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A Preliminary Study on Muscle Activation During Simulated Walk & Carry Task in Palm Oil Plantation

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Abstract. This paper presents an electromyography (EMG) analysis of EXOROBO, a newly developed exoskeleton designed specifically for palm oil harvesting tasks to reduce Musculoskeletal Disorders (MSDs) among palm oil harvesters. The study evaluates the muscular activity patterns of individuals operating EXOROBO & CANTAS™ compared to the harvesting method by using CANTAS™. This research seeks to provide valuable insights into the ergonomic benefits and biomechanical implications of employing EXOROBO in palm oil harvesting operations through EMG measurements. Results indicate a significant reduction in muscle activity in four key muscle groups; left Biceps Brachii (L_BB) by 51.30%, left Rectus femoris (L_RF) by 44.61%, right Biceps Brachii (R_BB) by 23.98% and right Rectus Femoris (R_RF) by 7.17%. The findings of this study contribute to the ongoing discourse on the development of ergonomic solutions for agricultural labour, particularly in addressing the prevalent issue of MSDs in the palm oil industry.

Keywords: EMG analysis, EXOROBO, exoskeleton, palm oil harvesting, Musculoskeletal Disorders (MSDs).

1. Introduction

1.1 Background

The prevalence of musculoskeletal disorders (MSDs) has risen across a numerous of occupations, particularly within palm oil industry, posing a serious health risk to its workers. Bhuanantanondh *et al.*, (2021) identified several contributing factors, including the use of manual tools and improper working practices, poor positioning, inadequate rest, carrying excessive weights, and inadequate training. Bhuanantanondh *et al.*, (2021) also added, these factors not only impair worker's quality of life and productivity but also can lead to long term disabilities.

To address these challenges, various technological solutions have been introduced to mitigate labour shortages and MSDs issues in the Malaysian palm oil industry. As noted by Ashta *et al.* (2023), developed countries have utilized exoskeletons to improve productivity in sectors like aerospace and manufacturing, suggesting that exoskeletons could be a promising solution to reduce unharvested palm oil crops, labour shortage, and MSDs issues in palm oil operations.

Building on the first passive lower limb exoskeleton designed to support palm oil harvesting operations, EXOROBO (Abdul Saad, W.A., *et al.*, 2023) marks a progress in this field in giving support for both and upper body extremities during palm oil harvesting activity. EXOROBO presents an innovative load redistribution mechanism that moves the weight of harvesting equipment through the exoskeleton's structure to the ground, therefore lowering muscle strain and fatigue. Its flexible and slimline form is specially created for difficult plantation conditions, where heavy gear is inappropriate and extra support is needed to promote good posture and lower the risk of strain-related injuries. Across the palm oil sector, EXOROBO's simplicity, durability, and low training needs make it an easily available and reasonably priced option.

This preliminary study aims to analysis the synergy between the newly developed exoskeleton; EXOROBO and MPOB's developed motorised cutter; CANTAS™ (Razak Jelani, A. *et al.*, 2008) during simulated walk-and-carry task in palm oil plantation. This preliminary study seeks to assess EXOROBO's effectiveness in reducing muscle activity through two simulated interventions: i) palm oil harvesting with CANTAS™ (No-Exo, With CANTAS™), and ii) a combined use of EXOROBO with CANTAS™ (With-Exo, With CANTAS™). In this study, the independent variable was the intervention method, encompassing both No-Exo, With CANTAS™ and With-Exo, With CANTAS™ conditions. Test subjects remained consistent across interventions, allowing for accurate comparative data, which was first recorded in the No-Exo, With CANTAS™ scenario, followed by the With-Exo, With CANTAS™ scenario.

1.2 Literature Review

In typical daily palm oil operation, harvesters begin by walking through the plantation to locate ripe fruit bunches by observing the presence of 1 or 2 loose fruitlets around palm oil tree trunks on the ground. Harvesters usually need to roam inside the plantation around 3 to 4 hectares per day to locate ripe fruit bunches. According to Kamaruzaman (2009), walking takes up 13% of the harvesting time. Walking, particularly in occupational settings such as palm oil plantations, can involve several ergonomic risk factors. According to studies conducted by Ng, Y.G., *et al.* (2015), risk factors in walk and carry in palm oil setting involve rapid, repetitive movements, prolonged static loading, awkward postures, external compressive forces, and vibrations, either alone or combined, which are stressful for various body regions. Ng, Y.G., *et al.* (2015) also discovered that the prevalence of MSDs among harvesters was significantly high, with 19% respondents reporting pain at both hand/arm and thigh muscle followed by elbow muscle with 18%.

Some studies have focused on exoskeletons, highlighting their application in palm oil harvesting and other agricultural tasks. Mohd, F. and Harith, H. (2019) and Harith, H. *et al.* (2021) conducted research to assess how well passive upper limb exoskeletons reduce muscle strain during manual harvesting tasks. Mohd, F. and Harith, H. (2019) has tested on 4 different test subjects and examined electromyography (EMG) signals of the anterior deltoid muscle when individual carried different loads with and without the exoskeleton. Later, Mohamad, M.F. (2022) expanded on the initial study by investigating a more advanced passive exoskeleton. They evaluated muscle activation strength of 3 test subjects during harvesting cycles and found a continuous decrease in muscle activity. Harith *et al.* (2021) did a preliminary investigation on a passive upper limb exoskeleton for simulated agricultural operations. They found a significant decrease in mean maximum voluntary contraction (%MVC) for muscles used during overhead activity. Alternatively, Islam *et al.* (2019) and Selamat (2023) investigated muscle strain in a hybrid upper limb exoskeleton on only one test subject, finding reduced muscle strain overall compared to not using an exoskeleton. However, they had difficulty during some movements due to the lack of joint support. The most recent exoskeleton was developed by Sanjaya *et al.* (2023) studied the impact of a soft exoskeleton on shoulder muscle activation during palm oil harvesting. The exoskeleton significantly reduced muscular activation, especially in the deltoid and trapezius muscles of 6 different individuals. In term of EMG data acquisition, Delsys EMGWorks and Consensys, as used by Mohamad (2022) and Harith *et al.* (2021), offer specialized EMG analysis capabilities, such as multi-channel synchronization and automated processing features, that can yield more precise interpretations of muscle activation. Sanjaya *et al.* (2023) go a step further by incorporating Delsys Trigno Discover software, which allows for real-time feedback and advanced EMG signal visualization. In term of data processing, all studies implement Butterworth filters for noise removal, with variations in order. All these studies consistently use Root Mean Square (RMS) for their feature extraction methods to quantify muscle activation, providing valuable insights into the physiological impact of manual harvesting tasks

In contrast to the mechanical exoskeletons used in palm oil harvesting, studies focusing on manual palm oil and other agricultural tasks emphasize the collection of EMG signals to understand muscle activation patterns and fatigue during prolonged activities. Studies by Abdullah *et al.* (2023) and Teo *et al.* (2023) explore manual palm oil harvesting tasks on 10 and 8 test subjects, respectively where workers engage in repetitive lifting and carrying by employing iMotion and the BiosignalPlux system. The primary muscle groups monitored include the trapezius, deltoids, and erector spinae, which are heavily involved in upper body posture and stability during such tasks. Similarly, Kim *et al.* (2024) includes both upper and lower limb muscles, using the Noraxon Ultium system to analyse muscles like the biceps femoris and gastrocnemius which extend beyond the arms on 20 different test subjects. This expanded focus may provide insights into whole-body muscular dynamics, potentially informing future exoskeleton designs that support both upper and lower limbs. Like EMG data analysis conducted on developed exoskeletons for palm oil harvesting, studies by Abdullah *et al.* (2023), Teo *et al.* (2023) and Kim *et al.* (2024) also consistently implement Butterworth filters for noise removal technique, with variation of orders and Root Mean Square (RMS) for their feature extraction methods to quantify muscle activation.

EXOROBO, a newly developed passive lower-limb exoskeleton, addresses challenges in palm oil plantations, such as rough terrain and repetitive arm extension. Its ergonomic and cost-effective design supports proper posture and reduces strain, making it accessible to a wide range of stakeholders. In contrast to its counterpart (active and hybrid exoskeletons), passive exoskeletons like EXOROBO rely on mechanical components like springs and levers, without the need for external power sources (Lowe, B.D., *et al.*, 2019). This design results in lighter, cost-effective, and more reliable exoskeleton compared to active models, enhancing user comfort and reducing fatigue during extended use. Such a passive mechanism suits palm oil harvesting, where repetitive arm extension is required to handle poles and complete cutting tasks (Mohd, F. and Harith, H., 2019). However, regardless of its benefits, there is no evidence-based analysis to support the developed passive lower limb exoskeleton efficacy in reducing muscular activation during palm oil activities, like walk-and-carry task, hence leaving a possible gap that may be filled.

2. Methodology

Proposed Methodology to run EMG Analysis on EXOROBO were shown in Figure 1. Five (5) right-handed and healthy males volunteered to participate in this preliminary study. The subjects indicated that they have not experienced any MSDs affecting their shoulder, back, or legs past 12-month period. The subjects are (23.6±6.95) years old, have heights of (1.682±0.036) meters, and weighs (65.2±15.45) kg. Their demographic data are described in Table 1.

The importance of having multiple subjects is underscored by recent studies (*Mohd, F. and Harith, H., 2019;* Mohamad, M.F., 2022; Harith, H. *et al.*, 2021; Sanjaya *et al.*, 2023; Abdullah *et al.*, 2023; Teo *et al.*, 2023; Kim *et al.*, 2024) on exoskeletons and muscle activation in palm oil harvesting. Including multiple subjects (ideally more than three) enhances the reliability of results by allowing researchers to calculate averages and analyse EMG signal patterns while minimising the effects of outliers and abnormalities. After receiving informed consent, the subjects were provided with detailed information about the simulated task and the exoskeleton. Subsequently, the researchers gathered demographic information about the individual, including age, gender, and anthropometric measurements. The exoskeleton was adjusted to ensure a comfortable fit for the subject's body, considering their hip height, knee height, and waist size.

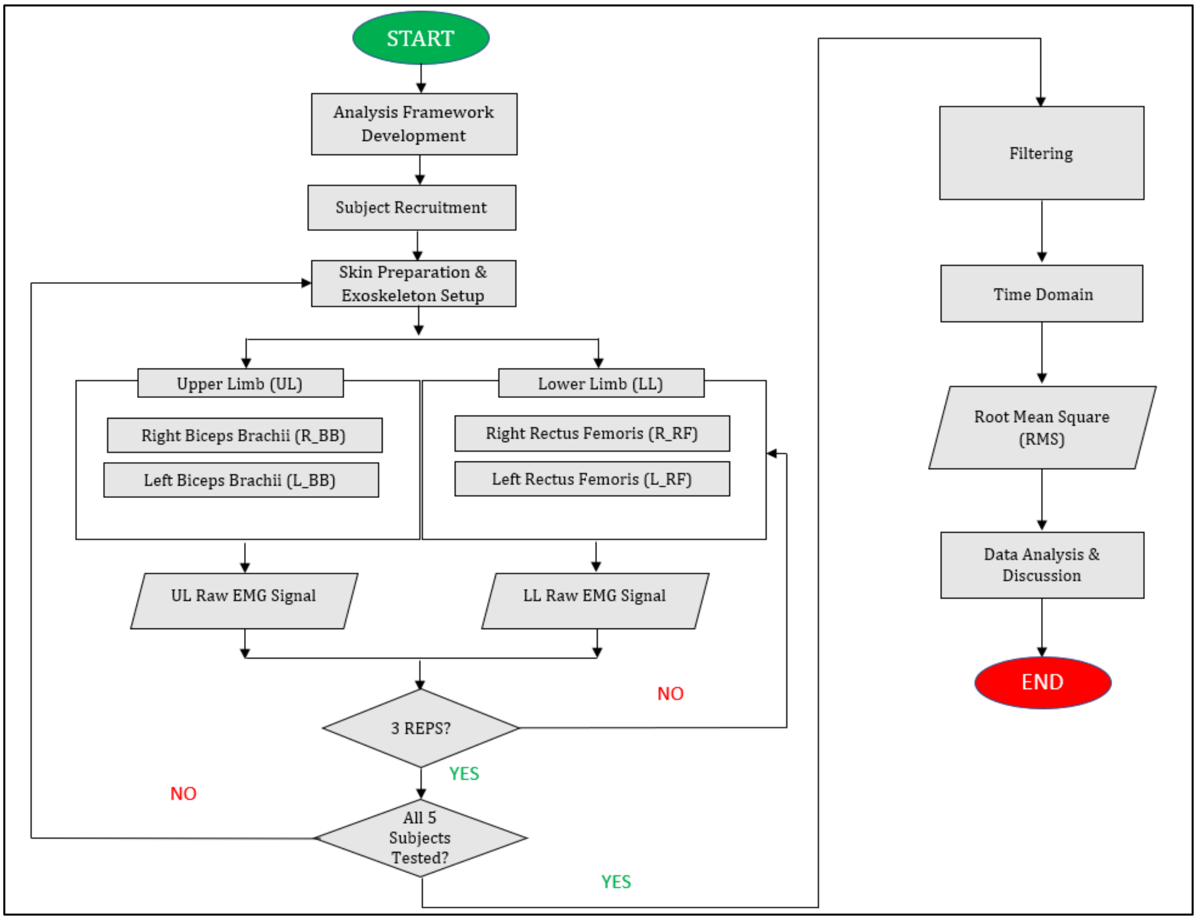

Figure 1. Proposed Methodology to run EMG Analysis on EXOROBO

Table 1. Subject's Demographic Data

Subject	Age	Height (m)	Weight (kg)
1	21	1.69	47.0
2	20	1.65	78.0
3	21	1.72	67.0
4	36	1.71	82.0
5	20	1.64	52.0

Referring to a study conducted by Teo, Y.X. *et al.* (2023), they identified activation in the Biceps Brachii, which help maintain stability and strength during carrying and tool use. Complementing this, Ivanenko, Y.P. *et al.* (2004) found that Rectus Femoris is engaged during walking, supporting essential leg movement and balance. The biceps brachii (BB) muscle is responsible for flexing the elbow joint, while the rectus femoris (RF) muscle is responsible for extending the knee joint. This study assessed the activation of the two muscle groups during the walk-and-carry task. Figure 2. shows Delsys Trigno Biofeedback System, developed by Delsys in the USA, was utilized for the recording of signals and subsequent data analysis. The accompanying software, known as Delsys EMGworks® Acquisition and Delsys EMGworks® Analysis, were used for these purposes as well. The EMG signal was recorded at a sampling rate of 1000 Hz.

Figure 2. Delsys Trigno Biofeedback System (jalimedical.com., n.d.)

To capture surface electromyography (sEMG) signals, it is necessary to position the electrode directly on the targeted muscles after thoroughly cleansing the skin surface. According to Herath *et al.* (2014), it is desirable to shave excess hair under optimal circumstances, although this may only be feasible in certain practical situations. A self-adhesive electrode, designed for use on dry skin, was attached to the skin in a manner that aligned to the muscle fibres and kept it separate from other muscle groups, following the guidelines set by the Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM) guidelines (Merletti, 2000).

Each subject was given instructions to execute the simulated walk-and-carry activity. Each subject moved 8 meters in a forward direction from the initial location while maintaining an upright position of the CANTAS™. The walk-and-carry activity was repeated three times, with one-minute breaks between each repetition. Standardized instructions and timing were implemented during the walk-and-carry activity to ensure consistency across all trials. This simulated walk-and-carry activity was conducted at the Department of Biomedical Engineering and Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia. The subjects were not constrained in terms of their whole-body position and the time took to complete the activity, to enable natural and comfortable movement and postures during the walk-and-carry task. Figure 3 shows 3D rendering of the developed EXOROBO and subject performing simulated walk-and-carry task while employing EXOROBO and CANTAS™.

Figure 3. a) 3D Rendering of EXOROBO b) Subject Performing Simulated Walk-and-Carry Task

The Delsys EMGworks® Analysis software was utilized for the processing of EMG signals and doing statistical analyses. The signal underwent band-pass filtering using the Butterworth filter with a frequency range of 10-500 Hz. The filtering was done bi-directionally. After filtering, the signal was fully rectified. The peak Root Mean Square (RMS) was computed separately for the left (L) and right (R) sides of each muscle group, namely the Biceps Brachii (BB) and Rectus Femoris (RF). The root mean square (RMS) is calculated by taking the square root of the arithmetic mean of the squared signal values (Yang, C. *et al.*, 2019). It is commonly used to measure the strength of a signal. RMS can be expressed as:

$$\textbf{Root Mean Square, RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \tag{1}$$

where N is the number of EMG signal samples and x_i represents i[th] EMG signal sample.

Figure 4 presents a sample of a raw EMG signal waveform meanwhile, Figure 5 visualises a sample of filtered and rectified (pre-processed) EMG signal. Recorded peak RMS for all tested muscles are subsequently compiled in Table 1 and analysed in detail in Section 3.

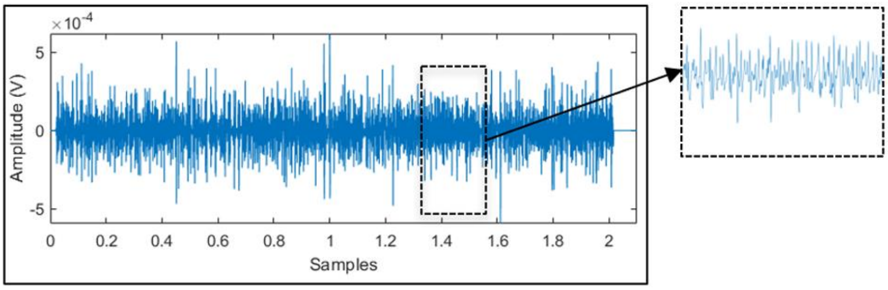

Figure 4. Raw EMG Signal Waveform

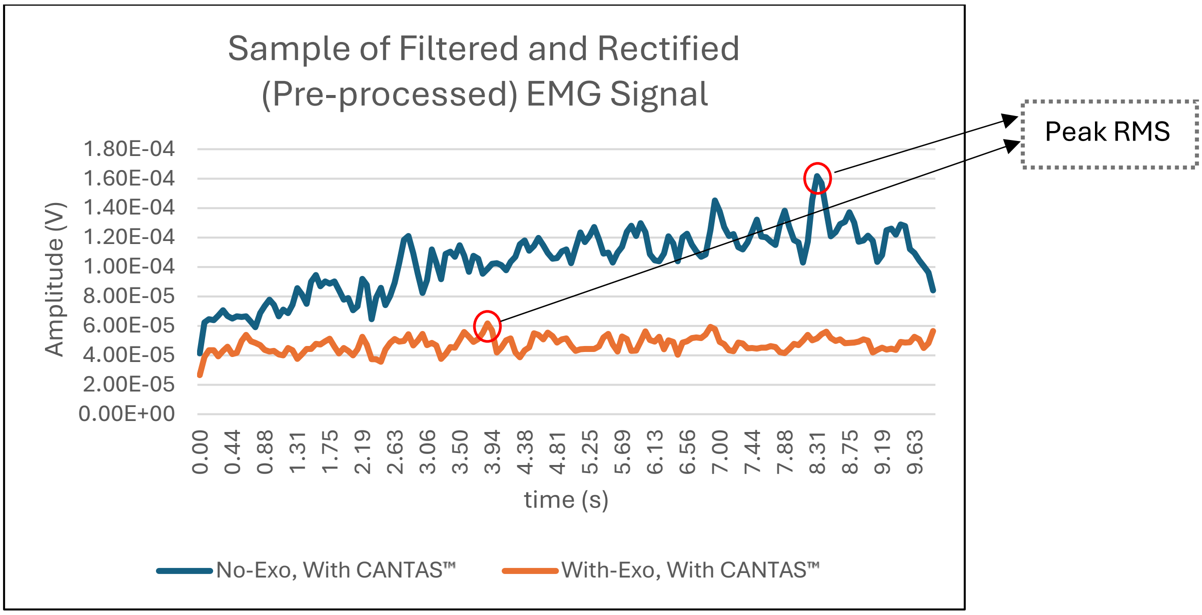

Figure 5. Pre-processed EMG Signal

3. Results & Discussion

3.1 Muscle Activity Analysis

Based on this preliminary study, the decrease in muscular activities observed when comparing the No-Exo and With-Exo interventions suggest that the developed exoskeleton promotes task performance. This supported by the variance calculations:

$$\boldsymbol{Variance, VAR} = \text{Peak RMS Value}_{\text{No}-\text{Exo}} - \text{Peak RMS Value}_{\text{With}-\text{Exo}} \quad (2)$$

$$\boldsymbol{Variance\ Percentage}, \%\boldsymbol{VAR} = \frac{VAR}{\text{Peak RMS Value}_{\text{No}-\text{Exo}}} X\ 100\% \quad (3)$$

An overall decline in muscle activity was noted during the simulated work. Referring to Table 1, the greatest decrease in peak root mean square (RMS) was observed in the Left BB muscle (L_BB: 51.30%), followed by the Left Rectus Femoris muscle (L_RF: 44.61%), the Right Biceps Brachii muscle (R_BB: 23.98%), and the Right Rectus Femoris muscle (R_BB: 7.17%). There's no significant difference in muscle activity in Right Rectus Femoris. However, during the walk-and-carry task, a significant difference in muscle activity can be observed on the Left BB, Right BB and Left RF.

Table 1. Recorded Peak RMS for Biceps Brachii (BB) and Rectus Femoris (RF) During Simulated Walk-and-Carry Task

Recorded Peak Root Mean Square (mV)

	Biceps Brachii (BB)		**Rectus Femoris (RF)**	
Intervention	**Left BB (L_BB)**	**Right BB (R_BB)**	**Left RF (L_RF)**	**Right RF (R_RF)**
No-Exo,With CANTAS™	0.1444	0.1615	0.0500	0.0236
With-Exo,With CANTAS™	0.0703	0.1228	0.0277	0.0219
VAR	-0.0741	-0.0387	-0.0223	-0.0017
%VAR (%)	-51.30	-23.98	-44.61	-7.170

* The negative values in VAR and %VAR (%) indicate a reduction in With-Exo muscle activation compared to No-Exo intervention.

The observed reduction in muscular activity in the designated muscles on the left-hand side can be attributed to both the setup of EXOROBO and the right-handedness of all five test subjects. During testing, EXOROBO's supplementary arm was positioned on the left side during testing, it provides targeted support to the left arm and leg, hence enhancing harvester's freedom and control with their dominant right hand while carrying CANTAS™. This configuration allowed the load of the CANTAS™'s load through the exoskeleton's structure down to the ground, thereby reducing muscle strain on the harvester's left side.

Figure 6 demonstrates a reduction in muscle activation in the Biceps Brachii and Rectus Femoris during the walk-and-carry test while using the With-Exo intervention. This is because the RMS feature can indicate the strength of a signal, which indirectly relates to muscle contraction while performing a specific task (Yang, C. *et al.*, 2019). This suggests that customized assistive forces for each side may be advantageous for end users. To this end, the findings indicate that the developed exoskeleton can effectively distribute the weight during walk-and-carry tasks in palm oil harvesting operations, based on the observed changes in muscle activation.

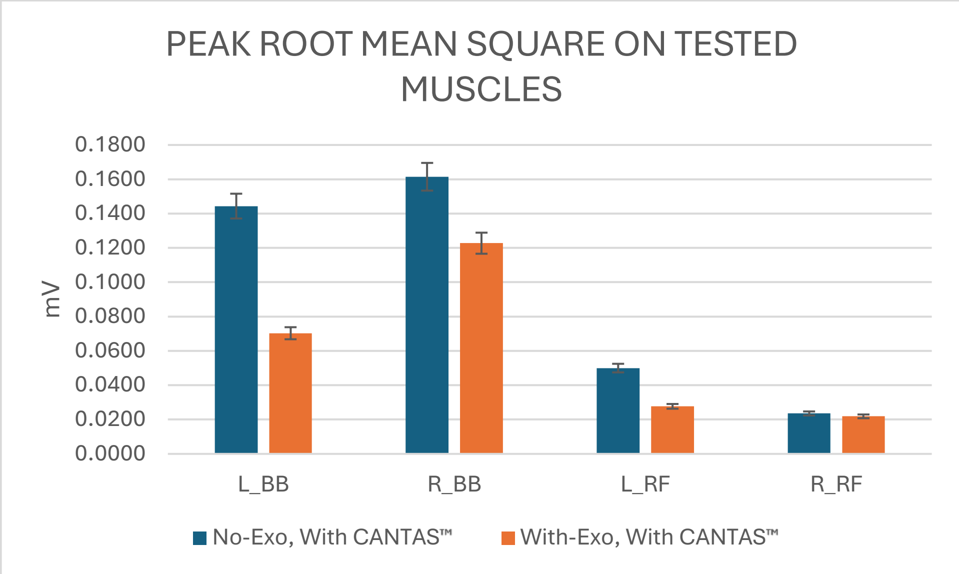

Figure 6. Peak RMS on Left (L_BB), Right Biceps Brachii (R_BB) and Left (L_RF), Right Rectus Femoris (R_RF)

3.2 Challenges and Moving Forward

This preliminary study has several limitations and needs a more extensive study to validate the probable effectiveness of the prototype. This preliminary study only evaluated the effectiveness of the developed exoskeleton during walk-and-carry tasks. It is also anticipated that the exoskeleton will be suitable for palm oil harvesting by using a motorized cutter like CANTAS™, hence allowing further study on muscle activation during palm oil FFB stalks cutting activity by using developed exoskeleton & CANTAS™ intervention. Since palm oil FFB stalks cutting activity requires dynamic postures, a field trial conducted in actual palm oil harvesting environments is recommended, to ensure the applicability and effectiveness of the developed exoskeleton.

The study is limited by a small sample size and a limited range of muscles included in the analysis. It is informed that only five (5) subjects have volunteered to participate in this simulated task trial. Only the Biceps Brachii and Rectus Femoris muscle groups were chosen for testing in this research. However, the observed decrease in muscle activation pattern of the With-Exo compared to the No-Exo intervention provides a positive indication of the effectiveness of the constructed exoskeleton. To overcome this limitation, it is possible to mitigate it by augmenting the sample size and examining electromyography (EMG) data from additional superficial muscle groups in subsequent research.

The trial's duration did not accurately represent the typical daily tasks of palm oil harvesters in palm oil fields, which involve walking and carrying for 4 to 8 hours. The frequency of repetition in this study did not accurately reflect on-site practice. For instance, palm oil harvesters must cover an area of 3 to 4 hectares every day in palm oil farms to find ripe FFBs by observing the presence of detached fruitlets on the ground around palm oil trees. However, given the demanding nature of the tasks and the environment in which they take place, it is crucial to prioritize the safety and well-being of the test subject.

To summarize, future research will use a thorough biomechanical study to examine the complete harvesting process. This analysis aims to determine the immediate and long-term impacts of exoskeletal support on the existing operating method, posture, and productivity. It would be beneficial to investigate the effectiveness of the created exoskeleton for harvesting while employing a motorized cutter like CANTAS™. To gain a more accurate understanding of the effectiveness, suitability, and user reception of the developed exoskeleton support, it is essential to conduct a field test with experienced palm oil harvesters in a real palm oil setting. Engaging

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experienced harvesters in a field test could provide a safer and less hazardous option, as they are well-acquainted with the tasks and the plantation environment. A longitudinal study design is also strongly advised for future works to observe the effects of extended exoskeleton usage on the prevention of MSDs. Nevertheless, due to the potential difficulties in conducting field trials, it is essential to establish appropriate experimental protocols and approaches to determine practical functional parameters that can effectively reflect the response of end-users to an exoskeleton when utilized in a plantation setting.

4 Conclusion

The importance of this preliminary study is in its broader influence on technological progress and practical implementation, as well as worker safety and health. The necessity for experimental verification is emphasized due to the uncertainties surrounding the effectiveness of EXOROBO in reducing musculoskeletal problems. This evidence-based study has the potential to improve the existing design of EXOROBO and promote its utilization in work environments. The objective is to enhance the efficiency and welfare of palm oil workers by creating safer and more efficient work settings. The first alterations in muscle activity of specific muscles during the walk-and-carry activity suggest the probable advantage of the prototype for jobs related to palm oil harvesting. To validate the efficacy of the developed exoskeleton for a whole harvesting shift, it is necessary to conduct a field test in an actual palm oil plantation with skilled harvesters.

Declaration of competing interest

The authors declare that they do not have conflicts of interest.

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