DIFFERENCES BETWEEN FORE- AND REARFOOT STRIKE RUNNING PATTERNS BASED ON KINETICS AND KINEMATICS

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Some sports physicians and coaches are adamant, that forefoot striking (FFS) compared to rearfoot striking (RFS) results in a reduction of joint loading and therefore reducing the incidence of overuse injuries. The present study investigates the influence of different running strike patterns on knee joint loading and on "conventional" dynamic variables, which have been proposed as major reasons for the cause of running injuries. Nineteen experienced male runners participated on the study. Kinematic data was collected using a 6-camera 3-dimensional Vicon System. Kinetic data was recorded by a Kistler force plate. Based on the findings of the present study it is concluded that FFS does not necessarily lead to a lower risk regarding the incidence and development of running related injuries. It is likely, however, that the location and the nature of injury/complaints can be influenced by the strike pattern.

KEY WORDS: strike pattern, running, kinetics, kinematics, joint loading, lower extremity

INTRODUCTION:

While 95% of distance runners are rearfoot strikers (RFS), only 5% have been analyzed to land with a flat foot (midfoot striker) or on the ball of their foot (forefoot striker-FFS) (Kleindienst 2003). However, some sports physicians as well as coaches advocate and recommend FFS as "natural running" particularly for recreational runners and promise - besides a faster running speed - a reduction of joint loading which leads to a prevention/reduction of overuse injuries (Wessinghage, 1996, Marquardt 2002).

The reported yearly incidence of running related injuries ranges between 37 and 56% (Clement et al. 1981, Van Mechelen, 1992). The knee has been shown to be a common site of injury for runners whereas Patellofemoral Pain Syndrome (PFPS) is the most common of the injuries to this joint. High abduction and external rotation moments in the knee joint are related to overuse injuries like PFPS (Stefanyshyn et al., 2001).

Therefore the main goal of the present study was to determine the influence of the different running strike patterns on knee joint loading. Moreover, "conventional" dynamic variables such as impact forces and loading rates as well as foot eversion and eversion velocity, which have been proposed as major reasons for the development of running injuries, were analyzed (Clement et al., 1981, Cook et al., 1990, Van Mechelen, 1992, Novacheck, 1998, Hreljac et al., 2000).

METHODS:

Nineteen male subjects (age: Ø 33 years; body height: Ø 177cm; body mass Ø 72kg) who were serious long distance runners with an average weekly running volume of 55km participated in the study. All the subjects were practiced RFS. Williams et al. (2000) determined that runners are able to quickly alter their gait pattern from a RFS to a FFS that is mechanically similar to that of a practiced FFS. This finding represents the precondition to collect data for both locomotion patterns – RFS as well as converted FFS – measured on the same subject. All subjects wore the same shoe during the study (adidas® Supernova).

Kinematic data was collected using a 6-camera 3-dimensional Vicon® System (200Hz). Reflective markers were placed on the pelvis, upper leg, lower leg, rearfoot and forefoot (3 per segment). Kinetic data were collected using a Kistler® force plate (1000Hz). Subjects ran across the force plate in the middle of a 25m runway at a controlled velocity of 4.0±0.2ms^{-1} carrying out in turn RFS and FFS. Kinematic and kinetic data were collected for 5 valid trials for each subject and condition. A lower body model, described by Michel et al. (2004) was used to determine joint centers and angles between segments. Three-dimensional knee joint moments were calculated during the stance phase using an inverse dynamics approach. Moreover the metatarsophalangeal (MTP) joint moments in the sagittal plane during stance phase were determined. In this context the midpoint between the first and fifth MTP marker, which were placed slightly distally of these joint cavities, was chosen to represent the MTP center of rotation. For RFS the MTP moment was considered to be zero until the heel elevated from the ground.

In order to determine the strike pattern, two high speed camera systems (Vosskühler®) running at 200Hz filmed all subjects from posterior and lateral during ground contact.

Selected values were determined from each curve and averaged for each condition and subject. Sig. differences between the conditions were detected using paired-samples T test and GLM with repeated measures ($p \leq 0.05$).

RESULTS:

The analysis of the knee extension moment shows a sig. lower moment (Ø13%) for FFS compared to RFS and it occurs during the midstance phase. The knee joint moments in the frontal plane (Fig. 1) revealed no sig. differences for the max. abduction moment. However, during landing, FFS indicated a sig. higher knee abduction moment, which can be explained by the specific strike pattern. The max. knee external rotation moment (Fig. 2), which occured at the end of midstance phase, was sig. higher in FFS (Ø33%). Moreover, during landing a sig. higher knee internal rotation moment for FFS can be observed (Ø22%). This pattern also could be caused by the initial foot strike.

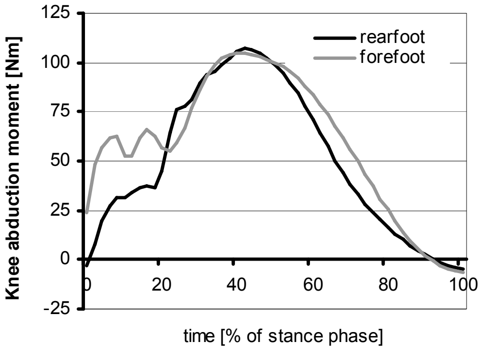

Figure 1: Knee abduction moments (n=19)

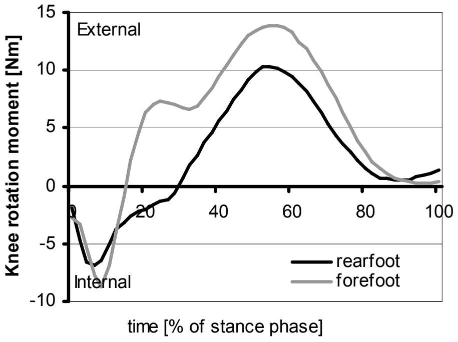

Figure 2: Knee rotation moment (n=19)

The max. plantarflexion moments of the ankle and the MTP joint (sagittal plane) revealed sig. higher values for FFS compared to RFS. The max. plantarflexion moment of the ankle occurs at the end of midstance and the MTP plantarflexion moment during push off. In this context, a sig. higher peak power absorption (eccentric work) could be observed concerning the MTP- and ankle joint (sagittal plane) for FFS compared to RFS. However, RFS demonstrated a sig. higher peak power absorption in the knee joint. There were no sig. differences in peak power absorption for the hip joint.

Regarding GRF, the main differences were in the vertical and anterior-posterior components. Looking at the vertical ground reaction forces, the initial force peak can only be detected for RFS and it is attenuated or absent in FFS (Fig.3). The initial force peak during RFS was caused by striking the ground with the heel and the later active peak reflects the propulsive phase of gait. The active peak of FFS reveals sig. higher forces than RFS. The vertical loading rate was sig. higher during RFS. The horizontal braking and acceleration forces as well as the loading rate (braking) indicated sig. higher values for FFS compared to RFS (Fig. 4). In this context a biphasic shape of the braking phase could be observed in FFS. This shape was due to the runner landing on his forefoot and the center of pressure moving posterior as the heel lowers.

Similar to the max. eversion ankle angle (calcaneus with reference to shank; $\beta_{max.}$) FFS exhibited a sig. lower max. rearfoot eversion (calcaneus with reference to global coordinate system - gcs; $\gamma_{max.}$) than RFS (Fig. 5). However, due to the sig. higher inversion angle at initial touch down, FFS provoked a sig. higher eversion velocity and sig. higher rearfoot excursion. On the other hand, the sig. higher sole angle in RFS (Fig. 6), which defined the rearfoot strike, led to a sig. higher sole angle velocity during RFS compared to FFS.

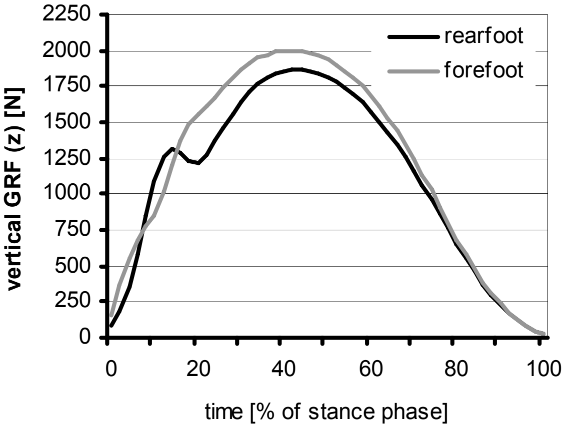

Figure 3: Vertical GRF (n=19)

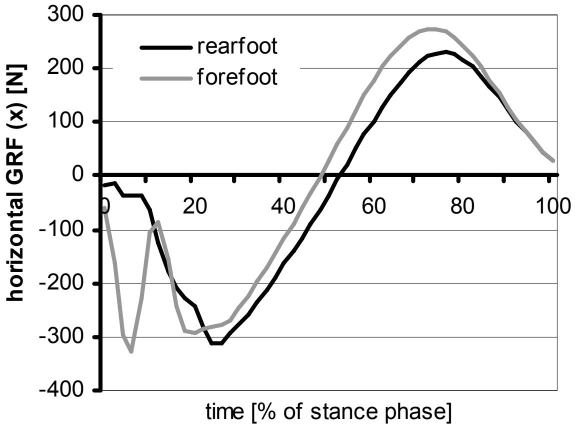

Figure 4: Horizontal GRF, a-p-direction (n=19)

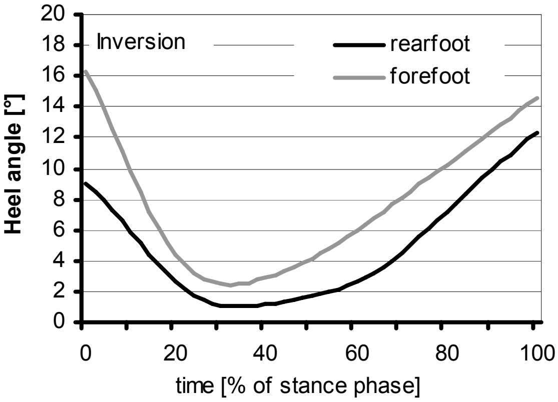

Figure 5: Heel angle, gcs; γ_{max} (n=19)

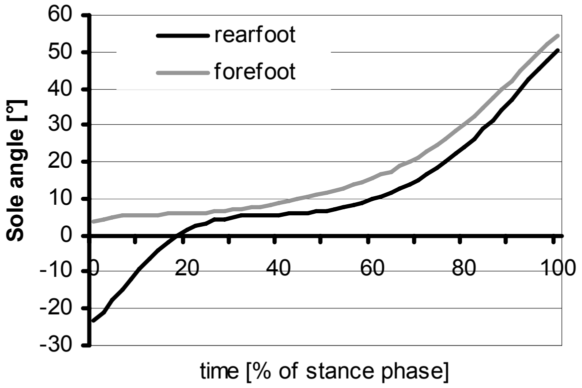

Figure 6: Sole angle, gcs (n=19)

DISCUSSION

The analyzed data of the present study are comparable to those from Williams et al. (2000) and Stackhouse et al. (2004). The results clearly demonstrate that the strike pattern affects kinetics and kinematics of lower extremities – particularly during landing and midstance phase. Along with the coupling of motion within the foot, there is a mechanical link between the foot-ankle complex and the knee through the shank. The mechanical linking leads to alterations in the knee (Williams et al. 2000).

It was shown that increased knee abduction and knee external rotation moments are directly linked to the incidence of PFPS (Stefanyshyn et al., 2001). Consequently, FFS seems to be more risky regarding the development of PFPS than RFS. With reference to the peak power absorption in the MTP and ankle joint, the FFS may overwork the gastrocsoleus muscle group and increase the risk for injury such as Achilles tendinitis (Williams et al. 2000, Walther, 2005). Conversely, FFS reveals less peak power absorption and eccentric work at the knee compared to RFS, which may result in lower demands of the quadriceps muscle group (Williams et al. 2000).

Besides, some of the analyzed “conventional” dynamic variables, which are associated with the development of running injuries, lead to similar deductions. There are variables such as eversion velocity, which verify the assumption of a lower risk regarding the incidence of injuries for RFS. Contrary, there are dynamic variables, which can not confirm a lower risk of running related injuries when performing RFS such as max. eversion angle and max. vertical loading rate.

Within a medical anamnesis of 471 runners, Kleindienst (2003) could not detect differences between RFS and FFS concerning the frequency of running related injuries. The same is valid for the incidence of foot deformities. However, the location of foot deformities depends on the strike pattern and the related forces and loads. Based on an epidemiological survey, analyzing 1203 runners, Walther (2005) came to a similar finding. There are no differences in the incidence of running related injuries between FFS and RFS. However, the location and the kind of injury and complaints are different.

CONCLUSION:

The results of the present study clearly indicate that FFS causes a higher risk regarding the development of PFPS compared to RFS. Furthermore, it is concluded, that the "conventional" dynamic variables does not lead necessarily to a lower risk of FFS regarding the development of running related injuries. It is likely that the location of the injuries/complaints can be influenced by the strike pattern. It has been suggested that altering the strike pattern may decrease the risk of developing certain injuries (Williams et al., 2000). However, the injury mechanisms are not completely understood. Moreover, it is questionable, whether the measured differences between RFS and FFS represent a clinically relevant reduction by means of these variables. Therefore it is necessary to conduct prospective epidemiological laboratory and field studies in order to investigate the influence of the strike pattern on the incidence of sport specific injuries and complaints.

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