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Ground reaction force estimation in football using inertial measurement units during alternate lateral bounding

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Introduction

Ground reaction force (GRF) is of interest to understand the mechanics of football shoe-surface interactions and the consequences for athletic performance (Luo & Stefanyshyn, 2011; Pedroza *et al.* 2010). Force platforms (FP) are the gold standard for measuring GRF; however, they are expensive devices, athletes may adjust their movements to target a specific area and installation is difficult outside the laboratory under football specific surfaces. Potential candidates to overcome these limitations and estimate GRFs in-field are inertial measurement units (IMU).

Purpose of the study

Examine the use of IMUs to estimate GRFs during alternate lateral bounding, a football-relevant movement which generates high vertical (F_V) and medial-lateral (F_{M-L}) forces.

Methods

After ethics approval, 25 male participants (age 24.5 ± 2.9 years; mass 78.0 ± 6.6 kg; height 1.78 ± 0.04 m) performed alternate lateral jumps of increasing distance (1.2, 1.4, 1.6, 1.8 and 1.9 m; Figure 1a) to and from a FP (Kistler AG, Switzerland), recording at 1000 Hz. Participants were asked to keep their arms flexed and close to their torso. GRF data were estimated using eight IMUs (STT-IWS iSen, STT Systems, Spain) sampling at 100 Hz, attached to the feet, shanks, thighs, pelvis and trunk. Acceleration data were transformed to the global coordinate system and filtered using a 2nd order, bi-directional low-pass Butterworth filter, with selected cut-off frequencies for each sensor and acceleration axis. GRF components were estimated from the filtered IMU acceleration data through Newtonian mechanics, using Zatsiorsky-Seluyanov's inertia parameters (de Leva, 1996) to determine segment masses.
Mean force values over each stance phase for measured and estimated F_{M-L} and F_V were compared using root mean square error (RMSE).

Results

A typical example of GRFs measured by FP and estimated by IMUs is plotted in Figure 1.
Table 1 reports the RMSE.

Stance phase	F_V		F_{M-L}	
	RMSE [N]	nRMSE [%]	RMSE [N]	nRMSE [%]
1st	43.42	4.45	55.93	11.98
2nd	52.17	5.23	65.66	12.75
3rd	76.21	7.51	65.22	12.10
4th	71.59	7.10	57.35	10.59

Table 1. RMSE and nRMSE for estimated F_V and F_{M-L} for each stance phase.

Discussion and conclusion

The graphical comparison (Figure 1) between measured and estimated forces shows that

IMUs are able to detect the stance phases with good alignment. The RMSE (Table 1) highlights that F_V was estimated with higher precision than F_{M-L}; however, the ability of IMUs to estimate F_V is related to the distance jumped during the exercise, since the RMSE increases from the first to third stance phase; this trend was not present in F_{M-L} estimates.

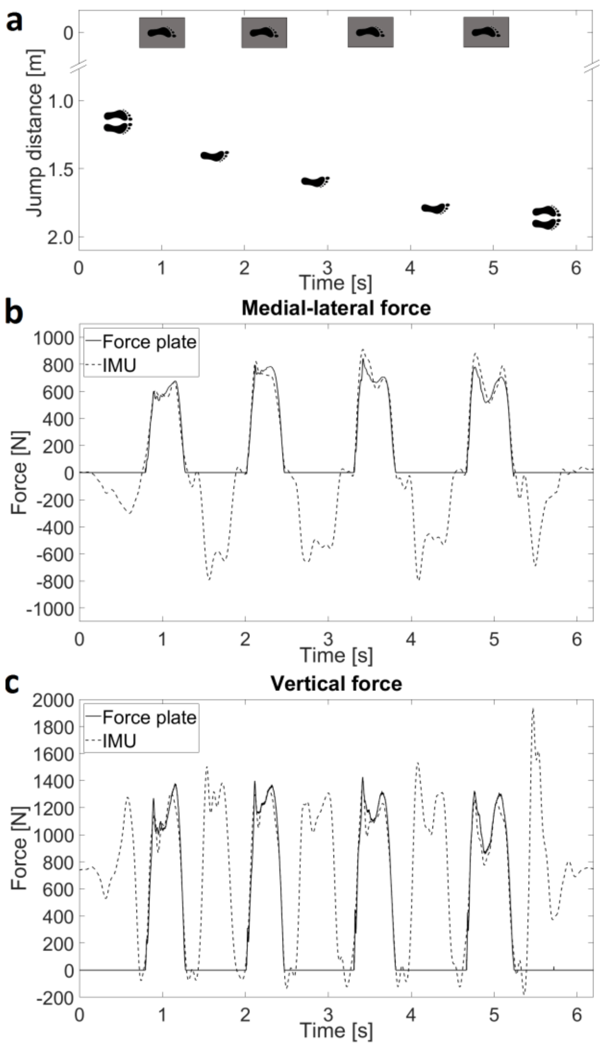

Figure 1. Schematic of the movement (a) and comparison between measured (continuous line) and estimated (dashed line) F_{M-L} (b) and F_V (c) for a single trial.

F_V estimation was similar to results of previous studies (Gurchiek *et al.* 2017; Setuain *et al.* 2017), which estimated GRFs using a single IMU placed on the sacrum during different dynamic movements. In contrast, F_{M-L} was predicted with higher accuracy in this study by using multiple sensors. Different oscillatory responses were observed between participants, for this reason, alternative filtering techniques are under further investigation.

It was concluded that the estimation of GRF using IMUs is a promising method to evaluate athlete kinetics in-field and characterise different football surfaces and shoes.

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