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 each participant

2. Initial Sensors placement (Fig. 1)

3. Data collection in simulated work tasks

Data Analysis Procedure

- Preprocessing
  - Filtering (3rd order low-pass Butterworth)
  - Data segmenting

- Compute 3D orientations
  - Euler-Cartesian angles

- Reference subtraction
  - Postural variables - reference

Postural Variables

- Joint angle
  - θ₁: Torso flexion
  - θ₂: Pelvis flexion
  - θ₃: Right hip flexion
  - θ₄: Right upper arm inclination

- Segments angle relative to the reference posture (T pose)
  - A: Torso
  - B: Pelvis
  - C: Right hip flexion
  - D: Upper arm

- Specialized Learning Methods for Relative Force Prediction
  - Multinomial logistic regression
  - Random Forest

External Load Prediction

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

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.

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.

Goal: Predict handle height (shoulder vs. hip) and force intensity (high vs. low)

Method: Random Forest

- Prediction accuracy: 71.3%
- Sensitivity: 67.2%

Extrinsic load prediction (%)

- Peak force on the handle

Risk Prediction

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

Risk prediction (N)

- Task 1: Pushing
- Task 2: Lowering
- Task 3: Carrying

Next Steps

- Include person-specific covariates such as anthropometry and strength measures to improve model prediction.

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

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

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

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

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.

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

Fig. 9. Use IS-derived posture to calculate low back compression force...

Fig. 10. Use IS-derived posture to calculate external load prediction (N)