The Effect of an on Body Personal Lift Assist Device (Jaipur Belt) on Trunk Muscle Fatiguability During a Repetitive Lifting Task in Manual Material Handlers – A Non-Randomized Single-Group Trial

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Abstract

Background: An on body personal lift assist device (OBPLAD) is a non-motorized, passive device in which the elastic elements act as an external muscle power generator to assist lifting thereby offloading the trunk muscles. Though there is enough evidence for the use of OBPLAD generated through laboratory studies, we found a scarcity of evidence on the use of OBPLAD in real-life work settings, especially in the Indian population. This study investigates the effect of the Jaipur belt, an OBPLAD, on trunk muscle fatiguability while performing repetitive lifting task in manual material handlers.

Methods:70 subjects engaged in manual material handling were recruited from industries in and around Mangalore, Karnataka in this non-randomized single group trial. Subjects were made to perform a repetitive lifting task over a period of 15 minutes with and without an OBPLAD. Electromyographic data were recorded from rectus abdominis, transverse abdominis, quadratus lumborum, and erector spinae from either side of the body, and the onset of fatigue was deduced from the changes in electromyographic parameters.

Results: We found a delay in the onset of fatigue in all the muscle groups studied while the lift was performed wearing the Jaipur belt. However, the findings were statistically significant only for right erector spinae, right rectus abdominis, left transverse abdominis, and left quadratus lumborum. It was found also that number of repetitions as well as time for which a task would be sustained were both found to be significantly better wearing an OBPLAD.

Conclusion: The findings of the study imply that the Jaipur belt could potentially delay the onset of fatigue in the trunk muscles while performing repetitive lifting task and hence, is proved to be useful in the prevention of fatigue-related musculoskeletal disorders of the lower back.

CTRI Registration date: 10/02/2020 **Trial registration number:** CTRI/2020/02/023219

Introduction

"Manual Material Handling (MMH) is defined as any activity that requires a person to exert a force to lift, lower, push, pull, carry, move, hold or restrain a person or an object. [1]" Research over the past three to four decades has shown that manual material handling has a highly significant association with the development, precipitation, and prognosis of work-related musculoskeletal disorders (WRMSD) especially affecting the lower back region. [2] Evidence, as found by the National Institute of Occupational Safety and Health (NIOSH), states that "there is a relationship between lifting heavy weights and lower back pain (LBP)". [3] According to an economic survey done in 2007–2008 in India, 98% of the employees in the country are employed in the informal sector, accounting for 53.9% of India's gross domestic product. The informal sector involves frequent MMH tasks like lifting heavy objects, performing repetitive tasks, maintaining a fixed posture for a longer duration of time, overexertion, and non-neutral posture which have been found to be physical risk factors of LBP. [4]

During lifting, the extensor muscles of the posterior trunk generate large compression, tension, and shear forces that are transferred to the joints and connective tissues (tendons, ligaments, fascia, and discs) either directly or indirectly within the lower back. When these forces exceed the structural tolerance, it ensues injury at a microscopic or macroscopic level which results in the release of inflammatory cytokines leading to acute or chronic LBP. [5]

Fatigue being one of the major risk factors of low back pain and back injuries leads to compensatory muscle recruitment patterns which cause decrements in the ratio of lift-strength vs task requirements and changes in spinal load. [6] Physical fatigue is described as decrements in muscular performance with continued effort accompanied by general sensations of tiredness or is alternatively defined as the inability to maintain the required power output to continue muscular work at a given intensity. It is classified 3 into two types central and peripheral. Peripheral fatigue occurs when the rate of energy delivery (ATP-PCr, anaerobic glycolysis, and oxidative metabolism) decreases, and metabolic by-products, such as lactate and H + get accumulated, leading to failure of the muscle fiber's contractile mechanism. Central fatigue occurs when there are alterations in the neural control of muscle contraction. [7]

With an intention to reduce the incidence of LBP, lifting aids have been developed, which are categorized as off-body and on-body lifting aids. When loads exceed human capability and require repetition, off-body lifting aids such as hoists and trolleys are often used whereas when the load is within human capability, an on-body lifting aid such as exoskeletons is used.[8] Exoskeleton which is a wearable, external structure adds mechanical power to the human body thereby decreasing the direct load placed on the back hence preventing the risk of WRMSDs. It is typically classified as active (motorized) or passive (non-motorized). Active systems consist of single or multiple operating units to increase human competency, whereas passive systems use materials that possess the ability to store and release energy during movements to assist workers to perform physical movements. [9, 10] On Body Personal Lift Assist Device (OBPLAD) is a non-motorized, passive device in which the elastic elements act as an external muscle power generator that gets compressed thereby storing energy during the descent phase of a lift. This stored energy is then released during the ascent phase of a lift. This device enables portions of forces and moments from the spinal column to be transferred to the shoulder, pelvic girdle, and knees. [11] Theoretically, the device reduces the energy demand placed on the back musculature on lifting which has been seen in a series of laboratory experiments where dynamic lifting and static trunk bending were performed. [9–12]

To the best of our knowledge majority of studies on the effect of OBPLAD on various physiological parameters and risk factors associated with lifting were done in laboratory settings, which is a simulation of actual work scenarios in a controlled environment. A need was identified to evaluate the effectiveness of these devices in real work environments involving actual material handlers. It was also found that there was a scarcity of retrievable data on the effectiveness of PLAD in Indian subjects.

Methodology

The study was conducted in and around Mangalore, a coastal city in Dakshin Kannada district of Karnataka in India, over a 14-month period. The study protocol was reviewed by the Institutional Ethics Committee of KMC Mangalore upon whose approval permission was sought from the district labor officer for recruiting manual material handlers working in medium-scale manufacturing and service industries related to fisheries, Ice making, tile making, and dockworkers working in vaious ports in and around the city.

The estimated sample size for the study was 70 with the criteria of inclusion being subjects of either gender in the age group of 20–70 years indulging primarily in manual material handling tasks. Subjects with a previous history of work-related or non-work-related low back pain/back injuries, any musculoskeletal, neurological, cardiovascular, or systemic illness which could potentially interfere with the task performance or data collection, and subjects with any measurable or observable deformities of lower back/extremities with the potential to interfere with the use of OBPLAD (Jaipur belt) were excluded.

For testing the hypothesis, subjects were made to perform a repetitive lifting task at a self-selected pace for a period of 15 minutes under two test conditions, (a) wearing OBPLAD (Jaipur belt), (b) without wearing OBPLAD in a random order (decided by the toss of a coin) interspersed with a washout period of 45 minutes. They were asked to lift a weight equivalent to 10% of their body weight from the floor to a slab/shelf placed at waist height. Electromyographic (EMG) data were collected from four key trunk muscles i.e., erector spinae, rectus abdominis, transverse abdominis, and quadratus lumborum on either side using Biometrics Ltd Data LITE, wireless surface EMG sensors system, while the lifting task was being performed. Subjects rated their self-perceived fatigue prior to the performance of task as well as immediately after task completion on the Swedish Occupational Fatigue Inventory (SOFI).[13]

Data Analysis

EMG data collected using wireless surface EMG sensors and systems were extracted in the native format. Changes in the EMG activity corresponding to muscle activation during each lift was identified for each of the muscles tested and a power spectrum analysis was done to obtain the median power frequency of the EMG output. The power median thus obtained for each contraction spike was plotted against the time stamp corresponding to each spike and the onset of fatigue was identified as the time point at which a reduction in the median power frequency occurs for each muscle. This data for each of the eight muscles studied was fed into Jamovi (version 1.6.4.0) along with demographic data and other outcome variables. Descriptive analysis was done for the demographic variables and the normality of distribution for continuous variables was tested using the Shapiro-Wilk test. The onset of fatigue, the components of SOFI, the duration for which the activity was sustained, and the number of repetitions performed across each of the two test conditions were compared using the Wilcoxon sign rank test.

Results

Based on the inclusion and exclusion criteria a total of 110 subjects were screened out of which 70 were recruited whose demographic data are represented in Table 1 below.

Table 1
Descriptive statistics for demographic variables

Demographic Variables	Mean ± Standard Deviation (SD) N = 70 Male = 59 Female = 11	Range
Age	36.8 ± 11.7	20–67 (Years)
Height	166 ± 9.37	140–188 (cm)
Weight	66.7 ± 13.6	38.9–97 (kg)

Table 2
Comparison of repetitive lifts and duration of sustained lifting with and without belt.

Variable	Conditions	Mean	Mean Difference	P-value
Duration of sustained activity	Belt	228.4571	28.9143s	0.007
	No Belt	199.5429		
Number of lifts	Belt	50.5857	8.1286	< 0.001
	No Belt	42.4571		

The results show that the work rate is sustained on an average of 30 seconds more while wearing the OBPLAD (Jaipur belt) as well as on an average 6 more repetitions of the task is seen to be performed while wearing the OBPLAD (Jaipur belt).

Table 3
Comparison of Swedish Occupational Fatigue Inventory (SOFI) components with and without belt.

Variable	Condition	Mean	Mean Difference	P-value
Lack of Energy	Belt	0.6500	-0.0286	0.868
	No Belt	0.6786		
Physical Exertion	Belt	0.8714	-0.0714	0.378
	No Belt	0.9429		
Physical Discomfort	Belt	0.7000	-0.0357	0.864
	No Belt	0.7357		
Lack of Motivation	Belt	0.0893	0.0400	0.203
	No Belt	0.0493		

.Domains of the Swedish Occupational Fatigue Inventory (SOFI) were compared between two test conditions with and without OBPLAD (Jaipur belt). No statistical difference was observed. However, it was observed that the SOFI scores across the domains were consistently low while wearing the OBPLAD (Jaipur belt).

Table 4
The difference in the onset of fatigue with and without the belt in various muscle groups while lifting.

Muscle Groups	Side	Condition	Mean	Mean Difference (s)	P-value
Erector Spinae	Left	Belt	95.7	15.8	0.072
		No belt	79.9		
	Right	Belt	117	25	0.008**
		No belt	91.9		
Rectus Abdominis	Left	Belt	118.5	16.8	0.057
		No belt	101.8		
	Right	Belt	125.4	22.9	0.001**
		No belt	102.5		
Transverse Abdominis	Left	Belt	124.4	29.4	0.011**
		No belt	95		
	Right	Belt	114.7	10.3	0.147
		No belt	104.4		
Quadratus Lumborum	Left	Belt	122.3	25.1	0.027**
		No belt	97.2		
	Right	Belt	131.1	34.8	0.055
		No belt	96.3		

Note: ** = significant

The onset of fatigue was found to be significantly delayed across all muscle groups while the activity was performed wearing the OBPLAD (Jaipur belt). However, the findings were statistically significant only for right erector spinae, right rectus abdominis, left transverse abdominis, and left quadratus lumborum muscles.

Discussion

The study was undertaken as a first of its kind endeavor in analyzing the effect of wearing an on body personal lift assist device (Jaipur belt) on work performance in real-life scenarios which hitherto have been confined to controlled environments inside laboratory settings. For the purpose of the study, a total of 70 Manual Material Handlers working across various organized sectors like brick and tile manufacturing, rubber processing, fishing, and fish processing as well as commercial ice-making, were recruited from various locations of Mangaluru. Covid enforced restrictions resulted in permission being denied for recruitment on multiple occasions from various other workplaces we approached. However, over a period of 14 months, we were able to screen a total of 110 industrial workers of whom 90 were found to be eligible for participation and ultimately 70 subjects were recruited as per the estimated sample size. A key hindrance to the collection of a larger sample size for such an undertaking would be the sheer amount of time it takes for usable data to be collected from a single subject. The total time duration required for subject screening, preparation, familiarization, and data recording was approximate 120 minutes per subject which severely restricted the number of subjects that can be recruited over a single working day. A keen observation with regard to data collection was that subjects required certain levels of familiarization with the Jaipur belt as they were apprehensive that it would interfere with their regular lifting practices. Hence, they were allowed to don the Jaipur belt and perform activities of their choice for 10–15 minutes prior to the collection of data. Collection of Electromyographic (EMG) data in a non-climate-controlled environment poses a challenge that profuse sweating can lead to de-adherence of EMG electrodes from their respective location, thereby rendering the data unusable. This particular finding corroborates the observations previously made across various populations in various trunk muscles that there is a significant reduction in fatiguability associated with the use of an on body personal lift assist device while lifting.

A study done on 10 healthy Canadian male subjects had shown that the use of an OBPLAD reduced or rather inhibited the fatiguability of erector spinae muscle while performing repetitive lifting task. [11] In our study, though fatiguability was noted in bilateral erector spinae muscle, in either of the test scenarios i.e., with and without an on body personal lift assist device, the onset of fatigue was significantly delayed while using Jaipur belt. Erector spinae is the key agonist for trunk extension in the ascent phase of the lift and eccentrically controls the velocity of trunk flexion in the descent phase of the lift. The significant torque assistance, which is estimated to be approximately 23–26 NM would of all muscles, affects this prime mover / antagonistic function of erector spinae the most. [10] The resistance offered by the on body personal lift assist device to gravity-driven trunk flexion in the descent phase of the lift and assistance offered by means of a rebound in the ascent phase of lift will significantly share the workload of erector spinae that may lead to reduced recruitment of muscle fibres. [11] This can be attributed to the observed delay in the fatiguability of erector spinae while using the Jaipur belt.

Though there is uncertainty regarding the role of transverse abdominis in spine functions, the general consensus is biased towards considering it as a key generator of intra-abdominal pressure as well as transmission of contraction force reflected via thoracolumbar fascia, so as to reduce the intersegmental movements at the lumbar spine. These activities are considered to be significant while performing exertional activities using upper and lower extremities as well as spinal stabilization during a lifting task. [14] In our study, there was a delay in onset of fatigue of transverse abdominis muscle bilateral while performing a repetitive lifting task wearing on body personal lift assist device but the result was statistically significant only for the left transverse abdominis muscle. To the best of our knowledge, this is the first study where transverse abdominis and quadratus lumborum activity with regard to lifting task under various contexts has been studied. The rigid elements of the Jaipur belt interconnected with a stiff elastic component will store and release energy while lifting may provide additional stability spanning multiple segments across the trunk which may be attributed to the reduced recruitment in transverse abdominis leading to delayed onset of fatigue.

Rectus Abdominis which is the prime flexor of the trunk plays a synergistic role along with internal oblique and external oblique muscles in the generation of stabilizing forces on the spine by co-activation during stressful activities. A dynamic role that the rectus abdominis would perform involves control of pelvis anteversion occurring in relation to the sagittal plane displacement of the trunk. In our trial, it was expected that the added resistance offered by the on body personal lift assist device to trunk flexion would in fact lead to greater recruitment of rectus abdominis. [15] However, the results show a considerable delay in fatiguability in rectus abdominis on using the Jaipur belt. This could again be attributed to the presence of rigid elements interspersed with elastic resistance transmitting forces between the trunk and lower extremity. The elastic recoil of on body personal lift assist device resists flexion movement at both trunk and pelvis and this could be probably be attributed to reduced fatiguability of rectus abdominis. However, it was noticed, previous studies done in laboratory settings reported no changes in Rectus Abdominis while using an on body personal lift. [12]

In accordance with the changes observed in muscle performance, we also found that subjects were able to sustain repetitive task for a longer duration as well as perform a greater number of repetitions while wearing the on body personal lift assist device. This finding could infer that the physiological changes observed in muscle functions have translated to real-world performance changes.

Scores of the Swedish Occupational Fatigue Inventory (SOFI) were found to be consistently low across the domains lack of energy, physical exertion, physical discomfort after the usage of Jaipur belt indicating low physical demand level. However, there was no statistically significant difference across the two test conditions.

Limitations

1. For the purpose of testing the dimensions of the load selected were uniform and there is ample evidence to show that not just the magnitude of the load but also the distribution of mass within the dimensions also influences lifting mechanics.
2. There is evidence that environmental conditions like humidity and ambient temperature can confound the electromyographic data recorded since our study was done in an industrial setting, the majority of the data was collected in a non-climate-controlled environment.

SCOPE OF FUTURE STUDIES

1. Future studies could aim at normalizing the dimension of the load along with the magnitude of the load so as to optimize the performance output of the studied subjects.
2. Studying the variability in the lower extremity kinetics along with that of the trunk would give greater insight into the effect of a personal lift assist device on lifting biomechanics.

Conclusion

The results of the study imply that using an on body personal lift assist device significantly reduces or delays the onset of fatigue in trunk musculature. There is also an observed improvement in performance in terms of the number of repetitive lifting that can be done and the total duration for which the task can be sustained. Therefore, it can be concluded that an on body personal lift assist device has the potential to mitigate the risk of work-related musculoskeletal disorders of the back related to muscle fatigue.

Abbreviations

EMG	Electromyography
LBP	Low Back Pain
MMH	Manual Material Handlers
NIOSH	National Institute of Occupational Safety and Health
OBPLAD	On Body Personal Lift Assist Device
SOFI	Swedish Occupational Fatigue Inventory
WRMSD	Work-related Musculoskeletal Disorders

Declarations

Ethical approval

The study protocol was reviewed by the Scientific and Institutional Ethics Committee of KMC Mangalore and the ethical approval was issued on 27/11/2019 (IEC KMC MLR 11-19/585.

Consent to participate

All procedures followed were in accordance with the ethical standards of the institutional and/ or national research committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all patients for being included in the study.

Availability of data and material

The data sets used and/or analysed during current study are available from the corresponding author on reasonable request.

Competing interests

The funding agency (Newndra Innovations) is a major stakeholder in the development of the Jaipur belt which is the on body personal lift device used. None of the investigators are in any way associated with the funding agency or the developers of the Jaipur belt in any other way than research. The testing was done completely independent of the interference of the direct/indirect interference of the developers of the product or any agencies related to them.

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Authors Contributions

1. Betty Thomas: Protocol preparation, data collection, data compilation, and manuscript preparation.
2. Shyam Krishnan K: Conceptualization, study design, data collection, data analysis, and result analysis.
3. Ashish John Prabhakar: Conceptualization and result analysis.
4. Megha M Nayak: Instructing the participants, supervising and controlling the electromyographic data collection, data compilation, and organization.
5. Charu Eapen: Conceptualization, subject screening, and result analysis.

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Figures

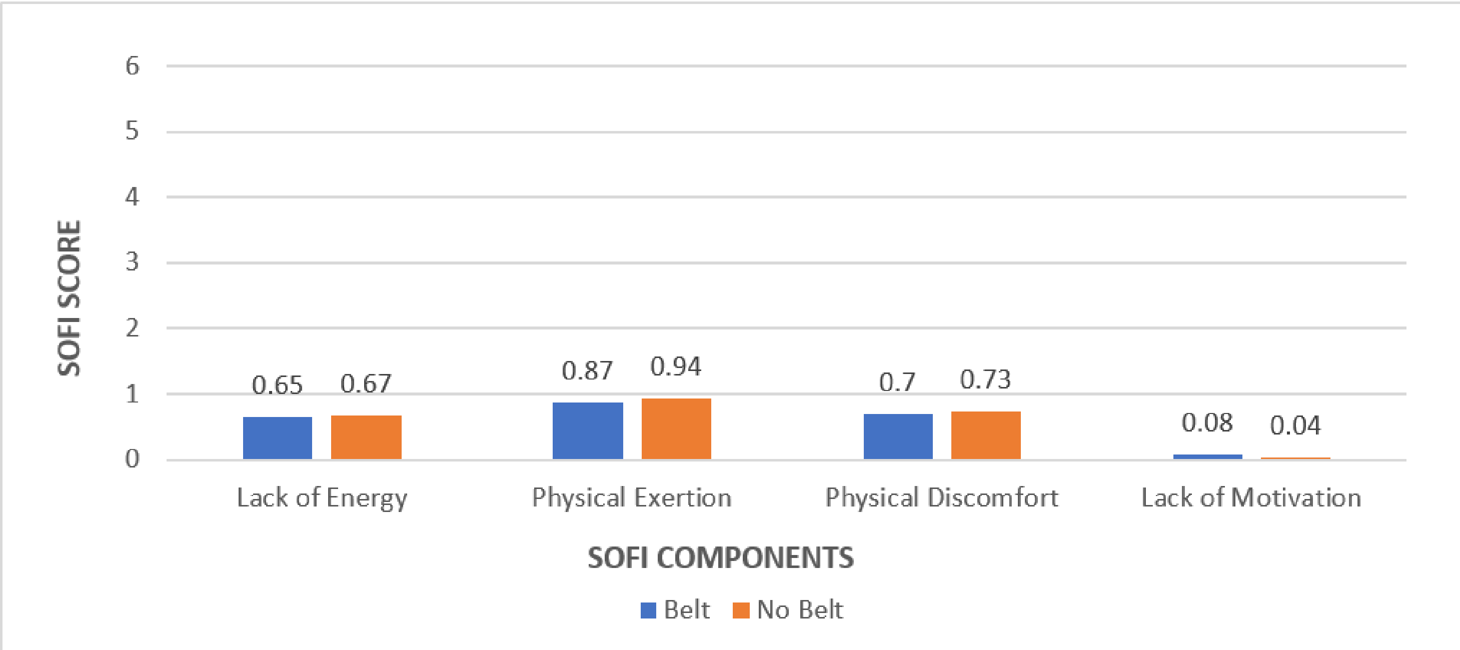

Figure 1

Difference in Swedish Occupational Fatigue Inventory (SOFI) scores with and without belt.

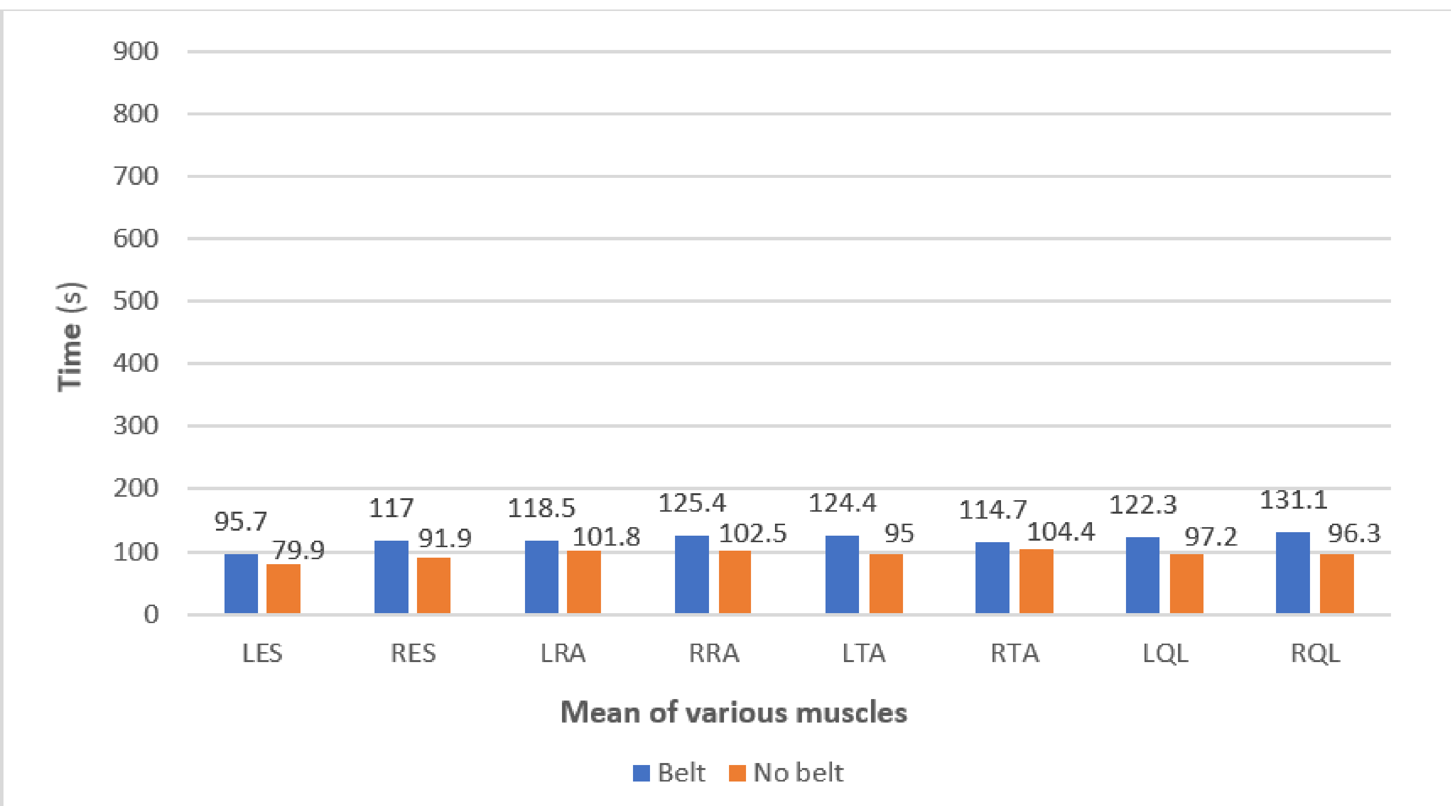

Figure 2

The difference in the onset of fatigue in various muscle groups across two test conditions i.e., with OBPLAD and without OBPLAD.