XVII International Symposium on Computer Simulation in Biomechanics
July 28th – 30th 2019, Alberta, Canada

ESTIMATION OF SPINAL LOADING DURING MANUAL MATERIALS HANDLING USING ONLY INERTIAL MOTION CAPTURE AND PREDICTED GROUND REACTION FORCES

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INTRODUCTION

Manual materials handling (MMH) is the most well-documented cause of work-related back disorders [1]. MMH tasks, such as lifting, imposes compression and shear forces on the spine, which can cause damage to the vertebras, intervertebral discs and spinal ligaments among other things [2]. However, the assessment of spinal loads *in vivo* is challenging and invasive, which has led to the development of computational models able to estimate these forces based on inverse dynamics (ID) [3]. Traditionally, ID models have relied on input data from laboratory-based systems, such as optical motion capture (OMC) and floor-mounted force plates (FP), but recent advances in inertial motion capture (IMC) and ground reaction force (GRF) prediction [4] has enabled the acquisition of these input data outside a laboratory setting. However, it has yet to be evaluated whether this methodology can be used to estimate spinal loads during MMH with a similar accuracy as the traditional approach. Therefore, the aim of this study was to evaluate an ID musculoskeletal model driven exclusively using IMC and ground reaction force prediction for estimating L4-L5 spinal loads during MMH by comparing it with a model driven by OMC and FP data.

METHODS

Thirteen healthy subjects volunteered to participate in the study and provided written informed consent. The experimental procedures included several lifting and transferring tasks with varying loads of which symmetrical (SYM) and asymmetrical lifting (ASYM) of a 10 kg box are presented here. To evaluate the IMC-based model, motion analysis was performed using the IMC and OMC system simultaneously. The IMC system consisted of the Xsens MVN Awinda wireless motion-tracker (Xsens Tech., The Netherlands), while the OMC system consisted of 42 reflective markers, 8 infrared cameras (Qualisys, Sweden) and 3 FPs (AMTI, US).

From the laboratory measurements, three musculoskeletal models were developed: 1) OMC and measured GRFs (OMC-MGRF), 2) OMC and predicted GRFs (OMC-PGRF) and 3) IMC and predicted GRFs (IMC-PGRF). The models were developed in the AnyBody Modeling System v. 7.1 (AnyBody Tech., Denmark) based on templates from the AnyBody Managed Model Repository v. 2.1. The model templates were identical, except for how the different input data were implemented for scaling and marker tracking (see Skals et al. [5] for further details). The muscles were modeled without contraction dynamics and their strength determined from the physiological cross-sectional area and a mass-fat scaling law, while the muscle forces were distributed by solving a third-order polynomial optimization problem. The GRFs were predicted for the IMC-PGRF and OMC-PGRF models using a method first presented in Fluit et al. [6], and further developed and validated in Skals et al. [7] and Karatsidis et al. [4]. 25 dynamic contact elements were attached under each foot of the musculoskeletal models, each able to generate a positive normal force as well as positive and negative static friction forces. The actuation of each contact element was determined by a threshold distance and velocity in relation to the ground plane, and was solved as part of the muscle recruitment algorithm.

Pearson's *r*, root-mean-square error (RMSE) and relative RMSE (rRMSE) were computed to determine the slope and magnitude differences for the following variables: erector spinae (ER) muscle force, L4-L5 axial compression (AC), anteroposterior (AP) shear and mediolateral (ML) shear force, and the vertical GRF for the right and left foot. All forces are expressed as percentage of bodyweight (%BW).

Results and Discussion

Time-series curves of the selected variables are depicted in Fig. 1 and the statistical computations listed in Table 1. The comparison of the OMC-MGRF and OMC-PGRF models is shown in the figure, but has been omitted from the table and will not be discussed further here. Overall, strong ($r \geq 0.68$) to excellent ($r \geq 0.90$) correlations were found for all analyzed variables with the exception of the ML force during both SYM and ASYM. Furthermore, with the exception of the shear forces, the magnitude errors were generally low, ranging from 21.4% to 28.8% for SYM and 14.7% to 24.9% for ASYM. However, discrepancies were identified for the AP force in the initial phase of lifting as well as the ML force during the end of the ASYM cycle (see Fig. 1).

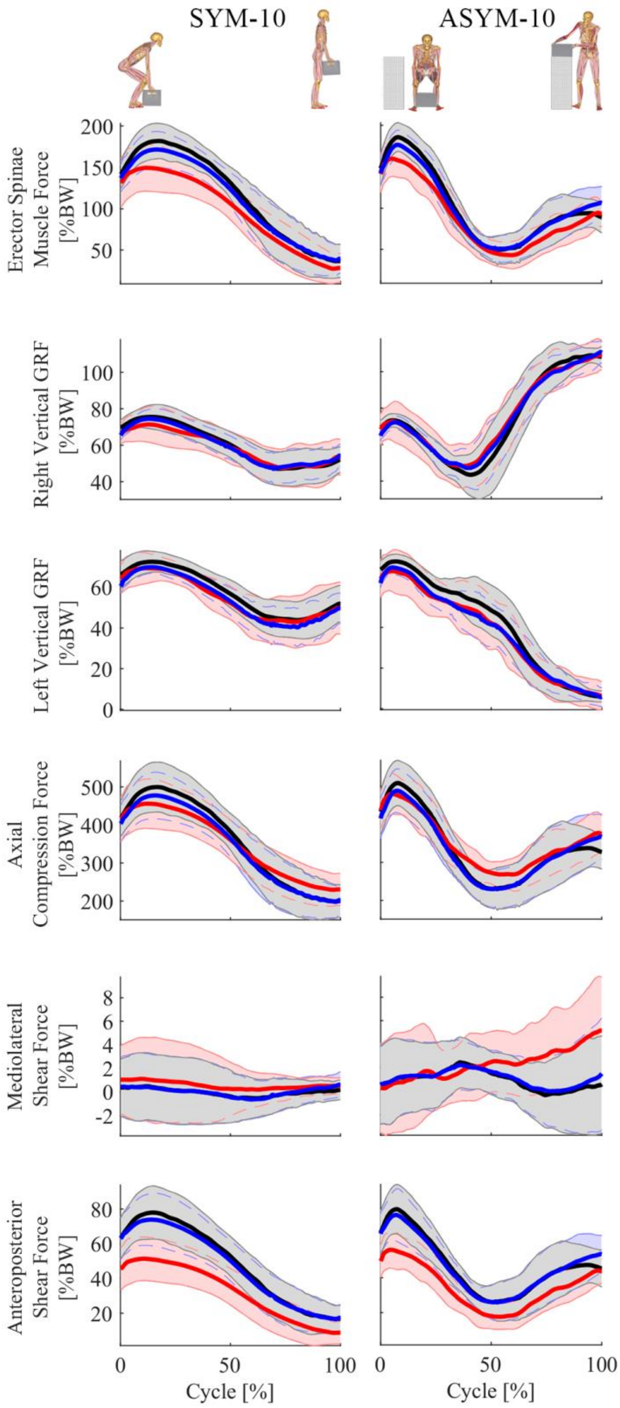

Fig 1: Mean forces (solid line) ± 1 SD (shaded area) for the OMC-MGRF (blue), OMC-PGRF (black) and IMC-PGRF (red) models during SYM and ASYM of a 10 kg box.

Table 1. Pearson's *r*, RMSE and rRMSE for the selected forces during SYM and ASYM of a 10 kg box.

	r	RMSE (%BW)	rRMSE (%)
SYM-10			
ER force	0.98	26.7 ± 12.3	23.3 ± 13.4
R-GRF	0.84	7.5 ± 3.2	28.8 ± 20.9
L-GRF	0.94	6.6 ± 3.0	21.4 ± 9.5
L4-L5 AC	0.99	66.9 ± 33.9	28.7 ± 12.2
L4-L5 ML	0.23	2.4 ± 1.5	78.5 ± 38.2
L4-L5 AP	0.99	18.9 ± 10.7	46.2 ± 29.4
ASYM-10			
ER force	0.96	20.8 ± 8.8	17.6 ± 9.5
R-GRF	0.97	10.1 ± 3.5	14.7 ± 5.4
L-GRF	0.98	9.6 ± 4.8	16.0 ± 11.0
L4-L5 AC	0.95	57.2 ± 31.1	24.9 ± 14.5
L4-L5 ML	0.17	4.0 ± 1.8	63.2 ± 27.2
L4-L5 AP	0.92	14.4 ± 8.3	36.6 ± 28.9

For the first time, the present study evaluated the predicted GRFs of an IMC-based model during MMH. The results were encouraging, showing low slope and magnitude differences for both the right and left foot, despite there being several closed kinematic chains involved in the tasks. Likewise, the ER and L4-L5 AC forces were comparable to those of the OMC-MGRF model during both SYM and ASYM. The results for the L4-L5 AC force are particularly valuable, as this is one of the most widely used variables to assess the risk of back injury during MMH. However, the model underestimated the AP force, particularly near maximal trunk flexion, as well as the ML force near maximal trunk rotation. Therefore, the model is not currently suitable for estimating the absolute shear forces in the spine during MMH tasks involving large trunk flexions and rotations.

CONCLUSIONS

This study showed that the IMC-PGRF model can be used to estimate L4-L5 AC forces during SYM and ASYM lifting with a reasonable accuracy, providing new, valuable opportunities for dynamic analysis of MMH in the field.

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