Top-down estimation of joint moments during manual lifting using inertial sensors

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1. Introduction

L5/S1 moments during manual lifting tasks have often been assessed in the laboratory either from a bottom-up approach, that is using one or more force plates measuring ground reaction forces (GRFs) and an optoelectronic system measuring positions and orientations of lower body segments up to L5/S1 joint (e.g. Plamondon et al., 2010), or from a top-down approach, that is using an instrumented box to measure hand forces and an optoelectronic system measuring positions and orientations of upper body segments and trunk down to L5/S1 joint. The usability of such systems for field measurements is limited by the restricted measurement volume of the optoelectronic system and the constraints imposed by the force plates. As a possible alternative, the use of inertial sensors for measuring segment kinematics combined with instrumented shoes to measure GRFs has been proposed (Faber et al., 2010), but has not been evaluated. However, a bottom-up approach using inertial sensors with force plates has been evaluated for lifting tasks, and a top-down approach for a carrying task with limited trunk motion (Kim and Nussbaum, 2013). To the authors' knowledge, however, use of a top-down approach with inertial sensors has yet to be evaluated for a lifting-lowering task.

This study thus aimed to assess the ability of a top-down approach using inertial sensors in conjunction with an instrumented box to measure hand forces for the quantification of the L5/S1 joint moment in a lifting-lowering task. Results of this study are intended to contribute to the development of a method based on inertial sensors for assessing manual materials handling tasks in the field.

2. Methods

2.1 Participants

A convenience sample of 6 participants (3 males and 3 females) was recruited from the local community; means (SD: Range) of age, stature and body mass were 24.2 (3.3: 21–30) yrs, 1.742 (0.078: 1.64–1.86) m, and 67.4 (6.5: 58–75) kg, respectively. All participants reported being physically active and with no musculoskeletal disorders within the past year. Informed consent was provided using procedures approved by the Ethics Committee of research on humans of Université de Sherbrooke.

2.2 Task

The task consisted in lifting/lowering/transferring the box between three shelves (A: 5 cm high, B 120 cm high; C: 5 cm high) separated by 1.2 m. One trial involved six actions: 1) lifting toward their right (from A to B); 2) lowering toward their right (from B to C); 3) lifting toward their left (from C to B); 4) lowering toward their left (from B to A); 5) transferring toward their right (A to C); 6) transferring toward their left (from C to A). Between each action, the participant had to adopt a standing posture. Each trial was repeated six times and one-minute rest was granted between each trial. These six trials were performed with a 9-kg box as well as with an 18-kg box. A five minute rest was granted between the two series of trials.

2.3 Models

A bottom-up approach (Plamondon et al. 2010) using an optoelectronic system to determine lower body segments' kinematics as well as three force plates (AMTI, Watertown, MA, USA) to measure ground reaction forces were used to estimate the L5/S1 joint moment. These L5/S1 joint moments served as the criterion measure.

The top-down approach that we aimed to assess, used six inertial sensors (lower and upper arms, upper trunk and pelvis) as well as a hand force measuring system (Kistler group, Winterthur, Switzerland) fixed on a box to measure three orthogonal forces at each hand. This model had 5 segments: both forearms (including hand), both arms, along with a trunk segment (including the neck and head). A segment-to-sensor calibration procedure (Luinge et al. 2007) was used for defining each segment coordinate system. Segment lengths were measured directly using a tape measure. Segmental inertial parameters were based on Dumas et al. (2007).

2.4 Analysis

To assess the correspondence between the L5/S1 joint moments time series of each trial obtained from the top-down model versus those from the bottom-up model (gold standard), two comparative measures were determined: the coefficient of determination (R^2) and the root mean square error (RMSE).

3. Results

RMSE for the L5/S1 joint moments were of 14.7 and 14.7 Nm about the sagittal axis (Mx), of 7.3 and 9.7 Nm about the longitudinal axis (My), and of 19.9 and 21.1 Nm about the transverse axis (Mz), for the 9-kg box and the 18-kg box, respectively. As for the coefficient of determination (R^2), they varied from 0.51 about the longitudinal axis up to 0.97 about the transverse axis.

4. Discussion

Relative to peak joint moments from the bottom-up model, the top-down model resulted in errors up to 30, 24 and 9%, about the longitudinal, sagittal and transverse axis respectively. This compares favourably to previously reported errors of ~ 38, 24 and 14% by Kim and Nussbaum (2013) and to ~ 15% reported by Faber et al. (2010) using orientation data from an optoelectronic system to simulate inertial sensors in a bottom-up model. Overall, the results of this study show that a top-down approach using inertial sensors demonstrates a reasonable capacity for estimating L5/S1 joint moment in manual material handling.

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