POWER DEVELOPED BY THE MIDFOOT JOINT DURING RUNNING WITH AND WITHOUT SHOES

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The purpose of this study was to remedy the lack of knowledge about the function of the midfoot joint during the propulsion phase of running and to assess the effect of footwear on this function compared to running barefoot. A valid model of the rearfoot was identified and 12 healthy male subjects performed five trials each of running with and without shoes while data was collected with a ten-camera and single force plate motion capture system. Analysis of the results showed that the midfoot joint generated 39% of total power from the foot region during barefoot running. This reduced to 25% when shoe-wearing as a result of a reduction in range of motion at the midfoot joint. The findings may have implications for running efficiency and injury but both these conjectures need further study.

KEY WORDS: running, propulsion, midfoot, ankle, footwear.

INTRODUCTION:

The kinematics and kinetics of the human foot and lower limb during gait have been investigated by researchers over the past five decades. However, despite there being three main regions of the foot (the rearfoot, the forefoot and the toes) the vast majority of research has been directed at the rearfoot and ankle joint complex. The kinematics of the calcaneus, probably because of its close relationship with the subtalar joint and the relative ease with which it can be measured during locomotion, has been referenced to that of the tibia to determine rearfoot angle during gait (eg Cornwall et al., 2002). The kinetics of the ankle joint comlex have also been studied (eg Hunt & Smith, 2004). How the midfoot area, considered as a joint, spread over the midtarsal articulations, might contribute to propulsion and running efficiency has not been addressed quantitatively in the literature. Proposals put forward about midfoot function during gait have been mainly derived from anatomical observations. Since most athletes use footwear when running, there is the further question of what effect footwear might have on foot function during running.

The first step in remedying these deficiencies in our knowledge was to propose a valid model for the kinetic analysis. (Wrbaski and Dowling 2007) used sagittal plane fluoroscopy to find the simplest foot model that would meet the criteria for traditional link-segment mechanics. By identifying markers that defined rigid segments and had a high correlation with underlying bone movement they were able to establish a valid three segment foot model. This model contained a rearfoot segment (calcaeus and talus) a forefoot segment (midtarsals and metatarsals) and a halux segment. It is an appropriate model to use for the study described here.

The aim of this study was to describe the post heel-rise sagittal plane mechanics of the midfoot and ankle joints during barefoot running and assess the effect of shoe-wearing on those mechanics.

METHOD:

Ten healthy males (height 1.78 ± 0.12m, weight 74 ± 2.1kg, age 24 ± 7 yrs, shoe size US 10 ± 2) gave their informed consent to participate in the study and ran overground at 2.95 ± 0.2 $m \cdot s^{-1}$ through the data collection area ofthe laboratory.

Three-dimensional kinematic data was collected with a three-marker wand attached to the calcaneus in addition to retro-reflective markers on the right halux, first and fifth metatarsal head, navicular, medial and lateral malleoli, medial, lateral and posterior calcaneus. In the shoe trials the wand was inserted through a hole in the posterior aspect of the heel counter. Each subject executed five trials each of barefoot running and running with shoes. The

forefoot was modeled by the navicular and metatarsal head markers which were mounted through holes in the shoe vamp for the shoe trials and the rearfoot by the three wand markers for all trials. The barefoot trial was used to assess the validity and reliability of the wand as a representation of the rearfoot segment. Other trials were conducted to check that the fore-shoe marker holes did not interfere with the forefoot support function of the shoe.
Ten cameras (Eagle, Motion Analysis Corporation, Santa Rosa, California) were used to record the positions of the markers at 120 Hz. A force plate (Kistler^{TM} 9287b, 120 Hz) was located in the running surface to obtain the ground reaction force and center of pressure during the stance phase. An inverse dynamics software package (KinTrak Version 6.2, University of Calgary, Canada) was used to calculate the post heel-rise three-dimensional dynamics from the input marker positions, anthropometric data, and force platform data. The marker positions were filtered at 18 Hz. A joint coordinate system (JCS) was adopted to calculate the relative angles between the fore- and rearfoot and the rearfoot and shank segments as reported by Smith et al. (2001). Repeated measures analysis of variance (Statistical Package for the Social Sciences, SPSS Inc., Chicago, USA) was used to determine if there was a significant difference in rearfoot motion and inverse dynamics among the walking conditions.

RESULTS:

After heel rise (~60% stance phase), the peak power from the midfoot joint in the sagittal plane during running (0.37 W/BW) was reduced by 30% when wearing shoes ($p < 0.001$) (0.23 watts/BW) (Figure 1). The moment was little different ($p = 0.401$) between the two conditions (Figure 3) but the range of motion ($p < 0.001$) and angular velocity was decreased

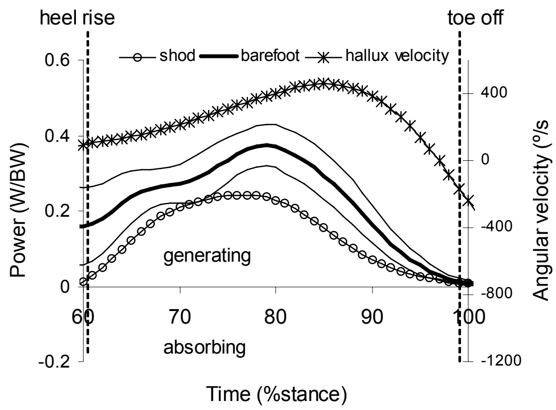

Figure 1 Barefoot and shod midfoot joint power during stance after heel rise and hallux velocity.

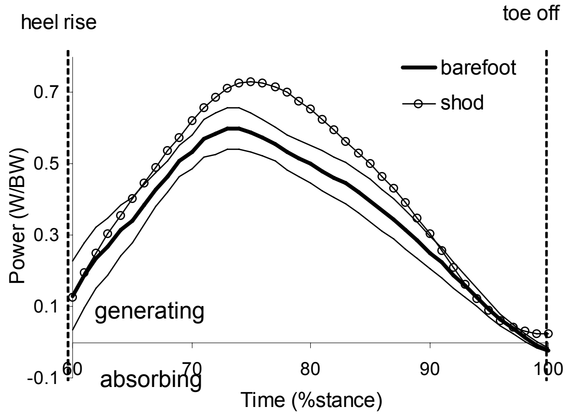

Figure 2 Barefoot and shod ankle joint power during stance after heel rise.

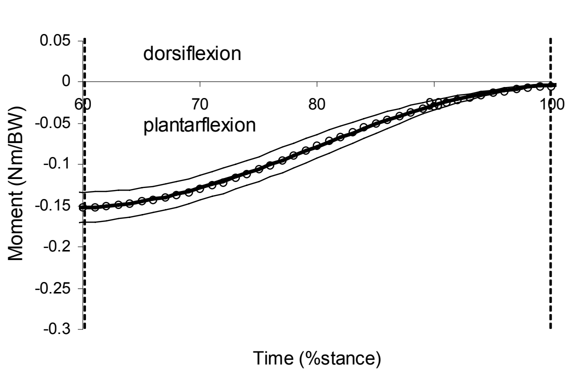

Figure 3 Sagittal plane moment at the midfoot. The heavy line is barefoot mean with 95% confidence intervals. The line with circles is the shoe condition mean.

Figure 4 Sagittal plane moment at the ankle. The heavy line is barefoot mean with 95% confidence intervals. The line with circles is the shoe condition mean.

in the shoe condition (Figure 5). On the other hand (Figure 2), the power at the ankle joint when wearing shoes (0.73 W/BW) was increased by 22% (p = 0.043) compared with the power developed when barefoot (0.60 W/BW). As was the case for the midfoot joint, the ankle joint sagittal plane moment was almost unchanged by the wearing of shoes compared with barefoot (Figure 4). The difference arises from the greater range of motion (p = 0.047 achieved in the ankle joint motion and thus the higher sagittal plane angular velocity (Figure 6).

Figure 5 Dorsiflexion/plantarflexion at the midfoot. The heavy line is barefoot mean with 95% confidence intervals. The line with circles is the shoe condition mean.

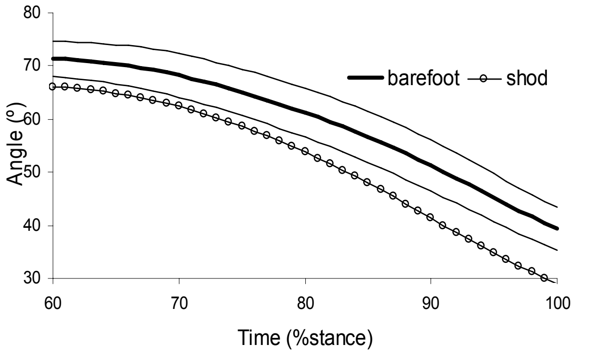

Figure 6 Dorsiflexion/plantarflexion at the ankle. The heavy line is barefoot mean with 95% confidence intervals. The line with circles is the shoe condition mean.

Calculating the total energy expenditure at the two joints during this phase of running stance it can be seen (Table 1) that the midfoot joint generates 39% of the total energy produce by the joint under discussion during the propulsion phase of stance of barefoot running. When shod this figures decreases to 25%. The total amount of power from this region remained relatively constant between the footwear conditions.

Table 1 Energy expenditure (J) at the midfoot and ankle joint in the sagittal plane during running while barefoot and shod for the period of stance phase after heel rise.

Joint/Footwear condition	Barefoot	Shod
Midfoot	23	14
Ankle	36	43
Total	59	57

DISCUSSION:

The experimental results quantified the power output from the midfoot region of the foot during the post heel-rise period of stance phase during running for the first time. The midfoot joint contributes a large proportion of the total energy during running barefoot. This is reduced by the wearing of shoes but is still an important component. The reduction of power from the midfoot when wearing shoes is compensated for by an increase in the power output of the ankle joint. Functionally, body weight support and the necessity for propulsion, is necessarily supplied by the sagittal plane moments at the midfoot and ankle joints. Therefore it is not surprising that the moments remain much the same between barefoot and shod conditions. The wearing of shoes, however, decreases the range of motion and thus angular velocity at the midfoot. This must be compensated by an increase in the range of motion at the ankle joint to maintain total power output in the sagittal plane.

It is possible that the splinting effect of the relative rigidity of the midshoe region of the running shoe was the cause of this reduced range of motion.

The effect of the change in power output tactics of the foot when going from barefoot to shoes on such important matters as efficiency and propensity for injury cannot be discerned from this experiment. However, as the midfoot plantarflexion is probably mediated by the (passive) windlass mechanism, one could hypothesise that efficiency of foot energy production during this period of stance is reduced.

CONCLUSION:

The midfoot joint plays an important role in energy production during the propulsion period of stance phase of running generating 39% of the total foot energy. This is reduced by the wearing of running shoes. The mechanism for this reduction in energy is the restriction to the range of motion of the midfoot joint when shoes are worn. The importance of this finding to running performance would be in the implications for efficiency and injury prpopensity. It could be hypothesised that effciency would be reduced by the wearing of shoes but this needs to be tested by subsequent experiments. The greater power output and range of motion requirements when shoe-wearing may also have implications for development of injuries such as in the achilles tendon. However this also needs further investigation.

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