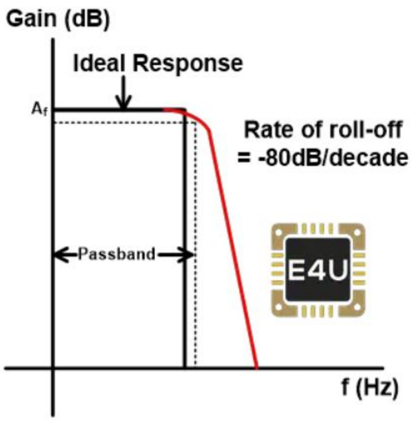



**Figure 21: Butterworth lowpass filter [12].**

### 2.16 Full Wave Rectification:

In full-wave rectification, the negative component of the input voltage is rectified in a diode bridge configuration to change the pulse rate coming from DC (pulse current) to an eventual positive voltage. Half-wave rectification, in contrast, simply removes the corresponding negative voltage source using a single diode before converting to DC [41].

**Advantages:**

- The ratio of the input frequency to the ripple frequency is two.
- Efficiency has improved.
- An impressive DC power output.
- Less of a rippling effect.
- In the instance of a full-wave rectifier, low ripple voltage and higher frequency necessitate a simple filtering circuit.
- The greater output of voltage.
- Higher usage factor for transformers.
- Use the two halves of the AC waveform.
- The ripple amplitude makes achieving smoothing easier.

**Disadvantages:**

- A more complicated half-wave rectifier.
- For the bridge rectifier, four diodes are required, compared to two using the centre tap rectifier.
- The diode has a higher PIV rating.
- Higher PIV diodes cost more and have a bigger size.
- The cost of the centre tap transformer seems high.
- The repeated frequency hum might become more audible on an audio circuit.
- On this rectifier, it is difficult to locate the middle tap of the secondary winding.
- Due to each diode using just 50% of the secondary voltages from the transformer, the DC output is minimal.
- When rectifying a low voltage, the full-wave rectifier circuit is ineffective [41].

## 2.17 Linear Envelop:

Finding the "linear envelope" of the signal is another name for the process of rectification and low pass filtering because the filtering functioning satisfies the mathematical definition of linearity (in contrast to the particular absolute value operation, which does not) and due to the fact that it captures the "envelope" of the signal because it is low pass [42].

## 2.18 Analysis of Variance (ANOVA):

With the help of the statistical analysis approach known as ANOVA, apparent aggregate variability within a data set is explained by separating systematic components from random factors. Statistics show that frequent but not arbitrary elements have an impact on the data set that is being displayed. The ANOVA test, also known as the Fisher analysis of variance, is used by analysts to determine the influence independent variables have on the dependent variable in regression analysis.

The phrase gained notoriety in 1925 after being included in Fisher's book, "Statistical Methods for Research Workers. "It was used in experimental psychology before being applied to more complicated topics [43].

We perform data analysis in Anova, and as a result, we obtain the p-value. It aids in the null hypothesis's rejection. If our p-value is lower, it means that our data are more convincing, and the null hypothesis is rejected because of this. The P-value needs to be equal to or less than 0.05 [43].

### 2.18.1 Formula for ANOVA:

$$F = \frac{MST}{MSE}$$

Where,

F = ANOVA coefficient

MST = Mean sum of squares due to treatment

MSE = Mean sum of squares due to error.

## Chapter – 3: Research Methodology

### 3.1 Overview:

The research procedure is briefly explained in this chapter. The methods by which the measurements were taken from the various setups and positions are also covered in this chapter. These methods show how the evolving EMG system can be used to assess the advantages of exoskeletons.

### 3.2 Volunteers (Participants):

For this study, measurements were conducted on five males, ages 26 to 36 (mean 303). The individuals had heights between 160 and 180 cm and weights between 65 and 90 kg. All participants provided informed consent and said they had no neurological or orthopaedic conditions before the exams. To ensure that the Exoskeleton would suit each volunteer and enable them to function as industrial employees, consideration was given to their height, weight, and body size. Volunteers were instructed to lift various weights (e.g., 5 to 15 kg) while wearing BackX.

### 3.3 Measurement Task:

The experiment involves various activities to assess the Exoskeleton's adaptability and its effects in multiple positions. Without an exoskeleton, each participant carried out the same task that they performed while wearing the exoskeleton. The measurement procedure is explained in greater depth below:

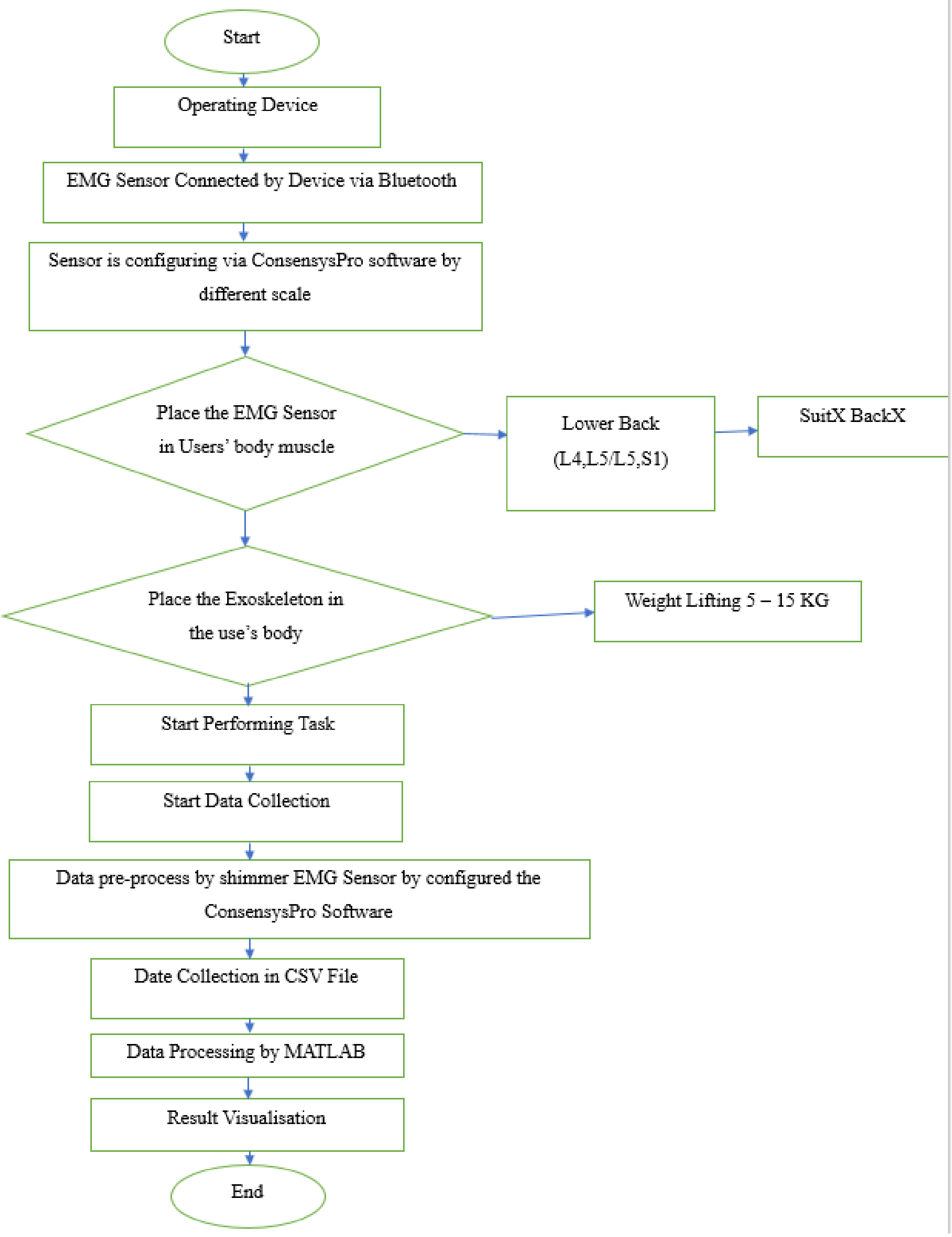
- Initially, we lined up five male volunteers at one place to perform the task while being in the same positions.
- Immediately after that, we placed shimmer sensors and EMG electrodes on people's lower backs to assess their lower back capacity.
- After that, they lifted the weights—ranging from 5kg, 10kg and 15 kg—from the ground to the table. Without an exoskeleton, the entire process was performed. We then used sensors to record their data on lower back muscles for 15 seconds.
- Then, the same procedure was repeated at the same place, but this time with the aid of an exoskeleton (BackX).

- Using 3DSSPP, we created 3D models of all five individuals based on their age, height, and body weight. We used those models to gather data on their lower backs to determine the effects of lifting this much weight on their lumbar spine (L4/L5 & L5/S1), lower back, upper back, and lower spine.
- The usage of 3DSSPP gives us the ability to understand how much weight an individual can lift based on their physical characteristics before conducting the actual practice. This enables us to know the possibilities for muscular injury or strain.

The task's main goal was to evaluate the Exoskeleton's potential advantages, including minimizing muscle strain, improving comfort, and enabling workers to stay in one place for prolonged periods [43].

### 3.4 Flow Chart:

The research workflow is depicted below in the flow chart. The operating device, i.e., the shimmer sensor, is connected to the laptop via Bluetooth. The sensor is configured using Consensys Pro software on the laptop. The shimmer (EMG sensor) is placed on the lower back of the participant's body near where the Exoskeleton (BackX) is placed. The data was gathered using an EMG sensor once the participants started performing tasks, i.e. squat lifting, in which participants were recorded lifting weights of 5, 10 and 15 kgs for the interval of 15 seconds each. The same procedure was repeated to gather the data without using the exoskeleton for the purpose of comparison. Finally, the raw data gathered using the EMG sensor was collected into a CVS file with the help of Consensys Pro software. The data is then processed using MATLAB, and the result is analyzed and presented in the form of graphs [43][44].


Start
Operating Device
EMG Sensor Connected by Device via Bluetooth
Sensor is configuring via ConsensysPro software by different scale
Place the EMG Sensor in Users' body muscle
Lower Back (L4,L5/L5,S1)
SuitX BackX
Place the Exoskeleton in the use's body
Weight Lifting 5 – 15 KG
Start Performing Task
Start Data Collection
Data pre-process by shimmer EMG Sensor by configured the ConsensysPro Software
Date Collection in CSV File
Data Processing by MATLAB
Result Visualisation
End

### 3.5 Description of Internal Structure and Parts:

The internal circuit schematic for the shimmer sensor has an EMG board that is biologically coupled to five electrodes. There are two dissimilar ports present in channel 1, comprising one negative (channel one negative) & another positive (channel one positive). Likewise, in channel 1, in channel two, there are again two dissimilar ports containing positive (channel two positive) and negative (channel two negative), and along with these ports, there is a neutral reference electrode(ref) that is present in the middle.

Three electrodes are employed in this procedure since the EMG signal's amplitude is typically relatively small in contrast to noise. The signal from each electrode consists of background noise and local electrical activity from the muscles nearest to the skin [44].

#### 3.5.1 Electrodes:

Electromyography is an electrodiagnostic medical technique for examining and recording the electrical activity produced by skeletal muscles. In addition, we use this sensor in our thesis to record the muscle data using a shimmer three sensor, which is connected by probes [45].

#### 3.5.2 Defibrillation Protection:

Equipment used for patient monitoring frequently undergoes testing to ensure it is defibrillator-proof.

#### 3.5.3 EMI Filter:

Delicate electronics can be harmed by high radiation levels generated by other electronic gadgets. EMI filters, however, can stop this from happening. They allow for the free passage of beneficial winds while removing undesired currents carried by cables or wires that can hamper power and signal lines. Approximately 3MHz is this filter's 3dB filter bandwidth, which lowers electromagnetic interference [45].

#### 3.5.4 Gathering Data Wirelessly:

We first installed the Shimmer sensor software on our device, and then we connected the Shimmer sensor to our laptop via Bluetooth. This entire process is referred to as the Dock process. The participant's body was subsequently attached with a Shimmer sensor after that. After connecting, we start the process and commence wirelessly receiving data from the lower-back muscle. We have a frequency of 512 Hz to us in order to execute this task [46].

### 3.5.5 Programmable Gain Amplifier:

An electrical amplifier (usually based on an operational amplifier) with programmable gain that external digital or analogue signals may influence is known as a programmable-gain amplifier (PGA) [47]

Basically, it is a usual method to filter EMG signals or data via a bandpass filter. Butterworth is a type of bandpass filter. In this thesis, two band-pass filters are used to make our data filter out for more accurate and refined signals or data. First, we use the Butterworth low pass filter to pass the lower frequency and the Butterworth high pass filter to pass the high frequency. High pass Butterworth filter gives permission to high-frequency signals to allow through while attenuating low-frequency signals. Low-pass Butterworth filter is the type of frequency domain filter that is used for smoothing the image [47].

### 3.5.6 Analog to Digital Converter:

A system that transforms an analogue signal into a digital one is known as an analogue-to-digital converter (ADC, A/D, or A-to-D) in electronics. An electrical device that converts an analogue input voltage or current into a digital number reflecting the magnitude of the voltage or current is an example of an ADC that can offer an isolated measurement. These transform analogue signals as input into digital representations of those signals by assigning a 24-bit signed integer value to each sample. The Shimmer3 processor receives these values, stores them on an SD card, or transmits them over Bluetooth [48].

## 3.6 Method for Recording the Data

The sensor setup for our volunteer positions has been finalized. We employ a surface electrode to capture muscle data while the participant lifts weights from the floor in a squat position. The erector spinae muscle was chosen as the location for the shimmer sensor's reference port on the lower back. The shimmer sensor was first installed on the left side of the muscle and later reattached on the right side. This arrangement was used to obtain the muscle's EMG data both with and without SuitX [49].

**Figure 22: Location of electrodes placement on participant's body**

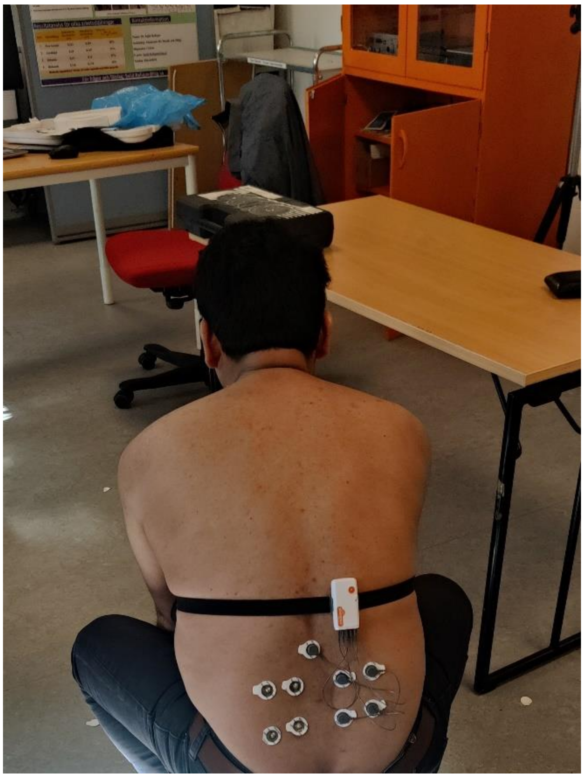


**Figure 23: Position of electrodes placement on the participant's body**

Consensys Basic and ConsensysPro software are the two versions available for use with the shimmer sensor. Shimmer ConsensysPro software was used to gather the data for this thesis experiment. Additionally, the following procedure was followed for data acquisition:

- Start by launching the ConsensysPro software. Then, use wire to dock the shimmer sensor. Set up the "FIRMWARE" program and choose "Manage device." Then, choose the 'LogAndStream' firmware options for data collection. Choose the experimentation Shimmer as well. The next step is to select the configure tools and then the "EMG" section.
- To gather EMG data, pick the gain and other desired values from the toolbar after choosing the name of Shimmer and the sample rate. To complete the setup, press the 'WRITE CONFIG' button. Press the NEXT button to release the shimmer sensor from its dock and establish a Bluetooth connection with the laptop. Once more, open the 'Live DATA' options and select the live Wi-Fi icon to connect. Then, use the steam button to begin steaming. The record button is pressed, and data begins to be recorded straight in the PC or shimmer SD card. Finally, 'Export' the data to the location needed for further experimental processing [49].

### 3.7 Analysis of the Exoskeleton

The Exoskeleton was made to support and provide strength to the lower back muscles, providing considerable improvement in the quality of work performed. The Embodiment Tendon's modular construction guarantees a dependable, flexible, and helpful system. The SuitX (BackX) exoskeletons for lower back support were first mentioned in Chapter 2. The parts can work together or separately as needed. Different parts of the subsystem are also helpful at the joint level. Lower amplitudes produce better results when using an EMG sensor to assess muscular contractions while performing industrial duties using an exoskeleton. Exoskeleton wearers use less energy to do tasks, especially when their body's energy or ability to contract their muscles is limited. When completing the same job without an exoskeleton as when wearing one, the amplitude of muscle contractions is higher. To compare the two exoskeleton parts, we ran numerous comparative scenarios and used a variety of data collection methodologies. These methods enabled a thorough examination of the subsystems [50].

#### 3.7.1 BackX:

For our thesis, we are considering BackX, an exoskeleton designed for the lower back, explicitly targeting the thoracolumbar and erector spinal (L4/L5, L5/S1) muscles to capture EMG signal data. We conducted squat lifting exercises with and without the Exoskeleton as part of our investigation. Additionally, we examined two different spring positions in the Exoskeleton, considering both positive and negative spring levels and their respective implications [43].

In this case, we combined and analyzed data from three volunteers using MATLAB. We calculated the maximum and average values from the resulting graph to facilitate comparison. The amplitude of each volunteer's EMG data in these three scenarios represented how the signals were affected by wearing the Exoskeleton, specifically BackX. This analysis helps us understand the movement changes caused by exoskeletons and their potential benefits for industrial workers [43].

### 3.7.2 Area Under Curve:

Determining the area under a curve relies on considering its equation, boundaries, and the axis it encompasses. While there is no specific formula for calculating the area under a curve, there are formulas available for computing the areas of common shapes such as squares, rectangles, quadrilaterals, polygons, and circles. Integration is crucial in identifying the desired location and solving the problem [43].

This section will explore methods for calculating the area under a curve concerning an axis and the space between a curve and a line. There are three straightforward approaches to computing the area under the curve. First, we need to understand the curve's equation (y = f(x)), establish the boundaries within which the area will be evaluated, and identify the axis that bounds the area. Then, we proceed with integrating the curve. To obtain the area under the curve, we sum the integral results by incorporating the upper and lower bounds and subtracting the outcomes accordingly [43].

$$Area = \int_a^b y.dx \tag{1}$$

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

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

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

This experiment involves collecting signal data to obtain both relaxation and working data. For this thesis, we have focused on estimating the working areas under each signal to evaluate the initial muscle contraction. This workspace enhances exoskeletons' effectiveness for various tasks (IEE).

### 3.8 Taking Averaging of Data:

Obtaining an average or typical input value can help better understand the essential elements within the information. Averaging the data allows users to move beyond random fluctuations and observe patterns based on the information source. Different averages exist, each serving a specific purpose and providing a somewhat different assessment of the predominant trend in a data set [51].

In the case of combining data from three volunteers, averaging is performed to obtain a single data line with an x-axis and a y-axis. This averaged data is essential for analysing the area under the curve, as each data point needs to be considered. In this study, the absolute mean analysis was employed to improve the combination of volunteer data.

The arithmetic mean, often called the mean, is one of the most commonly used techniques for averaging data sets in the computer and scientific fields. The norm is calculated by summing up all the items in the dataset and dividing the total by the number of components. The standard distributes the total evenly across the dataset. While the meaning is easy to understand and calculate, it has limitations [51].

**The arithmetic mean Is the most used type of average:**

$$Average = \frac{Sum}{Number} \tag{2}$$

There are three primary reasons for considering these averaging techniques:

- Utilising data averaging can help mitigate inconsistent results.
- The mean, median, and mode are the three most widely used types of averages.
- MaxBotix recommends employing the median or mode when averaging range value [50].

### 3.9 Data Analysis:

In this block diagram, the major components or purposes of the work are represented by blocks that are joined to generate shapes that show the links between the blocks.

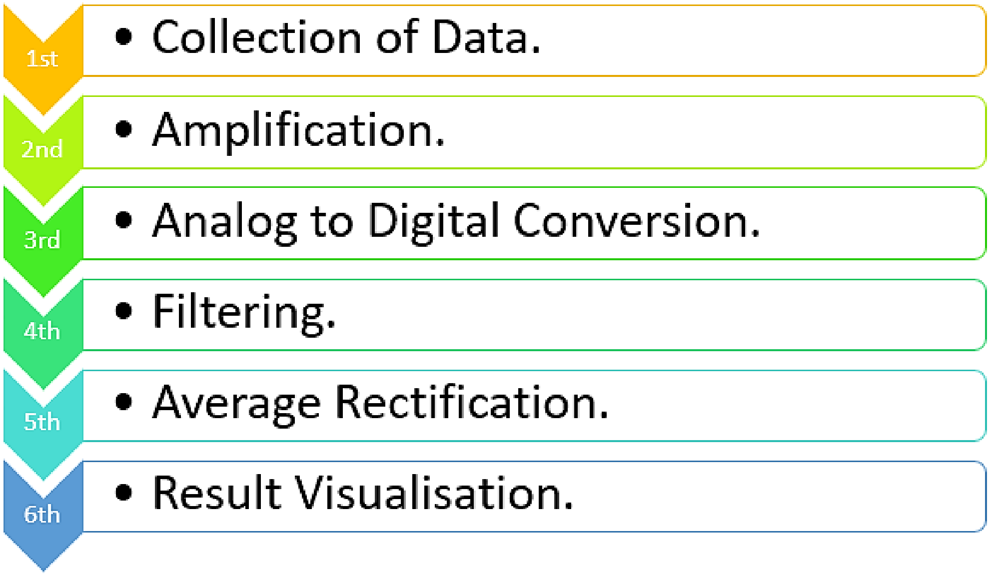



**Figure 24: Data analysis**

The previous block diagram illustrates some steps in processing the acquired signals. Firstly, the sensor device is configured on the participant's body. Raw data is then collected from different parts of the body. The Shimmer EMG device automatically preprocesses the data to prepare it for further analysis. Since the signal data was initially too small to be visible, it was amplified during preprocessing [52].

Next, the analogue-to-digital converter within the EMG device converts the amplified analogue data into digital format. The output of this conversion represents the raw data from the device. This raw data was reanalyzed to provide a final visual representation for the viewer. Filtering techniques were applied to isolate the EMG signal from noise and artefacts within the raw data. After filtering, the values were further modified by calculating their average to obtain the absolute value. The processed data was then presented on the screen, allowing users to observe the finalized diagram of the EMG system at this stage [52].

### 3.10 Analyses of Processed Data:

Data analysis involves examining data using quantitative or statistical methods to extract meaningful insights. Once the raw data is collected, it must undergo processing before conducting the investigation.

## Chapter – 4: Results and Analysis

### 4.1 Results and Analysis

This chapter will provide a quick summary of the key findings, based on the kind of study, descriptive and statistics. Experiments were done to evaluate the productivity of SuitX. Five vital young volunteers did identical upper-limb and lower-limb actions with the help of a SuitX robot in the studies.

#### 4.1.1 BackX Analysis:

In this section, I have discussed upper body BackX and carefully studied the different working positions of industrial workers with EMG data graphs and tables. I think about squat lifting for carefully reviewing the BackX properly. This position is weightlifting. In this analysis, I think about five volunteers individually for the position. I describe the position details more briefly below:

#### 4.1.2 Weightlifting:

We consider three weights to examine the weight-lifting position: 5 kg, 10 kg, and 15 kg. In this instance, we conduct the procedure with or without an exoskeleton. BackX exoskeleton has two springs, one each for the positive and negative signs. The positive spring level, which provides high support, is shown by a positive sign. In contrast, a negative sign in the exoskeleton indicates the lowest spring level, which provides inadequate support.

In our findings, the first graph depicts the relationship between force and angle, and the second graph displays muscle activity following time. All of the data was gathered via EMG sensors. Both of the graphs were built using MATLAB. With the help of the 3DSSPP model, the data for the first graph is produced. In addition, the x-axis and y-axis of the first graph define the angles and force, respectively. The second graph's x-axis displays time samples, and its y-axis indicates the amplitude of muscle activity of lower-back:

### 4.2 Weight work with 5 kg:

As seen in the graph, the force was acting on L4/L5 while our volunteer was in the squat position (which is practically an angle of 40 degrees at that position), with the minimum force being 249 N/m and the highest force being 285 N/m at 40 degrees. The force started to decrease when the position increased to over 40 degrees. The minimal force on L4/L5 was (216), and the maximum force was (286) when participants achieved an angle of 90 degrees.

A lesser force will be placed on taller participants' L4/L5 and L5/S1. Force varies according to the body's mass and changes with body weight and height. The force will be increased following the increase in body weight. Bending can be challenging for people with a chubby build and who are shorter in height.

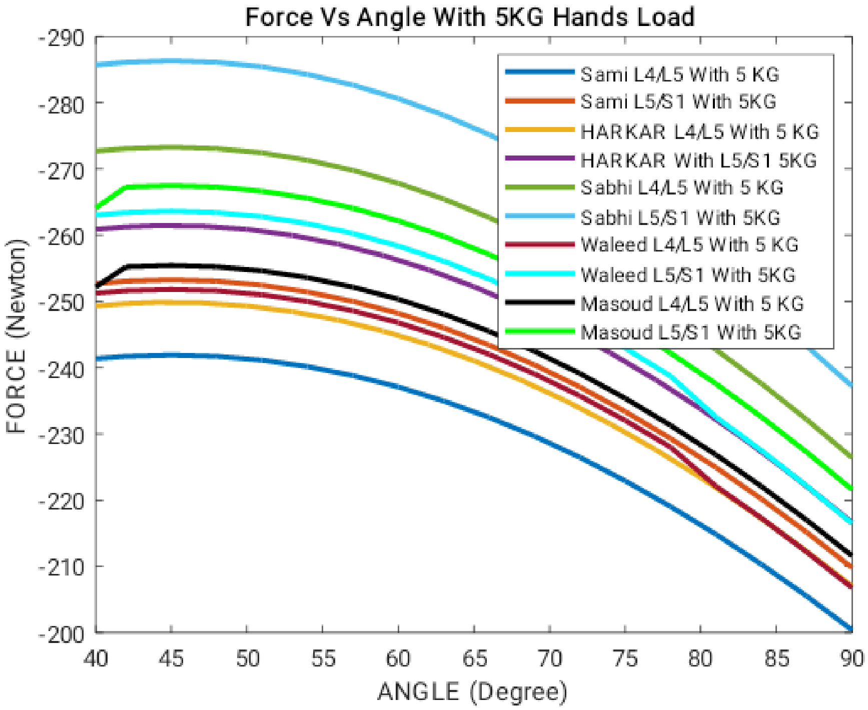



**Figure 25: Result of force 5KG acting on L4/L5 and L5/S1**

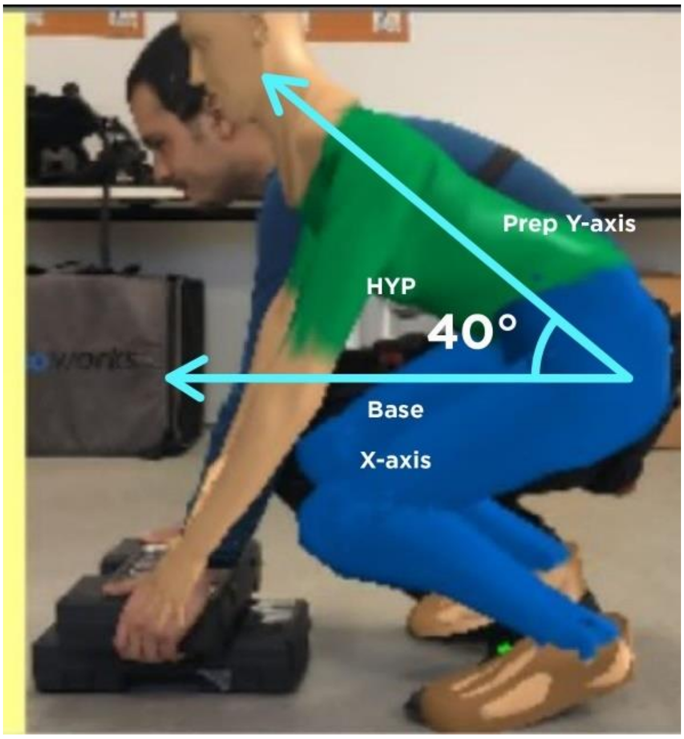



**Figure 26: Participant (Sami) at 40-degree squat position**

When raising a weight or any other object upwards from the earth's surface, the graph's y-axis has a negative sign, indicating that gravity is exerting its force in the opposite direction from the earth's surface.

The EMG average signal graph for postures used in BackX weightlifting is shown in the other graph. Both graphs incorporate three different types of line graphs.

These line graphs show the average EMG line data graph for all volunteers. The time in seconds is shown on the X-axis of these graphs, and the muscle activity's amplitude is shown on the Y-axis in mV.

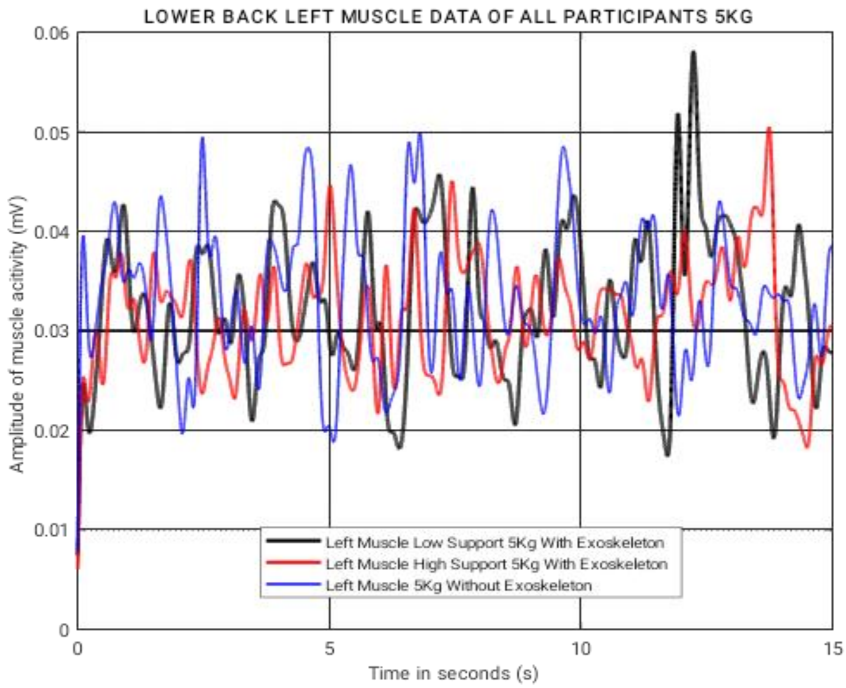



**Figure 27: Lower back left muscle data with 5KG**

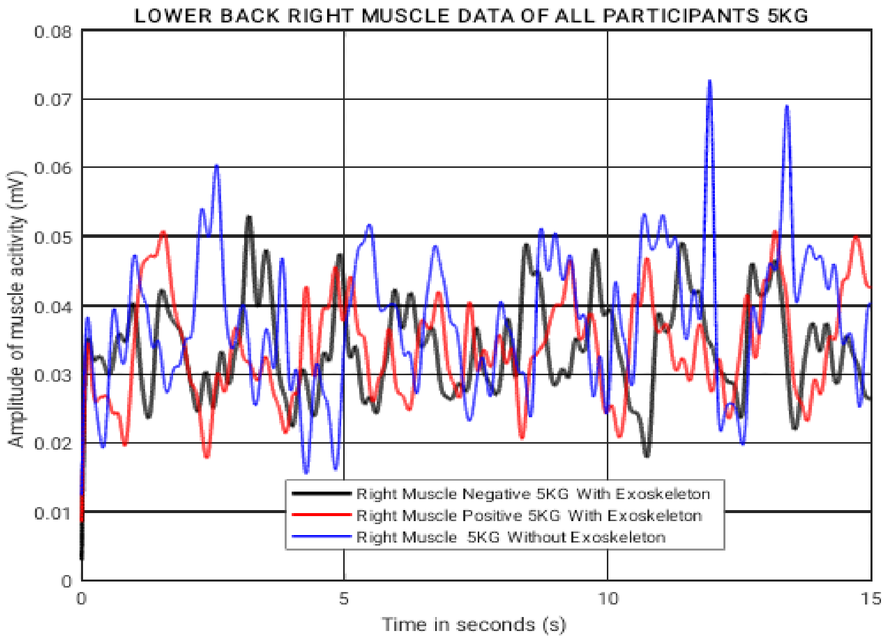



**Figure 28: Lower back right muscle data with 5KG**

In the same way, the black line (low support) represents the activity with an exoskeleton, whereas the red line (high support) indicates the activity without an exoskeleton. However, the blue line shows us executing the task without an exoskeleton. Further, they demonstrate the EMG average signal for all volunteers lifting 5 kg. According to our analysis, the line graph with the lowest average amplitude is the most efficient because it saves the highest amount of energy, and the line graph with the highest amplitude possesses the lowest efficiency level because it saves the least amount of energy.

On the graph, each signal represents both the working and relaxation phases of a muscle contraction. Only the working region of the graph, which can reveal how much of the efficiency correlates to the average, should be used to calculate efficiency in this instance. For a more thorough analysis, we consider a table that considers weight-lifting postures for 5kg with high support and low support spring levels.

The above image has three columns, the first demonstrating the spring levels with or without an exoskeleton and the second and third exhibiting two distinct weights. In the second and third columns, two sub-columns show the average value of the working area and the effectiveness of this average working area for various spring levels without exoskeleton value as our reference value. The following chapter, which discusses the efficiency bar graph, provides a clearer perspective. We employ an equation that is provided below to calculate this efficiency:

### 4.3 Weight work with 10kg:

As can be seen in the graph, our volunteer was in a squat position, which is almost a 40-degree angle, when the force was applied to the L4/L5 joint. The lowest force measured at 249 N/m and the greatest at 285 N/m at 40 degrees. When the angle exceeded 40 degrees, the force began to decrease. When participants reached a 90-degree angle, the minimum force on L4/L5 was (253), while the highest force was (338).

Taller participants will experience less force on the L4/L5 and the L5/S1 joints. Force is affected by the body's mass and changes with both height and weight. With an increase in body weight, the force will also increase. Bending might be difficult for people with a fat build and those who are lower in height.

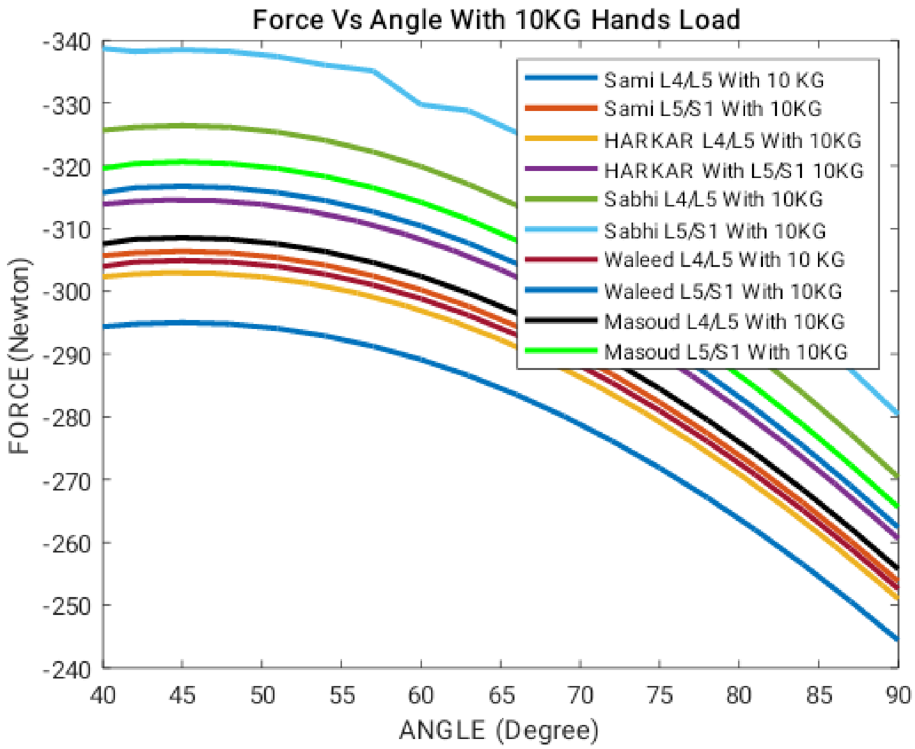



**Figure 29: Result of force 10KG acting on L4/L5 and L5/S1**

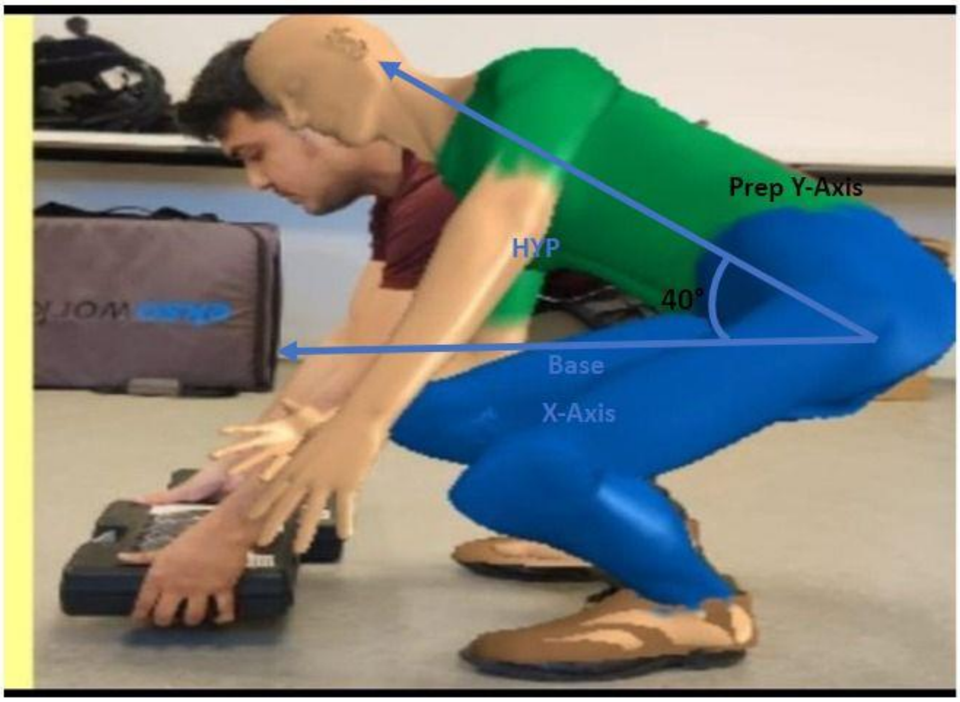



**Figure 30: Participant (Masud) at 40-degree squat position**

The graph's y-axis shows low support when lifting a weight or any other object upward from the earth's surface, showing that gravity is acting in the opposite direction from the earth's surface.

The other graph displays the EMG average signal graph for the lifting positions used in SuitX. Both graphs combine three distinct line graph types. The average EMG line data graph for all volunteers is displayed in these line graphs.

These graphs have an X-axis representing time in seconds and a Y-axis representing the amplitude of muscle activity in mV.

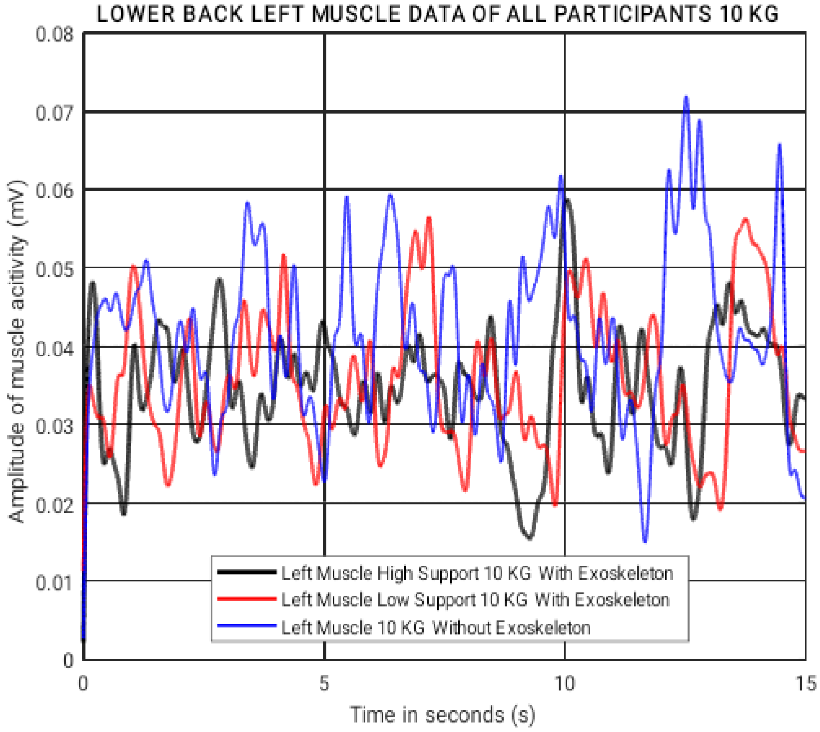



**Figure 31: Lower back muscle data with 10 KG**

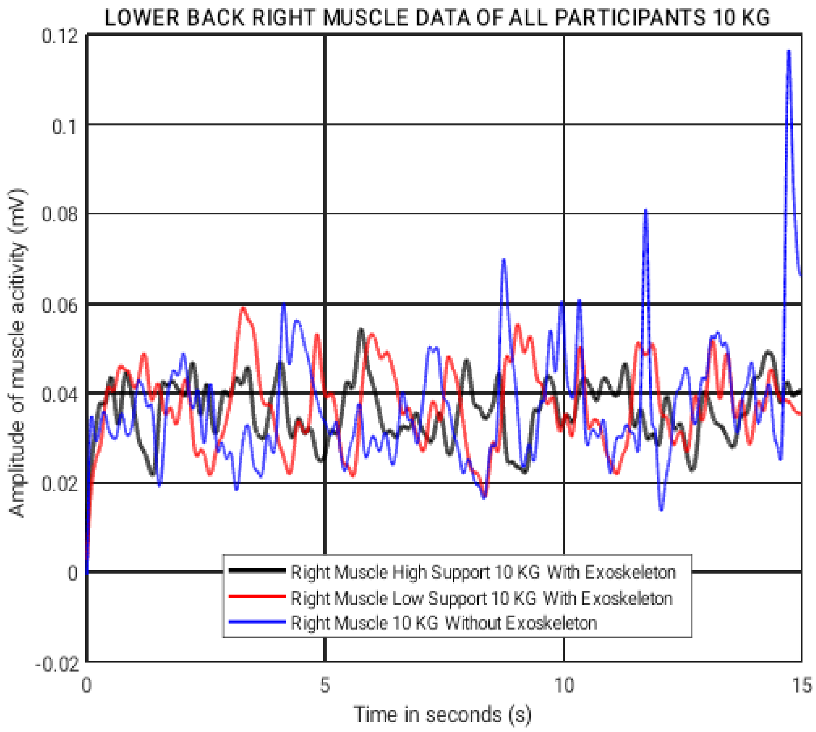



**Figure 32: Lower back right muscle data with 10 KG**

The red line (high support) denotes activity without an exoskeleton, whereas the black line (low support) reflects activity with an exoskeleton. The blue line, on the other hand, depicts us performing the activity without an exoskeleton.

They also show the average EMG signal generated when all volunteers lift 10 kg. Our study shows that the efficiency is highest for the line graph with the lowest average amplitude because it saves the most energy, and the efficiency is lowest for the line graph with the highest amplitude because it saves the least energy.

Each signal on the graph corresponds to a muscle contraction's working and relaxing stages. To calculate efficiency in this situation, only the working zone of the graph should be used since it can show how much of the efficiency correlates to the average. We use a table that includes weight-lifting positions for 10 kg with high and low support spring levels for a more detailed study.

The first column of the above table shows the spring levels with or without an exoskeleton, whereas the second and third columns show two different weights. Two additional sub-columns in the second and third columns display the average working area value and efficacy for varied spring levels without using the exoskeleton value as our reference value.

The efficiency bar graph in the following chapter gives a fuller picture of the circumstance. We use the following equation to get this efficiency:

### 4.4 Weight work with 15kg:

As can be seen from the graph, when the force was applied to the L4/L5 together, our volunteer was in a squat position, which is almost a 40-degree angle.

A force at 40 degrees was measured to have a minimum of 249 N/m and a maximum of 285 N/m. Over a 40-degree angle, the force started to diminish. The lowest and maximum forces on L4/L5 were applied when participants' angles were 90 degrees and 180 degrees, respectively.

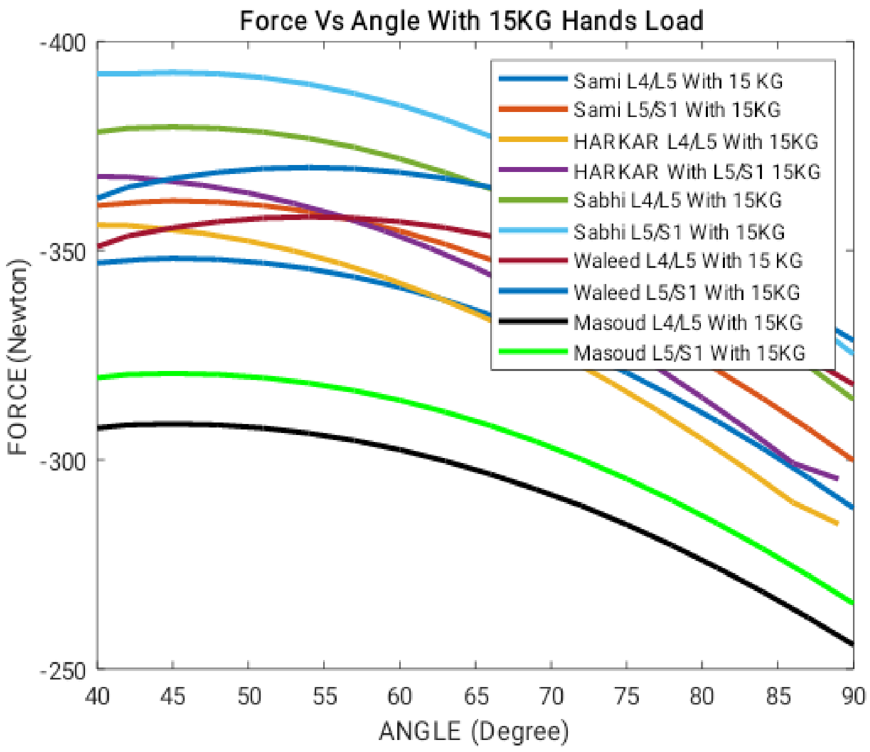



**Figure 33: Result of force 15KG acting on L4/L5 and L5/S1**

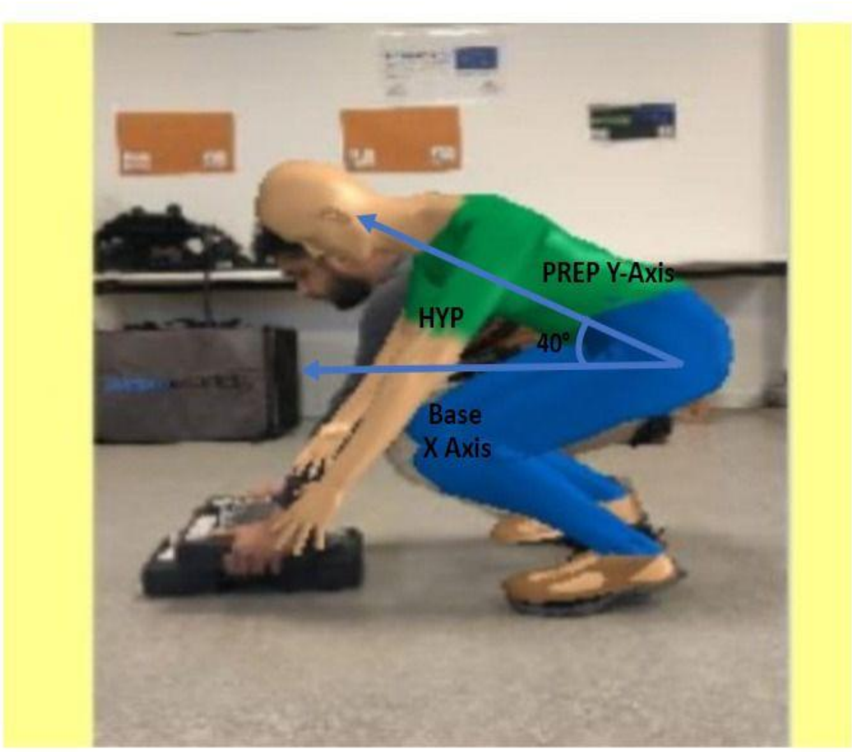



**Figure 34: Participant (Waleed) at 40-degree squat position**

Lifting a weight or any other object upward from the earth's surface can demonstrate how the graph's y-axis has low support, indicating that gravity works in the opposite direction from the earth's surface.

The EMG average signal graph for the lifting postures used in SuitX is shown in the other graph. Three different line graph types are combined in both graphs. These line graphs provide the average EMG line data graph for all volunteers. These graphs contain two axes: an X-axis for seconds and a Y-axis for the magnitude of muscle activity in mV.

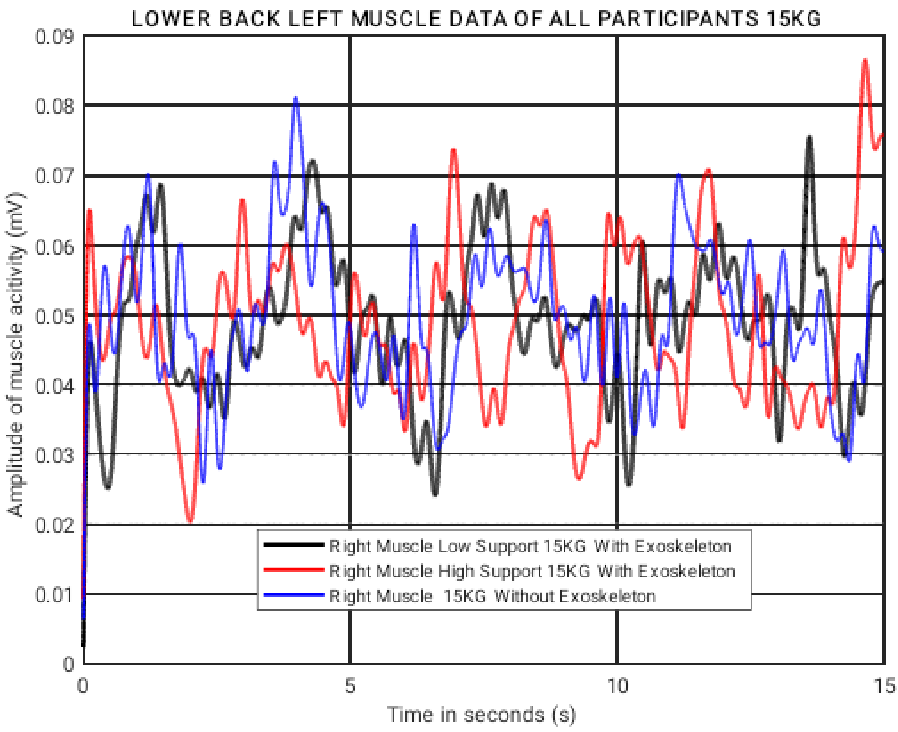



**Figure 35: Lower back left muscle data with 15KG**

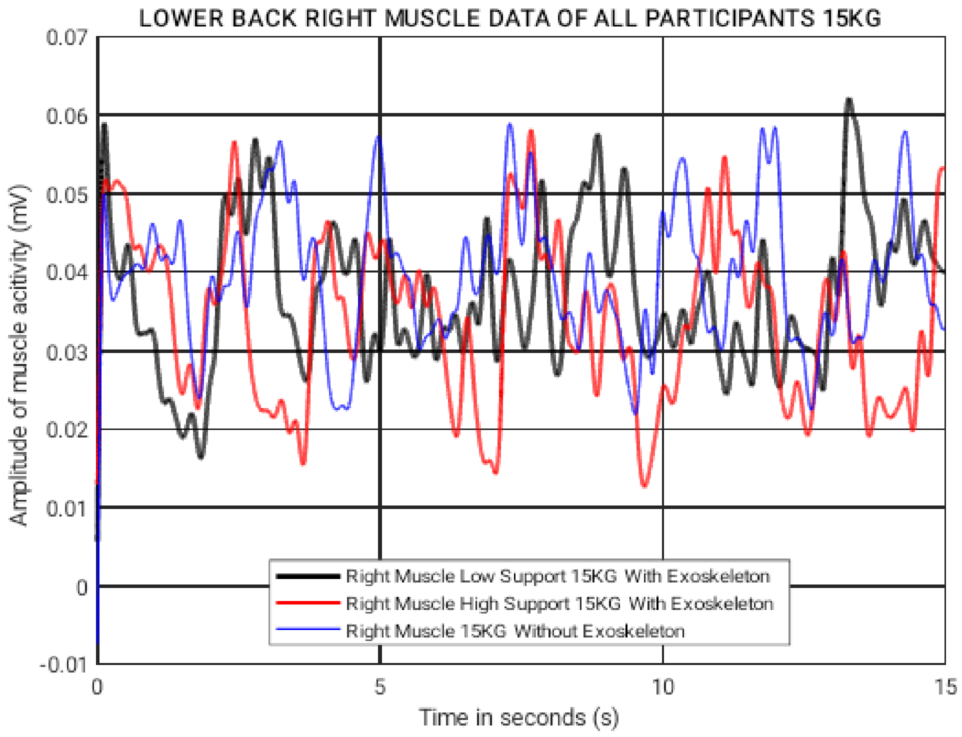



**Figure 36: Lower back right muscle data with 15KG**

The black line (low support) represents activity involving the exoskeleton, whereas the red line (high support) represents activity involving the absence of the exoskeleton. Contrarily, the blue line shows us engaging in exercise without an exoskeleton. Additionally, they display the average EMG signal produced when each volunteer lifts 15 kg. According to our research, the line graph with the lowest average amplitude has the most efficiency because it conserves the most energy, and the line graph with the highest amplitude has the lowest efficiency because it does the opposite.

Each signal on the graph represents a muscle contraction during its working and resting phases. Only the working zone of the graph should be utilised to calculate efficiency in this case since it may demonstrate how closely the efficiency relates to the average. We use a table that lists weight-lifting positions for 15 kg with high support and low support spring levels to do a more thorough analysis.

### 4.5 Analysis of Variance (ANOVA):

We conduct Analysis of variance (ANOVA) analysis on our data once we have all the desired data that we have obtained from the forces and the weight work. The P-value simply tells you how probable it is that the data you observed happened under the null hypothesis. If the p-value is less than your significance threshold (usually p 0.05), you can reject the null hypothesis, but this does not necessarily imply that your alternative hypothesis is correct.

In the tables of "ANOVA" inserted below, the parameters are L4/L5 and L5/S1, which are the parts of our lower back. Basically, L4/L5 are the two lowest vertebrae of the lumber spine. L5/S1 is known as the lumbosacral joint, which is the part of the spinal cord.

The dependent variable in our study is the force being applied on L4/L5 (Min & Max), L5/S1(Max) and L5/S1(Min) and the independent variable is the number of people on which the test was performed, i.e., five people.

**Table 3: ANOVA single factor of 5kg force**

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Force on L4/L5 (Max) | 5 | 1269.9 | 253.98 | 135.602 |
| Force on L4/L5 (Min) | 5 | 1050.87 | 210.174 | 97.81738 |
| Force on L5/S1 (Max) | 5 | 1279.32 | 255.864 | 650.55248 |
| Force on L5/S1(Min) | 5 | 1099 | 219.8 | 110.7 |

**ANOVA**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 8214.544455 | 3 | 2738.181485 | 11.0113962 | 0.05361 | 3.238872 |
| Within Groups | 3978.68744 | 16 | 248.667965 | | | |
| Total | 12193.2319 | 19 | | | | |

We performed the "ANOVA" one-way analysis by applying the force of 5 on L4/L5 and L5/S1. The results showed that when the test was performed, the degree of freedom (df) between the groups was three and, within groups, was 16 and altogether was 19. The P-value of 0.05361 was calculated when 5kg force was applied.

**Table 4: ANOVA single factor of 10kg force**

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Force on L4/L5 (Max) | 5 | 1560.398 | 312.0796 | 194.4115343 |
| Force on L4/L5 (Min) | 5 | 1289.5 | 257.9 | 141.46 |
| Force on L4/S1 (Max) | 5 | 1590.3915 | 318.0783 | 190.7944845 |
| Force on L5/S1(Min) | 5 | 1312.6 | 262.52 | 111.152 |

**ANOVA**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 15196.33037 | 3 | 5065.443458 | 31.76732742 | 0.05667 | 3.238872 |
| Within Groups | 2551.272075 | 16 | 159.4545047 | | | |
| | | | | | | |
| Total | 17747.60245 | 19 | | | | |

In Table No. 4, we performed the "ANOVA" one-way analysis by applying the force of 10 kg on L4/L5 and L5/S1. The results showed that when the test was performed, the degree of freedom (df) between the groups was three and, within groups, was 16, and after, the sum was 19. The P-value of 0.05667 was calculated when 10kg force was applied

**Table 5: ANOVA single factor of 15kg force**

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Force on L4/L5 (Max) | 5 | 1750.206 | 350.0412 | 673.5660937 |
| Force on L4/L5 (Min) | 5 | 1490.09 | 298.018 | 762.0923435 |
| Force on L4/S1 (Max) | 5 | 1746.0045 | 349.2009 | 592.3176378 |
| Force on L5/S1(Min) | 5 | 1581.833 | 316.3666 | 2310.486368 |

**ANOVA**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 9844.437198 | 3 | 3281.479066 | 3.025476522 | 0.059016 | 3.238872 |
| Within Groups | 17353.84977 | 16 | 1084.615611 | | | |
| | | | | | | |
| Total | 27198.28697 | 19 | | | | |

We performed the "ANOVA" one-way analysis by applying the force of 15 kg on L4/L5 and L5/S1. The results showed that when the test was performed, the degree of freedom (df) between the groups was three and within groups was 16, and after addition, we got 19. The P-value of 0.059016 was calculated when 15kg force was applied.

**4.6 Data Tables of Lower Back Muscle Activity Data:**

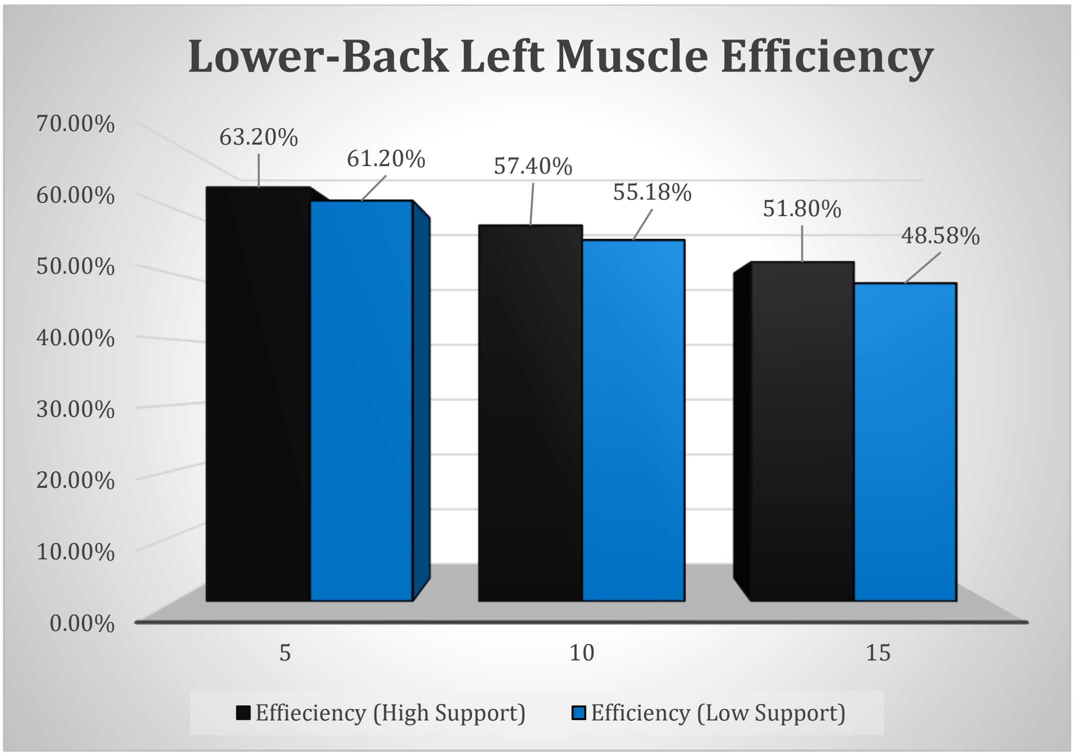



**Figure 37: Left muscle lower back efficiency**

In Table 6, three different weights of 5kg, 10kg and 15kg are being used to calculate efficiency with the help of the area under the curve with and without an exoskeleton with high and low support.

When the weight of 5kg is applied, using high support, the area under the curve with an exoskeleton is 0.4201, and without using an exoskeleton, it is 1.0961, which gives the efficiency of 63.3%, whereas when low support is applied, the area under the curve with an exoskeleton is 0.4501 and without exoskeleton is 1.0961, resulting in an efficiency of 58.93%.

Similarly, when the weight of 10kg is applied, using high support, the area under the curve with an exoskeleton is 0.5652 and without an exoskeleton is 1.3294, resulting in an efficiency of 57.4%. When low support is applied, the area under the curve with an exoskeleton is 0.5928 and without an exoskeleton is 1.3294, resulting in an efficiency of 55%.

Lastly, when the weight of 15kg is applied, using high support, the area under the curve using an exoskeleton is 0.6694 and without an exoskeleton is 1.3890, arriving at an efficiency of 51.80%. Whereas with low support, the area under the curve using an exoskeleton is 0.7141, and without an exoskeleton is 1.3890, resulting in an efficiency of 48.58%.

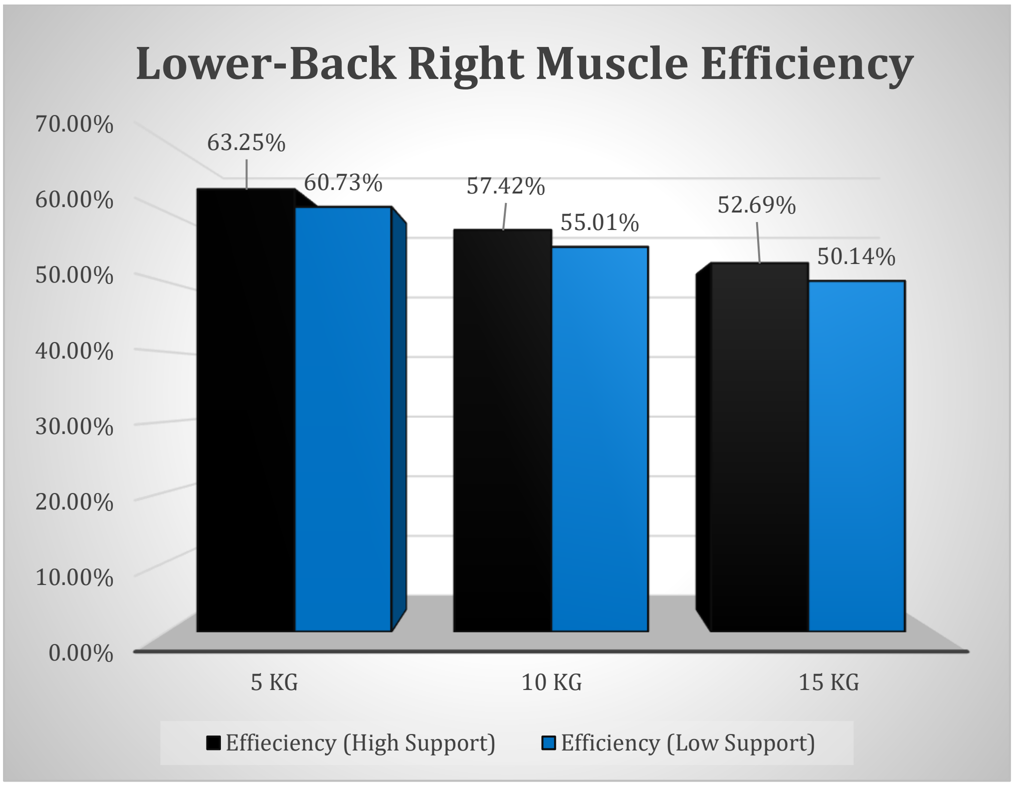



**Figure 38: Right muscle lower back efficiency**

In Table No. 7, three different weights of 5kg, 10kg, and 15kg are utilized to calculate efficiency with and without an exoskeleton with high and low support using the area under the curve.

When a 5kg weight is applied, the area under the curve with an exoskeleton is 0.5697 and without an exoskeleton is 1.5504, resulting in an efficiency of 63.25, whereas when a low weight is applied, the area under the curve with an exoskeleton is 0.6087 and without an exoskeleton is 1.5504, resulting in an efficiency of 60.73%.

Similarly, when a weight of 10kg is applied with high support, the area under the curve with an exoskeleton is 0.5891 and 1.3837 without an exoskeleton, resulting in a 57.42% efficiency. When low support is supplied, the area under the curve with an exoskeleton is 0.6225 and 1.3837 without an exoskeleton, resulting in 55.01% efficiency.

Finally, when a weight of 15kg is applied with strong support, the area under the curve with an exoskeleton is 0.6615 and without an exoskeleton is 1.3984, yielding a 52.69% efficiency. With little support, the area under the curve with an exoskeleton is 0.6972 and without an exoskeleton is 1.3984, resulting in a 50.14% efficiency.

**4.6.3 Enumeration Analysis:**

The statistical evaluation of the exoskeleton was covered in this part. For BackX analysis, we carried out this analysis. This analysis aims to assess the exoskeleton's consistency regarding the average working area under the curve (mV/s). Data regarding BackX's squat postures of activity were collected. Using BackX, we hope to demonstrate that the lower-back muscles are supported adequately.

**4.6.4 Statistical Analysis of BackX:**

We consider squat positions, which are weightlifting, in the BackX statistical analysis. The x-axis in the bar graph below shows weights, and the y-axis denotes efficiency. Here, the brown bar represents low support weight-lifting efficiency, while the blue bar represents high support weight-lifting efficiency.

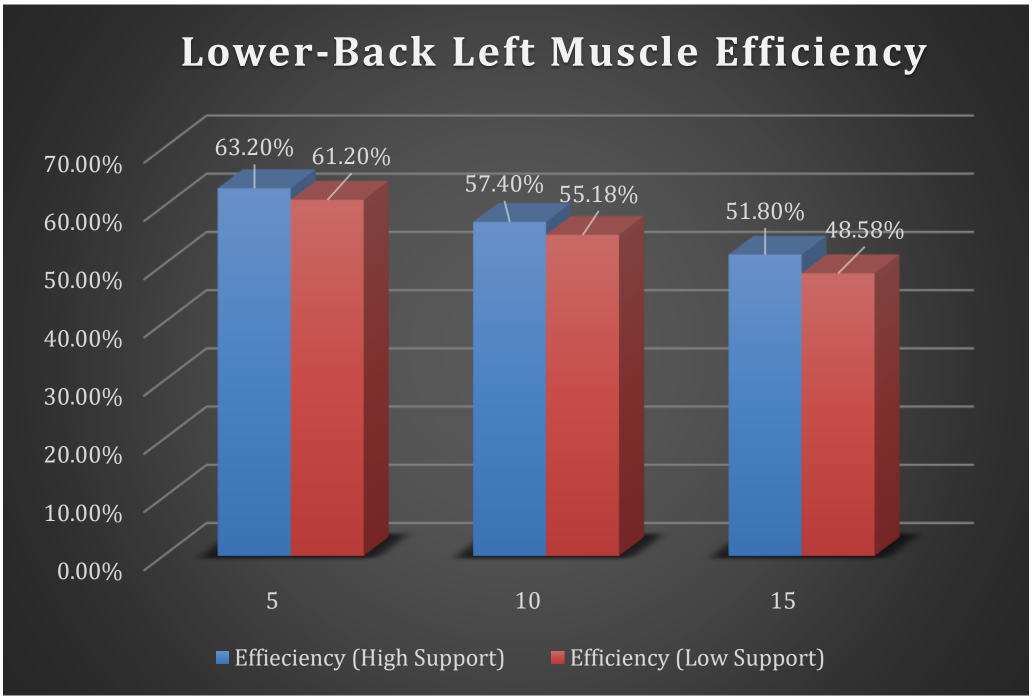



**Figure 39: Lower back left muscle efficiency**

In contrast, the left muscle's bar graph shows efficiency on the y-axis and weights on the x-axis. Regarding efficiency of high support, the bar graph demonstrates that 15 kg of weight yields a 51.80% efficiency, compared to 10 kg at 57.40% and 5 kg at 63.20%, suggesting that efficiency tends to fall as weight increases considerably. Like how weight discloses the efficiency (low support), 15 kg reveals an efficiency of 48.58%, 10 kg reveals an efficiency of 55.18%, and 5 kg reveals an efficiency of 61.20%.

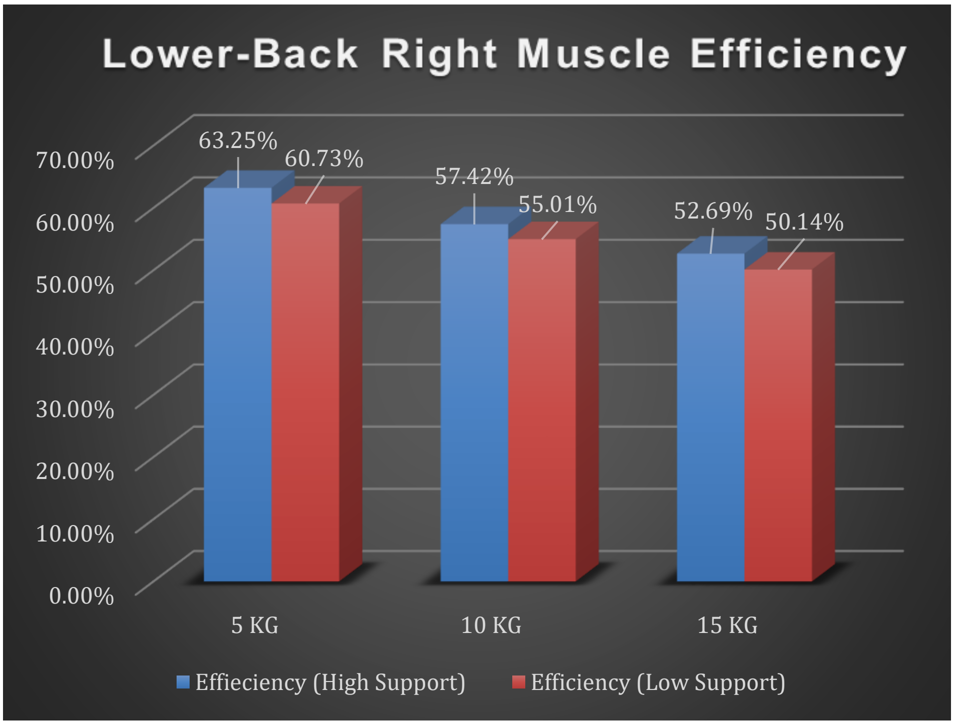



**Figure 40: Lower back right muscle efficiency**

The efficiency of lifting weights concerning the right muscle is demonstrated by this bar graph. Weights are shown on the x-axis in kg, and efficiency is shown on the y-axis. Regarding the efficiency of high support, the bar graph shows that 15 kg of weight results in 52.69% efficiency, compared to 10 kg at 57.42% and 5 kg at 63.25%, indicating that efficiency tends to decline somewhat when weight is increased. Similar to how the weight shows the efficiency (low support), 15 kg reveals an efficiency of 50.14%, 10 kg reveals an efficiency of 55.01%, and 5 kg reveals an efficiency of 60.73%. Using the lower body exoskeleton for work requires less energy than standard work.

Similarly, the graph analysis displays the results for the squat position, and we have the same weights: 5 kg, 10 kg, and 15 kg. In this graph, the grey line represents results without exoskeletons. In contrast, the brown line indicates results with an exoskeleton (low support), and the blue bar shows us the results with an exoskeleton (high support).

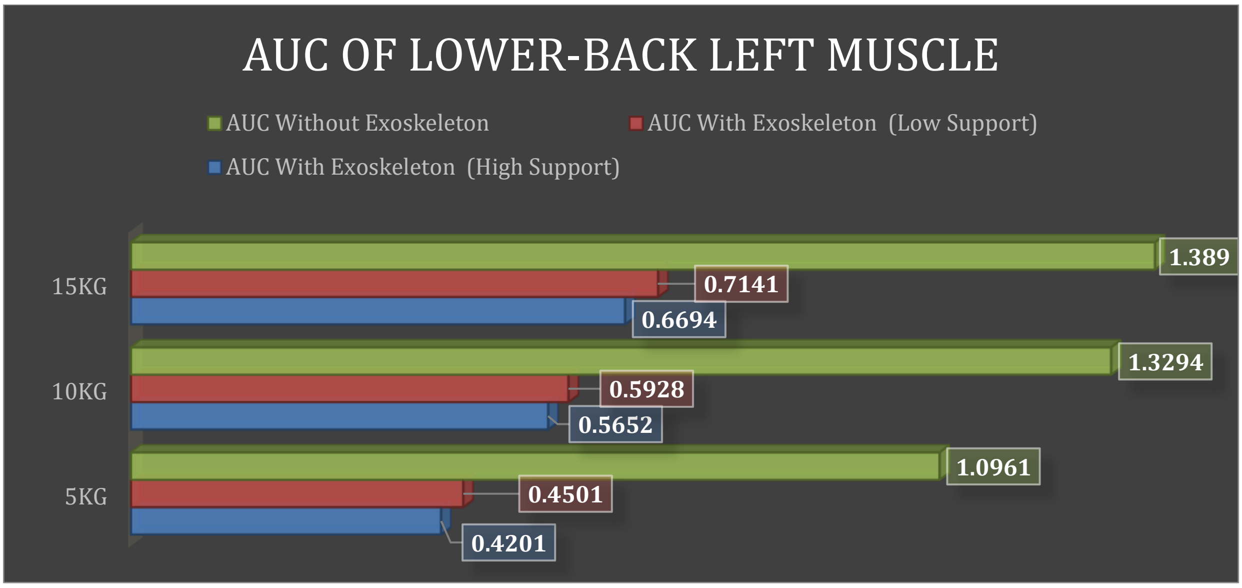



**Figure 41: Area the curve of the lower back left muscle**

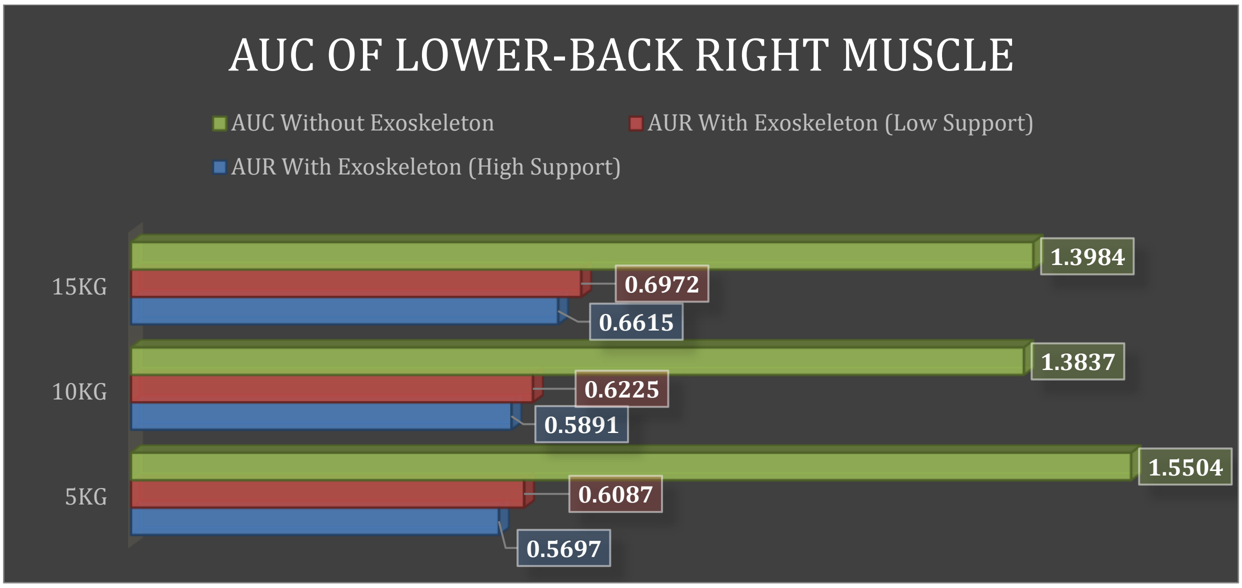



**Figure 42: Area under the curve of the lower back right muscle**

The findings of the area under the cover for the right muscle without the exoskeleton are shown in grey along a line, and they are 1.3984 for 15 kg, 1.3837 for 10 kg, and 1.5504 for 5 kg. The brown line, in a similar manner, displays the AUC with exoskeleton (low support) results, which are 0.6972 for 15 kg, 0.6225 for 10 kg, and 0.6087 for 5 kg. Additionally, the blue line in this graph shows AUC values of 0.6615 for 15 kg, 0.5891 for 10 kg and 0.5697 for 5 kg with an exoskeleton (high support). Similar results are shown for the left muscle, with an AUC of 1.0961 for 5 kg and 1.389 for 15 kg without an exoskeleton, which is indicated by the grey line. The brown line displays the AUC with exoskeleton (low support) results, respectively, 0.7141 for 15 kg, 0.5928 for 10 kg, and 0.4501 for 5 kg. Additionally, areas undercover with an exoskeleton (high support) depicted by a blue line are 0.6694, 0.5652, and 0.4201 for 15 kg, 10 kg, and 5 kg

### 4.5 Discussion

A brief overview of the main findings is given in this chapter. We will show our methodology based on all subsequent results for each experimental situation once we have analyzed all measurements. A discussion of the lower back exoskeleton will also be included in this study. In the sequence stated below, the discussion for this is provided.

Chapter 4 shows the results graph of simultaneous weightlifting of 5 kg, 10 kg, and 15 kg for the investigation of the lower back exoskeleton. Each graph's signal amplitude decreases as the spring is raised from a low support to a high support value. Both the spring level signals are compared in the table (with or without SuitX). The user's lower back is fully supported at the high support spring level, which results in relatively little muscular contraction. And because the user didn't feel any support when they weren't wearing SuitX, the signal without SuitX shows a high level of muscle contraction.

Muscle contraction will decline as angles rise, which will result in less force being applied to the L4/L5 and L5/S1 joints. When wearing an exoskeleton, our lower back receives high support, which lessens the strain on our L4/L5 and L5/S1 joints. Lower-back injuries and muscle contractions are reduced because of the exoskeleton.

The efficiency of lifting weights with respect to the right muscle is demonstrated by a bar graph; weights are shown on the x-axis in kg, and efficiency is shown on the y-axis. In terms of efficiency of high support, the bar graph shows that 15 kg of weight results in a 52.69% efficiency, compared to 10 kg at 57.42% and 5 kg at 63.25%, indicating that when weight is increased, efficiency tends to somewhat decline. Similar to how the efficiency of low support is shown by the weight, 15 kg reveals an efficiency of 50.14%, 10 kg reveals an efficiency of 55.01%, and 5 kg reveals an efficiency of 60.73%. Using the lower body exoskeleton for work typically requires more energy than doing standard work.

The left muscle's bar graph, in contrast, shows efficiency on the y-axis and weights on the x-axis. In terms of efficiency of high support, the bar graph demonstrates that 15 kg of weight yields a 51.80% efficiency, compared to 10 kg at 57.40% and 5 kg at 63.20%, suggesting that efficiency tends to fall considerably as weight is increased. In a manner similar to how weight discloses the efficiency of low support, 15 kg reveals an efficiency of 48.58%, 10 kg reveals an efficiency of 55.18%, and 5 kg reveals an efficiency of 61.20%.

The results graph for the location of the squat weightlifting is shown in Chapter 4. The amplitude of each signal is decreased in all of the graphs when the spring is raised from a low support to a high support value, as shown in the tables given. There, the lack of a SuitX is contrasted with the

signals from both the spring levels. Because the lower body is completely supported by the positive (high support) spring level, there is very little muscular contraction. Additionally, when the user is not wearing the SuitX, they do not feel any support, which explains why the signal without the SuitX exoskeleton shows such high levels of muscular contraction.
Both of the aforementioned bar graphs show the efficacy of weightlifting while squatting. In those graphs, the area under the curve without an exoskeleton and with an exoskeleton (with low and high support) is shown on the x-axis, and weights are shown on the y-axis.

For the right muscle, the use of the exoskeleton with High support is represented by the blue bar, whereas the exoskeleton with low support is represented by the brown bar. Further, the grey bar represents the area under the curve without an exoskeleton.

The AUC with an exoskeleton (high support) of 15 kg, 10 kg, and 5 kg for the right muscle of the graph is 0.6615, 0.58910, and 0.5697, respectively, while the AUC with an exoskeleton (low support) of 15 kg, 10 kg, and 5 kg for the right muscle is 0.6972, 0.6225, and 0.6087, respectively. The AUC without exoskeleton shows the results for 15 kg, 10 kg, and 5 kg are 1.3984, 1.3837, and 1.5504, respectively.

Additionally, for the left muscle, we can explain AUC with exoskeleton high support using a bar graph, where 15 kg weight shows results of 0.6694, 10 kg, and 5 kg weight shows results 0.5625 and 0.4201 for the left muscle of the graph, and the area under curve (low support) for 15 kg, 10 kg, and 5 kg for the left muscle of the graph are 0.7141, 0.5928, and 0.4501, respectively. Additionally, for 15 kg, 10 kg, and 5 kg, the area under the curve without the exoskeleton is 1.389, 1.3294, and 1.0961, respectively.

In light of this, the area under the curve rises when we increase weight. Compared to typical working methods, operating with a lower-body exoskeleton uses less energy. Finally, it can be claimed that exoskeletons enable workers to keep their flexibility and ease of movement whilst enhancing the standard, consistency, and reliability of their industrial labor.

The results graph for the squat position is displayed in Chapter 4 Figures. The graph above, which included weights of 5 kg, 10 kg, and 15 kg, allowed us to analyze how much more pressure is placed on a person's lower back when they are not utilizing an exoskeleton, and because of it, the amplitude is high and requires more energy. However, when we wear an exoskeleton, it offers high lower-back support with minimal muscle contractions, and the amplitude we receive is similarly low. Lastly, we performed ANOVA analysis on our desired data, which we got from the lower back muscle data and forces data of L4/L5 and L5/S1 with the help of 3DSSPP.

## 5. Conclusion

The present study has been conducted to analyze the effectiveness of exoskeleton namely BackX manufactured by SuitX company and how it helps the lower backs of the workers at the overhead assembly operations as well as from a general perspective.

This research study presented a wearable robotic system that uses a passive exoskeleton (BackX) to ease load on worker's body, provide a safer working posture and avoid chances of injuries in the industrial setting which prevents them from taking detrimental positions while encouraging them to adopt healthier and more enjoyable body positions.

Previous research has examined (at the Hogskolon i Gavle) the efficacy of exoskeletons for the upper body (ExsoVest by EksoBionics) and the legs (Exoskeleton LegX by SuitX). However, when compared to these earlier studies, the current study, which focuses on the lower body, unequivocally demonstrates that the exoskeleton BackX by SuitX is the most effective option due to its design, increased comfort, and availability of both high and low support, which makes it more advantageous for industrial workers.

Workers' posture problems need to be addressed promptly since body straining activities like weightlifting can cause musculoskeletal injury as well as leg knee pain and injuries,. The best support for all workers is given by the wearable exoskeleton BackX by SuitX, which increases muscle strength, restores mobility, lowers load, and prevents serious muscle issues. The results made it abundantly evident that exoskeleton technology can be used by industrial users as a safety measure.

The biggest muscle in the human body, the thoracic-lumber fascia, is studied in this study, which differs from previous studies in that it examines the effects of exoskeleton on this muscle as it is closest to the spinal cord in the lower back.

Further analysis of the force vs angle relationship in our study demonstrates that force reduces with increasing angle and vice versa. Thirdly, the research employs a methodology that has not been employed in any previous studies: the 3DSSPP software tool.

In this a 3D model was created of the participant having same height and weight which was then used to calculate how much force each angle would apply to lower back if the individual lifted the weight in any position without the use of an exoskeleton.

This test might be used to investigate the effects of force from as many angles as possible on the lower back. Finally, an ANOVA result analysis was conducted on the study's data to demonstrate the results' dependability, accuracy, and degree of scientific validation.

The exoskeleton technology has been analyzed in a variety of approaches by leveraging the EMG sensor. The EMG signal analysis was used to help measure the muscular activity of the five participants to conclude the impact of exoskeleton on the workers working in the industrial sector. The EMG sensor was deployed on the participant’s lower backs to capture the EMG signal data from the lower back muscles of their body.

Hence, it makes the EMG sensor a very crucial component in this study to measure the viability of exoskeleton. The system's components are all exhibited along with the real-time EMG signal data obtained while using the exoskeleton in various operating squat positions for various loaded weight-lifting techniques.

This study is viable to comprehend muscular endurance power following the use of an exoskeleton in different industrial working situations.

The exoskeleton for lower back aims to lessen the physical problems and limitations that industrial workers experience while improving their work efficiency. Conclusively, exoskeletons are a safer option for industrial employees who spend a lot of time at work.

Regarding the degree to which the findings of our study are comparable to those of previous studies, it is clear that there are none because we employed a different type of exoskeleton, our participants were of varying heights and weights, and we used a different body part, the lower back in our study.

Furthermore, there is no overlap in the methodology between our study and other studies since the positions utilized in this investigation such as the squat position, lower back bending, chair position, etc.are completely different, as is the duration of data collecting.

## 5.1 Future study:

Future studies centering on a range of themes should broaden the research. The technology must first handle it more easily and gain a particular viewpoint on the many components of a user's body. In the recommended approach, the exoskeleton is required to do more varied tasks related to industrial activity, such as lifting large objects off the surface. We must prioritize researching the benefits of exoskeletons by gathering data as thoroughly as possible while removing as many sounds and artefacts as is practical. Not to mention, this cutting-edge exoskeleton technology provides a helpful example of the concept of tracking and analyzing the benefits of industrial workers who utilize exoskeletons in various working conditions.

We must prioritize researching the benefits of exoskeletons by gathering data as thoroughly as possible while removing as many sounds and artefacts as is practical. Not to mention, this cutting-edge exoskeleton technology provides a helpful example of the concept of tracking and analyzing the benefits of industrial workers who utilize exoskeletons in various working conditions. The technology concentrates on all areas, and ideally, the EMG technique will also be improved to develop a stronger reaction for the biological function of the exoskeleton. Since ancient times, people have used robotic exoskeletons to provide them with enhanced protection, power, and help.

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