Concurrent Validation of Markered and Markerless Motion Capture During Load Carriage in OpenSim

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Summary

Marker-based (MB) motion capture (MoCap) is common in biomechanics, but it is not well suited for military applications since equipment obstructs markers. Markerless (ML) MoCap is an alternative for analysing participants wearing bulky equipment, but validating the system is a challenge without ground truth measurements and differences to the MB system: systematic errors and kinematic discrepancies. This study evaluates the use of virtual markers (ML-VMs) in ML data to reduce error between ML and MB MoCap. The error in lower limb joint angles (JAs) and joint reaction forces (JRFs) between MB and two methods for ML data were compared: ML-A, which used angles and joint centers (JCs) output by Theia3D, and ML-VM. Results showed that JA and JRF agreement between MB and ML methods generally improved when using ML-VMs versus ML-A. ML-VMs also reduced residuals in the ML model.

Introduction

Advancements in protective equipment increase soldiers' survivability, but increased body-borne loads can increase the risk of injury [1,2]. ML MoCap is a promising solution for analysing the biomechanical impact of these loads but validating ML using MB systems is challenging. ML data can be used within musculoskeletal modeling platforms such as OpenSim by directly inputting JAs and JCs obtained from Theia3D [3], but differences in kinematic models can affect the results [4]. This study added ML-VMs on each segment that were tracked in OpenSim to determine JAs and JRFs. We hypothesized that using ML-VMs to determine kinematics in OpenSim will improve agreement between MB and ML systems when compared to directly using JAs and JCs.

Methods

The data of 16 participants walking and running over six meters were used in this study. Both dynamic movements were performed three times each under four increasing loading conditions: C1) 5 kg (boots, helmet), C2) 21 kg (C1+ vests), C3) 35 kg (C2 + 14 kg pack), and C4) 41 kg (C2 + 20 kg rucksack) [3]. The data were collected using two Bertec force plates in combination with Vicon Vantage V5 cameras and Vicon Vue cameras for MB and ML, respectively. Theia3D was used to obtain the location of ML Jas as well as JCs. ML data were then inputted to OpenSim using two methods: ML-A, where JCs and JAs from Theia's kinematic model were the input, and ML-VM where three virtual markers on each segment, offset in x-, y-, and z-axes, were the input. After, JAs and JRFs were determined in OpenSim. For the JRFs, the Euclidean norm was used to determine magnitude. The results from the ML-A and ML-VM methods were compared to MB with root mean square error (RMSE).

Results and Discussion

Table 1 presents the RMSE of the JAs and JRFs for ML-A and ML-VM data compared to MB, averaged across all participants and conditions, along with the mean force residuals and angle adjustments from OpenSim's Residual Reduction Algorithm.

Table 1. RMSEs and Residuals for Walking and Running Trials.

Joint	Ankle		Knee		Hip	
Methods	ML-A	ML-VM	ML-A	ML-VM	ML-A	ML-VM
Joint Angle RMSE [Degrees]						
Walk	5.2	5.3	8.7	6.3	11.1	9.2
Run	5.6	5.6	6.8	5.2	12.1	9.7
Angle Adjustments [Degrees]						
Walk	1.2	1.0	0.7	0.6	0.6	0.4
Run	1.9	1.8	0.9	0.8	0.8	0.6
Joint Reaction force RMSE [Newtons]						
Walk	264.4	359.4	196.7	184.1	222.8	166.4
Run	256.3	332.2	385.2	309.2	313.9	218.4
JRF Residuals [% BW]						
	Fx ML-A	Fx ML-VM	Fy ML-A	Fy ML-VM	Fz ML-A	Fz ML-VM
Walk	1.5	1.8	1.2	0.9	1.6	1.6
Run	1.2	1.5	0.8	0.7	1.4	1.2

The comparison of MB data with ML-A and ML-VM data showed that ML-VMs improved agreement to MB MoCap for JAs, especially at the knee and hip joints. At the ankle, RMSE was similar across methods. For JRFs, ML-VMs did not consistently reduce error, and while agreement improved at the hip and the knee, the ML-VMs resulted in decreased agreement at the ankle. For angle adjustments and residuals, the ML-VMs largely resulted in decreases across both.

Conclusions

This study highlights a new method for importing ML data to OpenSim and how it influences the results. These findings demonstrate that using ML-VMs generally enhances JA agreement with MB, but that it has mixed effects on JRF agreement, depending on the joint analysed. ML-VMs also demonstrate lower residuals, which indicates decreased discrepancies between kinematic and kinetic data for the ML model than when inputting the ML-As into OpenSim.

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References

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