Scientific Research Publishing

Open Journal of Therapy and Rehabilitation, 2023, 11, 149-157
https://www.scirp.org/journal/ojtr
ISSN Online: 2332-1830
ISSN Print: 2332-1822

Exploring Passive Exoskeleton-Induced Changes in Lumbar Muscle Activity

Ryo Fujitani[1], Hiroko Kawasaki[1], Mika Suzuki[1], Shogo Sakai[1], Souma Hori[1], Ryoga Muranishi[1], Shinichi Noguchi[1], Takumi Jiroumaru[2], Michio Wachi[2], Kouhei Okuyama[2]

[1]Department of Physical Therapy, Biwako Professional University of Rehabilitation, Higashiomi, Japan
[2]Department of Physical Therapy, Bukkyo University, Kyoto, Japan
Email: r-fujitani@pt-si.aino.ac.jp

How to cite this paper: Fujitani, R., Kawasaki, H., Suzuki, M., Sakai, S., Hori, S., Muranishi, R., Noguchi, S., Jiroumaru, T., Wachi, M. and Okuyama, K. (2023) Exploring Passive Exoskeleton-Induced Changes in Lumbar Muscle Activity. *Open Journal of Therapy and Rehabilitation*, **11**, 149-157.
https://doi.org/10.4236/ojtr.2023.114011

Received: August 7, 2023
Accepted: September 12, 2023
Published: September 15, 2023

Abstract

Purpose: The purpose of this study was to evaluate the effect of using a passive exoskeleton on lumbar muscle activity during lifting movements, and to determine whether muscle activity remains altered after exoskeleton removal. This study sought to identify the potential risks and benefits associated with the use of passive exoskeletons for the prevention and treatment of low back pain. **Methods:** Eighteen healthy adult participants lifted a 10 kg suitcase while wearing a passive exoskeleton. Muscle activity and postures were measured during lifting and before, during, and after exoskeleton use. This study examined whether the reduced muscle activity observed during exoskeleton use persisted after exoskeleton removal. Muscle activity was assessed using electromyography and postures were recorded using reflective markers and a camera. **Results:** The study found that Lumbar muscle activity decreased significantly (approximately 40%) during exoskeleton use compared to that without exoskeleton use. Importantly, lumbar muscle activity remained low after exoskeleton removal, at levels similar to those observed during exoskeleton use. This suggests that individuals adapted to the exoskeleton support and maintained altered muscle control, even without the exoskeleton. **Conclusion:** This study demonstrates that passive exoskeletons significantly reduce lumbar muscle activity during lifting tasks, and that this altered muscle control persists after exoskeleton removal. These findings contribute to the understanding of the risks and benefits of passive exoskeletons, potentially aiding their development and informing their use in the prevention and treatment of low back pain.

Keywords

Passive Exoskeleton, Low Back Pain, Muscle Activity, Adaptation

1. Introduction

Occupational low back pain is the most common work-related pain in Japan and has shown an increasing trend in all industries in recent years [1]. Occupational low back pain is caused or aggravated by the nature of the job or the immediate work environment. The etiology of occupational low back pain is multifactorial [1]. Lifting is a physiological factor in the workplace that may have a causal relationship with low back pain [2]. In Japan, the incidence is significantly higher in the insurance and healthcare industries, and inland transportation. Preventive measures should benefit not only the affected workers but also the employer and the country since occupational back pain is associated with significant costs not only to the health of the workers but also to the company and the country [3]. The worsening demographic shortage in our country has worsened the conditions in the workplace and increased the importance of maintaining employees' health for as long as possible during the work process [4].

Repetitive lifting and holding motions have been identified as causes of occupational back pain in the transportation and healthcare industries. Machines that can reduce these physically demanding loads are called exoskeletons, which are mechanical structures that are attached to the human body to support the user's musculoskeletal system during certain movements and postures [5]. In recent years, assistive technologies, such as passive exoskeletons, have been introduced to assist with locomotion. Devices that augment bodily functions began in the late 1960s, and were intended to increase the wearer's strength. Passive exoskeletons are less expensive and easier to use than lifts, but there is a lack of scientific knowledge about how they prevent and affect people with back pain. Therefore, one of the issues to be addressed by the government is to study the safe use of equipment for handling heavy objects [1].

To ensure that the use of passive exoskeletons contributes to the prevention of back pain in workers, it is important to evaluate them. Research interest in this field is growing, which is evident from the substantial increase in related publications over the last few years [6] [7] [8] [9]. A parameter often considered in general biometric studies is the muscle activity of the lumbar back, measured by electromyography (EMG) [6] [7] [10]; Kermavnar *et al.* (2021), and a study on the influence of the passive exoskeleton on back muscle activity showed a significant decrease with the exoskeleton compared with the same task performed without the passive exoskeleton [8].

Thus, it is clear from previous studies that assistive technology extends bodily functions while wearing a suit, thereby reducing muscle activity and strain in the lumbar dorsal muscle group. However, when lifting movements are performed without the passive exoskeleton immediately after donning and doffing the suit, there is a risk of low back pain if dorsal lumbar muscle activity remains low. Clarification of this fact would be valuable when considering the safe use of passive exoskeletons.

In this study, we investigated whether the use of a passive exoskeleton that prolongs the lifting motion, as in previous studies, causes a decrease in the muscle activity of the dorsal lumbar muscles during the lifting motion, and whether the dorsal lumbar muscles were disoriented when the patient performed the lifting motion after donning and doffing the passive exoskeleton. The purpose of this study was to evaluate the changes in lumbar muscle activity after the use of a passive exoskeleton and to identify the risks of using the passive exoskeleton in the prevention and treatment of low back pain.

2. Participants and Methods

2.1. Participants

All participants were healthy adults. (17 males, 1 female) mean age = 25.3 ± 10.0 years, height = 171.0 ± 5.2 cm, weight = 64.6 ± 10.6 kg]. Before the study, Healthy adults were defined as those who 1) had no neurological or orthopedic disease within the previous six months and 2) had FRP in the lumbar iliocostal muscles, one of the thoracolumbar extensor muscle groups. Each participant signed an informed consent form, based on the requirements of the Helsinki Declaration. This study was approved by the Ethics Committee of the Kanazawa Orthopedic Sports Medicine Clinic (Kanazawa-OSMC-2023-001).

2.2. Methods

The lifting posture to be measured was the standing position with the subject shoulder width apart. Posture and muscle activities during static lifting were measured while lifting a suitcase (10 kg) with a handle placed in front of the subject to a height of approximately 10 cm. The upper limb was placed in extension without flexion of the elbow joint, and posture was maintained for 10 s while lifting the case. The posture and muscle activities were recorded (**Figure 1**).

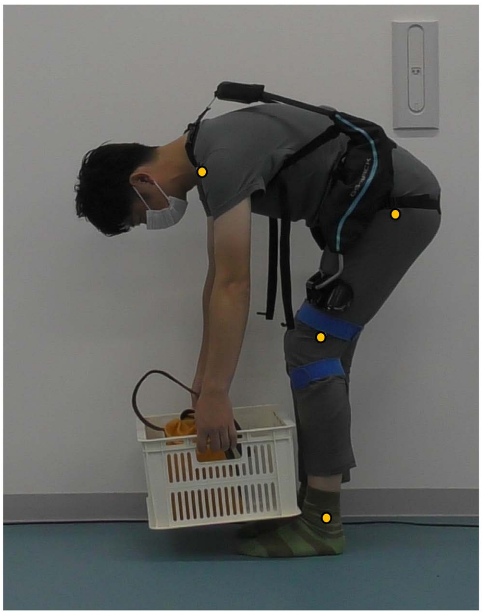

Figure 1. Lifting posture. Subject wearing the Every® exoskeleton.

The muscle suit used was every passive exoskeleton Every® (INNOPHYS LTD., Japan), and posture and muscle activity were measured while lifting a 10 kg load under three conditions: before, during, and after wearing the passive exoskeleton. After wearing the passive exoskeleton, the subjects performed squatting and forward-bending movements for 5 min to become sufficiently accustomed to the passive assistance provided by the passive exoskeleton.

To measure posture, 14 mm diameter reflective markers were attached to anatomical landmarks, and sagittal plane images were captured with a digital camera. Image processing software (ImageJ version 1.48, NIH) was used to calculate the trunk tilt angle (acromion - greater trochanter), knee joint flexion angle (greater trochanter - lateral center of knee joint - outer edge), and tibia tilt angle (lateral center of knee joint - outer edge).

Muscle activity was measured using a wireless electromyograph (Trigno wireless System, DELSYS) at 2000 Hz. Both the left and right sides of the lumbar iliocostalis and lumbar multifidus were measured as measurement muscles [11] [12]. The EMG data were full wave rectified, filtered (band-pass 20 - 500 Hz), and normalized based on the activity of each muscle during unsupported lifting.

2.3. Statistics

One-way ANOVA was performed for each angle and muscle activity before, during, and after passive exoskeleton wear, followed by a post-hoc multiple comparison test using the Bonferroni method. The significance level was set at $p < 5\%$ for each case. The level of significance was set at $p < 0.05$. The statistical software used was SPSS for Windows (version 24.0; IBM Corp., Armonk, New York, USA).

3. Results

No significant differences were found in the trunk tilt, knee joint angle, or lower leg tilt (**Figure 2**) before, during, or after wearing the passive exoskeleton in the elevated position ($p > 0.05$). Therefore, since there was no change in posture

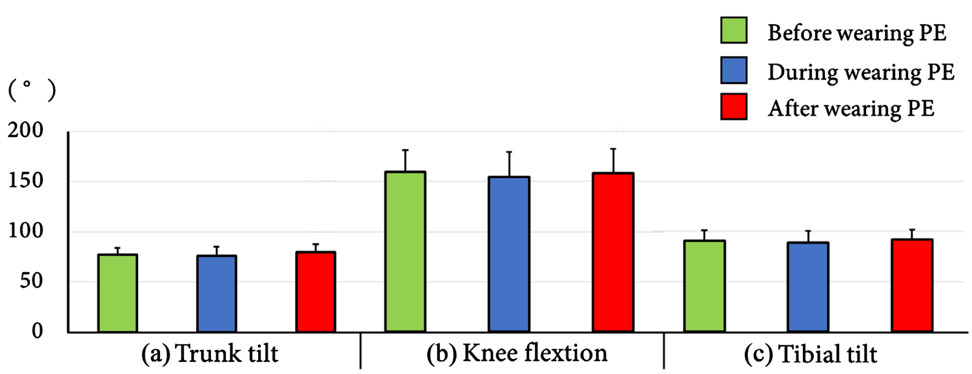

Figure 2. Comparison of each angle (˚) in trunk tilt, knee flexion and tibial tilt across before, during and wearing passive exoskeleton (PE). The vertical bar represents the median angle under the different lifting conditions. The whiskers extend to the largest angle achieved. No significantly from each other (p > 0.05).

before, during, or after wearing the passive exoskeleton, there was no problem in comparing lumbar muscle activity with and without wearing the passive exoskeleton.

Compared with the level of lumbar muscle activity (**Figure 3**) before and during passive exoskeleton wear, both the left and right lumbar iliocostalis and multifidus showed a significant decrease during passive exoskeleton wear ($p <$ 0.05). The degree of decrease was approximately 40% in both muscles.

After wearing the garment, both the left and right lumbar iliocostalis and multifidus muscles showed a greater decrease during garment wear ($p < 0.05$). However, there was no significant difference in muscle activity before and during wear ($p > 0.05$).

4. Discussion

After confirming the effects of passive exoskeleton wear, this study examined whether lower back muscle control remained low after the passive exoskeleton was removed from the wearer during the same task. The results of this study showed that lumbar muscle activity during lifting was significantly lower after passive exoskeleton removal than without the passive exoskeleton, and the muscle activity was like that when the passive exoskeleton was worn. This suggests that by wearing the passive exoskeleton and receiving assistance from the machine during the lifting task, the muscular control of the lumbar muscle activity

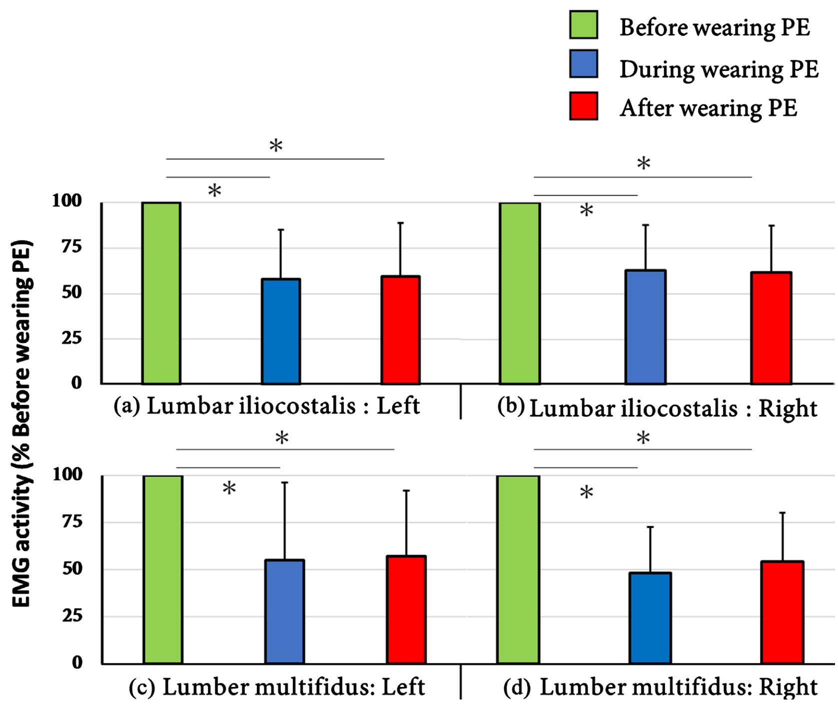

Figure 3. Comparison of EMG activity (percentage of Before wearing passive exoskeleton) in 2 muscles across 3 lifting condition. The each vertical bar represents the median RMS under the different main lifting conditions. The whiskers extend to the largest RMS activity achieved. The horizontal bars with the symbol * thereby mark the conditions that differ significantly from each other ($p < 0.05$).

necessary for lifting is relearned to adapt to the passive exoskeleton, and the learning is maintained after the passive exoskeleton is removed.

With respect to the passive exoskeleton wearer's lumbar muscle load, a significant average 50% reduction in muscle activity was observed during wear compared to before [8], as in previous studies. In previous studies, the effect of reduced muscle activity in the passive exoskeleton has ranged from 10% - 40%. [13] [14] [15] [16]. The lumbar dorsal muscle activity was also significantly lower at 50% and 25% in the LOW and HIGH lifting positions [17]. The low lifting position of 10 cm in this study may have exerted a significant reduction owing to the strong trunk extension moment from the passive exoskeleton. Such a positive effect of the passive exoskeleton may contribute to the prevention of low back pain by reducing muscle fatigue caused by the repetition of similar tasks.

However, a novel finding of this study is that lumbar muscle activity after wearing the passive exoskeleton remained at the same level as during wearing (low activity state). A previous gait study showed low muscle activity even after wearing an ankle passive exoskeleton for 5 to 10 min [6]. However, this study is the first to show disruption of muscle activity by lumbar muscle groups after wearing a passive exoskeleton designed to reduce lumbar strain, which was developed in recent years.

This finding may be because the subject's lumbar dorsal muscle groups adapted to the lifting motion while wearing the passive exoskeleton, and a new cooperative relationship with the passive exoskeleton persisted after the passive exoskeleton was donned and removed. There are no previous studies on whether the adaptation of muscle activity in passive exoskeleton wear persists after donning or doffing. However, previous studies on the application of ankle-foot orthoses have reported no change in muscle response after prolonged wear (Cordova *et al.*, 2000). However, we believe that the brain is different in a passive exoskeleton with a high contribution of tension, as opposed to an orthosis that excels in immobilization rather than assistive performance. Several studies have reported that the lumbar dorsal muscles adapt to the optimal amount of muscle activity for lifting movements during wear. However, whether this cooperative relationship with the passive exoskeleton continues after wear has not yet been investigated. It is interesting to note that the present study showed that the same level of efficacy was observed post-wear when the passive exoskeleton was worn, suggesting that there are risks associated with post-wear movements.

As a clinical application of the findings, the decreased contribution of the lumbar muscle groups to lifting movements after donning and doffing may result in the loading of non-contractile elements of the joints and ligaments during lifting movements and other exercises after donning and doffing, which may be a precaution in use. Second, in patients with chronic low back pain who exhibit excessive lumbar muscle activity in clinical situations, it is necessary to relearn lumbar muscle activity to a low-tension or relaxation state during activity and rest. Such relearning may reduce the risk of disability and physical and psychological burden, which may make daily life more comfortable and lead to the improvement of chronic low back pain.

The limitation of this study is that we examined only transient changes, and it is unclear how long the decrease in lumbar dorsal muscle strength persisted after passive exoskeleton removal. In addition, this was a static trunk deep flexion movement with a light 10 kg (10 cm) object, and it is not clear whether similar responses could be obtained by changing the weight or height or during the movement itself. Previous studies have shown that increasing height reduces the passive exoskeleton-induced decrease in muscle activity in the lumbar dorsal muscles [6]; therefore, there may not be a significant gap when working in a higher position.

Passive exoskeletons and other exoskeletal technologies continue to develop, but there are still many unknowns about the risks of their use with respect to the collaborative relationship between technology and humans. We believe that the results of this study will lead to risk management of passive exoskeletons, which will be beneficial for the development of this technology. In the future, it will be necessary to study joints and other muscle groups after wearing the passive exoskeleton, as well as whether wearing the passive exoskeleton is effective in relearning to reduce excessive muscle activity in the lumbar muscle groups of people with low back pain.

5. Conclusion

The study showed that wearing a passive exoskeleton during lifting tasks resulted in a reduction in lumbar muscle activity, and this altered muscle control persisted after the exoskeleton was removed. The results highlight the potential benefits and risks associated with the use of passive exoskeletons and suggest the need for further research to better understand their effects on muscle activity and joint dynamics, particularly in individuals with low back pain.

Acknowledgements

We are grateful to all the individuals who gave their time and effort to participate in this study. The authors would like to thank INNOPHYS LTD. for providing one of their passive exoskeletons (Every®) free of charge for the duration of the study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ministry of Health, Labor and Welfare (2023) The 14th Industrial Accident Prevention Plan in Japanese, 10-13.

[2] National Institute for Occupational Safety and Health (1997) Musculoskeletal Dis-

orders and Work-Place Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. 87-97.

[3] Akira, K. (2002) Occupational Low Back Pain; Present Andfuture. *Journal of Lumbar Spine and Disorder*, **8**, 10-15. (In Japanese) https://doi.org/10.3753/yotsu.8.10

[4] Schick, R. (2018) Einsatz von Exoskeletten in der Arbeitswelt. *Zentralblatt für Arbeitsmedizin*, *Arbeitsschutz und Ergonomie*, **68**, 266-269. https://doi.org/10.1007/s40664-018-0299-0

[5] Kaupe, V. and Feldmann, C. (2021) Exoskelette in der Intralogistik: Erfolgreich implemen-tieren und Prozesse optimieren. Springer Fachmedien Wiesbaden, Wiesbaden.

[6] Koopman, A.S., Toxiri, S., Power, V., Kingma, I., van Dieën, J.H. and Ortiz, J. (2019) The Effect of Control Strategies for an Active Back-Support Exoskeleton on Spine Loading and Kine-Matics during Lifting. *Journal of Biomechanics*, **91**, 14-22. https://doi.org/10.1016/j.jbiomech.2019.04.044

[7] Lazzaroni, M., Toxiri, S., Caldwell, D.G., Anastasi, S., Monica, L. and Momi, E.D. (2019) Acceleration-Based Assistive Strategy to Control a Back-Support Exoskeleton for Load Handling: Preliminary Evaluation. 2019 *IEEE* 16*th International Conference on Rehabilitation Robotics* (*ICORR*), Toronto, 24-28 June 2019, 625-630. https://doi.org/10.1109/ICORR.2019.8779392

[8] Kermavnar, T., Vries, A.W.D., Looze, M.P.D. and O'Sullivan, L.W. (2021) Effects of Industrial Back-Support Exoskeletons on Body Loading and User Experience: An Updated Systematic Review. *Ergonomics*, **64**, 685-711. https://doi.org/10.1080/00140139.2020.1870162

[9] Pesenti, M., Antonietti, A., Gandolla, M. and Pedrocchi, A. (2021) Towards a Functional Performance Validation Standard for Industrial Low-Back Exoskeletons: State of the Art Review. *Sensors*, **21**, Article 808. https://doi.org/10.3390/s21030808

[10] Tobias, W., Norman, S. and Tobias, S. (2023) Active Exoskeleton Reduces Erector Spinae Muscle Activity during Lifting. *Frontiers in Bioengineering and Biotechnology*, **11**, 1-12. https://doi.org/10.3389/fbioe.2023.1143926

[11] Ng, J.K. and Richardson, C.A. (1996) Reliability of Electromyographic Power Spectral Analysis of Back Muscle Endurance in Healthy Subjects. *Archives of Physical Medicine and Rehabilitation*, **77**, 259-264. https://doi.org/10.1016/S0003-9993(96)90108-2

[12] Roy, S.H., De Luca, C.J. and Casavant, D.A. (1989) Lumbar Muscle Fatigue and Chronic Lower Back Pain. *Spine*, **14**, 992-1001. https://doi.org/10.1097/00007632-198909000-00014

[13] Mohammad, A., Michael, A. and Joan, S. (2006) An On-Body Personal Lift Augmentation Device (PLAD) Reduces EMG Amplitude of Erector Spinae during Lifting Tasks. *Clinical Biomechanics*, **21**, 456-465. https://doi.org/10.1016/j.clinbiomech.2005.12.021

[14] Mohammad, A. and Joan, S. (2008) The Effect of On-Body Lifts Assistive Device on the Lumbar 3D Dynamic Moments and EMG during Asymmetric Freestyle Lifting. *Clinical Biomechanics*, **23**, 372-380. https://doi.org/10.1016/j.clinbiomech.2007.10.012

[15] Pieter, C., Vincent, G., Aafje, B., Jaap, D., Monique, H., Allard, J. and Alex, B. (2014) The Effect of Lifting during Work on Low Back Pain: A Health Impact Assessment Based on a Meta-Analysis. *Occupational and Environmental Medicine*, **71**, 871-877. https://doi.org/10.1136/oemed-2014-102346

[16] Pieter, C., Idsart, K., Cécile, R., Boot, W., Twisk, P. and Bongers, H. (2013) Cumulative Low Back Load at Work as a Risk Factor of Low Back Pain: A Prospective Cohort Study. *Journal of Occupational Rehabilitation*, **23**, 11-18. https://doi.org/10.1007/s10926-012-9375-z

[17] Tim, B., Jennifer, E., Karlijn, K. and Michiel, L. (2016) The Effects of a Passive Exoskeleton on Muscle Activity, Discomfort and Endurance Time in Forward Bending Work. *Applied Ergonomics*, **54**, 212-217. https://doi.org/10.1016/j.apergo.2015.12.003

[18] Cordova, M.L., Cardona, C.V., Ingersoll, C.D. and Sandrey, M. (2000) Long-Term Ankle Brace Use Does Not Affect Peroneus Longus Muscle Latency during Sudden Inversion in Normal Subjects. *Journal of Athletic Training*, **35**, 407-411. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1323365/