

Estimating Lumbar Loading with Wearable Sensors over a Broad Range of Manual Lifting Tasks

Emily S Matijevich¹, Peter Volgyesi¹, Karl E. Zelik¹

¹Vanderbilt University, Nashville, TN, USA

Email: *emily.matijevich@vanderbilt.edu

Introduction

Low back pain is a disabling condition experienced by 60-85% of adults within their lifetime [1]. High and/or repetitive forces on lumbar muscles and discs are known to be major risk factors. There are numerous opportunities for reducing pain and overuse injury risk if the repetitive forces on the back could be easily monitored in daily life (e.g. via biofeedback).

Wearable sensors are an exciting tool for monitoring human movement non-invasively in daily life. However, there are many complex and intertwined questions involved in using wearable sensors to estimate musculoskeletal loading. The objective of this study was to estimate lumbar moment (torque about the L5/S1 joint) over time using wearable sensors for a diverse range of manual lifting tasks. Specifically, we 1) adapted a machine learning algorithm to estimate sagittal lumbar moment using wearable sensor signals and 2) identified a minimal set of sensor signals necessary for estimation.

Methods

This study involves participants each performing >300 manual lifting tasks in a motion analysis lab; one of the largest data sets of its kind. Here we summarize results from the first participant. Testing is ongoing and multi-subject results will be presented at the conference. Tasks covered a broad range of leaning, twisting, and lateral bending postures while moving boxes of 5-23 kg (Fig. 1). Full-body kinematics and ground reaction forces were collected. *Lab-based* lumbar moment was estimated using bottom-up inverse dynamics (M_{lumbar}), and was chosen as the target metric for this study due to its relation to lumbar muscle forces and resulting compressive spine force [2].

Inertial measurement unit (IMU) based kinematics (XSENS) and plantar pressures (Novel Pedar) were collected synchronously with lab-based data. These *wearable* data were normalized and used as feature inputs to a machine learning model to provide time-series *wearable* lumbar moment estimates (M'_{lumbar}). Wearable features were: lower limb and lumbar joint kinematics, and normal force and center of pressure under each foot. The regression model was built with Gradient Boosted Decision Trees [4] using 200 estimators. The dataset was divided so 85% of samples were used for model training and 15% were reserved for testing. The root mean squared (RMS) error was computed for this test set. Our target accuracy was 10% of the expected peak M_{lumbar} , or <35 Nm, a desired error used by other wearables [3]. The trained model also returns normalized feature importances, indicating how valuable each feature was in estimating lumbar moment.

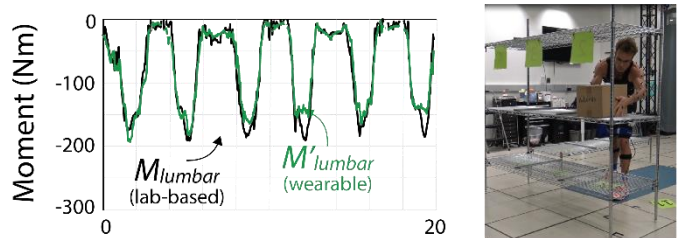
Results and Discussion

Our *wearable* algorithm estimated sagittal lumbar moment with average RMS error of 20 Nm. M_{lumbar} and M'_{lumbar} were strongly correlated ($r^2=0.9$). Thus this wearable algorithm distinguishes tasks of lower vs. higher lumbar moment (Fig. 1).

Model training identified four features as having a relative importance >5%. Retraining the model using only these key features yielded an RMS error of 21 Nm, a similar error to the

model using all the feature inputs. For reference, an error of 20 Nm in lumbar moment equates to ~0.5 bodyweights of error in compressive spine force using a single equivalent muscle approximation. It is promising that a wearable device embedded with just a small set of sensors could estimate sagittal lumbar moment with this accuracy across a broad range of manual lifting tasks.

A) Placing a 5kg box at 3 locations on a waist height shelf



B) Moving a 15kg box between the floor and a low shelf

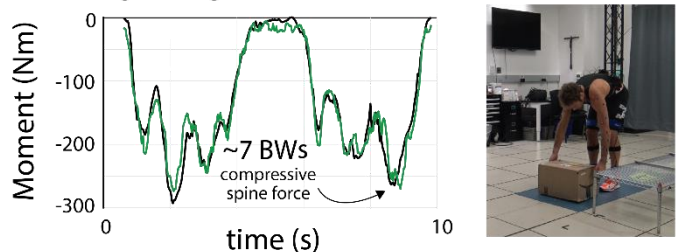


Figure 1: Lab-based (M_{lumbar}) and wearable algorithm (M'_{lumbar}) estimates of sagittal lumbar moment across two subsets (A, B) of the ~300 manual lifting tasks. Of note, subset (A) was part of the test set, and subset (B) was part of the model training set. BWs = bodyweights.

Significance

To the authors' knowledge, this is the first study to synchronously collect both lab-based and wearable kinematic and kinetic data over such a broad range of manual lifting tasks. Errors <21 Nm suggest wearable sensors can be used to estimate lumbar moments outside the lab environment, providing exciting opportunities for understanding lumbar spine loading and preventing low back pain and overuse injury risk.

Acknowledgments

Funding provided by NIH 1R01EB028105-01.

References

- [1] WHO. Priority diseases and reasons for inclusion: low back pain. (2013).
- [2] McGill & Cholewicki. Mechanical stability of the in vivo lumbar spine. *Clinical Biomechanics*. (1996).
- [3] Faber et al. Validation of a wearable system for 3D ambulatory L5/S1 moment. *J Biomechanics*. (2020).
- [4] Natekin, Alexey, and Alois Knoll. Gradient boosting machines, a tutorial. *Frontiers in neurorobotics* (2013).