Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

REARFOOT ANGLE VELOCITIES DURING RUNNING - A COMPARISON BETWEEN OPTOELECTRONIC AND GYROSCOPIC MOTION ANALYSIS

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The aim of this study was a verification of a gyroscopic measurement device mounted on the heel counter of a running shoe. For this purpose 15 subjects performed 10 running trials in a laboratory environment. Rearfoot angular velocities from the gyroscope were compared qualitatively and quantitatively to rearfoot angular velocities observed with a 3D motion analysis system (VICON). Based on the qualitative and quantitative analysis the results are very good in the sagittal plane, good in the frontal plane and poor in the transverse plane.

KEY WORDS: gyroscope, running kinematics, motion capture, rearfoot.

INTRODUCTION: A complete and accurate analysis of the kinetics and kinematics of human gait requires 3D camera based motion capture systems, a forceplate to monitor ground reaction forces, and additionally wireless EMG to register muscular activity, i.e. it requires a laboratory environment.
The lab-based technical devices for human gait and running analysis suffer from several limitations. These systems are expensive and require a large space. Additionally, only one or two steps of a running movement can be measured and analyzed. More recently portable sensors, which are used primarily in the aerospace and car industry, have been developed to measure and analyze the human gait (Pappas et al., 2001; Tong & Granat, 1999). Accelerometers and gyroscopes can be placed on anatomical landmarks of the human body and thus provide information about the orientation and position of a human body segment. The benefits of these systems are that the sensors are compact and less expensive. Additionally it is possible to perform tests for a large number of steps under field conditions. This study investigated rearfoot angle velocities during running at stance phase with a 3D gyroscope mounted on a heel counter of a running shoe. The data was compared to the output of an optoelectronic measurement device.

METHODS: Fifteen subjects (one female, fourteen male, age: 31.2 ± 6.8 yr, height: 178.2 ± 4.8m, weight: 75.8 ± 6.6Kg) with an identical shoe size (UK 8.5) participated in this study. All subjects were rearfoot strikers and injury free at the time of data collection.
The measurement was carried out in a laboratory with a 25 m runway. A KISTLER force plate (Type: 9287BA, KISTLER, Winterthur, Switzerland) was positioned at the center of the runway in a level with the floor. Around the force plate a six-camera VICON motion analysis system (VICON, Oxford Metrics, Oxford, UK) was arranged. The VICON Workstation recorded kinematics and kinetics data synchronously. The vertical force threshold was set to 20 N to define foot contact and toe off. Two photoelectric cells were positioned before and after the force plate to control the running speed and to work as a trigger for the motion analysis system, the force plate and the gyroscope (Memsense®, effective range: ± 1200 °/s). A wireless transmitter was installed to send a high pass signal to the data logger of the gyroscope when the subject passed the first photoelectric cell. The subjects were given a number of practice trials prior to data collection in order to familiarize with the experimental conditions and to ensure a natural running pattern. As can be seen in Fig.1, nine retro-reflective markers were attached at the rearfoot and forefoot segment of the running shoe and on the gyroscope box.
The gyroscope box served as an additional segment to track the kinematics of the box. The forefoot segment was not part of this study. The gyroscope was placed in the box made of the same material as the heel counter of the shoe as the box is a part of the heel counter.

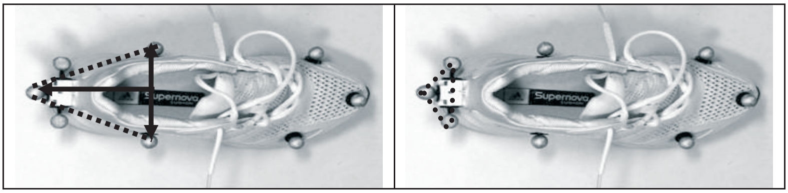

Figure 1: Marker placement of the shoe model (rearfoot segment: left picture; gyroscope_box segment: right picture)

This was constructed to minimize the relative movement between the sensor and the shoe. The modified shoe model (developed by Campe 2006) was used to calculate the three-dimensional joint angles (Euler angles) and their derivatives in reference to the global coordinate system. The gyroscope provided absolute angular velocities in the sagittal, frontal and transverse planes, which were recorded on a data logger. Ten valid running trials were collected for each subject. A valid trial was given when the subject landed on the force plate with the right foot at a controlled speed of 4.0 m/s ± 0.2 m/s in a natural running style. Kinematic (200 Hz), ground reaction force data (1000 Hz) and gyroscopic data (1000 Hz) were recorded for the stance phase of the right foot. Kinematic data was smoothed using a spline of 10th order (Woltring, 1995) and exported for further processing using Matlab® R14 (The Mathworks). The gyroscope data was re-sampled at 200 Hz and smoothed with a chebbychev filter (cut off frequency: 30Hz). Each angular velocity curve was normalized to 100% of the stance phase. Ten trials of each subject were averaged to give the composite mean curve for each subject. The gyroscopic data was aligned with the VICON data using a cross-correlation function.
Qualitative analysis considered the comparison of the signals in angular velocity – time graphs, scatter plots and difference plots according to the BLAND-ALTMAN method (Bland & Altman, 1986). Quantitative analysis considered the Bravis-Pearson's correlation coefficient and the root mean square error (RMSE). Paired samples t-tests (α=0.05) were run to determine differences between the maximal sole angular velocity and the maximal pronation velocity of the gyroscopic and the optoelectronic measurement devices respectively. Statistical evaluation was carried out using Matlab (The Mathworks).

RESULTS: The comparison of the rearfoot segment and the gyroscopic data revealed a good agreement for the angular velocities in the sagittal plane for every subject in the qualitative analysis (Fig. 2 left side, $0.86 < r < 0.99$; mean RMSE: 48.2 °/s ± 19.02 °/s). The comparison of the gyroscope_box segment with the gyroscope data showed good agreement in the sagittal plane (Fig.2 right side, $0.86 < r < 0.99$; mean RMSE: 69.6 °/s ± 24.0°/s).
In the frontal plane the data were in good agreement. However, the maximal pronation velocity of the rearfoot segment was much lower than the angular velocity of the gyroscope (Fig. 2 left side, $0.85 < r < 0.88$; mean RMSE: 43.6 °/s ± 17.0 °/s). Almost the same result can be seen in the comparison of the gyroscope_box segment and the gyroscope angular velocities (Fig. 2 right side $0.85 < r < 0.99$; mean RMSE: 51.3 °/s ± 24.1 °/s). In the transverse plane correlation strongly varied from subject to subject ($-0.83 < r < 0.9$; mean RMSE: 51.9 °/s ± 10.7 °/s). Similarly, the comparison of gyroscope_box segment and gyroscope data revealed large variations ($-0.83 < r < 0.85$; mean RMSE: 70.3 °/s ± 22.5 °/s).
The paired samples t-test revealed significant difference between the maximum sole angular velocities in the rearfoot segment and the gyroscope and no significant difference in sole angular velocity obtained at the gyroscope_box segment and the gyroscope respectively ($p < 0.05$). There was no significant difference in maximum pronation velocity between the gyroscope_box segment and the gyroscope and a significant difference was found for the rearfoot segment – gyroscope comparison ($p < 0.05$) in the frontal plane.

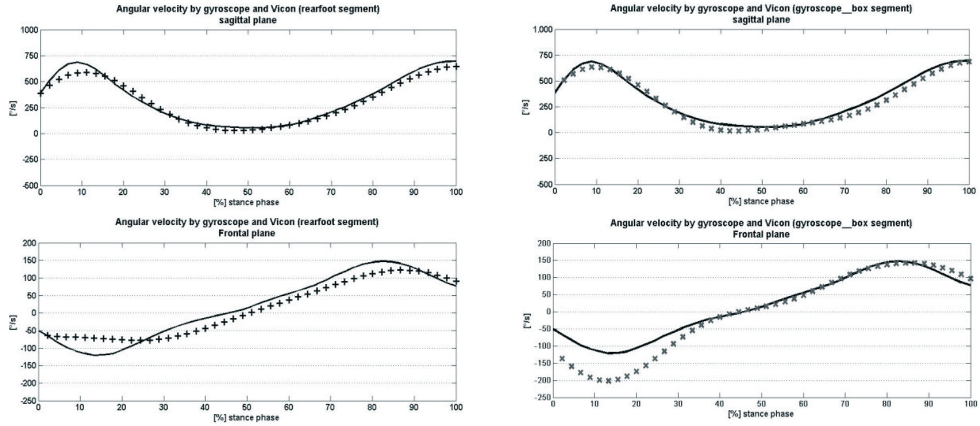

Figure 2: Representative time-velocity graphs to illustrate comparisons in the sagittal and frontal plane; subject number 1, rearfoot segment: + (left side); gyroscope_box segment: x (right side); Gyroscope: solid line

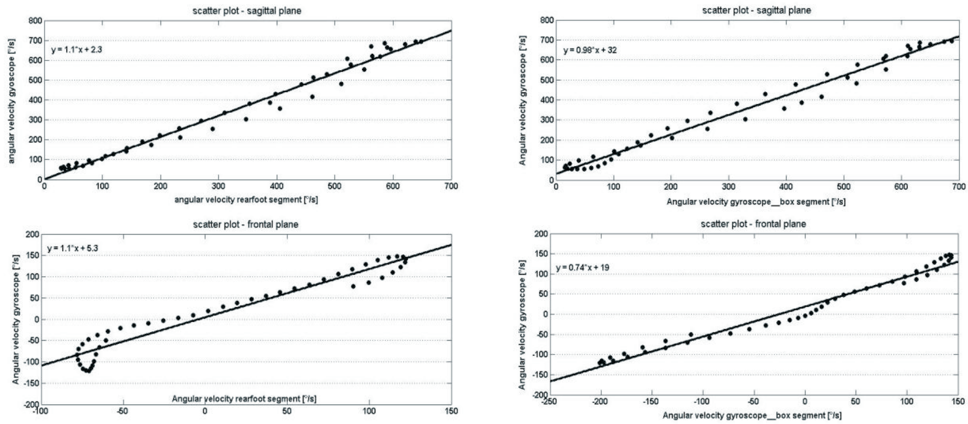

Figure 3: Scatterplots to illustrate the linear relationship in the sagittal and frontal plane; subject number 1

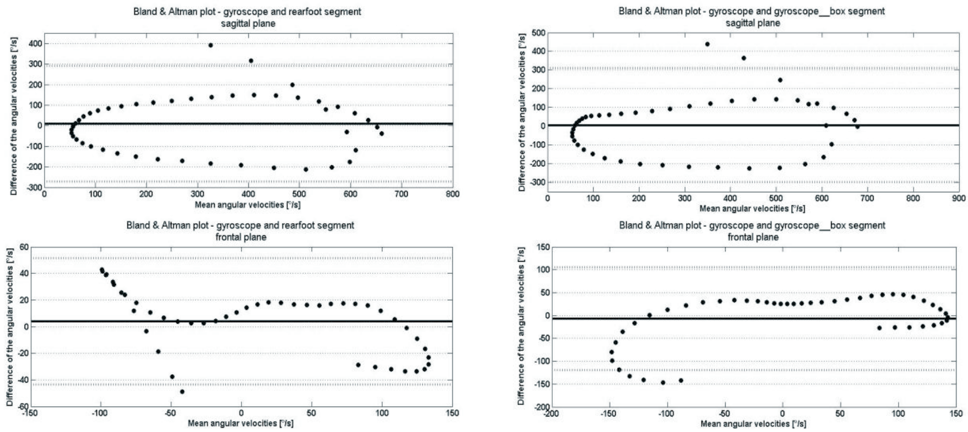

Figure 4: Bland & Altman plots of the rearfoot segment – gyroscope and gyroscope_box – gyroscope comparison in the sagittal and frontal plane; subject number 1

DISCUSSION: The purpose of this study was to verify angular velocities from the rearfoot during heel running from a gyroscopic measurement device with an optoelectronic measurement device in the sagittal, frontal, and transverse plane. The results revealed a good agreement of the angular velocities in the sagittal plane, which is also reported in the literature (Tong & Granat 1999, Pappas et al. 2001). In the frontal plane the agreement was good. However the gyroscope measured higher maximum angular velocities in the frontal plane. Kleindienst et al. (2007) reported similar maximal angular velocities. Therefore the results of the frontal plane should be regarded with caution. Marker - artifacts could lead to an explanation of different maximal velocities as well as the fact that the gyroscope is measuring absolute angle velocities and the shoe model calculates velocities in an Euler rotation. The calculation model of the VICON™ also explains the poor agreement in the transverse plane between the gyroscopic and the optoelectronic measurement device as the model shows clear intraindividual differences especially in the transverse plane (Campe, 2006). Furthermore it was not possible to align the gyroscope box 100% perpendicular to the global coordinate system which can also lead to an error when comparing the angular velocities of the two measurement systems.

CONCLUSION: Beside the poor agreement in the transverse plane and the fact that the kinematics of this plane are not the main focus of sport shoe research the gyroscopic measurement device can serve as a substitute for a laboratory fixed camera system. This study verified the gyroscopic device and gives the recommendation to use it in field studies. A possible research application for the gyroscope could be influence of fatigue on foot kinematics. The kinematics of the different regions other than the rearfoot are also of interest. By mounting another gyroscopic device on the forefoot, the torsion of the shoe could be measured. The question of how a shoe acts on different and uneven grounds could be an interesting field of application of this measurement device. Nevertheless, the maximal angular velocities in the frontal plane should be interpreted with caution, particularly when comparing different shoes. Future studies will reveal whether the device is able to distinguish different angular velocities induced by different footwear. The main aspect of concern will be the constant alignment of the sensor-box to the ground on every shoe model.

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Acknowledgment:
The study was supported by the adidas AG.