Carbitex **2016**

Evaluation of Gearing Footwear

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UNIVERSITY OF CALGARY KINESIOLOGY

A research report for Carbitex to evaluate gearing footwear during walking, running and kicking.

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Executive Summary

Carbitex, has developed proprietary materials which allow for stiffness modifications as a function of flexion angle. This exclusive technology is well-suited to the function of many aspects of athletic footwear, including footwear gearing. While mechanically the materials perform as designed, Carbitex would like to know how the technology functions under realistic movements, such as during walking, running and sprinting. Additionally, Carbitex's latest developments include material systems with variable directional stiffness. This concept is also relevant within soccer footwear as it could provide support for the foot during kicking by preventing excessive MTP flexion.

Therefore, the purpose of this project was to evaluate the influence of gearing technology (a variable and directional forefoot bending stiffness shoe) on 1) the amount of forefoot bending and position of the center of pressure under the foot during locomotion and 2) amount of forefoot bending during kicking.

Ten athletes participated in this study and performed walking and running at various speeds in three footwear conditions that had different magnitudes of forefoot bending stiffness: Control, F016 and F070. Additionally, athletes performed maximal effort kicking in two footwear conditions that had different magnitudes of forefoot bending stiffness: Control and F073. Kinematic and kinetic data were recorded during each movement to determine the potential performance benefit and injury risk that result from each footwear condition.

At the MTP joint, as running speed increased (and normal MTP bending range of motion increased) the stiff insoles reduced the amount of MTP being of the shoes and shifted the centre of pressure more anteriorly, while reducing the medial-lateral movement of the centre of pressure. Athlete movement patterns were also influenced by the stiff insoles, with athletes increasing their body lean, which increased their ability to generate a higher knee joint moment. Additionally, the stiff Carbitex insoles reduced key biomechanical injury risk variables, such as non-sagittal plane joint loading at the knee and ankle joints.

During kicking, while no increased kicking performance was observed, the Carbitex insole displayed a strong trend of restricting the amount of MTP flexion during ball contact. This result is encouraging as it suggests that the Carbitex insole has the potential to reduce the risk of athletes suffering a foot injury during kicking.

While these initial Carbitex insoles did provide positive results to the athletes, potential exists to further tune and utilize the gearing aspects of these insoles during running. Specifically, insoles that have increased bending stiffness at lower bending angles should be investigated to potentially facilitate these gearing benefits for athletes at lower running speeds.

Introduction

The gearing of footwear, which alters the metatarsalphalangeal (MTP) joint bending as a function of forefoot bending stiffness, has been postulated as a method of improving athletic performance and reducing the risk of injury during many sports, specifically soccer. As the shoe moves through greater amounts of bending, forefoot stiffness should increase non-linearly, to shift the centre of pressure forward (improving performance), while restricting forefoot bending into regions where turf-toe injury may result.

Carbitex, has developed proprietary materials which allow for stiffness modifications as a function of flexion angle. This exclusive technology is well-suited to the function of many aspects of athletic footwear, including footwear gearing. While mechanically the materials perform as designed, Carbitex would like to know how the technology functions under realistic movements, such as during walking, running and sprinting. Specifically, it remains to be determined if the changes in bending stiffness are sufficient to limit excessive forefoot bending (reduce injury) and shift the center of pressure (alter the lever arm – improve performance). Additionally, Carbitex's latest developments include material systems with variable directional stiffness. This concept is also relevant within soccer footwear as it provides support for the foot during kicking by preventing excessive MTP flexion. During the kick, excessive MTP joint flexion could cause toe injury or could reduce kicking performance due to this flexion causing a loss of energy at the MTP joint, however, both aspects need to be verified.

Therefore, the purpose of this project was to evaluate the influence of gearing technology (a variable and directional forefoot bending stiffness shoe) on 1) the amount of forefoot bending and position of the center of pressure under the foot during locomotion and 2) amount of forefoot bending during kicking.

Methods

Ten male recreational athletes participated in this study with the characteristics of the participants displayed in Table 1. Informed written consent was obtained from all participants prior to data collection in accordance with the Conjoint Health Research Ethics Board at the University of Calgary. Four footwear conditions were investigated in this experiment, with all footwear conditions consisting of an altered US 10 adidas 16.4 FXG cleat (Figure 1). The footwear was altered by placing carbon fibre insoles, custom made by Carbitex, into the adidas cleat. Placing different insoles into the footwear created four different footwear conditions: Control, F016, F070 and F073.

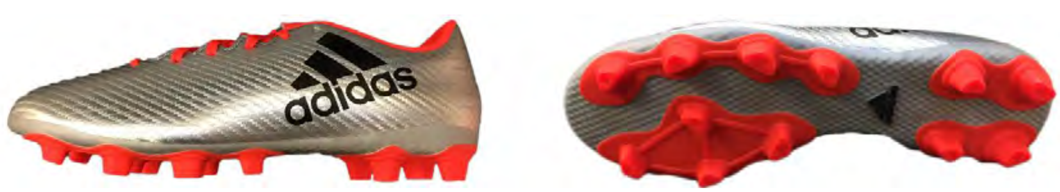

Figure 1. Photographs of the footwear used by all participants during biomechanical testing.

Table 1. Characteristics of the ten athletes that participated in the study.

Athlete	Height [m]	Mass [kg]
1	1.90	82.0
2	1.74	74.5
3	1.78	77.0
4	1.81	76.0
5	1.73	59.5
6	1.68	64.0
7	1.78	78.5
8	1.83	76.0
9	1.80	55.0
10	1.85	81.0
Mean	1.79	72.4

The Control footwear consisted of the standard adidas cleat; F016 and F070 consisted of the adidas cleat with different gearing insoles inserted into the footwear, while F073 was the adidas cleat with a special kicking insole inserted that resisted hyper-flexion of the toes. The stiffness of the Control (adidas cleat with no insole) and the F016 and F070 gearing insoles was measured using the FAST forefoot bending stiffness tester (Figure 3).

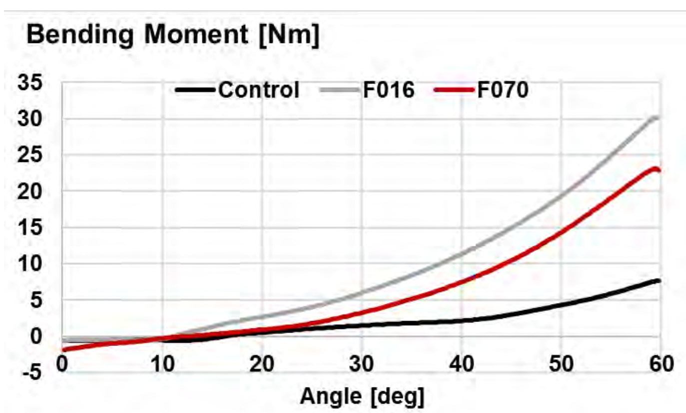

Figure 3. Results of the FAST forefoot bending stiffness measurement system of the different footwear conditions.

The experiment consisted of athletes performing linear locomotion at five different speeds: 1.5 m/s (Walking), 3.5 m/s (Slow Run), 5.0 m/s (Medium Run), 7.5 m/s (Fast Run) and at maximum effort (Sprint). Five successful trials were obtained for each movement speed with data being collected on the left foot and lower leg. Movement speed was controlled using photocells placed 2.0 m apart. For the maximal effort sprint, the athletes were given the freedom to start from whatever position was comfortable to them and they were instructed to land with their second footfall (with their left foot) in the center of the force platform (Figure 4). Performance was also measured during the Sprint and was defined as the time it took the athlete to travel 5-meters measured with Brower timing lights. Participants performed walking, running and sprinting trials in three footwear conditions: Control, F016 and F070.

Figure 4. Photograph of a participant performing the Sprint.

Additionally, data was collected during maximal effort kicking. For the kicking trials, the soccer ball was placed at the side of the force platform and the athletes were instructed to perform a maximal effort shot (Figure 5). Participants performed kicking trials in two footwear conditions: Control and F073.

Figure 5. Photograph of a participant performing a kicking trial.

During each running and kicking trial, kinetic and kinematic data were collected for the left foot/leg using a Kistler force platform operating at 2400 Hz and an 8-camera motion analysis system operating at 240 Hz. Spherical retro-reflective markers were attached to the shank and shoe for kinematic data collection (Figure 6). The metatarsophalangeal (MTP), ankle and knee joint center were determined using a standing neutral trial with additional markers placed on the head of the first and fifth metatarsal (MTP), the medial and lateral malleolus (ankle) and medial and lateral epicondyles (knee).

Figure 6. Photograph of the marker placement on the lower leg.

Statistics

The kinematic and kinetic data were analyzed with Kintrak 7.0.25 (Human Performance Laboratory, University of Calgary, Canada) and Matlab. For joint moments, the internal resultant joint moments were calculated using an inverse dynamics approach. Data were then compared using a paired t-test at the 95% level of confidence with trends in the data being highlighted at a 90% level of confidence. All comparisons were made relative to the Control condition only (F016 to Control, F070 to Control and F073 to Control).

Results and Discussion

Running Performance

No performance differences were observed during the 5-meter sprint in any of the footwear conditions (Figure 7).

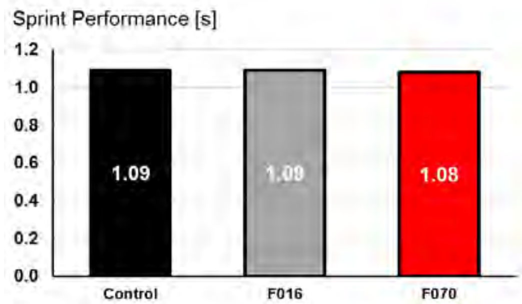

Figure 7. Performance during the 5-meter sprint in the three different insole conditions. Data represent the mean of all ten participants.

The amount of MTP bending during the stance phase of running at the four different speeds is shown in Figure 8. During the slow, medium and fast running speeds no significant differences in MTP bending were present in either gearing shoe condition when compared to the Control. However, during the sprint movement where larger MTP range of motion occurred, peak MTP bending was significantly reduced in the F070 condition, with a strong trend of reduced MTP bending also occurring for the F016 insole. This result indicates that the gearing aspect of the shoe is functional with the reduced MTP bending occurring at greater bending angles (~40°) where the insoles become stiffer. Overall, the Carbitex insoles were most successful at implementing the desired gearing functionality at the faster running speeds. Future iterations of Carbitex insoles could alter the bending stiffness profile to introduce aspects of gearing at lower running speeds, thus providing the potential benefits of gearing to athletes across a wide range of speeds.

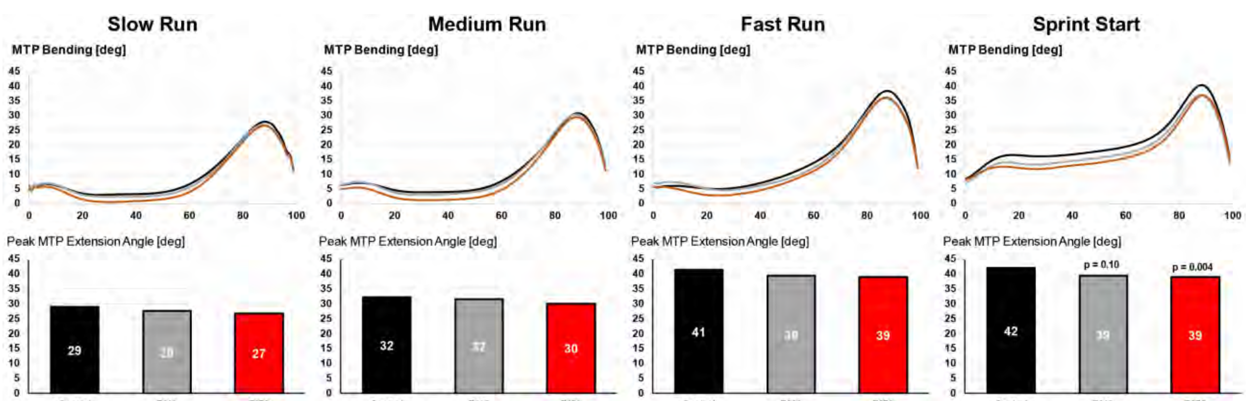

Figure 8. MTP bending angle curves and peak values during the Slow Run (column 1), Medium Run (column 2), Fast Run (column 3) and Sprint start (column 4). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

When the center of pressure was examined (Figure 9), in general the F016 moved the center of pressure more anteriorly and closer to the midline of the foot (medial-lateral) when compared to the Control. The F070 did not move the center of pressure anteriorly, but shifted the center of pressure closer to the midline of the foot (medial-lateral).

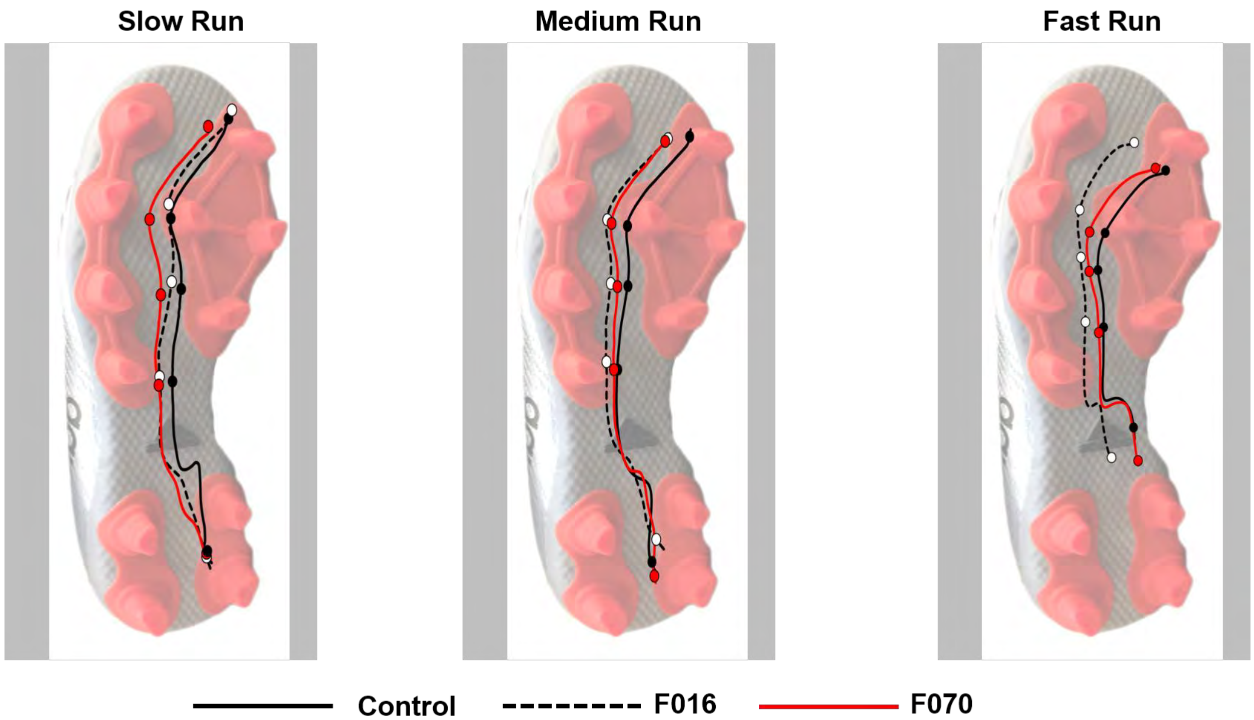

Figure 9. Movement of the centre of pressure under the foot during running.

Aside from shifting the center of pressure, the increased forefoot bending stiffness of the gearing footwear caused the athletes to place their foot in a more plantarflexed position on the ground (Figure 10), in addition to increasing the amount of ankle dorsiflexion (Figure 11).

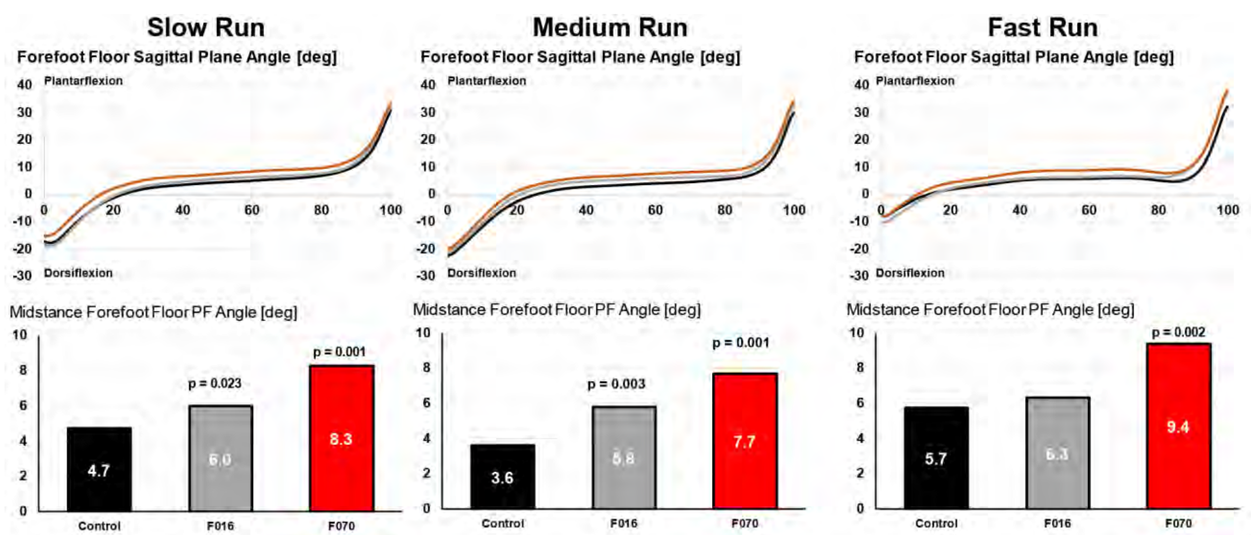

Figure 10. Forefoot floor sagittal plane angle curves and peak values during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

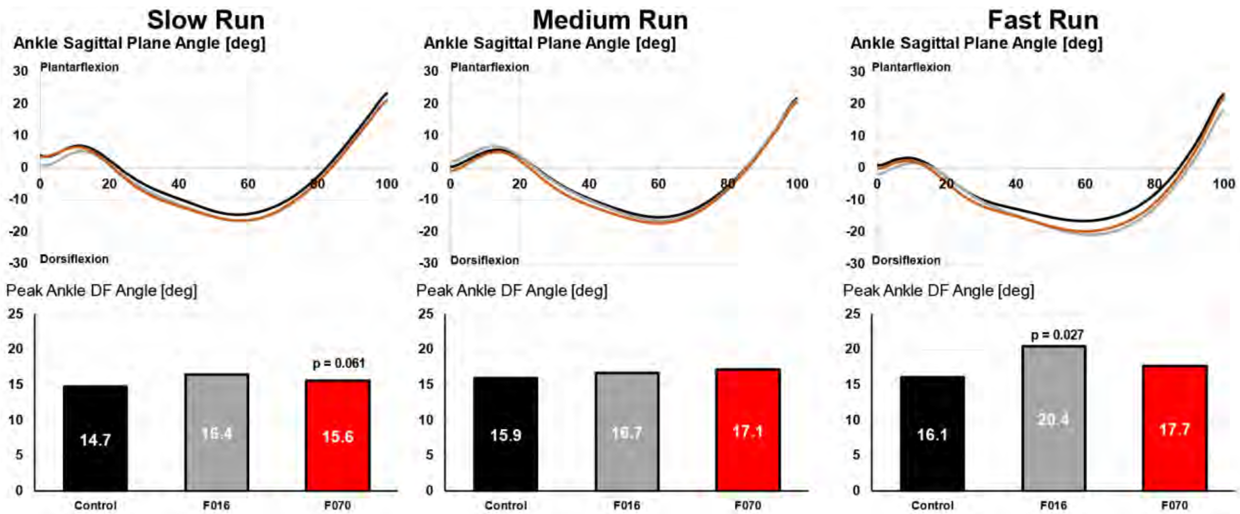

Figure 11. Ankle sagittal plane angle curves and peak values during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

By increasing the foot plantarflexion and maintaining or slightly increasing the amount of ankle dorsiflexion, the athletes attained a more forward-leaning orientation, with the forward lean being represented by the amount of shank lean (shank angle relative to the floor) during each run (Figure 12). An overview of the changes in movement patterns for the athletes when running in the stiff insoles is shown in Figure 13.

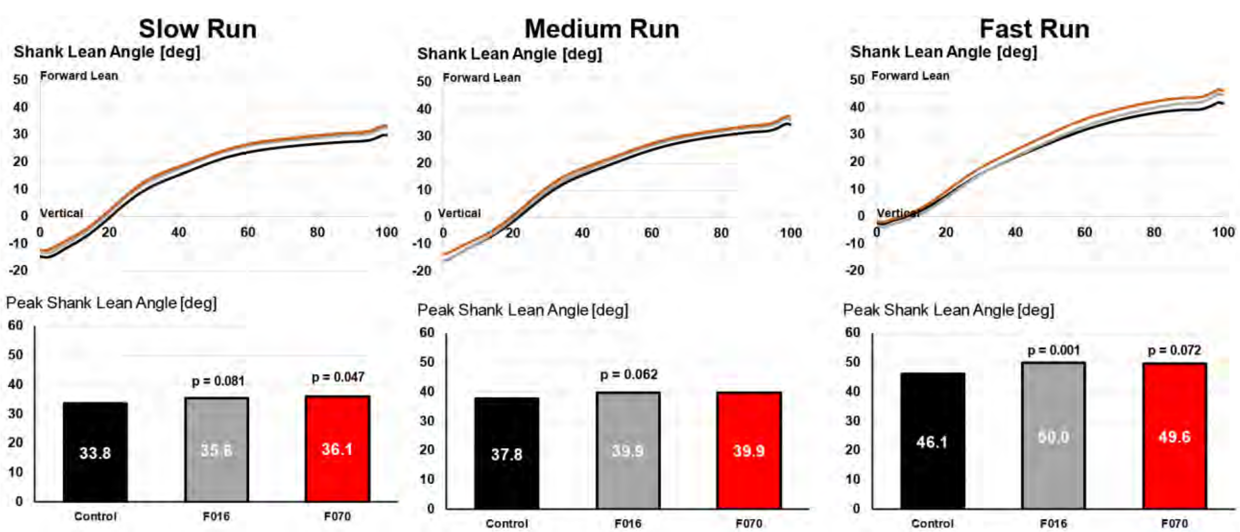

Figure 12. Shank floor sagittal plane angle curves and peak values during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

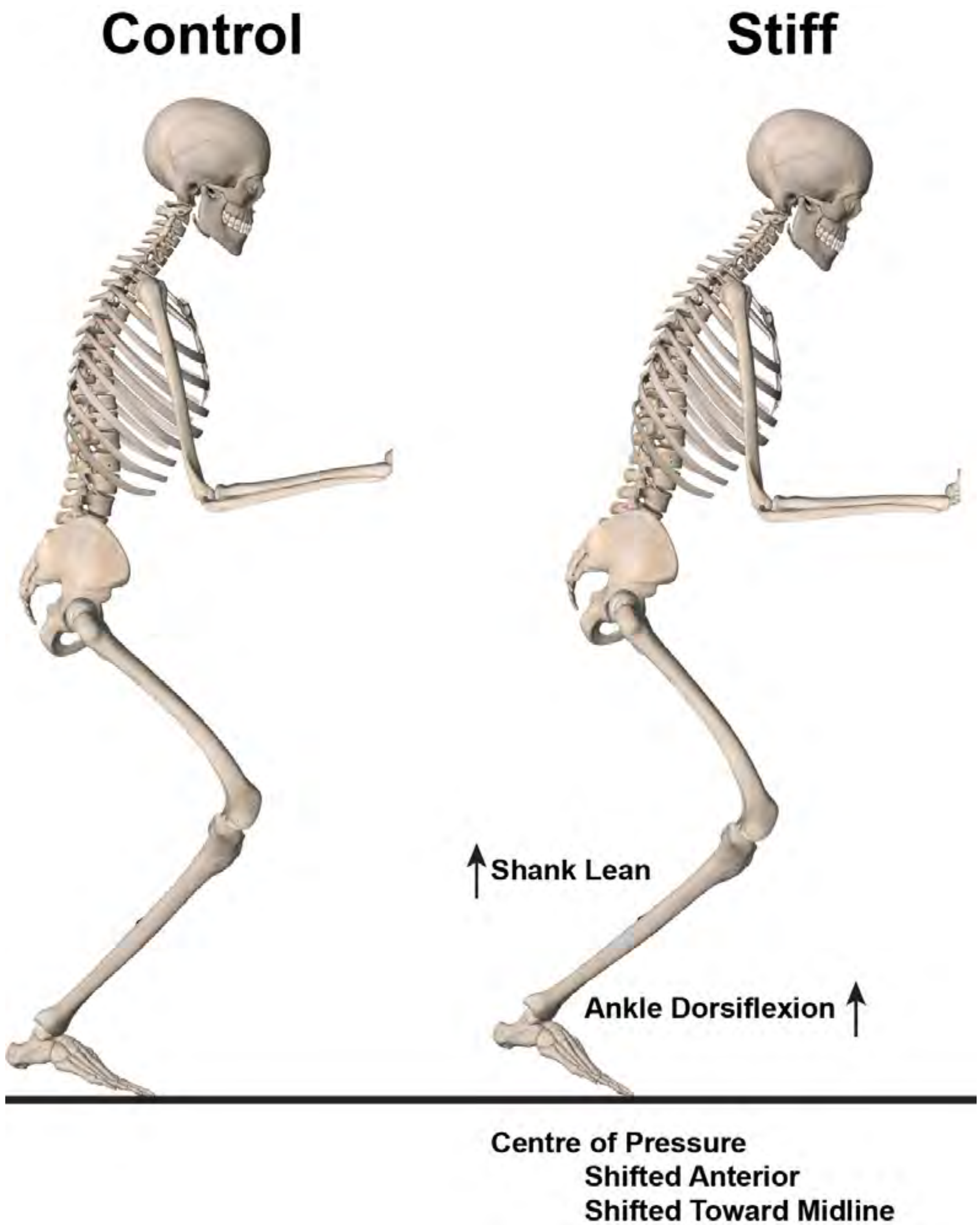

Figure 13. Overview of movement pattern changes of the athletes.

As the athletes increased their shank (body) lean, the sagittal plane joint loading at the knee joint increased (Figure 14) while the joint loading at the ankle joint was kept constant (Figure 15), independent of running speed. Sagittal plane joint loading is thought to be associated with the performance of linear movements, therefore this increased joint loading at the knee may assist in flexing and extending the leg during running, leading to increased performance.

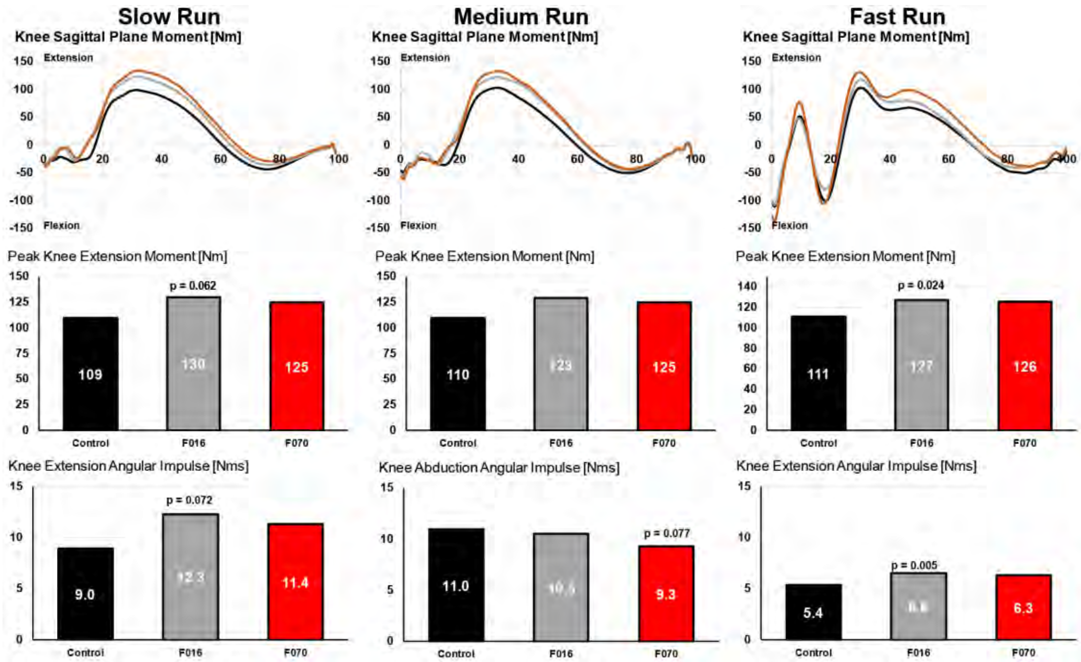

Figure 14. Knee joint sagittal plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

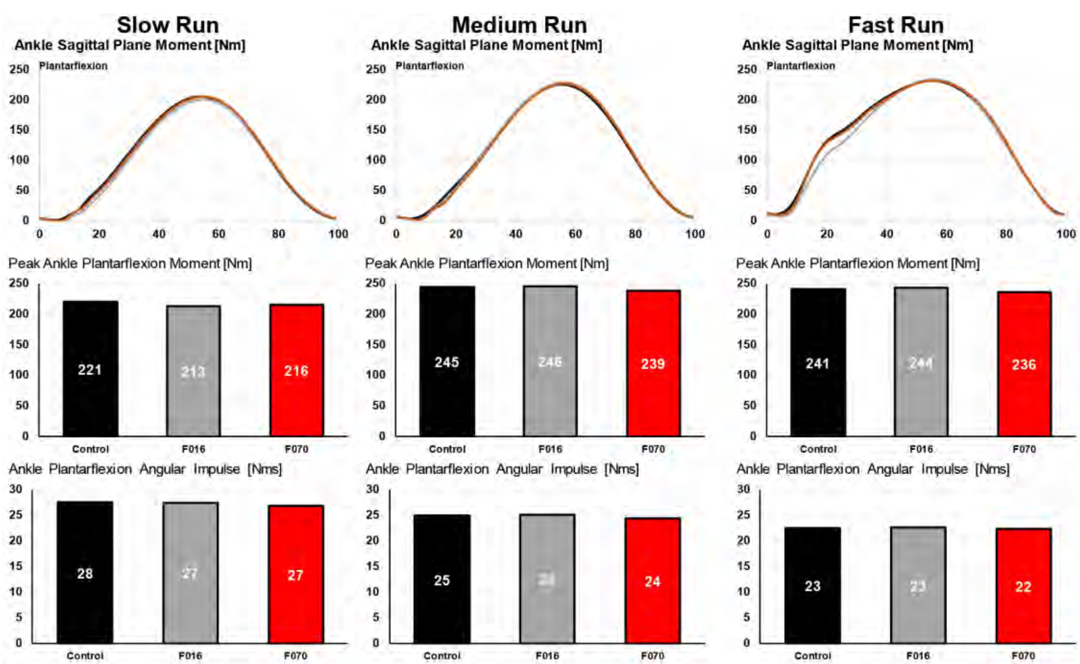

Figure 15. Ankle joint sagittal plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Running Injury Risk

In addition to the performance variables that were analyzed, biomechanical variables associated with injury risk were also investigated. It is generally thought that increased non-sagittal plane joint loading can lead to joint injury (Hewett et al. 2005; Sharma et al. 1998; Shin et al. 2009; Stefanyshyn et al. 2006). In biomechanics research, joint loading is estimated by calculating resultant joint moments, which represent the net torque or twisting loads on the joint, and joint angular impulse, which represents the cumulative loading experienced by the joint throughout the stance phase of a movement (calculated as the integral of the resultant joint moment vs. time curve). While joint moments and angular impulse calculated from inverse dynamics cannot determine the exact loading on the actual joint structures, these measures have been used as valid predictors of the total load across a joint (Hurwitz et al. 1998; Thorp et al. 2006).

In general, both gearing insoles had a positive effect in terms of reducing potential injury risk. At the ankle joint, inserting the F070 gearing insole reduced the peak and cumulative transverse plane joint loading during the medium and slow runs (Figure 16).

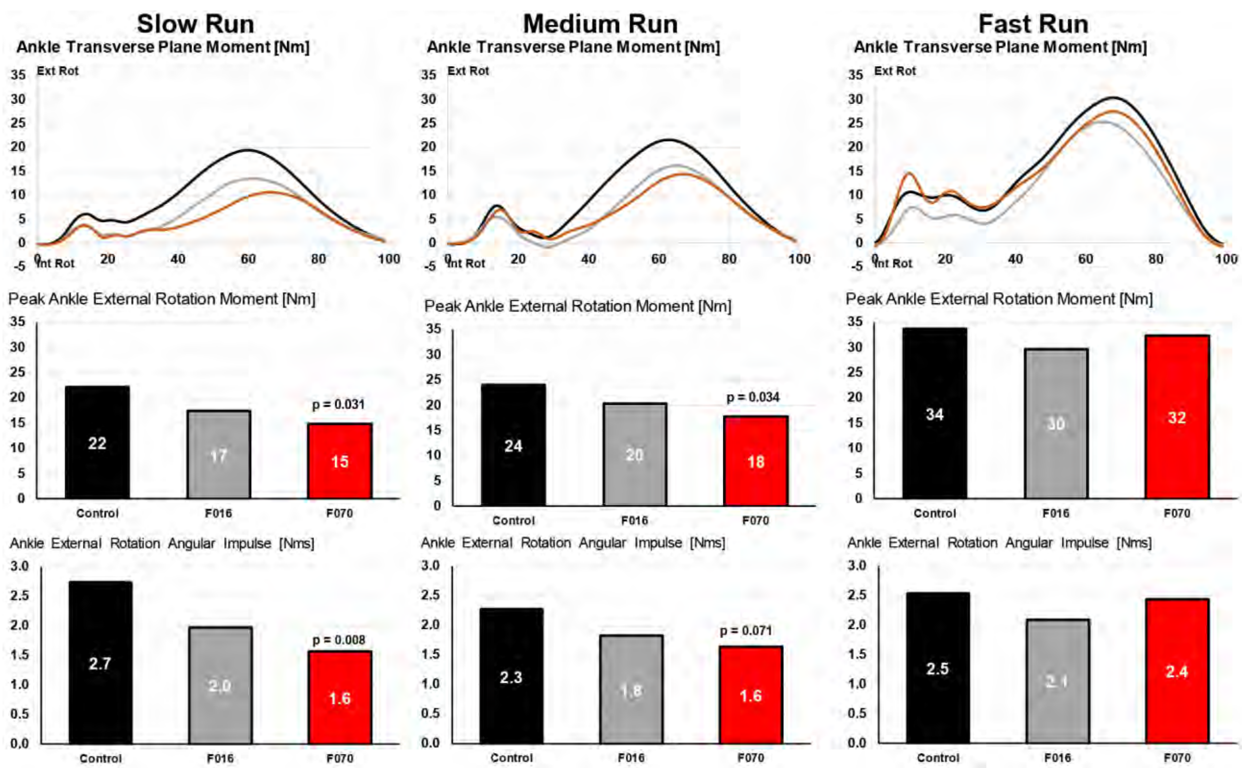

Figure 16. Ankle joint transverse plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Similarly, in the frontal plane at the ankle joint, the F070 significantly reduced the cumulative loading during the slow and fast runs (Figure 17). This result is very positive as it has been shown that 90% of all ligamentous injuries at the ankle are caused by internal rotation (transverse plane movement) and inversion (frontal plane movement) of the foot (Stacoff et al. 1996).

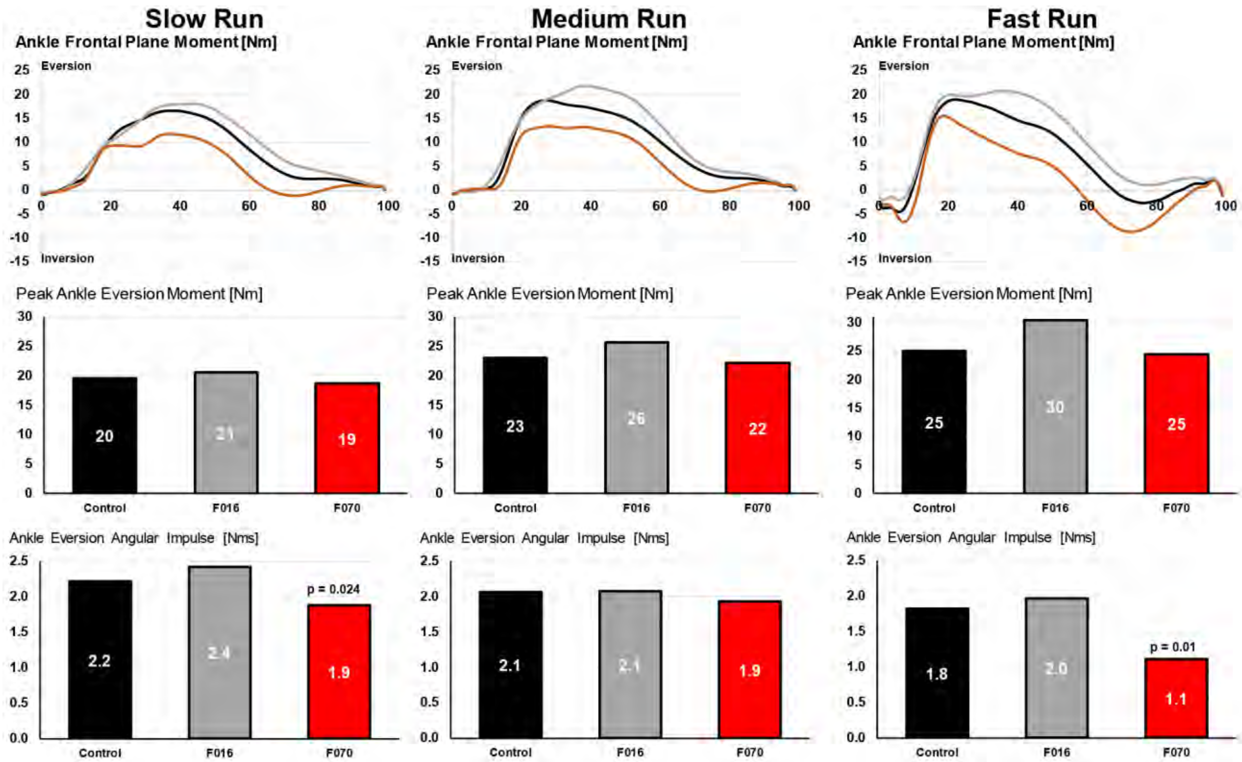

Figure 17. Ankle joint frontal plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Similar results were seen at the knee joint, with the gearing insoles (both the F016 and F070) having the trend of significantly reducing the peak and cumulative transverse (Figure 18) and frontal plane joint loading (Figure 19).

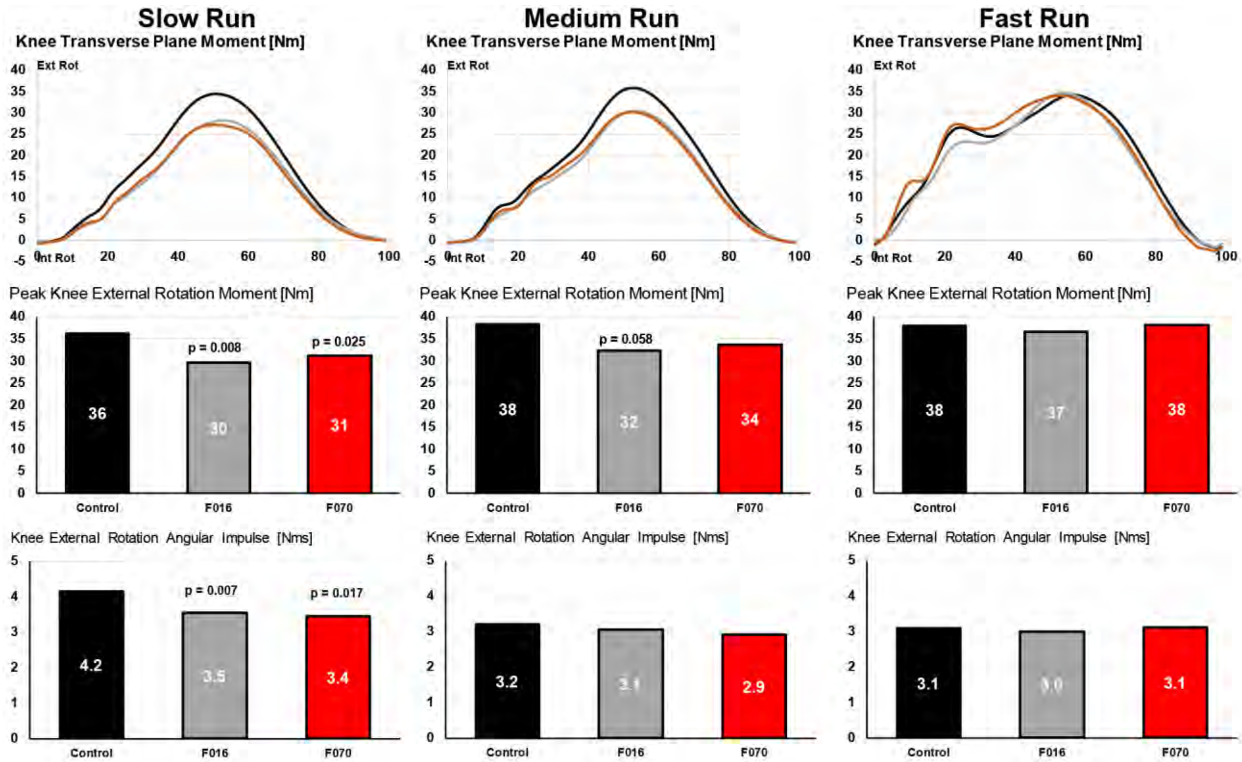

Figure 18. Knee joint transverse plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Again, this result is positive in terms of injury risk as increases in cumulative loading have been directly linked to chronic types of injuries such as patellofemoral pain syndrome (Stefanyshyn et al. 2006) and osteoarthritis (Thorp et al. 2006). Therefore, utilization of these gearing insoles in athletic footwear would reduce the joint loading at the knee and ankle joint during running, which may decrease the injury risk of athletes.

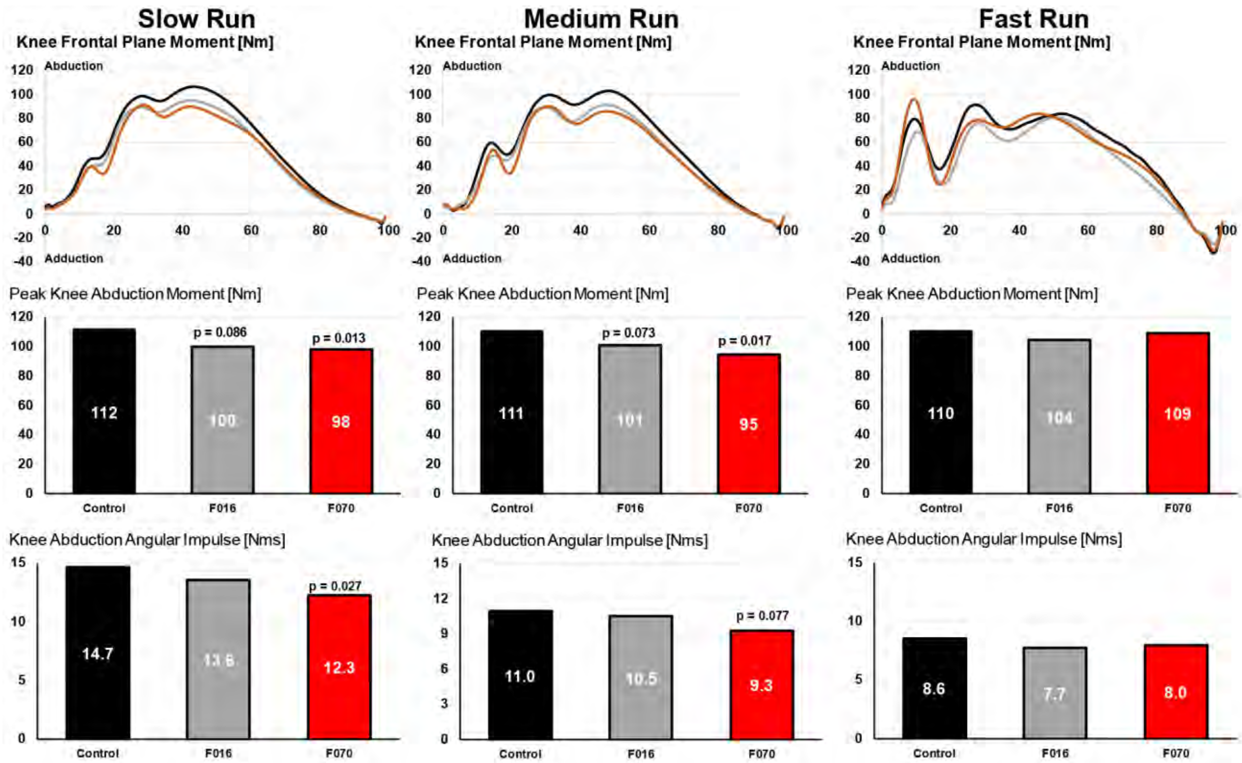

Figure 19. Knee joint frontal plane moment curves (top row), peak values (middle row) and angular impulse (bottom row) during the Slow Run (column 1), Medium Run (column 2) and Fast Run (column 3). Data represent the mean of all ten athletes. P-values indicates significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Kicking

There were no significant differences in terms of kicking performance when the stiff insole was inserted into the shoe, as maximum ball velocity was similar between conditions (Figure 20).

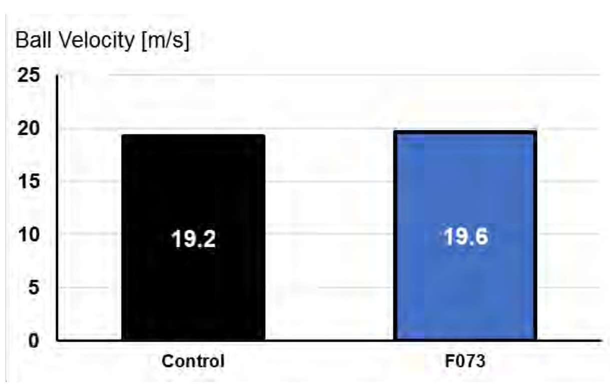

Figure 20. Maximum ball velocity measured during the kicking movement. Data represent the mean of all ten athletes.

Although there was no difference in kicking performance, the stiff insole had the trend of reducing the peak amount of MTP bending during the kick (Figure 21). This reduction in bending could result in a decrease in kicking toe flexion injuries during soccer. While the peak MTP flexion angle was reduced, no change in ankle angle was seen.

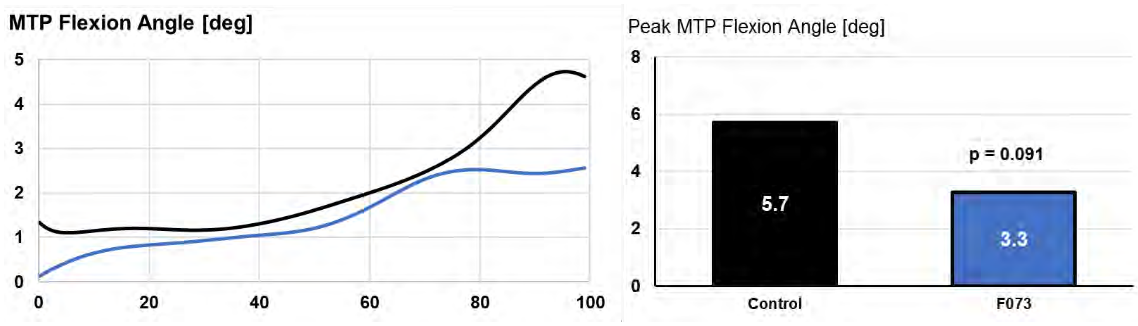

Figure 21. MTP flexion angle curves (left) and peak MTP flexion angle during the kick. Data is normalized from initial ball contact (0) to maximum ball velocity (100). Data represent the mean of all ten athletes. P-values indicate significant differences ($p < 0.05$) and trends ($p < 0.10$) when compared with the Control condition.

Summary

The purpose of the study was to investigate the influence of gearing technology on lower extremity biomechanics during walking, running, sprinting and kicking. The results of the study indicate that the Carbitex insoles created for the study did provide athletes with gearing functionality and positively influenced their lower extremity biomechanics.

At the MTP joint, as running speed increased (and normal MTP bending range of motion increased) the stiff insoles reduced the amount of MTP being of the shoes and shifted the centre of pressure more anteriorly, while reducing the medial-lateral movement of the centre of pressure. Athlete movement patterns were also influenced by the stiff insoles, with athletes increasing their body lean, which increased their ability to generate a higher knee joint moment. Additionally, the stiff Carbitex insoles reduced key biomechanical injury risk variables, such as non-sagittal plane joint loading at the knee and ankle joints.

During kicking, while no increased kicking performance was observed, the Carbitex insole displayed a strong trend of restricting the amount of MTP flexion during ball contact. This result is encouraging as it suggests that the Carbitex insole has the potential to reduce the risk of athletes suffering a toe injury during kicking.

While these initial Carbitex insoles did provide positive results to the athletes, potential exists to further tune and utilize the gearing aspects of these insoles during running. Specifically, insoles that have increased bending stiffness at lower bending angles should be investigated to potentially facilitate these gearing benefits for athletes at lower running speeds.

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