

FOOTWEAR AFFECTS GEARING IN THE MUSCULO-SKELETAL SYSTEM IN RUNNING

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The purpose of this study was to evaluate the impact of barefoot running on grass versus shod running regarding the effectiveness of running mechanics. Fourteen male runners performed five valid running trials at $4.0\text{m/s} \pm 0.2$. Running kinetics and running kinematics were recorded for one barefoot and five shod conditions. The comparison of barefoot and shod running showed different effects concerning the gear ratio at the ankle and knee joint. Running with shoes showed mechanical advantages at the ankle joint in the first, second and fifth part of the ground reaction phase but caused disadvantages at the knee joint.

KEY WORDS: running mechanics, footwear, gear ratio, turf

INTRODUCTION: The results in relation to the influence of environmental conditions on running mechanics are contradictory. Recent results indicate that the locomotor system keeps the general kinematic and kinetic situation similar for a given task (Nigg, 2001). Biewener (2004) und Carrier (1994) suggest that the gear ratio between the extensor muscles and the point of application of the force on the ground is related to the locomotor performance. The gear ratio quantifies the mechanical disadvantage of the acting muscles during the contact phase of running. The results in relation to the influence of shoes on running mechanics are contradictory (Nigg, 2001). The purpose of this study was to evaluate the impact of barefoot running on grass versus shod running on the effectiveness of running mechanics.

METHOD: Fourteen healthy, competitive male runners participated in the study. All subjects (28.2 ± 4.5 yrs., 182 ± 6 cm, 79.5 ± 6.5 kg) were free of injuries for at least 2 years. The study was held in a movement analysis laboratory with a floor mounted force plate (Kistler, Winterthur; 1250Hz; 60x90cm) on an 20m running track. Additionally, 12 infrared cameras (Vicon, 250Hz) with a data processing unit (Vicon 624) were used to measure 3D kinematics. Five reflective markers (\varnothing 9mm) were attached on the right leg of every subject on the following anatomical landmarks **(a)** medial malleolus; **(b)** lateral malleolus; **(c)** medial femoral condyle; **(d)** lateral femoral condyle; **(e)** trochanter major. Every subject performed several running trials in six different conditions. Five valid running trials were analyzed for every running condition. Running velocity ($4.0\text{m/s} \pm 0.2$) was controlled from 0.5m in front to 0.5m behind the force-plate by two timing-gates. The 6 conditions (barefoot on grass, conventional running Shoe1-5 on tartan) were performed in a randomized order after the individual warm-up of every subject. 3D coordinates and force plate data were smoothed using a Woltring filter routine (Woltring 1986) with minimum mean square value of 15. Anova for repeated measures (SPSS 11) was used for statistical analysis.

Analyzed parameters are:

The moment arm (R) of the ground reaction force acting about the ankle and knee joint and the ratio of the moment arm of the ground reaction force to the moment arm of the tendon (r) acting about both joints (gear ratio (R/r)). The moment arms (r) of the Achilles tendon and patellar tendon were calculated using the data provided by Maganaris et al. (1998) and Herzog and Read (1993). These two parameters were calculated as the average values for five intervals throughout the ground contact phase (Part1: average value from 5-20%, Part2: 20-40%, Part3: 40-60%, Part4: 60-80%, Part5: 80-95% of the contact phase). The first and the last 5% of the contact phase were excluded from the analysis because GRF are too

small to allow an accurate calculation of the moment arm (R) due to the inaccuracies in the estimation of the point of force application from the force plate data.

RESULTS: Regarding the traditional parameters of running mechanics, a significant ($p < 0.05$) lower maximum vertical ground reaction force (Barefoot: 27.8 N/Kg; Shoe1: 28.8 N/Kg; Shoe2: 28.9 N/Kg; Shoe3: 28.8 N/Kg; Shoe4: 28.8 N/Kg; Shoe5: 28.7 N/Kg) and significant shorter contact times ($p < 0.05$) during barefoot versus shod running were found. However, the differences in contact time don't exceed 12ms ($p < 0.05$). In relation to joint kinetics and kinematics an increase in knee extension and a lower maximum knee joint moment in middle stance (Figure 1) for the barefoot condition, was detected.

Compared to shod running conditions, barefoot running on grass showed higher gear ratio values (R/r) at the ankle joint in the first and second part of the ground contact phase (Figure 1, $p < 0.05$). In the fifth part (80%-95%) the gear ratio at the ankle joint during barefoot running showed significantly lower values ($p < 0.01$).

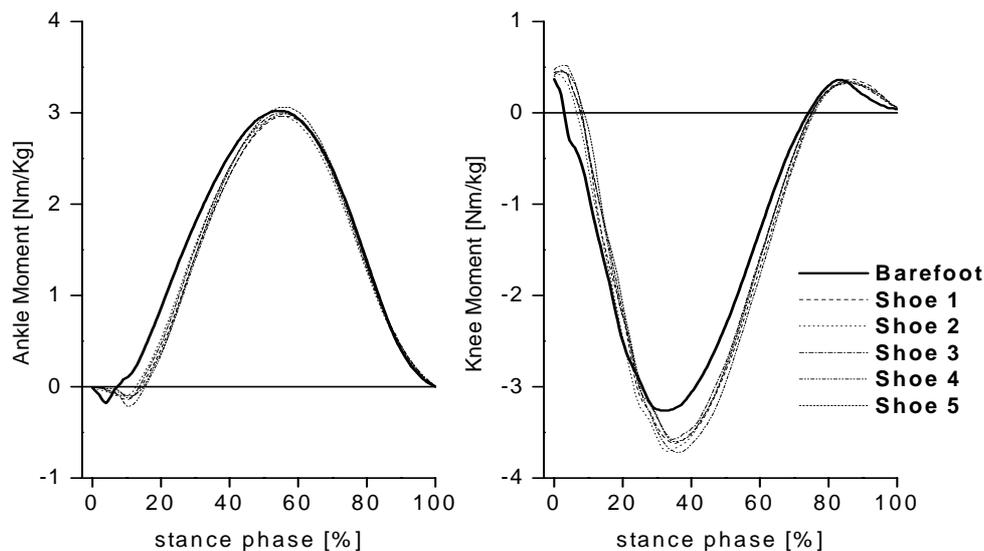


Figure 1: Sagittal plane knee and ankle moments for barefoot and the five shod conditions. The data were normalized as follows: 0% to 100%, ground contact.

The deviating gear ratios (Figure 2) are due mainly to the differences in the moment arm (Figure 1) of the ground reaction force acting about the ankle joint. In part 1-3 the moment arm of the ground reaction force (GRF) acting about the ankle joint in barefoot running is significantly longer ($p > 0.05$) than in shod running, which results in significantly ($p > 0.05$) higher ankle moments for the barefoot condition in the first part of stance (5%-20%). In the fifth part, the moment arm of the ground reaction force to the ankle joint centre is significantly smaller ($p < 0.01$) as in shod running.

Regarding differences between the shoes we only detect differences between two shoes in the first part of ground contact phase. Compared with shoe2 a greater ($p < 0.01$) moment arm of the GRF while running with shoe4 in the first part of the ground contact phase was found. This results in a significantly lower ($p < 0.01$) gear ratio value in the first part for shoe2.

At the knee joint barefoot running caused a higher gear ratio during the first part (5%-20%) of contact phase. Those differences are significant ($p < 0.05$) in relation to shoe 2, 4 and 5. In part three, barefoot running on grass showed significantly lower gear ratio values ($p < 0.01$) than shod running.

Logically consistent in part three, the moment arm of the GRF acting about the knee joint during barefoot running is smaller ($p < 0.01$ for shoe 1,2,3,4; $p < 0.05$ for shoe5) than in shod running (Figure 2). In difference to the gear ratio at ankle joint the changed gear ratio at the knee joint in part three is due to changes in the moment arm of the GRF ($p < 0.01$ for shoe 1,2,3,4; $p < 0.05$ for shoe5) and the moment arm of the patellar tendon ($p < 0.01$). The changes

in moment arm length of the patellar tendon result from different kinematics in the knee joint. Compared with the changes of the moment arm of the GRF, the changes of the moment arm of the patellar tendon are to be neglected.

Similar to part three, during the fifth part (80-95%) of the ground contact, the gear ratio at the knee joint is significantly ($p < 0.01$) lower (lower negative values) in barefoot running compared to shod running. Consistently, the moment arm of the GRF acting about the knee joint is significantly ($p < 0.01$) smaller in barefoot running (Figure 2). The five different shoe conditions showed no functionally relevant differences concerning the gear ratios, moment arms or angles at the knee and ankle joint.

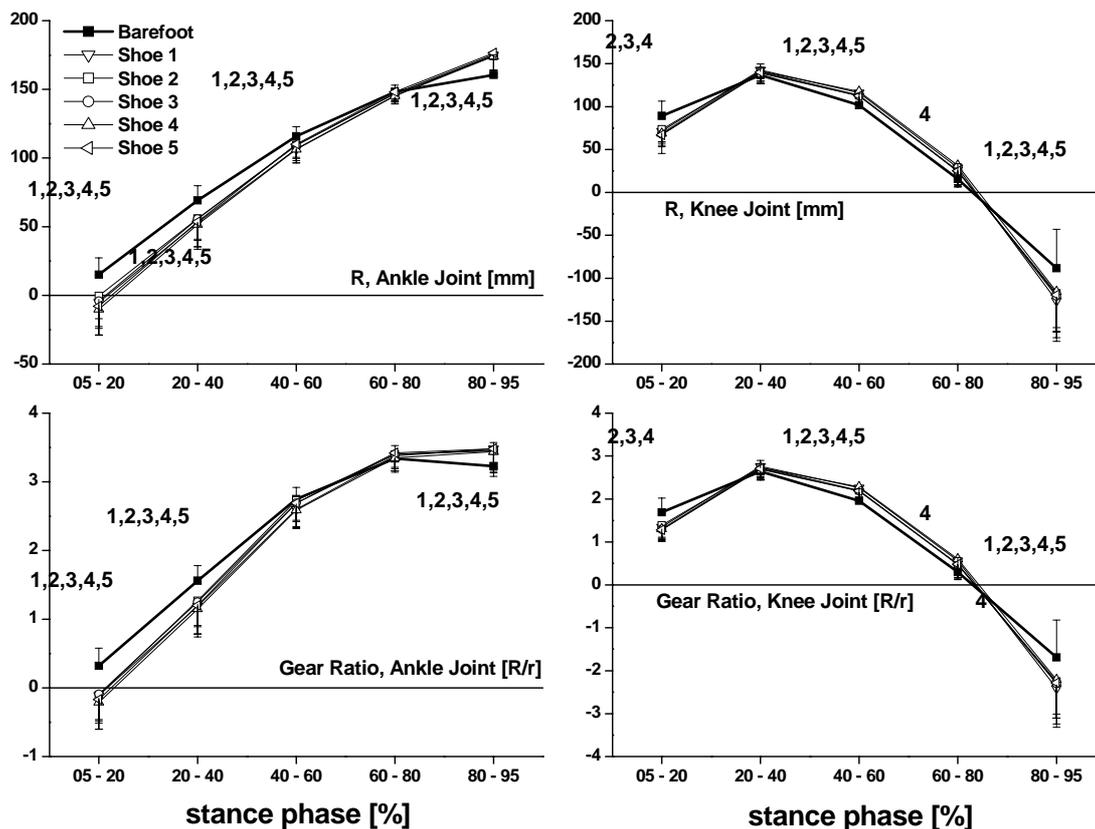


Figure 2: Moment arms of the GRF (R) and gear ratios (R/r) at the ankle and knee joint during stance.

- ¹ statistically significant differences ($p < 0.05$) of the barefoot condition to Shoe 1
- ² statistically significant differences ($p < 0.05$) of the barefoot condition to Shoe 2
- ³ statistically significant differences ($p < 0.05$) of the barefoot condition to Shoe 3
- ⁴ statistically significant differences ($p < 0.05$) of the barefoot condition to Shoe 4
- ⁵ statistically significant differences ($p < 0.05$) of the barefoot condition to Shoe 5

DISCUSSION: The comparison of running barefoot on grass and shod running on tartan showed differences in the gear ratio depending on the external conditions. This effect is contrary in the knee versus the ankle joint. A lower gear ratio increases the mechanical advantage for the muscles (Biewener 2004). Therefore, the increased mechanical advantage could contribute to effectiveness of running mechanics. The gear ratio and, as a consequence, the effective mechanical advantage of the muscles can be changed by influencing the moment arm of the GRF and/or the moment arm of the muscles. According to De Wit et al. (2000) in this study the knee joint is more extended (during 40%-60% of stance) while running barefoot compared to shod running, which results in significantly higher moment arm of the patellar tendon in barefoot condition. At the knee joint the comparison of barefoot and shod running showed higher mechanical advantages for the barefoot running condition.

Oppositely, during the final part of the ground contact phase, where GRF are lower, a high gear ratio at the ankle should be related to keeping the muscle operating at a lower velocity and in the higher force portion of the force-velocity curve (Carrier, 1994). This way the muscles may have a higher potential to generate forces due to their force velocity relationship. In relation to running effectiveness, the results of the gear ratio at the ankle joint (first and second part higher; last part lower during barefoot), could be interpreted as a disadvantage for the barefoot condition.

This study does not allow the conclusion that the differences are due to the surface or to the shoes. Regarding the influence of different shoe types, the results indicate that there might be an influence on the gear ratio at the ankle in the first part of ground reaction phase.

CONCLUSION: In conclusion the comparison of barefoot and shod running showed different effects concerning the gear ratio at the ankle and knee joint. Running with shoes showed mechanical advantages at the ankle joint in the first, second and fifth part of the ground contact phase but caused disadvantages at the knee joint in the third and fifth part of stance.

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