Do different running shoes affect the joint moments on hip, knee, and ankle?

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Introduction: Running is a popular sport, but it is associated with a high risk of injury. Previous research has shown that running shoes are a factor. However, fewer studies have investigated how the different features affect internal loading while many have focused on ground reaction force. The aim of this study is to investigate how wearing five different types of running shoes, ranging from minimalist to carbon running shoes, affects the joint moments around hip, knee and ankle.

Method: 28 participants attended a test session where they had to wear five different running shoes in a randomized order. Each measurement lasted for 4.5 minutes, during which they had to run at a speed of 2.78 m/s (10 km/h). Kinetic and kinematic data were measured during each session to estimate the joint moments on hip, knee and ankle.

Results: showed significant differences when comparing each of the shoes with each other. Specifically, minimalist shoes resulted in higher peak ankle moments, while maximalist shoes resulted in lower peak hip moments.

Conclusion: The findings suggest that shoe design influences peak joint moment, showing the importance of selecting appropriate footwear for injury prevention and performance optimization in runners. Further research is needed to investigate how the running shoes effect on tissue level but also to investigate if there are any gender differences in response to different shoe designs.

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Abstract

Running is a popular activity known for its mental and psychological benefits, but it also carries a high risk of injury, particularly to the lower limbs. While previous studies have identified several factors contributing to this risk, including running shoes, fewer have investigated how different types of shoes affect internal loading. Most studies have focused on ground reaction forces despite not being a good predictor of the load experienced during running. Therefore, this study aims to investigate how wearing five different types of running shoes, ranging from minimalist to carbon models, affects joint moments around hip, knee, and ankle. 28 participants attended the Computer Assisted Rehabilitation Environment system once, wearing five different running shoes in a randomized order for each 4.5-minute measurement, running at 2.78 m/s (10 km/h). Kinematic and kinetic data were collected using motion capture cameras from Vicon Nexus and force plates integrated in the treadmill. A linear mixed model was performed to investigate the relationship between the five different running shoes and peak joint moments. The results showed significant differences when comparing each of the shoes with each other. Specifically, minimalist shoes resulted in higher peak ankle moments, while maximalist shoes resulted in lower peak hip moments. The findings suggest that shoe design influences peak joint moment, showing the importance of selecting appropriate footwear for injury prevention and performance optimization in runners. Further research is needed to investigate how the running shoes affect the loads on tissue level. Moreover, whether there are gender differences in response to different shoe designs needs to be investigated.

Keywords

Injury prevention, Musculoskeletal model, Training, Biomechanics, Lower limb.

Introduction

Running is a popular activity enjoyed worldwide due to clear mental and physical health benefits (Kulmala et al., 2018). Despite these benefits, running is associated with a high risk of getting injured, with an incidence rate ranging between 19.4% and 79% (Relph et al., 2022). Notably, 97% of these injuries occur in the lower limb, specifically around the knee, lower leg, foot, and ankle (Kulmala et al., 2018; Relph et al., 2022). The most common injuries among runners are patellofemoral pain, medial tibial stress syndrome, Achilles tendinopathy, and plantar fasciitis. These injuries are defined as overuse injuries and result from repetitive loading on the musculoskeletal system that exceeds the structure's capacity, leaving the body with not enough time to adapt to the applied load (Kulmala et al., 2018; Burke et al., 2023; Bertelsen et al., 2017). Different factors have been associated with an increased risk of injuries, such as the surface, running technique, and running shoes (Bertelsen et al., 2017). One approach to prevent these types of injuries is to change the design features of running shoes to reduce the impact on muscles and joints (Sinclair et al., 2016).

Running shoes have been developed with different focus areas such as motion control, amount of cushioning, and heel drop, all aimed at reducing the risk of injuries and improving performance (Relph et al., 2022). One type of running shoe is described as minimalist, designed to have limited cushioning, be flexible, and have less support to the arch (Relph et al., 2022; Agresta et al., 2022). They aim to make the runner adopt a more barefoot running style that promotes a forefoot strike pattern (Davis, 2014; Agresta et al., 2022). Another type of running shoe is maximalist. Unlike minimalist running shoes, maximalist shoes lack a standardized definition (Agresta et al., 2022). They are characterized by having a cushioning of more than 20 mm and minimal support structure, promoting a more natural running pattern similar to minimalist shoes (Agresta et al., 2022). The cushioning of maximalist running shoes can vary, with some featuring a softer sole while others has incorporated a carbon plate in the midsole, which limit the bending stiffness of the shoe. With the inclusion of a carbon plate, the runner adapts to landing more on the forefoot (Nigg et al., 2022).

Most studies have investigated how different running shoe features affect external loading such as the ground reaction force due to the relationship between loading and the risk of injury (Bertelsen et al., 2017). A study by Malisoux et al., 2020 investigated how variations in shoe cushioning affect vertical peak vertical ground reaction forces and loading rate. Another study by Squadrone and Gallozzi, 2009 investigated the difference between minimalist shoes and neutral cushioned shoes focusing on whether there was any difference in the vertical ground reaction force. Only few studies have investigated how different types of running shoes affect internal loading, despite its importance in reducing risk of injury (Arya & Kulig, 2010). This is despite that using external loading does not necessarily represent the internal load experienced during running (Gruber, 2023). Previous studies have suggested that ground reaction force may not be the most accurate predictor of injury risk, as it has been found that joint moments and angles can provide better insight into understanding internal loading (Gruber, 2023; Matijevich et al., 2019).

Some studies have investigated how different features of running shoes affect the internal loading but most of them have compared two or three specifications of the running shoes. A study by Zhang et al., 2021 investigated how four running shoes varying heel-to-toe drops affected vertical loading rate, peak knee extension moment, and peak ankle plantarflexion moment. The study found that running in shoes with larger heel-to-toe drops decreased vertical loading rate and increased peak knee extension moment. Another study by Paquette et al., 2013 investigated the acute effects of wearing minimal shoes, barefoot running, and regular running shoes on how it would affect the ground reaction force, ankle and knee kinematics and kinetics. The study showed when running, wearing minimal shoes resulted in increased ankle plantarflexor moments, while both barefoot and minimal shoes showed decreased knee flexion moments compared to traditional running shoes. Other studies have investigated carbon running shoes, but they have mostly focused on how they improve running economy, while fewer studies have focused on their impact on lower limb mechanics (Ortega et al., 2021). A study by Hoogkamer et al., 2018 aimed to investigate the enhanced running economy by analyzing lower limb mechanics, including joint moments and angles, and comparing them with two cushioned racing shoes. The study concluded that there were no significant differences in peak knee flexion moment among the different running shoes (Hoogkamer et al., 2018). The study suggest that these results could be due to a low sample size, as the study only included 10 participants. Furthermore, it was proposed to incorporate various types of running shoes, as this would help in comparing how various shoe features impact running biomechanics (Hoogkamer et al., 2018).

Therefore, this study aims to investigate how wearing five different types of running shoes, ranging from minimalist to carbon running shoes, affects the joint moments around the hip, knee, and ankle. Additionally, spatial parameters such as cadence, stance, and step time were included to see if there were any differences when wearing the five types of running shoes and to determine if these parameters could explain any possible variations in the joint moments.

Methods

This study was part of a larger test session in which participants were required to participate in three different experiments in addition to this study. This study aims to investigate how wearing five different types of running shoes, ranging from minimalist to carbon running shoes, affects the joint moments around hip, knee and ankle.

Participants

In this study, 28 participants at the age of 24.96 years (+-SD: 4.95), with 4.88 (+-SD: 3.48) years of running experience, attended the study. All the participants met the following inclusion criteria; being a healthy male between 18-45 years old, not defined as a beginner or elite runner and having been injury-free for the last six months. All participants completed the entire test session without any issues or injuries. Prior to the test session, all participants were provided with an informed consent. Furthermore, the participants were explained about the purpose and risk of participating in this study. This study was approved by the local ethics committee (FHML-REC/2023/017).

Procedure

The participants attended one test session at the Computer Assisted Rehabilitation Environment system (CAREN, Motek, The Netherlands). Before the test session, participants were asked to avoid any heavy physical activity for 36 hours, drinking alcohol within 24 hours, drinking caffeine within 6 hours, and eating a big meal within 1 hour prior to the measurement.

The test session did not include a warm-up because the participant had already completed one experiment prior to this one. Throughout the test session, the participant underwent five conditions where they wore five different running shoes in a randomized order: Saucony FastTwitch 9, Asics MetaSpeed Sky+, Decathlon KS900Light, Decathlon Kiprun carbonplate KD900X, and their own running shoes. It was chosen to include these shoes as they were different in weight, drop, stack height and stiffness which could impact the body in different ways (see appendix). The participants own running shoe was chosen to be included as it allowed for a comparison of how the selected shoes differ from what the runner already knows and prefers (Morio et al., 2020).

For each pair of running shoes, the participant ran for approximately 4.5 minutes at 10 km/h (2.78 m/s). This speed was selected because this allowed participants to complete the total running session in fully aerobic conditions. After completing the run with each pair of shoes, they were asked questions about the comfort of the shoes. During the test session, the participant was asked to run as they would outdoors.

Data collection

Before the measurement, 46 reflective markers were placed on the body according to the full human body (Human body model version 3) (Van Den Bogert et al., 2013). These markers were placed to measure the movement of the anatomical landmarks: trunk (four markers), pelvis (four markers), leg (four markers on each side), feet (five on each), head (four markers), upper arm (four markers on each) and forearm/ hand (four markers on each). Prior to the measurement, a subject calibration was performed during which the participant stood with their feet hip-width apart, maintained a straight back, and extended their arms out to the sides. This was completed to determine the position of the joint centers, bone lengths and joint axes (Van Den Bogert et al., 2013). Additionally, it also functioned as a reference frame to make sure the Human Body model (HBM) accurately corresponded to the anatomical lengths of the participant during the measurement (Van Den Bogert et al., 2013).

For each condition, kinematic data and kinetic data were captured at a sampling frequency of 100 Hz using the CAREN. The system consisted of 12 motion capture cameras (Vicon Nexus, version 2.8.1, Oxford Metrics Group, Oxford, UK) positioned around the treadmill. Kinetic data was measured with the force plates integrated in the split treadmill (length and width per. belt 2.15 ×0.5m, 6.28 kW motor per belt). For each condition, both kinematic and kinetic data were captured for approximately 4.5 minutes.

Data processing

Musculoskeletal model

The measured kinematic and kinetic data were imported into the Gait Offline Analysis Tool 4.2 (Motek ForceLink B.V., Amsterdam) aiming to estimate joint moments for the hip, knee, and ankle. Before estimating the joint moments, a low-pass Butterworth filter at 20 Hz was applied on the data to remove any unwanted noise.

To estimate the joint moment for each measurement, the musculoskeletal Human body model (HBM version 3), consisting of 18 segments, 46 degrees of freedom, and 300 muscles, was used. The mass and dimensions of the musculoskeletal model were scaled to match the participant's proportions and total body mass. This was determined during the calibration pose, where the markers placed on the participant served as joint centers and were used to calculate the lengths of each segment (Van Den Bogert et al., 2013). Inverse kinematics were performed to determine the joint angles and positions of the markers. This process was executed during the calibration pose, during which the system established a subject reference frame that was adjusted to fit real-time marker position using a global optimization approach. Inverse dynamics was performed to determine the moments and forces acting on each joint (Van Den Bogert et al., 2013).

The output from inverse dynamics was imported into a customized Matlab script, which was used to time normalize each measurement from 0% to 100% of the gait cycle over a 60-second period of steady-speed running. The peak joint moment was taken for the 60 seconds of steady speed running which then was normalized relative to the participant's weight. The peak values for the joint moments of hip flexion, knee extension, and plantarflexion ankle were used for statistical analysis because they can describe how the different running shoes affect the loading on these joints (Holder et al., 2020).

Statistics

The statistical analysis was performed using SPSS (IBM, version 29.00), where a linear mixed model was performed to investigate the relationship between the dependent variable, defined as the peak joint moments for the hip flexion, knee extension, and plantarflexion ankle, and the independent variable, which was the five different running shoes: Saucony FastTwitch 9, Asics MetaSpeed Sky+, Decathlon KS900Light, Decathlon Kiprun Carbonplate KD900X, and their own running shoes. Additionally, another linear mixed model was executed to investigate the relationship between spatial parameters and the five running shoes (Schielzeth et al., 2020). Prior to running the linear mixed model, the data were checked to ensure normal distribution by examining boxplots. In the case of the boxplots showing any skewed distribution then outliers were removed. Specifically, 5 measurements were excluded for the peak hip flexion moment, 12 for the knee moment, and 6 for the ankle angle moment. These measurements were removed because they significantly impacted the results and might have been affected by technical errors (see Appendix). The new boxplots for peak joint moments were used for the analysis.

Pairwise comparison was used to analyze the data, as it could detect between which shoes there were significant differences. Furthermore, marginal means were used to calculate the averages for peak joint moments and spatial parameters, aiming to investigate how the different running shoes affect these parameters. The significance level was set at 0.05.

Results

28 participants were used for the statistical analysis as they completed the entire measurement without any technical issues.

Peak hip flexion moment

The outcome of the linear mixed model showed a significant difference between various pairs of shoes. The comparison between Decathlon KS900Light and Asics MetaSpeed Sky+ showed a significant difference (mean difference = 0.078, 95% CI [0.125, 0.031], $p < 0.002$). Similarly, there was a significant difference between Decathlon KS900Light and Kiprun Carbonplate KD900X (mean difference = 0.077, 95% CI [0.125, 0.028], $p < 0.002$), as well as between Decathlon KS900Light and participants' own running shoes (mean difference = 0.054, 95% CI [0.103, 0.006], $p < 0.029$). It shows that Decathlon KS900Light had a higher peak hip flexion moment compared to the other running shoes. Furthermore, Saucony FastTwitch 9 showed a significant difference compared to both Asics MetaSpeed Sky+ (mean difference = 0.064, 95% CI [0.016, 0.112], $p = 0.009$) and Kiprun Carbonplate KD900X (mean difference = 0.063, 95% CI [0.014, 0.112], $p < 0.012$), indicating that Saucony FastTwitch 9 had a higher peak flexion moment compared to these two other running shoes. A boxplot showed the distribution of peak hip flexion moments across the different running shoes (See figure 1). Table 2 presents the mean and standard deviation for the peak hip flexion moment.

Peak knee extension moment

There were significant differences among various pairs of running shoes according to the results of the linear mixed model. Specifically, the comparison between Asics MetaSpeed Sky+ and Kiprun Carbonplate KD900X showed a significant mean difference of -0.150 (95% CI [-0.300, -0.01], $p < 0.049$), indicating that Kiprun Carbonplate KD900X had a lower peak knee extension moment. Similarly, Asics MetaSpeed Sky+ showed a significant difference compared to Decathlon KS900Light (mean difference=-0.173, 95% CI [-0.322, -0.024], $p < 0.023$), with Asics MetaSpeed Sky+ having a lower peak knee extension moment. In contrast, Kiprun Carbonplate KD900X showed a significant difference compared to Saucony FastTwitch 9 (mean difference = 0.174, 95% CI [0.029, 0.319], $p < 0.019$), indicating that Kiprun Carbonplate KD900X had a higher peak knee extension moment. Additionally, Decathlon KS900Light showed a significant difference compared to the participants' own shoes (mean difference = 0.197, 95% CI [0.052, 0.342], $p < 0.008$), suggesting that Decathlon KS900Light had a higher peak knee extension moment. A boxplot was created to show the distribution of the peak knee extension moment across the different running shoes (See figure 1). Table 2 provides details on the mean and standard deviation for the peak knee extension moment.

Peak ankle plantarflexion moment

The outcome of the linear mixed model indicated a significant difference between Saucony FastTwitch 9 and both Kiprun Carbonplate KD900X (mean difference = 0.117, 95% CI [0.011, 0.222], $p < 0.030$) and participants' own running shoes (mean difference = 0.124, 95% CI [0.020, 0.228], $p < 0.020$). These results indicate that the peak ankle plantarflexion moment was higher for Saucony FastTwitch 9 compared to both Kiprun Carbonplate KD900X and participants' own running shoes. A boxplot showing the distribution of the peak ankle plantarflexion moment across the different running shoes was created (See figure 1). Table 2 presents the mean and standard deviation for the peak ankle plantarflexion moment.

Cadence

The outcome of the linear mixed model showed a significant difference between various pairs of running shoes. The comparison between Asics MetaSpeed Sky+ and Saucony FastTwitch 9 showed a significant mean difference of -0.983 (95% CI [-1.761, -0.205], $p < 0.014$), indicating that wearing Asics MetaSpeed Sky+ results in a lower cadence. Similarly, Kiprun Carbonplate KD900X showed a significant difference compared to both the participants' own running shoes (mean difference = -0.899, 95% CI [-1.682, -0.115], $p < 0.025$) and Saucony FastTwitch 9 (mean difference = -1.530, 95% CI [-2.314, -0.747], $p < 0.001$), showing that wearing Kiprun Carbonplate KD900X generally resulted in a lower cadence. Similarly, Decathlon S900Light also showed a significant difference compared to Saucony FastTwitch 9 (mean difference = -.873, 95% CI [-1.657, -0.090], $p < 0.029$), indicating a lower cadence for the Decathlon KS900Light compared to the Saucony FastTwitch 9. A boxplot showing the distribution of the cadence across the different running shoes was created (See figure 1). Table 1 presents the mean and standard deviation of the cadence.

Stance time

The outcome of the linear mixed model showed significant differences between various pairs of running shoes. Asics MetaSpeed Sky+ showed significant differences compared to both Kiprun Carbonplate KD900X (mean difference: -0.006, 95% CI [-0.009, -0.003], $p < 0.001$) and Decathlon KS900Light (mean difference: -0.003, 95% CI [-0.006, -0.001], $p < 0.016$), indicating that Asics MetaSpeed Sky+ had a significantly shorter stance time compared to the two other shoes. Similarly, Kiprun Carbonplate KD900X showed significant differences compared to Decathlon KS900Light (mean difference: 0.003, 95% CI [0.00, 0.05], $p < 0.041$), participants' own running shoes (mean difference: 0.003, 95% CI [0.00, 0.05], $p < 0.041$), and Saucony FastTwitch 9 (mean difference: 0.004, 95% CI [0.02, 0.07], $p < 0.002$), indicating that Kiprun Carbonplate KD900X had a significantly longer stance time compared to the other running shoes. A boxplot showing the distribution of the stance time across the different running shoes was generated (See figure 1). Table 1 presents the mean and standard deviation of the stance time.

Step time

The outcome of the linear mixed model showed significant differences between various pairs of running shoes. Asics MetaSpeed Sky+ showed significant differences compared to Saucony FastTwitch 9 (mean difference: 0.002, 95% CI [0.00, 0.004], $p < 0.034$), indicating that Asics MetaSpeed Sky+ had a significantly longer step time compared to Saucony FastTwitch 9. Similarly, the Kiprun Carbonplate D900X showed significant differences compared to Saucony FastTwitch 9 (mean difference: 0.003, 95% CI [0.01, 0.05], $p < 0.011$), indicating that Kiprun Carbonplate KD900X had a longer step time compared to Saucony FastTwitch 9. A boxplot showing the distribution of the step time across the different running shoes was created (See figure 1). Table 1 presents the mean and standard deviation of the step time.

	Cadence (step/min)	**Stance time (s)**	**Step time (s)**
Asics MetaSpeed Sky+	162 ± 1.73 **	0.275 ± 0.004	0.370 ± 0.004
Kiprun carbonplate KD900X	162 ± 1.73	0.281 ± 0.004	0.370 ± 0.004
Decathlon KS900Light	163 ± 1.73	0.278 ± 0.004	0.369 ± 0.004
Participants own running shoes	163 ± 1.73	0.276 ± 0.004	0.369 ± 0.004
Saucony FastTwitch 9	163 ± 1.73	0.276 ± 0.004	0.367 ± 0.004

Table 1: showing mean and standard deviation for spatial parameters

	Peak hip flexion moment (Nm/kg)	**Peak knee extension moment (Nm/kg)**	**Peak ankle plantarflexion moment (Nm/kg)**
Asics MetaSpeed Sky+	-0.93 ± 0.030	2.31 ± 0.074	2.41 ± 0.085
Kiprun carbonplate KD900X	-0.93 ± 0.030	2.46 ± 0.073	2.39 ± 0.085
Decathlon KS900Light	-1.01 ± 0.030	2.48 ± 0.073	2.44 ± 0.085
Participants own running shoes	-0.96 ± 0.030	2.42 ± 0.071	2.37 ± 0.085
Saucon FastTwitch 9	-0.99 ± 0.030	2.29 ± 0.071	2.49 ± 0.085

Table 2: showing mean and standard deviation for peak joint moments for hip, knee and ankle

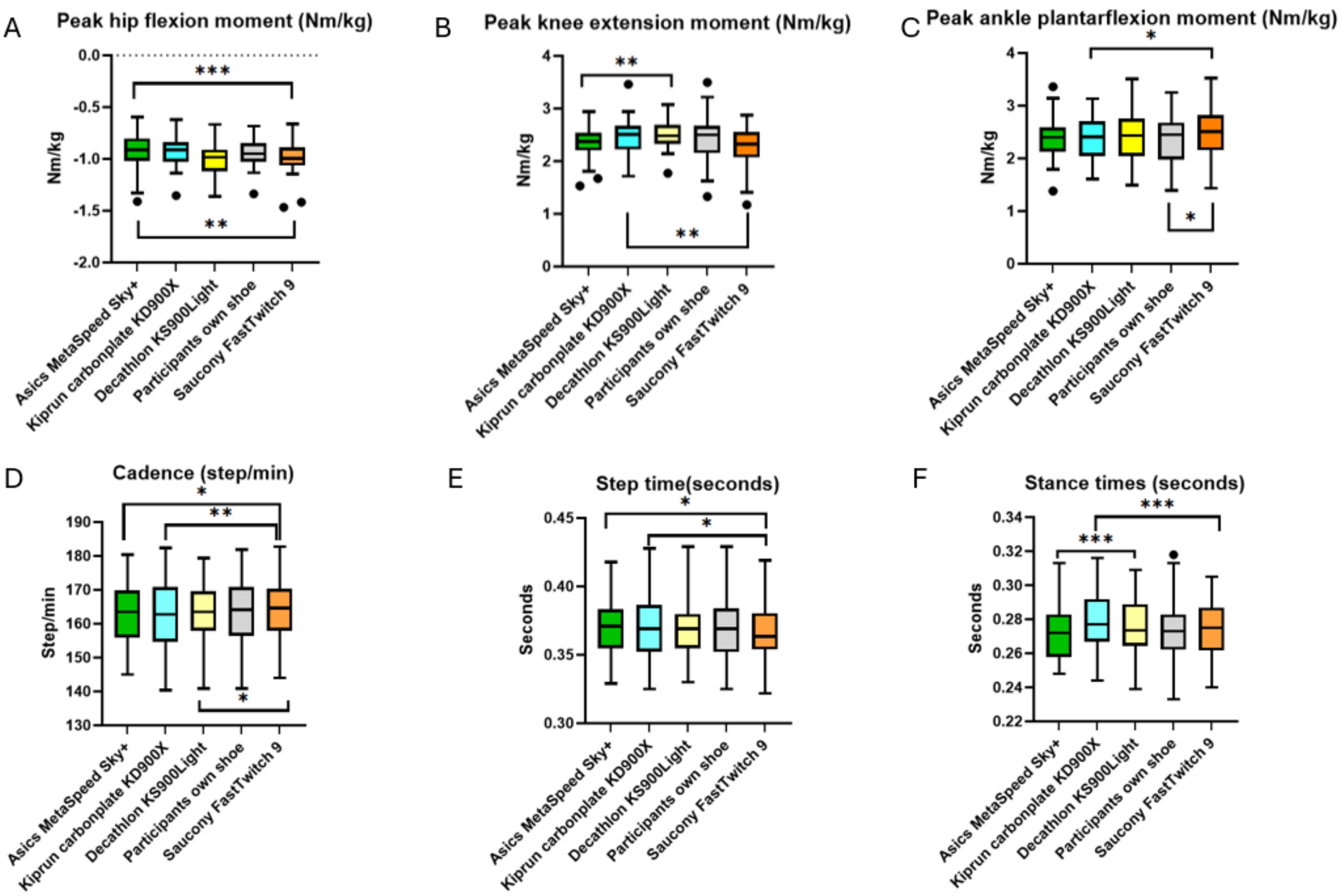

*Figure 1:Boxplow showing peak joint moment for hip (A), knee (B) and ankle (C) but also for cadence(D), step time (E) and stance time (F). Each boxplot is represented with whiskers that show the median and interquartile range. The small dots show outliers, and * represents where a significant difference was found between two running shoes (p-value < 0.05).*

Discussion

This study investigated the influence of five different types of running shoes, ranging from minimalist to carbon running shoes, on joint moments at the hip, knee, and ankle among 28 participants. The results demonstrate that the various designs of the running shoes significantly affect peak hip flexion, knee, and ankle moments (p-values < 0.05). Additionally, the findings indicate that the different features of the shoes significantly impact cadence, stance time, and step time (p-values < 0.05).

Peak hip flexion and knee moment

The results indicated that wearing either Asics MetaSpeed Sky+ resulted in a lower peak hip flexion moment compared to Decathlon KS900Light. Similarly, it was found that the other carbon running shoe, Kiprun Carbonplate KD900X, resulted in a lower peak hip flexion moment compared to Decathlon KS900Light and

Saucony FastTwitch 9. This shows that both of the carbon running shoes result in lower peak hip moment, which can be associated with the fact that they also had a lower cadence but also a higher stance time compared to the other running shoes. A study by Chen et al., 2022 found similar results as they investigated how different types of carbon running shoes affected the joint kinematic and kinetics of lower limb. This study found that carbon shoes with higher bending stiffness resulted in a lower peak hip moment due to a reduced hip flexion angle during the stance phase, indicating decreased hip activity. This decreased engagement of the hip joint can lead to a lower peak hip moment, which means the forces that would normally be absorbed or generated by the hip might be transferred to the lower leg muscles and joints (Chen et al., 2022). This is consistent with looking at the results of peak knee moment from our study, which showed that wearing Kiprun Carbonplate KD900X resulted in a higher peak knee extension moment compared to Saucony FastTwitch 9. This shows that wearing the Kiprun Carbonplate KD900X results in a lower peak hip moment but a higher peak knee moment, potentially increasing the force on Quadriceps muscles, increasing the risk of patellofemoral pain syndrome (Chen et al., 2022). More detailed musculoskeletal modelling is needed to confirm if wearing Kiprun Carbonplate KD900X would increase force on quadriceps but also on the patellofemoral joint.

Additionally, the results from peak knee extension moment indicated that wearing Decathlon KS900Light resulted in a higher peak knee moment compared to Asics MetaSpeed Sky+ and Kiprun Carbonplate KD900X. This is likely due to the higher heel drop of the Decathlon KS900Light in contrast to the other running shoes, potentially altering participants' running style and leading to increased heel striking. This finding agrees with a study by Zhang et al., 2021, which examined four running shoes with varying heel drops. The study by Zhang et al. 2021 found that shoes with a higher drop resulted in higher peak knee moment, as participants tended to initially land on their heels, positioning the leg further away the body's center of mass, potentially increasing the peak knee moment. Furthermore, the results showed that wearing Asics MetaSpeed Sky+ resulted in a lower peak knee moment compared to Kiprun Carbonplate KD900X. The results also showed that wearing Asics MetaSpeed Sky+ had a shorter stance time in comparison to Kiprun Carbonplate KD900X. This suggests a potentially faster transition from the landing phase to the push-off phase. Although the two carbon-fiber running shoes do not significantly differ in design, the higher energy return of the Asics MetaSpeed Sky+ results in greater energy absorption, consequently reducing the force transferred to the knee joint upon landing (Willwacher et al., 2014).

Peak ankle plantarflexion moment

The results indicate that wearing the Kiprun Carbonplate KD900X results in a smaller peak ankle plantarflexion moment compared to the Saucony FastTwitch 9. This lower peak ankle moment is likely due to the higher stack height, higher energy return, and greater maximal displacement of the Kiprun Carbonplate KD900X.

The increased stack height and maximal displacement provide better shock absorption, thereby reducing the moment around the ankle. These findings are consistent with the study by Hoogkamer et al., 2018, which showed that running in carbon running shoes resulted in a lower peak ankle plantarflexion moment compared to cushioned running shoes. The study by Hoogkamer et al., 2018, explained that the decreased peak ankle moment was due to the stiffer midsole compressing less, potentially resulting in less deformation of the shoe.

This study results indicate that wearing the Kiprun Carbonplate KD900X led to a lower cadence and longer step, and stance times compared to the SauconyFastTwitch 9. This suggests that the Kiprun Carbonplate KD900X promotes longer steps, potentially due to its higher energy return. In contrast, wearing the Saucony FastTwitch 9 resulted in a higher cadence and shorter stance and step times, indicating reduced contact time with the ground. This could potentially explain the higher peak ankle plantarflexion moment observed, as participants progress faster through the gait cycle, creating higher moments around the ankle. Another possible explanation is that runners change their running style when they wear running shoes with limited cushioning. This is consistent with findings from the study by Sinclair et al., 2016, who found that wearing minimalist running shoes resulted in a more plantarflexed angle during the stance phase, showing that the runners might have adopted a more forefoot strike. Previous studies have shown that this is associated with a higher peak ankle moment, which is also associated with increased force on the Achilles tendon. Based on the findings from this study, it might be that wearing the Saucony FastTwitch 9 results in higher loading on the Achilles tendon (Firminger and Edwards, 2016; Stoneham et al., 2021). However, further research specifically investigating the force on the Achilles tendon is necessary to confirm this.

Limitations

This study was conducted over one test session, which means that the results show the acute effects of wearing each of the five running shoes on the joint moments of hip, knee and ankle. Therefore, these results need to be taken into consideration, as they do not provide any information about the long-term effects of wearing these running shoes. Participants may respond differently when they wear the running shoes for a longer period and there may adopt a new running style that could change where the loading is highest on the body. Further research is needed to investigate how wearing each of these running shoes influence the loading on the joints. Another possible limitation is that the participants had already completed a prior experiment, during which they had to run for approximately 29 minutes and received feedback on cadence, foot strike angle, and loading rate. This could have influenced the results, as participants might have been more tired which could have changed their running style (Möhler et al., 2021).

Another potential limitation is the inclusion of only male participants, which could limit the generalizability of the findings to female runners. Previous studies have found that female runners often exhibit higher hip flexion, adduction angle, and internal rotation angle, but also decreased knee flexion angle compared to male runners (Xie et al., 2022). This suggests that if female runners had participated, the results might have been different. Specifically, the hip, knee, and ankle moments might have been different, as female runners could show a higher peak hip moment compared to male runners. Further research is needed, specifically focusing on female runners, to investigate whether wearing these specific running shoes would have a similar effect on the joint moments of the hip, knee, and ankle as the results observed in this study.

Furthermore, while this study provides insights into joint loading patterns, it does not offer information on how different types of running shoes affect the body at the tissue level. It should be noted that the results of this study only provide information on how the different design of running shoes affect joint moment which can be used to estimate which muscles will be affected (Ruiz-Alias, Molina-Molina, et al., 2022). Further research should be performed to investigate how different designs of running shoes affect tissue level, especially focusing on areas such as the knee, Achilles tendon, and foot, as most running injuries occur there (Ruiz-Alias, Molina-Molina, et al., 2022).

Additionally, the estimation of joint moments using the Human Body Model has some limitations (Van Den Bogert et al, 2013). When using this model, it should be noted that there are assumptions about how the joints are connected. Previous studies have shown that using inverse dynamics has some limitations, as it assumes that joints have specific degrees of freedom (Van Den Bogert et al., 2013; Flux et al., 2020). With these assumptions, it can limit the degrees of freedom for the model, and it has been found that the model may have difficulty detecting changes in movement patterns or load distribution (Van Den Bogert et al, 2013). This could affect the accuracy of the results of the estimated peak moments for the hip, knee, and ankle, as the model might find it difficult to detect small differences.

Implications

The findings of this study can be used by runners and sports store as it provides information that might be helpful to reduce the risk of injuries and enhance performance. With the findings showing that wearing Saucony Fastwitch 9 increases the peak ankle moment which is associated with a higher risk of Achilles tendinopathy in contrast wearing the Kiprun carbonplate KD900X and Decathlon KS900Light might increase the risk of patellofemoral pain as they showed a higher peak knee moment. This insight can sport stores use to guide runners in the selection of running shoes. For instance, if runners experience problem with Achilles tendon pain, then the store could guide people not to select Saucony Fastwitch 9 running shoes. Runners can also use this information to target their training for instance if a runner is running in Kiprun carbonplate KD900X or

Decathlon KS900Light then they might try to increase the strength of Quadriceps (Ferber et al., 2015).

Conclusion

This study aimed to investigate the influence of wearing five different types of running shoes, ranging from minimalist to carbon variants, on joint moments at the hip, knee, and ankle. Results revealed significant differences in peak joint moments across different shoe designs. Specifically, wearing the Saucony FastTwitch 9, characterized by limited cushioning, led to higher peak ankle moments compared to the Kiprun Carbonplate KD900X. In contrast, wearing the Decathlon KS900Light resulted in higher peak knee moments compared to other shoe models, likely due to its increased heel-to-toe drop.

Furthermore, findings indicated that the Kiprun Carbonplate KD900X and Asics MetaSpeed Sky+ were associated with lower peak hip moments, while the former induced higher peak knee moments. This study used peak joint moments as a parameter for how the five different running shoes would affect the loading on the body. This does not provide any information on how running shoes varying in design affect the body on a tissue level. Future research should include muscle forces and joint contact forces for a more comprehensive understanding of the lower extremity and how different running shoes affect the body on a tissue level.

Reference list

- Agresta, C., Giacomazzi, C., Harrast, M. A., & Zendler, J. D. (2022). Running Injury Paradigms and Their Influence on Footwear design features and runner Assessment Methods: A Focused Review to Advance Evidence-Based Practice for Running Medicine Clinicians. Frontiers in Sports and Active Living, 4. https://doi.org/10.3389/fspor.2022.815675
- Arya, S., & Kulig, K. (2010). Tendinopathy alters mechanical and material properties of the Achilles tendon. Journal of Applied Physiology, 108(3), 670–675. https://doi.org/10.1152/japplphysiol.00259.2009
- Bertelsen, M. L., Hulme, A., Petersen, J., Brund, R. B. K., Sørensen, H. T., Finch, C. F., Parner, E. T., & Nielsen, R. O. (2017). A framework for the etiology of running-related injuries. Scandinavian Journal of Medicine & Science in Sports, 27(11), 1170–1180. https://doi.org/10.1111/sms.12883
- Burke, A., Dillon, S., O'Connor, S., Whyte, E., Gore, S., & Moran, K. (2023). Aetiological Factors of Running-Related Injuries: A 12 month prospective "Running Injury Surveillance Centre" (RISC) study. Sports Medicine - Open, 9(1). https://doi.org/10.1186/s40798-023-00589-1
- Chen, H., Shao, E., Sun, D., Xuan, R., Baker, J. S., & Gu, Y. (2022). Effects of footwear with different longitudinal bending stiffness on biomechanical characteristics and muscular mechanics of lower limbs in adolescent runners. Frontiers in Physiology, 13. https://doi.org/10.3389/fphys.2022.907016
- Davis, I. S. (2014). The re-emergence of the minimal running shoe. Journal of Orthopaedic & Sports Physical Therapy, 44(10), 775–784. https://doi.org/10.2519/jospt.2014.5521
- Edwards, W. B. (2018). Modeling overuse injuries in sport as a mechanical fatigue phenomenon. Exercise and Sport Sciences Reviews, 46(4), 224–231. https://doi.org/10.1249/jes.0000000000000163
- Ferber, R., Bolgla, L., Earl-Boehm, J. E., Emery, C., & Hamstra-Wright, K. (2015). Strengthening of the hip and core versus knee muscles for the treatment of patellofemoral pain: a multicenter randomized controlled trial. Journal of Athletic Training, 50(4), 366–377. https://doi.org/10.4085/1062-6050-49.3.70
- Firminger, C. R., & Edwards, W. B. (2016b). The influence of minimalist footwear and stride length reduction on lower-extremity running mechanics and cumulative loading. Journal of Science and Medicine in Sport, 19(12), 975–979. https://doi.org/10.1016/j.jsams.2016.03.003
- Flux, E., Van Der Krogt, M., Cappa, P., Petrarca, M., Desloovere, K., & Harlaar, J. (2020). The Human Body Model versus conventional gait models for kinematic gait analysis in children with cerebral palsy. Human Movement Science, 70, 102585. https://doi.org/10.1016/j.humov.2020.1025

wearable tech. PloS One, 14(1), e0210000. https://doi.org/10.1371/journal.pone.0210000

- Gruber, A. H. (2023). The “impacts cause injury” hypothesis: Running in circles or making new strides? Journal of Biomechanics, 156, 111694. https://doi.org/10.1016/j.jbiomech.2023.111694
- Holder, J., Trinler, U., Meurer, A., & Stief, F. (2020). A systematic review of the associations between inverse dynamics and musculoskeletal modeling to investigate joint loading in a clinical environment. Frontiers in Bioengineering and Biotechnology, 8. https://doi.org/10.3389/fbioe.2020.603907
- Hoogkamer, W., Kipp, S., & Kram, R. (2018). The biomechanics of competitive male runners in three marathon racing shoes: a randomized crossover study. Sports Medicine, 49(1), 133–143. https://doi.org/10.1007/s40279-018-1024-z
- Kakouris, N., Yener, N., & Fong, D. (2021). A systematic review of running-related musculoskeletal injuries in runners. Journal of Sport and Health Science, 10(5), 513–522. https://doi.org/10.1016/j.jshs.2021.04.001
- Kulmala, J., Kosonen, J., Nurminen, J., & Avela, J. (2018). Running in highly cushioned shoes increases leg stiffness and amplifies impact loading. Scientific Reports, 8(1). https://doi.org/10.1038/s41598-018-35980-6
- Matijevich, E. S., Branscombe, L. M., Scott, L. R., & Zelik, K. E. (2019). Ground reaction force metrics are not strongly correlated with tibial bone load when running across speeds and slopes: Implications for science, sport and
- Morio, Cédric & Bouten, Laura & Duraffourg, Simon & Delattre, Nicolas. (2020). A multidisciplinary approach to the engineering of footwear cushioning: A practical example of gym training shoes. Proceedings of the Institution of Mechanical Engineers Part P Journal of Sports Engineering and Technology. 236. 10.1177/1754337120957227.
- Möhler, F., Fadillioglu, C., & Stein, T. (2021). Fatigue-Related changes in spatiotemporal parameters, joint kinematics and leg stiffness in expert runners during a Middle-Distance run. Frontiers in Sports and Active Living, 3. https://doi.org/10.3389/fspor.2021.634258
- Nigg, B. M., Subramanium, A., & Matijevich, E. (2022). Towards a biomechanical understanding of performance improvement with advanced running shoes. Footwear Science, 14(3), 133–137. https://doi.org/10.1080/19424280.2022.2127543
- Relph, N., Greaves, H., Armstrong, R., Prior, T. D., Spencer, S., Griffiths, I. B., Dey, P., & Langley, B. (2022). Running shoes for preventing lower limb running injuries in adults. The Cochrane Library, 2022(8). https://doi.org/10.1002/14651858.cd013368.pub2
- Ruiz-Alias, S. A., Molina-Molina, A., Soto-Hermoso, V. M., & García-Pinillos, F. (2022). A systematic review of the effect of running shoes on running economy, performance and biomechanics: analysis by brand and model.

- Sports Biomechanics, 22(3), 388–409. https://doi.org/10.1080/14763141.2022.2089589
- Schielzeth, H., Dingemanse, N. J., Nakagawa, S., Westneat, D. F., Allegue, H., Teplitsky, C., Réale, D., Dochtermann, N. A., Garamszegi, L. Z., & Araya-Ajoy, Y. G. (2020). Robustness of linear mixed-effects models to violations of distributional assumptions. Methods in Ecology and Evolution, 11(9), 1141–1152. https://doi.org/10.1111/2041-210x.13434
- Sinclair, J. K., Brooks, D., Taylor, P. J., & Liles, N. B. (2021). Effects of running in minimal, maximal and traditional running shoes: a musculoskeletal simulation exploration using statistical parametric mapping and Bayesian analyses. Footwear Science, 13(2), 143–156. https://doi.org/10.1080/19424280.2021.1892834
- Squadrone, R., & Gallozzi, C. (2009). Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. PubMed, 49(1), 6–13. https://pubmed.ncbi.nlm.nih.gov/19188889
- Sylvester, A. D., Lautzenheiser, S. G., & Kramer, P. A. (2021). A review of musculoskeletal modelling of human locomotion. Interface Focus, 11(5), 20200060. https://doi.org/10.1098/rsfs.2020.0060
- Van Den Bogert, A. J., Geijtenbeek, T., Even-Zohar, O., Steenbrink, F., & Hardin, E. C. (2013). A real-time system for biomechanical analysis of human movement and muscle function. Medical & Biological Engineering & Computing, 51(10), 1069–1077. https://doi.org/10.1007/s11517-013-1076-
- Xie, P., Bíró, I., & Liang, M. (2022). Sex-specific differences in biomechanics among runners: A systematic review with meta-analysis. Frontiers in Physiology, 13. https://doi.org/10.3389/fphys.2022.994076
- Zhang, M., Zhou, X., Zhang, L., Liu, H., & Yu, B. (2022). The effect of heel-to-toe drop of running shoes on patellofemoral joint stress during running. Gait & Posture, 93, 230–234. https://doi.org/10.1016/j.gaitpost.2022.02.008

Appendix

	 Asics MetaSpeed Sky+	 Kiprun carbonplate KD900X	 Decathlon KS900Light	 Saucony FastTwitch 9
Weight (g)	193	211	252	171
Drop (mm)	5	4	8	5
Stack height (mm)	36,4	34,0	31,8	21,8
Stiffness 400-600N (N/mm)	55.3	52,3	60,1	89,3
Deflection (%)	46	54	46	59
Energy return (%)	-78	-65	-56	-56

Table 1:Specifications of the tested running shoes

The original boxplots for peak joint moments at the hip, knee, and ankle before the outliers were removed.