Preliminary Investigation of External Load Prediction in Manual Material Handling

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Introduction

- Excessive physical workload resulting from prolonged manual work in awkward constrained postures and requiring high force exertions are known risk factors for musculoskeletal injuries.
- Wearable low-cost inertial sensors have strong potential for field-based ergonomics assessments.

Objective

- Develop algorithms for estimating external load and injury risk of work tasks using Inertial Sensor (IS)-derived body postural kinematics.
- The algorithms aim to leverage relationships between posture kinematics and external load demands in manual material handling.

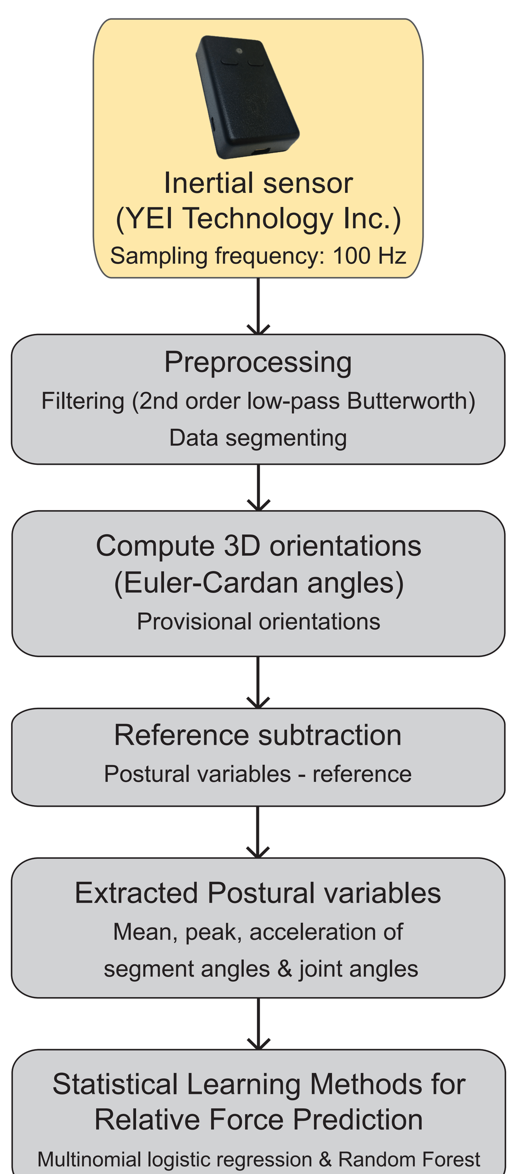
Methods

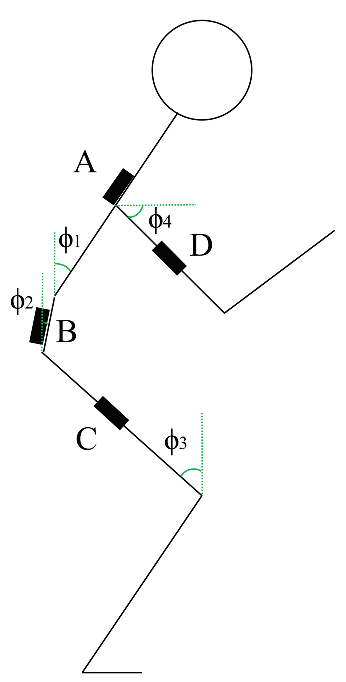
Participants: Fifteen healthy right-handed males (age: 23.9 ± 3.7)

Experimental Procedure

1. **Functional Capacity Assessment**
   - Demographic, health and handedness questionnaire
   - Static anthropometry measurements
   - Measurement of isometric maximum voluntary exertion (MVE) for Power grip, Low back lifting, and Two-handed horizontal push force
2. **Initial Sensors placement (Fig. 1)**
3. **Data collection in simulated work tasks**

Data Analysis Procedure





Segments
A. Torso
B. Pelvis
C. Thigh
D. Upper arm

Segment angle relative to the reference posture (T pose)

ϕ1, Torso flexion
ϕ2, Pelvis flexion
ϕ3, Right thigh inclination
ϕ4, Right upper arm inclination

Joint angle
ϕ1 - ϕ2, Lumbar flexion
180° - (ϕ2 – ϕ3), Hip flexion

Fig.1. Anatomical reference locations for the inertial sensors (black squares; T6, L5/S1, right thigh, right upper arm) placements on a participant and associated body & joint segment angles

External Load Prediction

Task Description

Task 1: Pushing

- Participants exerted a horizontal isometric push force on a height-adjustable handle instrumented with a 6 dof load cell
- Task goal: match a target force level for a 3s duration

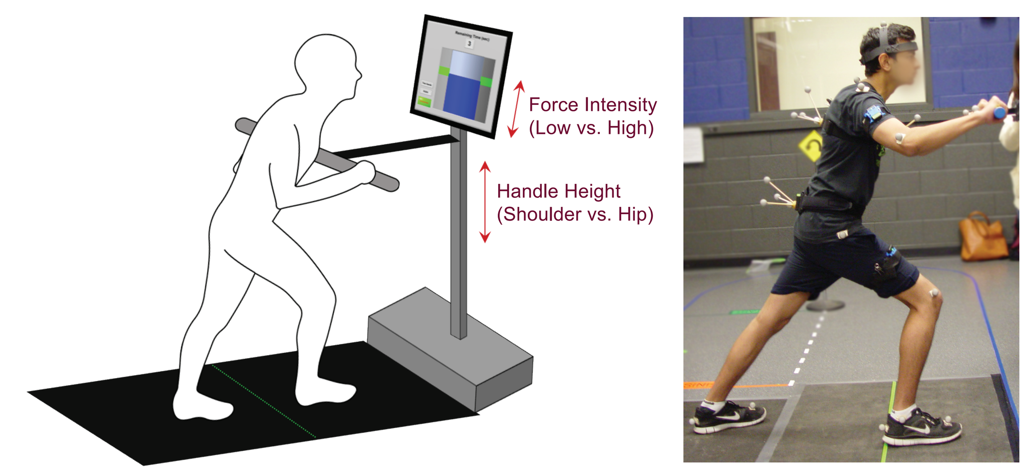


Fig. 2. Schematic representation of the experiment conditions (left) and participant performing a 2-handed pushing (right).

Task 2: Lowering

- Participants lifted and lowered a weighted box (3 levels: 20%, 30%, 40% of low-back MVE) using stoop (left) and squat (right) posture (Fig. 3), for 3 repetitions at a pre-assigned pace.

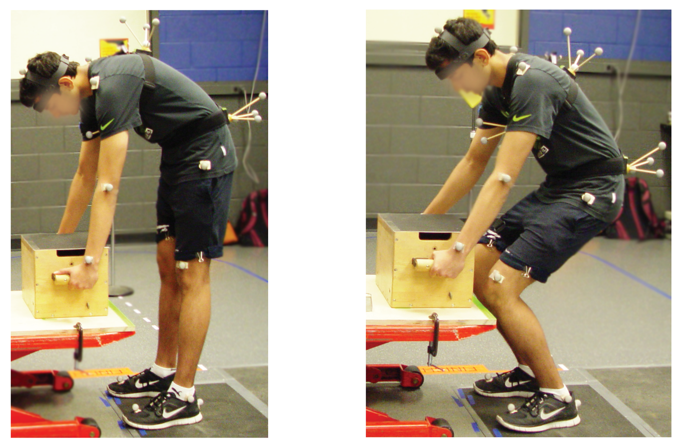


Fig. 3. Participants lowering a weighted box using stoop (left) & squat (right)

Task 3: Carrying

- Participants walked along the circular track (Fig. 4) carrying a loaded box (3 levels: no box, 20%, 30% MVE), for 2 repetitions at self- selected pace.

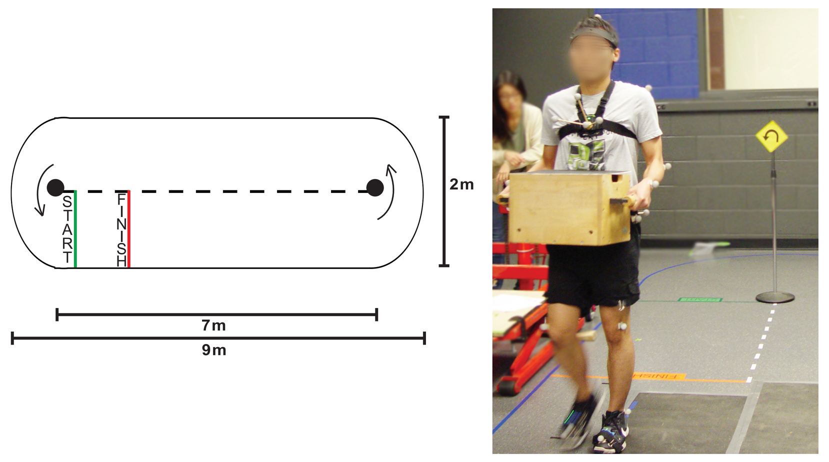


Fig. 4. Participants walking the circular track (left) with carrying a loaded box. The task involves turning and walking

Postural Variables

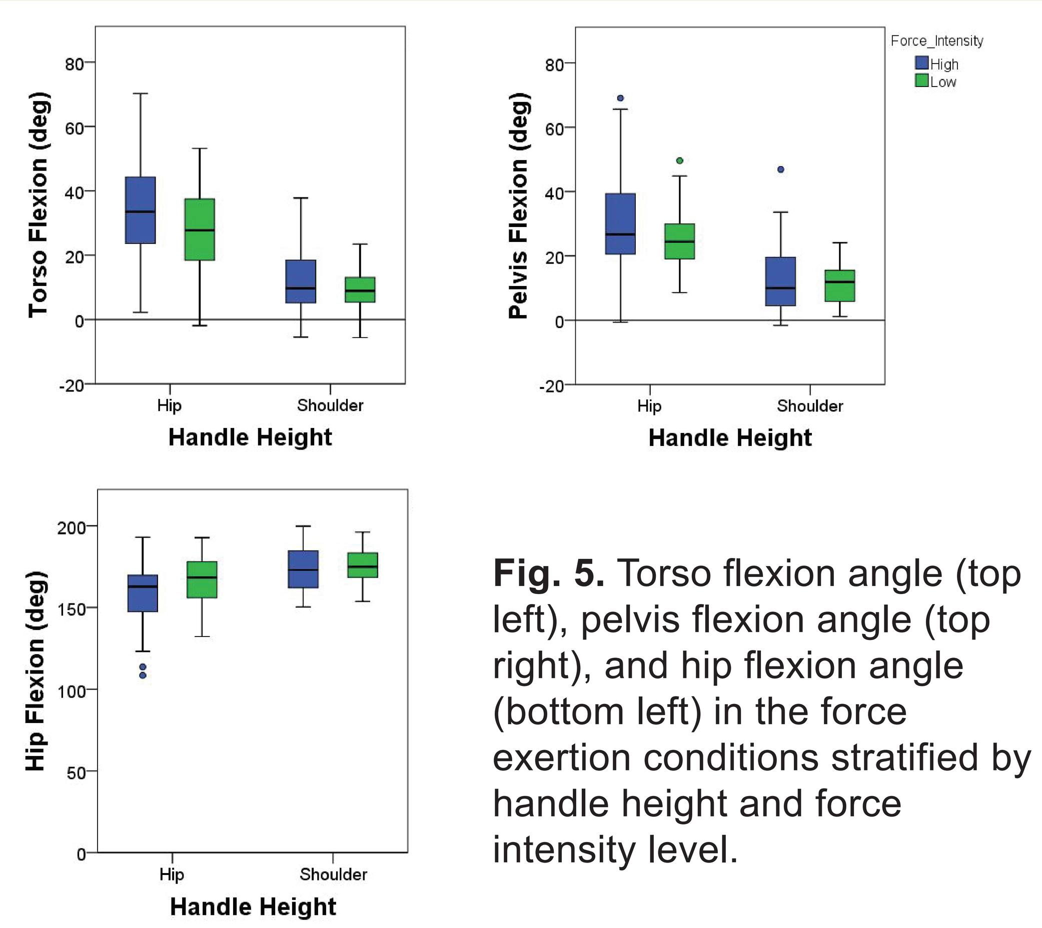


Fig. 5. Torso flexion angle (top left), pelvis flexion angle (top right), and hip flexion angle (bottom left) in the force exertion conditions stratified by handle height and force intensity level.

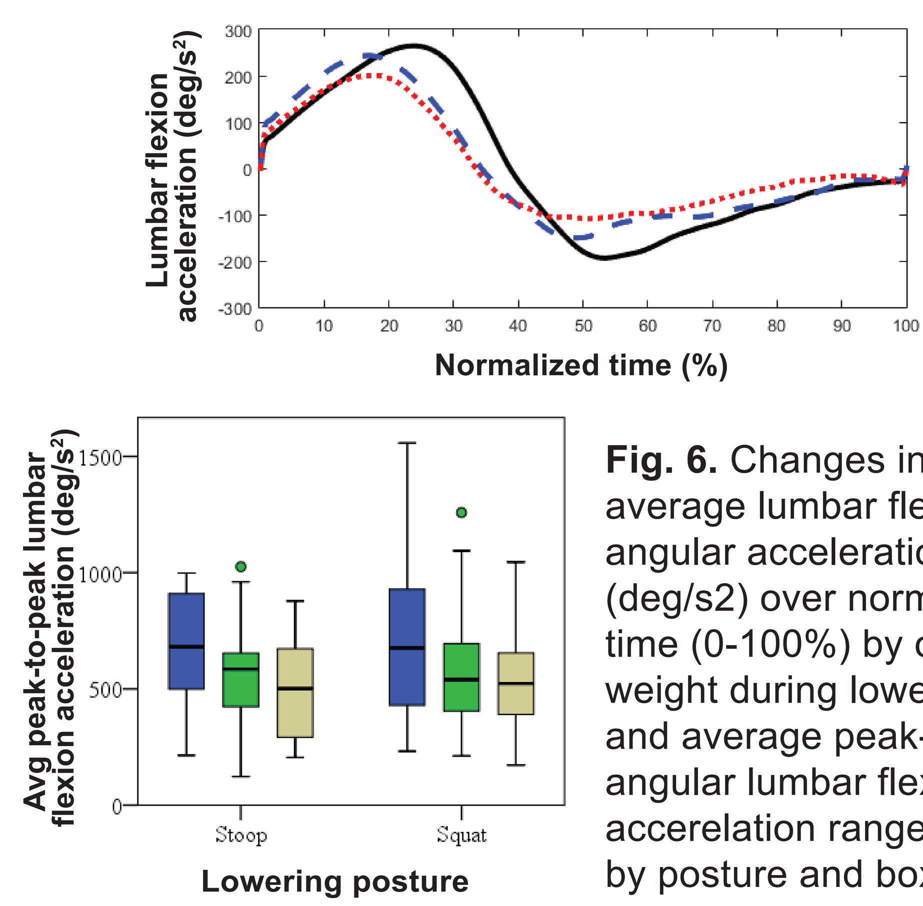


Fig. 6. Changes in the average lumbar flexion angular acceleration (deg/s2) over normalized time (0-100%) by object weight during lowering (left) and average peak-to-peak angular lumbar flexion acceleration range stratified by posture and box load.

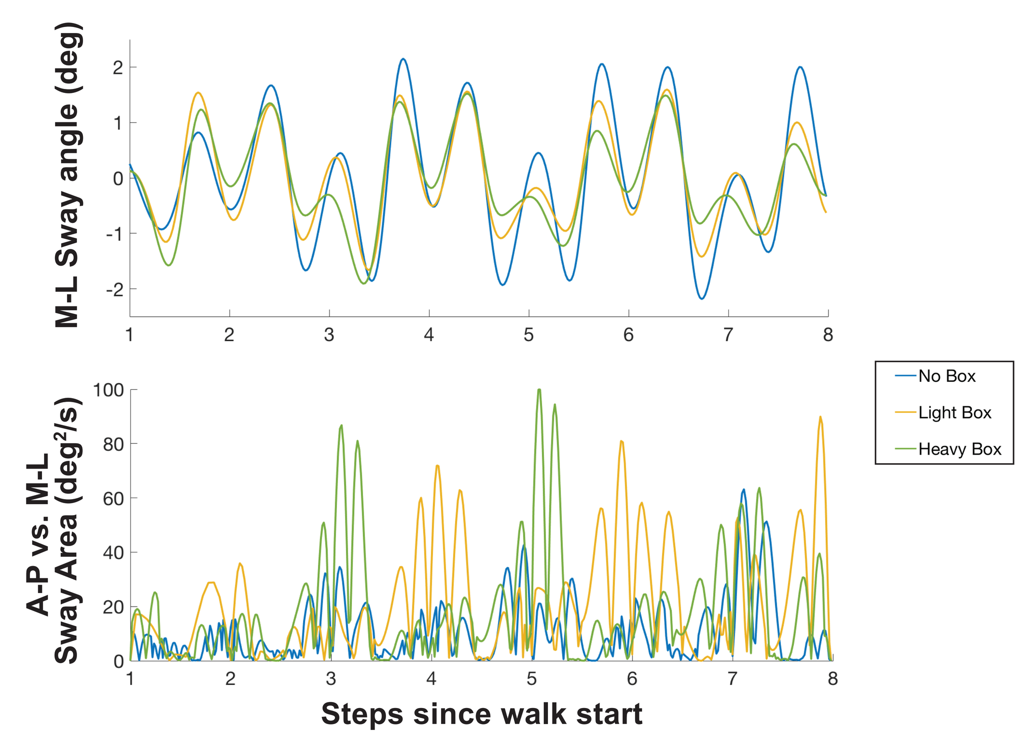
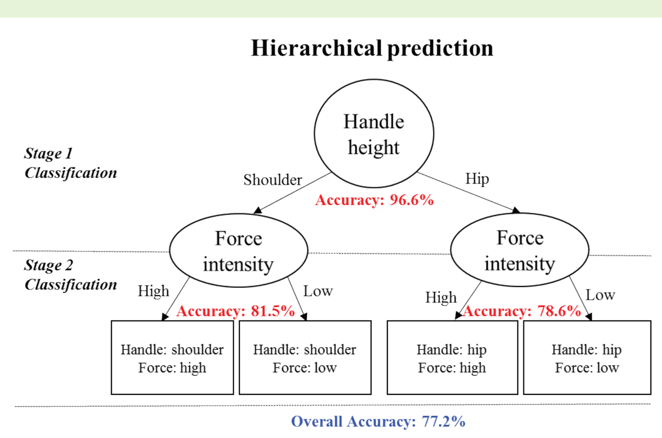


Fig. 7. Sample data showing the change in maximum medial-lateral (M-L) sway angle (left) and Anterior-posterior (A-P) vs. medial-lateral (M-L) sway area (right) by load.

External load Prediction (%)

Task 1: Pushing

- Goal: Predict handle height (shoulder vs. hip) and force intensity (high vs. low)
- Method: Random Forest
- Prediction accuracy: 77.2%



Task 2: Lowering

- Goal: Predict odds of High vs. Low load condition
- Method: Multinomial logistic regression

logit (P=High vs. Low) = -1.27 - 0.004∗*Lumbar angular accel range (Peak-to-Peak)* + 0.031∗*Max Torso Flexion*(θ) + 0.037∗*Max Thigh Flexion*(θ)

- Prediction accuracy: 65.6%; Sensitivity: 67.2%

Task 3: Carrying

- Goal: Predict the odds of No load, Low, Mid condition
- Method: Multinomial logistic regression

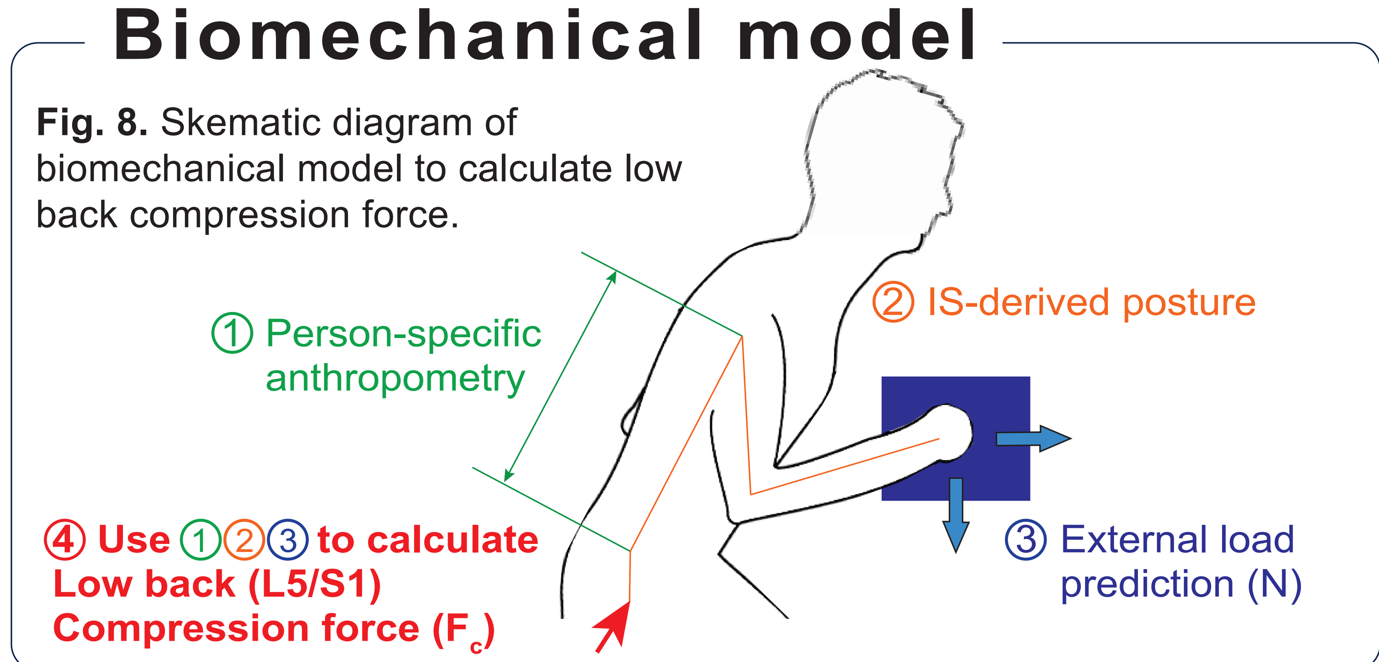
logit (P=Low vs. No load) = 37.53 - 5.86∗*Max A-P Sway*(T6, θ) - 13.42∗*Max M-L Sway*(T6,θ) - 15.74∗*Max M-L Sway*(L5/S1,θ) + 0.802∗*Sway Area*(T6,θ) + 0.519∗*Sway Area*(L5/S1,θ)

logit (P=Mid vs. No load) = 41.59 - 6.74∗*Max A-P Sway*(T6, θ) - 16.4∗*Max M-L Sway*(T6,θ) - 17.22∗*Max M-L Sway*(L5/S1,θ) + 0.962∗*Sway Area*(T6,θ) + 0.611∗*Sway Area*(L5/S1,θ)

- Prediction accuracy: 71.3%

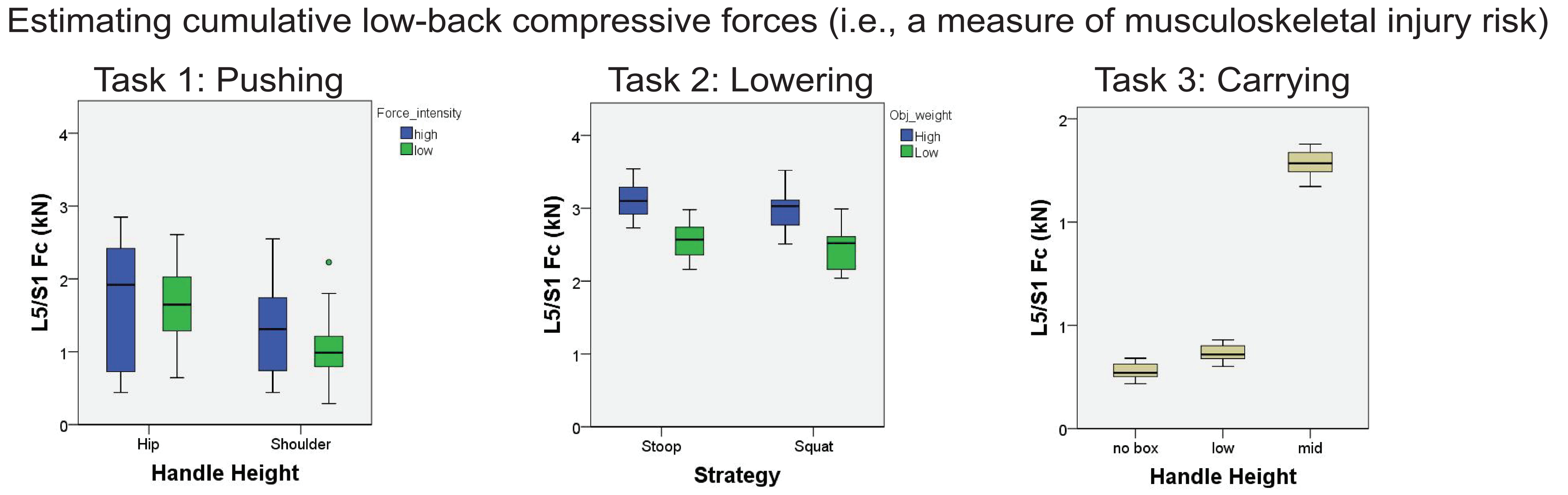
Biomechanical model

Fig. 8. Skematic diagram of biomechanical model to calculate low back compression force.



Risk Prediction

- Estimating cumulative low-back compressive forces (i.e., a measure of musculoskeletal injury risk)



Next Steps

- Increase sensor attachment locations to calculate shoulder, elbow, knee joint angles.
- Vary external load conditions to increase differences in kinematics between task conditions.
- Include person-specific covariates such as anthropometry and strength measures to improve model prediction.

Acknowledgements

This study was supported by the training grant T42 OH008455 from the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, and by National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR; grant # 90IF-0094-01-00).

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