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*Published in:*
Program & Abstracts: 12th Annual Meeting of the Danish Society of Biomechanics.

*Publication date:*
2020

*Document Version*
Accepted author manuscript, peer reviewed version

# BIOMECHANICAL INVESTIGATION OF A PASSIVE UPPER EXTREMITY EXOSKELETON FOR MANUAL MATERIAL HANDLING – A COMPUTATIONAL PARAMETER STUDY

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## INTRODUCTION

Manual material handling (MMH) is a well-known risk factor for developing work-related musculoskeletal disorders (WMSD). Grocery work involves extensive MMH and is ranked within the top 25 occupations with the highest prevalence of WMSD with shoulder and lower back disorders accounting for approximatly 40% [1]. As a solution to protect workers, passive upper-extremity exoskeletons are increasingly being used to decrease the risk of developing WMSD. However, the current litterature is mostly limited to laboratory measurements. Therefore, we wanted to design a method to evaluate the biomechanical risk factors associated with using an exoskeleton based on inertial motion capture data of MMH performed in two supermarkets.

## METHODS

An inertial motion capture system, Xsens Awinda (Xsens Technologies BV, Enschede, The Netherlands) sampling at 60 Hz, was used to capture full-body kinematics of 15 grocery workers who lifted a bread-case (7.9 kg) onto shopping shelfs (145.5 cm). The kinematic data were used to drive a detailed human-exoskeleton model based on inverse dynamics, modelling the interaction between the human and external objects (i.e. exoskeleton, lifted object, and ground) (Figure 1). The detailed human-exoskeletal model was built in the AnyBody Modelling System v.7.2 (AnyBody Technology A/S, Aalborg, Denmark) and was based on the BVH_XSENS model template from the AnyBody Managed Model Repository v.2.3, which includes a method for predicting ground reaction forces and moments [2].

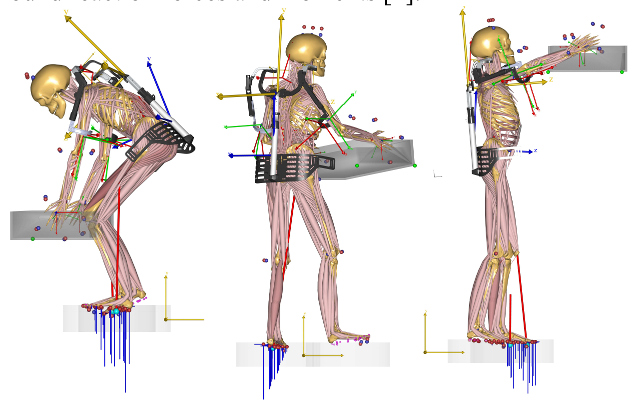

**Fig. 1** The manual material task performed by the detailed human-exoskeleton model.

The exoskeleton, ShoulderX_V3 (SuitX, USA), has control settings of the support by allowing changes to the arm elevation angles at which the torque occurs and the torque amplitudes themselves [3]. Different torque profiles were used to run a computational parameter study with five different support angles (60, 75, 90, 105 and 120°) and seven different support torque levels (No: no exoskeleton, 0: no torque, 1: 5.5 Nm, 2: 6.8 Nm, 3: 8.2 Nm, 4: 9.7 Nm and 5: 11.2 Nm). Dependent measures consisted of peak and impulse shoulder muscle force, and 3D spine and shoulder joint reaction forces. All peak forces were normalized to percentage of body weight (%BW) and impulse to %BW per second (BW·s).

## RESULTS AND DISCUSSION

Simulations of various settings revealed that working with the exoskeleton could have both positive and negative effects on musculoskeletal loading. Generally, simulations with maximum torque combined with a peak angle setting between 75-105° led to the highest reductions of L4-L5 compression and anterior-posterior shear forces, glenohumeral contact forces and shoulder flexor muscle forces (Figure 2). Contrarily, in some cases, inappropriate settings with maximum torque combined with peak angle settings of 60° led to additional musculoskeletal loading compared to not wearing the exoskeleton.

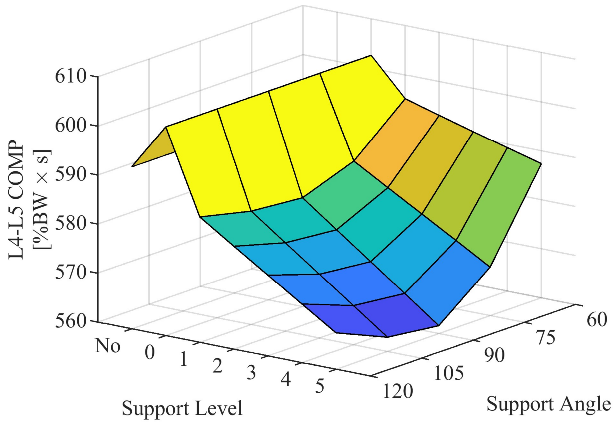


**Fig. 2** L4-L5 compression impulse presented as a function of variations in the support level and support angle of the exoskeleton.

## CONCLUSIONS

The passive exoskeleton appeared to be an efficient tool to potentially reduce work-related exposure during MMH. However, some support settings increased joint reaction forces, suggesting that not adjusting the exoskeleton properly could be detrimental to the protective effect of the device. Additionally, we demonstrated how musculoskeletal modelling can be a useful tool to evaluate exoskeletons during MMH based on field data.

## ACKNOWLEDGEMENTS

A special thanks to SuitX for providing us with the necessary CAD model of the ShoulderX_V3 exoskeleton.

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