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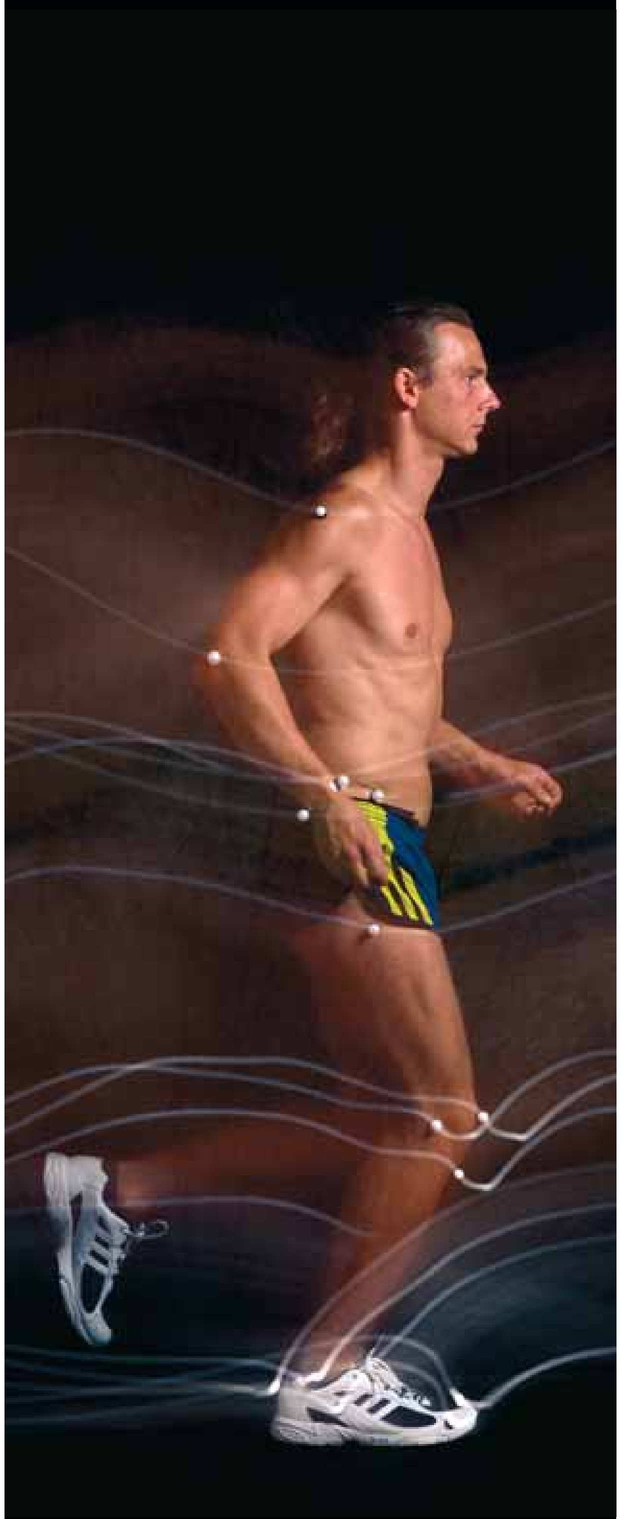


DEVELOPMENT OF A LOWER EXTREMITY MODEL FOR SPORT SHOE RESEARCH

Katja J. Michel, Frank I. Kleindienst, Berthold Krabbe

INTRODUCTION

The use of 3D motion analysis has become increasingly important for biomechanical studies in the sport shoe research area. Nevertheless, models provided by the manufacturers are primarily intended for clinical purposes (e.g. Plug-In Gait, Vicon).
There is a lack of models which can reliably detect small differences of foot and ankle kinematics in the frontal plane, as well as incorporate applicable marker placements which do not interfere with running movements.

Overuse injuries are a major problem for runners and the knee joint is a common site of injury. Patellofemoral Pain Syndrome (PFPS) is the most common complaint regarding injuries to the knee.

High abduction and external rotation moments
In the knee joint are related to overuse injuries
like PFPS *(Stefanyshyn et al., 2001)*.

It has been shown that shoe constructions influence kinetics *(Frederick et al., 1986)* and kinematics *(Stacoff et al., 2000)*.

It has also been shown that knee joint moments of runners are influenced by varying the midsole hardness of running shoes *(Michel et al., 2004)*.

Therefore, it is of great interest for sport shoe research to combine the measurement of knee joint moments with measurements of conventional kinematic data (e.g. y- and ß-angles) which are used to describe stability properties of running shoes.

Aim of the study: Development of a lower extremity model capable of providing conventional foot and ankle angles as well as kinetic data (knee and ankle joint moments).

MATERIAL and METHODS

The model was programmed in Bodybuilder and can be used with Workstation (Vicon, Oxford Metrics, Oxford, UK).

Reflective markers were placed on the pelvis, upper leg, lower leg, rearfoot and forefoot (3 per segment).

The knee joint center was defined as the midpoint between the medial and lateral epicondyles.

The ankle joint center was defined as the midpoint between the medial and lateral malleoli.

The medial epicondyle marker was removed for the dynamic trials and the offset from the lateral epicondyle collected during the static trial was used to recalculate its position within the upper leg segment.

The zero position of the foot was determined by three markers on the rearfoot which created a coordinate system aligned with the floor where the y-angle was zero in "neutral-0-position". The alignment was done during the static trial with the subject standing in a reference frame.

The foot was devided into two segments to provide the possibility of describing torsionability around the longitudinal foot axis and forefoot flexion.

Evaluation of the model

Subjects:
4 runners (3 male, 1 female)

Ø age: 35 years
Ø weight: 66 kg
Ø height: 173 cm
Ø mileage: 46 km/week

Shoe:

A standard running shoe (adidas® Unity) was used for the running trials.

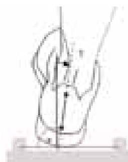
Experimental Setup

Subjects ran across the force plate in the middle of a 25m runway at a velocity of 3.6 ± 0.2ms^{-1}.

For each subject 5 valid trials were collected.

2D kinematic data was collected by a high speed video system (HCC-1000) from posterior (230Hz): **HCC**

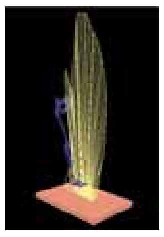
Two markers were placed central on the midsole and on the upper edge of the heel counter.



The eversion of the heel in the frontal plane (y-angle) was determined at touch down (impact angle) and at maximum eversion by means of the software WINanalize *(Kleindienst, 2003)*.

3D kinematic data was collected using a 6-camera Vicon System (200Hz): V1 and V2

Kinetic data was collected using a Kistler force plate (1000Hz).



To investigate reliability all markers were removed and put on again by the same examiner for another 5 valid trials (V1 and V2).

3D knee joint moments were calculated using an inverse dynamics approach and normalized to bodyweight.

Selected values of angle and moment curves were determined and averaged for each condition:

- y-angle: frontal plane angle between the heel segment and the global coordinate system (positive angle: Eversion)
  - impact angle (at touchdown)
  - maximum eversion
  - path of motion
- Displacement angle: transversal plane angle between the heel segment and the global coordinate system (positive angle: Exorotation)
  - Displ. Angle impact (at touchdown)
  - Displ. Angle stance (during foot flat)
- Knee extension moment: Sagittal plane moment in the knee joint
  - Maximum moment
- Knee abduction moment: frontal plane moment in the knee joint
  - Maximum moment
- Knee rotation moment: external rotation moment in the knee joint
  - Maximum moment

RESULTS

Table 1: Rearfoot angles of all subjects [°], positive: eversion, exorotation resp.; negative: inversion, endorotation resp.

		Impact Angle (γ-angle)	Dis pl. Angle (Impact)	Max. Eversion (γ-angle)	Dis pl. Angle (Stance)	POM (γ-angle)
Subject 1	V1	-7.2	4.7	3.3	4.2	10.5
	V2	-6.7	5.0	3.4	3.6	10.1
	HCC	-10.1		3.1		13.2
Subject 2	V1	-3.1	6.1	1.8	2.9	4.9
	V2	-3.4	5.8	2.2	3.2	5.0
	HCC	-6.0		2.0		8.0
Subject 3	V1	-6.4	1.5	-0.2	0.2	6.2
	V2	-7.0	2.6	-1.0	0.1	6.0
	HCC	-7.8		-0.2		7.6
Subject 4	V1	-3.3	-1.3	1.3	-1.8	4.6
	V2	-2.4	-1.6	1.3	-2.1	3.7
	HCC	-1.4		0.9		2.3

The comparison between Vicon data (V1, V2) and high speed video analysis (HCC) shows expected results (Table 1) when known differences of the 2D analysis due to the displacement angles are taken into account *(Areblad et al., 1990)*.

When the sole angle (sagittal plane) is large, as during touch down, an exorotation of the foot (transversal plane) increases the 2D supination angle (frontal plane) wheras an endorotation of the foot (transversal plane) decreases the 2D supination angle (frontal plane).

Table 2: Maximum Knee Joint Moments of all subjects [Nmkg^{-1}]

		Knee Ext. Moment	Knee Abd. Moment	Knee Ext. Rot. Moment
Subject 1	V1	2.45	0.40	0.11
	V2	2.40	0.36	0.13
Subject 2	V1	3.43	1.15	0.12
	V2	3.25	1.24	0.11
Subject 3	V1	2.48	1.76	0.40
	V2	2.32	1.76	0.38
Subject 4	V1	2.59	1.00	0.26
	V2	2.39	0.95	0.27

The two Vicon measurements (V1 vs. V2) reveal a strong reliability for angles as well as for moments (Table 1, Table 2). Moreover, the absolute values of the knee joint moments are comparable to the data in the literature *(Stefanyshyn et al., 2003; Stergiou et al., submitted)*.

CONCLUSION and OUTLOOK

Foot eversion described by the new model corresponds well with expectations from 2D measurements when alignment problems of the longitudinal and transversal axis of the foot with the camera axis are taken into account *(Areblad et al., 1990)*.

The angles calculated by the new model are independent of the rotation of the foot in the transversal plane. Therefore, the results are more reliable than those from 2D measurements.

The determined knee joint moments show similar values to those described in the literature for similar studies *(Stefanyshyn et al., 2003; Stergiou et al., submitted)*.

The reliability of the analysed data meets the requirements to judge differences in various footwear conditions.

The lower extremity model which is able to determine rearfoot kinematics as well as knee joint moments reliably, provides the basis for studies in the sport shoe research area.

Further studies are in progress, e.g. the simultaneous determination of rearfoot angles and knee joint moments of different groups of runners in order to develop appropriate running shoes for groups of people differing in gender, bodyweight, running style, performance level and/or foot type.
This is now possible by using the Vicon system only, without additional video filming which was always complicated because of the interfering of the needed lights for filming and the Vicon cameras.

REFERENCES

Areblad, M. et al., 1990, *J. Biomech.*, 23, 933-940.
Frederick. E.C., Hagy, J.L., 1986, *Int. J. Sport Biomech.*, 14, 498.
Kleindienst, F. (2003). *Gradierung funktioneller Sportschuhparameter am Laufschuh.* Aachen: Shaker.
Michel K.J. et al., *Am. Soc. Biomech. Annual Meeting*, 2004, Portland, (USA).
Stefanyshyn, D.J. et al., *Proc. of the 5th Symp. on Footwear Biomechanics*, 2001, Zürich, (Switzerland), 74-75.
Stergiou, P. et al., submitted, *Med Sci Sports Exerc.*, "Knee joint moments and PFPS in runners".