Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 72 (2014) 208 – 213

Procedia Engineering

www.elsevier.com/locate/procedia

The 2014 conference of the International Sports Engineering Association

Portable inertial motion unit for continuous assessment of in-shoe foot movement

Nicolai L. Mifsud; Nils H. Kristensen; Morten Villumsen; John Hansen, Uwe G. Kersting*

Department of Health Science and Technology, Aalborg University, Denmark

Abstract

Objective. The validity and reliability of a new prototype (PT) to measure tibio-calcaneal eversion/inversion, internal/external rotation, and plantar/dorsiflexion angle during running were investigated. Design. Test-retest measurements by a 3D accelerometer and gyroscope inertial motion unit (IMU) were compared to a motion capture (MC) based system both capturing in-shoe rearfoot and tibia kinematics. Background. Laboratory running tests may not reflect movement characteristics experienced during outdoor training. Lower extremity running kinematics have not been obtained by 3D IMU measurement within the shoe previously. Methods. 3D motion of two IMUs attached to the tibia and calcaneus, as well as retroreflective markers through windows in the running shoes, were determined during running. Intersegmental motion was extracted by a complementary filter fusing accelerometer data with integrated gyroscope angular velocity. PT measurements for motion along main anatomical axes were similar to MC derived curves based on coefficients of multiple correlation. Intraclass correlation correlations (ICC) showed a low correlation between PT and MC in three out of four parameters, but high repeatability for PT between test and retest measures. PT underestimated angular motion with a root mean square error (RMSe) of 182.5°/s and bias of 176.3°/s. Eversion was underestimated by PT with RMSe of 6.3°. The PT method was found inadequate to determine valid tibio-calcaneal motion while it was reliable for repeated tests and may allow for intra-subject comparisons of different footwear or inserts.

Keywords: Running injuries, eversion, tibio-calcaneal movement, in shoe measurements, gyroscope, accelerometer, IMU, complementary filter

* Corresponding author.
E-mail address: uwek@hst.aau.dk

doi:10.1016/j.proeng.2014.06.035

1. Introduction

Increasing interest in running activities makes injury prevention through correct footwear ever more important. Injury mechanisms have often been related to tibia-calcaneal movements Nigg (2001). However, studies regarding injury mechanisms often use laboratory tests creating shortcomings in regard to ecological validity. Wiegerinck et al. (2009) indicated that the short running distance used may not represent regular running training outdoors which would make measurements during training much more relevant. Further, external shoe markers have often been used to estimate skeletal movement with overestimating eversion compared to skin markers observed through windows cut into the heel cup (Reinschmidt et al. 1997).

Advances in sensor technology may provide the basis for the collection of data in the true training situation (Mathie et al. 2004). Mayagoitia et al. (2002) have successfully implemented inertial motion units (IMUs) to measure sagittal plane kinematics while walking. Externally positioned gyroscopes were used to measure eversion angular velocity (Lederer et al. 2011). To our knowledge, no previous study employed a portable measurement device to record tibio-calcaneal skeletal movement inside a shoe.

The aim of this study was to investigate the validity and reliability of a proposed new measurement device for tibio-calcaneal skeletal movement. A prototype was constructed using two IMUs located on tibia and calcaneus, with an algorithm to obtain orientation estimations. The prototype was compared to a traditional MC system.

2. Method

Seventeen male subjects (age 28.6, SD 7.5 years), running on average 31.7 (SD 16.6) km/week participated under informed consent by the local ethics committee (N-20130015).

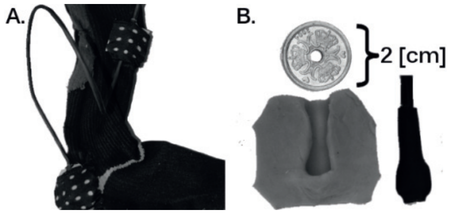

Figure 1. A; compression sock with pockets and IMU inserted. B; a silicone fitted material and IMU

2.1. Materials

The PT consisted of two IMUs placed on bony landmarks (medial tibial aspect and calcaneus lateralis). Each IMU was fitted into silicone material and inserted in a commercial compression sock (Fig. 1). Each IMU consisted of a 3D accelerometer and gyroscope (16 g and 800°/s, 16 bit) (Debus und Diebold Messsysteme, GmbH). Both IMUs were connected to a data logger placed on the lower back (800 Hz). 3D local axes of the IMUs were manually aligned that their x-axes pointing anteriorly, y-axes medially and z-axes vertically.

Eight cameras recorded passive retroreflective markers (*diameter*: 1.5 cm) at 200 Hz (Oqus 300, Qualisys A/S) placed according to ISB recommendations (Wu et al. 2002). Shank markers were placed directly on the skin. Metatarsal 1 and 5 markers were glued externally on the shoe. Calcaneus lateralis, posterior and medialis markers were placed as skin markers on removable 14-mm rods and windows were cut in the running shoe (ECCO Biom B). A force plate (AMTI-OR6-7-2000) recorded ground reaction force at 800 Hz. A wireless trigger (Noraxon, USA 232 Transmitter) was used for synchronization of PT and MC.

2.2. Experimental setup and procedure

Following sufficient familiarization time subjects ran along a 10 meter at 12 ± 1.2 km/h controlled by two infrared timing gates. Subjects were recorded while standing in a neutral reference position and when the leg was