

VU Research Portal

Effects of an inclination-controlled active spinal exoskeleton on spinal compression forces

Koopman, A. S.; Toxiri, S.; de Looze, M. P.; Kingma, I.; van Dieën, J. H.

published in

Wearable Robotics: Challenges and Trends
2019

DOI (link to publisher)

[10.1007/978-3-030-01887-0_98](https://doi.org/10.1007/978-3-030-01887-0_98)

document version

Publisher's PDF, also known as Version of record

document license

Article 25fa Dutch Copyright Act

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Koopman, A. S., Toxiri, S., de Looze, M. P., Kingma, I., & van Dieën, J. H. (2019). Effects of an inclination-controlled active spinal exoskeleton on spinal compression forces. In M. C. Carrozza, S. Micera, & J. L. Pons (Eds.), *Wearable Robotics: Challenges and Trends: Proceedings of the 4th International Symposium on Wearable Robotics, WeRob2018, October 16-20, 2018, Pisa, Italy* (pp. 505-509). (Biosystems and Biorobotics; Vol. 22). Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-030-01887-0_98

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl



Effects of an Inclination-Controlled Active Spinal Exoskeleton on Spinal Compression Forces

A. S. Koopman¹(✉), S. Toxiri², M. P. de Looze¹, I. Kingma¹,
and J. H. van Dieën¹

¹ Department of Human Movement Sciences,
Faculty of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam,
Amsterdam Movement Sciences, Amsterdam, The Netherlands

a.s.koopman@vu.nl

² Department of Advanced Robotics, Istituto Italiano di Tecnologia, Genoa, Italy

Abstract. Mechanical loading of the spine is a known risk factor for the development of low-back pain. The objective of this study was to assess the effect of an inclination-controlled exoskeleton on spinal compression forces during lifting with various techniques. Peak compression decreased on average by around 20%, and this was largely independent of lifting technique.

1 Introduction

Low-back pain (LBP) is the number one cause of disability in the world [1], with a lifetime prevalence between 75–84% [2]. Mechanical loading of the spine has been shown to be an important risk factor for the development of LBP [3]. Although physically demanding tasks are gradually taken over by robots and cranes, still many workers have to repeatedly lift heavy loads in jobs [4] that depend on the versatile capabilities of the human.

Therefore, assistive devices have been developed that aim to support the trunk during forward bending and lifting tasks. One goal of such devices is to reduce the spinal compression forces, by taking over a part of the required muscular moment. Active devices are stronger and more versatile compared to passive devices, and allow for controlling the torque applied by the exoskeleton. However, it is still unclear how the generated torque should be controlled, and how this interacts with human behavior.

The objective of this study was to assess the effect of an inclination-controlled exoskeleton on spinal compression forces during lifting with various techniques.

This work was supported in part by the European Union's Seventh Framework Programme under grant agreement Robo-Mate no. 608979, in part by the European Union's Horizon 2020 through the SPEXOR project, contract no. 687662, in part by the People Programme (Marie Curie Actions) under REA grant agreement SMART-E no. 608022 and in part by the Italian Workers' Compensation Authority (INAIL).

Secondly, it was investigated how well the inclination-controlled torque matched the users need in terms of timing of the support torque relative to the required torque.

2 Methods

2.1 Exoskeleton

The device used in this study was developed as part of the EU-funded project Robo-Mate, a revised second version (Mk2B) was used in this experiment (Fig. 1). Details of the device (the EXO) can be found in Toxiri et al. (2018) [5]. Two actuators, approximately aligned with hip flexion-extension axis, could generate a maximum torque of 20Nm each. The controller provided the support as a sine function of the inclination of the thorax.

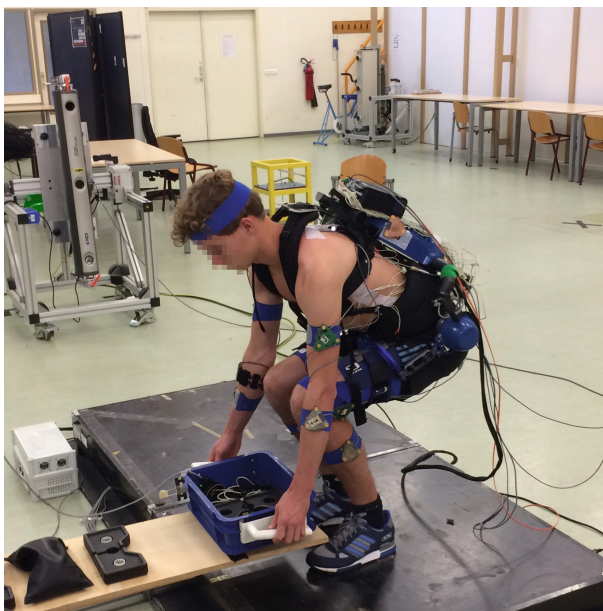


Fig. 1. The experimental setup including; force plate, optotrak camera, marker clusters, EMG and the EXO.

2.2 Participants & Experimental Procedure

Eleven healthy young males participated in the experiment. None of the participants had a history of low-back pain. After signing an informed consent, each subject was instructed to complete a lifting task with three different techniques; FREE, SQUAT and

STOOP, once WITH and once WITHOUT the EXO. Participants had to grasp an object of 15 kg from mid-shin height and return to upright stance and subsequently place the object back and return to upright stance once more. Full-body 3-D kinematics, ground reaction forces and back and abdominal muscle activity were measured.

2.3 Data Analysis

A dynamic bottom-up 3-D linked segment model [6] was used to calculate the net moment (M_{L5S1}) and reaction force (F_{L5S1}) at the L5S1 intervertebral disc. Linear envelopes of the EMG signals were normalized to maximum voluntary contractions and used as an input to an EMG driven trunk muscle model [7, 8]. For each participant, a best fit between M_{L5S1} and the muscle moment was obtained by optimizing three parameters (overall muscle maximum stress, rest length, and passive muscle force scaling factor) over all lifts performed by a participant in the WITHOUT condition. Compression forces at the L5S1 intervertebral disc (F_{comp_L5S1}) were finally obtained by summing the muscle forces and net reaction forces and projecting them on the coordinate system of the L5S1 disc.

2.4 Statistics

Statistical differences in compression forces were tested along the complete time series of outcome values using one-dimensional statistical parametric mapping (SPM1D). A SPM1D two-way repeated measures ANOVA with the factor EXO (WITHOUT & WITH) and factor technique (FREE, SQUAT & STOOP) was conducted.

3 Results and Discussion

A significant main effect of EXO was found in phases of forward bending (Fig. 2). Although some short significant episodes were found, no relevant main effects of or interaction with technique were found. Furthermore, the instant of peak support of Mrobo neither coincided with the instant of peak inclination, nor with the instant of peak M_{L5S1} (Fig. 3). The misalignment of the Mrobo peak and the inclination peak was due to performance limitations of the actuators. The difference between the inclination peak and loading peak is an inherent feature of lifting.

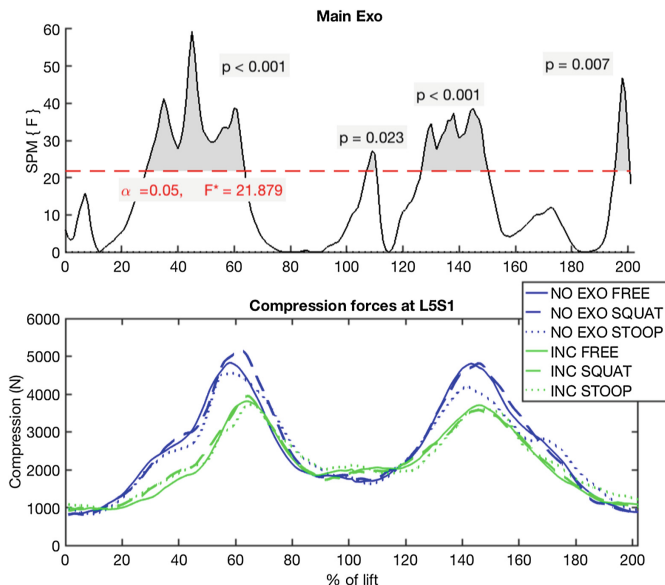


Fig. 2. SPM 1D output, showing the main effect of EXO, Technique and their interaction on spinal compression forces. Significant intervals are indicated with a grey area. Lower panel shows the mean spinal compression time series averaged over subjects for all conditions.

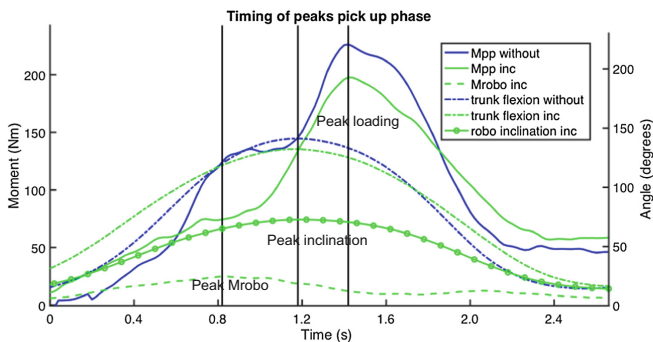


Fig. 3. Timing differences between the peak of the subject generated moment (Mpp) and trunk flexion for a FREE lift without and with (INC) EXO. For the WITH condition, also the peak of the support torque (Mrobo) and the inclination angle (Robo inclination) are shown.

4 Conclusion

The EXO with inclination-controlled torques substantially reduced compression forces at L5S1 during phases of forward bending. Peak compression decreased on average by around 20%, and this was largely independent of lifting technique. Apart from

generating larger moments, support could be improved by an improved control method that generates peak support at the instant of peak loading.

REFERENCES

1. Hartvigsen, J., et al.: What low back pain is and why we need to pay attention. *The Lancet* (2018)
2. Thiese, M.S., et al.: Prevalence of low back pain by anatomic location and intensity in an occupational population. *BMC Musculoskelet Disord* **15**(1), 283 (2014)
3. Coenen, P., et al.: The effect of lifting during work on low back pain: a health impact assessment based on a meta-analysis. *Occup. Environ. Med.* **71**(12), 871–877 (2014)
4. Eurofound, Trends in job quality in Europe. Publications Office of the European Union, Luxembourg (2012)
5. Toxiri, S., et al., *Rationale, Implementation and Evaluation of Assistive Strategies for an Active Back-Support Exoskeleton*. *Frontiers in Robotics and AI*, 2018. **5**(53): p
6. Kingma, I., et al.: Validation of a full body 3-D dynamic linked segment model. *Hum. Mov. Sci.* **15**(6), 833–860 (1996)
7. van Dieën, J.H.: Are recruitment patterns of the trunk musculature compatible with a synergy based on the maximization of endurance? *J. Biomech.* **30**(11–12), 1095–1100 (1997)
8. van Dieën, J.H., Kingma, I.: Effects of antagonistic co-contraction on differences between electromyography based and optimization based estimates of spinal forces. *Ergonomics* **48**(4), 411–426 (2005)