2021-01-01

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Extended Abstract from 21st Triennial Congress of the International Ergonomics Association, Vancouver, June 13 – 18, 2021

BACK LOADING ASSESSMENT DURING MANUAL MATERIAL HANDLING WITH INERTIAL MOTION CAPTURE: A PILOT STUDY

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SUMMATIVE STATEMENT
Back loading was estimated during manual material handling (MMH) tasks only based on inertial motion capture. On average for all tasks on one subject, the L5/S1 moment errors were about 12 Nm for flexion and 7 Nm asymmetrically.

KEYWORDS: L5/S1 joint moment; lifting; inverse dynamics; ground reaction forces; inertial measurement unit.

PROBLEM STATEMENT
Magnetic and inertial measurement units (MIMUs) are portable, which allow ergonomic workplace assessment. MIMUs kinematics have been extensively validated in the laboratory. However, physical exposure indicators based on kinetic variables such as back loading represent valuable information during ergonomic assessment. A contact model for feet and hands during manual material handling (MMH) tasks could help to estimate kinetic variables from inertial motion capture system (IMC) on the basis of dynamics equations (Muller et al., 2020a). This approach has been used to assess MMH tasks, but either using standardized tasks or optical motion capture (OMC) (Muller et al., 2020b).

RESEARCH OBJECTIVE/QUESTION
The aim of the current work was to estimate back loading during MMH tasks only with MIMUs. The evaluation consists in comparing L5/S1 joint moments estimated with IMC to those obtained with OMC and a force platform (OMC + FP).

METHODS
Motion analysis was performed simultaneously with IMC and OMC on one male subject. The IMC system is composed of 17 MIMUs sampled at 240 Hz. Eight cameras recorded at 40 Hz the 3-D coordinates of four-marker clusters rigidly fixed on each MIMU. 48 anatomical landmarks were identified. The ground reaction forces (GRF) were measured by a large homemade force platform. The tasks consisted in transferring boxes from a lifting to a deposit location, 1.5 m apart. Three masses (2, 10 and 20 kg) and three heights for the lifting and deposit location (16, 116 and 190 cm) allowed to simulate a large variety of MMH tasks for a total of 36 boxes transferred.
The OMC biomechanical model was composed of 18 rigid segments linked by 17 joints corresponding to 43 degrees of freedom. The geometrical parameters were subject-specific calibrated using motion capture data and an optimization-based method. From the positions of the anatomical landmarks the joint coordinates were computed in an inverse kinematics step. An inverse dynamics step was then performed to obtain L5/S1 joint moments. The measured GRF were used in a recursive Newton-Euler algorithm with a bottom-up approach. The velocities and the accelerations were computed with a 2-order finite-difference method.
Data from MIMU were processed with MVN Analyze, which integrates a sensor fusion algorithm. The joint coordinates and the biomechanical model were extracted from this software. The IMC biomechanical model was composed of 23 rigid segments where each joint is assimilated to a spherical joint. For both models, body segment inertial parameters were

estimated from an anthropometric table. The external forces were estimated by using a prediction method (Muller et al., 2020a). To map the contact area, 8 points under each foot and 8 points on each hand were defined.
Four phases were manually identified with video recordings: pre-grip, transfer, post-deposit and return. During the pre-grip, post-deposit and return phases, only external forces applied on the feet were considered, while hand contacts were also considered during the transfer phase. At each instant, prediction of the external forces and moments was performed through an optimization procedure that consisted of minimizing the sum of squared contact forces respecting the dynamics equations applied on the subject (all phases) and applied on the load (only during the transfer phase). An inverse dynamics step was then performed to obtain L5/S1 joint moments. The predicted GRF were used in a recursive Newton-Euler algorithm with a bottom-up approach. The velocities and the accelerations were computed with a 2-order finite-difference method. Only the transfer and the return phases were analysed. L5/S1 joint moments between OMC+FP and IMC were compared with the RMSE, relative RMSE (rRMSE) and Pearson correlation coefficient (r). L5/S1 asymmetric moment was computed as the combination of the lateral flexion and twist components.

RESULTS

The comparison between L5/S1 joint moments estimated with OMC+FP and IMC showed RMSE of 12.6 Nm and 7.0 Nm, rRMSE of 7.8% and 12.8% and r of 0.88 and 0.6 respectively in flexion and in asymmetry.

DISCUSSION

The mean error in the flexion moment estimation is higher than for the asymmetric moment but since the amplitude of the moment is the most important along this axis, the relative error is lower. On simpler tasks of trunk bending (Faber et al., 2016), the use of MIMU allowed to estimate L5/S1 joint flexion and symmetric moments
with an error below 10 Nm. On similar tasks (Muller et al., 2020b), errors of the same magnitude of 14 Nm for flexion and 9 Nm for asymmetric moments were reported with OMC. Further validation on a larger cohort with different anthropometries is warranted. Moreover, the use of MIMUs could be sensitive to magnetic disturbances which can be particularly present in the workplace.

CONCLUSIONS

The proposed method seems promising since it allows the estimation of the L5/S1 joint moments with a limited error by using only IMC under a variety of experimental conditions. A complete ergonomic assessment of MMH tasks could be achieved outside the laboratory, directly in the workplace.

ACKNOWLEDGEMENTS

Partial funding for this project was obtained from IRSST [grant #2017-0019] and its scholarship programs, and Mitacs Acceleration program. The authors are grateful to Christian Larue for his help during the development of the experimental protocol.

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