ESTIMATION OF GROUND REACTION FORCES AND JOINT MOMENTS DURING STOP JUMPING FROM SMARTPHONE-BASED MARKERLESS MOTION CAPTURE WITH BI-LSTM MODEL

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Summary

This study aimed to develop a model for estimating three-dimensional ground reaction forces (GRFs) and lower limb joint moments during stop-jumping tasks to facilitate biomechanical analysis. Data were collected from 21 male athletes using marker-based motion capture, force plates, and markerless motion capture systems. A deep learning model employing a bidirectional long short-term memory (BI-LSTM) architecture with two layers was implemented. The model demonstrated the highest accuracy for predicting vertical GRF and sagittal plane joint moments but moderate accuracy for non-sagittal joint moments.

Introduction

Stop-jumps are associated with the risk of injuries, especially anterior cruciate ligament injuries. Biomechanical parameters such as ground reaction forces (GRFs) and joint moments are vital for identifying injury risk factors [1]. While marker-based 3D motion capture systems (MB) and force plates provide high accuracy for joint moments calculation, their use is constrained by laboratory settings. Recent advancements in markless motion capture (MMC) and deep learning have created opportunities to predict GRFs and joint moments without MB and force plates. However, the application of these techniques to stop-jumps remains largely unexplored. This study addresses this gap by employing MMC combined with a BI-LSTM deep learning model to estimate GRFs and joint moments during stop-jumps, aiming to boost the efficiency and accuracy of out-lab biomechanical analysis.

Methods

Data were collected from 21 recreational male athletes (aged 26.86 ± 9.03 years) performing stop-jump tasks using MB, 3D force plates, and MMC (OpenCap) systems. Joint angles and body weight-normalized joint moments for the hip, knee, and ankle were calculated using inverse kinematics and inverse dynamics in Visual3D. To align marker-based and MMC system, the time-series around peak knee flexion angles were identified, and the region of highest curve correlation between the two systems was used for synchronization. The dataset was divided into training (60%), validation (20%), and testing (20%) subsets. Visual3D outputs served as the ground truth, while the inputs to the model included 20 kinematic features extracted from OpenCap and anthropometric parameters (height and weight). A deep learning model was developed. The model consists of two layers of BI-LSTM units, each containing 128 hidden units with linear activation functions. It generates 12-dimensional outputs, which include 3D GRFs and joint moments for the hip, knee, and ankle joints.

Results and Discussion

The BI-LSTM model demonstrated robust performance in predicting 3D GRFs and joint moments during stop-jumps. Predictions for vGRF exhibited the highest accuracy ($r = 0.900 \pm 0.075$), whereas anterior-posterior ($r = 0.883 \pm 0.074$) and medial-lateral ($r = 0.820 \pm 0.136$) GRF components showed more variability. Sagittal plane moment predictions ($r = 0.846 \sim 0.934$) showed strong correlations, while non-sagittal moment predictions ($r = 0.291 \sim 0.778$) showed moderate accuracy. The model performed better during the take-off phase than the landing phase.

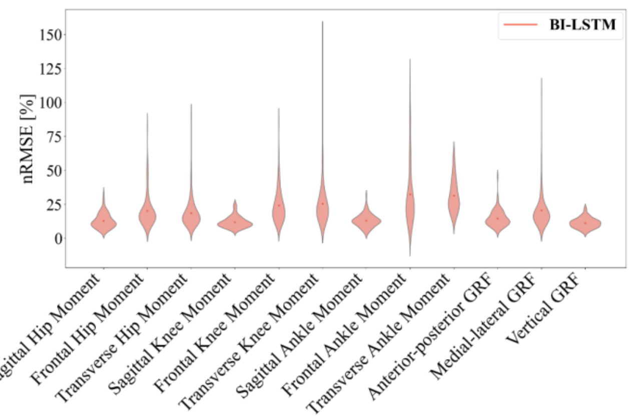

Figure 1: Violin plots of nRMSE for ground reaction forces and joint moments. Data range is shown by the height, density by the width, and the mean by points.

Conclusions

The developed BI-LSTM model exhibited promising performance in predicting 3D GRFs and joint moments during the landing and take-off phases of the stop-jump task, achieving a relatively high level of accuracy. Nevertheless, further optimization and refinement are necessary to reach the precision required by out-lab biomechanical analysis.

References

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