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Running is frequently used as a means of physical activity and exercise for the modern active person. However, due to the mixture of kinematic and kinetic forces involved over long distances (Almeida, Davis, & Lopes, 2015), runners frequently experience lower-extremity injuries up to eighty percent (van Gent et al., 2007). Furthermore, the majority of runners are rearfoot strikers (Cheung & Davis, 2016). Therefore, there has been much research on the topic of strike patterns and influences on biomechanics and injury rates for runners. Runners are trying to alter their foot strike pattern based on “unsubstantiated claims” that forefoot and midfoot running can decrease injuries or improve performance (Daoud et al., 2012, p. 1326). There are many implications of how the biomechanics of strike patterning affects the kinematics and kinetics over long distances for runners, and therefore, provides a necessity for research to determine how to decrease these high injury rates (Daoud et al., 2012).

Rearfoot Strike Pattern

Almost ninety percent of runners utilize a rearfoot strike pattern (Almeida et al., 2015; Kuhman, Melcher, & Paquette, 2015). The origin for this shocking majority of runners to develop this strike pattern has been attributed to the modern running shoe with its increased heel lift of cushion. This extra lift will cause a runner to land on his/her heel due to the closer proximity of the heel to the ground (Almeida et al., 2015). Biomechanically, this will initiate the following running form during the initial stance phase: the foot lands ahead of the body, allowing the knee to extend and the ankle to dorsiflex, invert, and abduct. To propel the runner, the calf must contract with enough force to allow the runner to move over the foot and go into swing phase (Daoud et al., 2012). Utilizing a rearfoot strike pattern will stress the knee joint in the sagittal and frontal planes (Stearne, Alderson, Green, Donnelly, & Rubenson, 2014).

A rearfoot strike pattern causes increased vertical loading rates during running (Almeida et al., 2015; Cheung & Davis, 2016; Kuhman et al., 2015; Goss et al., 2015) as well as overall vertical impact forces (Bishop, Fiolkowski, Conrad, Brunt, & Horodyski, 2006; Kulmala, Avele, Pasanen, & Parkkari, 2013; Yong et al, 2014). Rearfoot runners demonstrated two peaks of vertical force data during the initial foot strike (Cavanagh & Lafortune, 1980). The initial spike is known as an impact transient. It occurs during the first fifty milliseconds of the heel strike and is followed by the main GRF (Valenzuela, Lynn, Mikelson, Noffal, & Judelson, 2015). It is generated by the initial high-force impact from the heel onto the ground accompanying minute energy absorption; therefore, transferring the GRF directly up the lower extremity chain (Almeida et al., 2015). The impact transient is only seen in rearfoot runners and is thought to contribute to the increased injuries seen with runners who utilize this foot-strike pattern (Valenzuela et al., 2015). Due to these increased forces, rearfoot runners are usually shod runners (Almeida et al., 2015). If they transition to minimalist shoes, these runners tend to develop a forefoot strike pattern to decrease the large GRF initiated on the calcaneous (Boyer, Rooney, & Derrick, 2015).

Rearfoot Strike Joint Effects in Research

The ankle joint shows increased dorsiflexion during initial foot strike. This coincides with increased tibialis anterior stimulation and peak dorsiflexion moments (Kuhman et al., 2015; Yong, Silder, & Delp, 2014). Another study showed increased ankle joint moment in rearfoot runners during initial foot contact. Also, foot contact angle and foot contact angle variability are increased in rearfoot runners (Paquette, Milner, & Melcher, 2016). One study has observed decreased rearfoot eversion for shod runners who utilize a rearfoot strike pattern (Almeida et al., 2015). Another study proves GRF places axial and shear compression during running on the tibia at the ankle joint (Sasimontonkul, Bay, & Pavol, 2007). Joint stiffness has also been thought to play a major role in injury rate. Studies observing the rearfoot strike pattern have determined that the ankle joint is stiffer than the knee. However, increasing the velocity demonstrates a greater increase with knee stiffness (Butler, Crowell, & Davis, 2003). Frontal plane pronation effects increase directly with increasing in sole height in shoes (Daoud et al., 2012).

The knee joint demonstrated an overall increased knee range of motion (ROM), as well as an increased knee moment during flexion (Bishop et al., 2006; Daoud et al., 2012; Stearne et al., 2014), peak extension due to the increased ROM in the sagittal plane, and increased loading at the knee joint (Kuhman, et al., 2015). Increased knee flexion ROM was observed for natural shod rearfoot strikers (Almeida et al., 2015). Furthermore, increases in knee varus and internal rotation moments were also observed in rearfoot running (Daoud et al., 2012). Negative work and power at the knee are higher compared to the forefoot strike pattern. Also, rearfoot strikers exhibit a greater instantaneous power absorption at the knee joint (Stearne et al., 2014). One study observed an increased peak knee eccentric extensor power while utilizing a natural rearfoot strike pattern (Kuhman et al., 2015). A rearfoot strike pattern has been associated with increased injury rates at the knee and hip (Daoud et al., 2012). The hip also demonstrates increased ROM (Bishop et al., 2006) with increases in external rotation moments (Daoud et al., 2012).

Forefoot Strike Pattern

A forefoot strike pattern has been associated with increased velocity in runners compared to their rearfoot counterparts (Bishop et al., 2006; Stearne et al., 2014). Also, forefoot strikers tend to run with a shorter stride length (Bishop et al., 2006), decreased duration in stance phase, and increased stride frequency. The forefoot (and midfoot) strike pattern is more utilized in elite, rather than recreational, runners. Utilizing a forefoot strike pattern will place more stress on the ankle joint in the sagittal plane for a runner (Stearne et al., 2014).

Forefoot Strike Joint Effects in Research

Landing on the ball of the foot allows increased ankle plantarflexion at impact to be observed with increased gastrocnemius and soleus activation (Yong et al., 2014), concurrent with increased eccentric plantarflexion power (Kuhman et al., 2015; Stearne et al., 2014) and plantarflexion moments (Stearne et al., 2014). This has been shown to increase ankle ROM for the runner (Bishop et al., 2006), increase stresses on the Achilles tendon (Kulmala et al., 2013; Rooney & Derrick, 2013), and lead to increased instability that can pose injury risks to forefoot runners (Fredericks et al., 2015). Even though the Achilles tendon is known for its ability for eccentric control, overstressing the tendon through the increased negative power from the forefoot strike can lead to overuse injuries (Stearne et al., 2014). This foot strike pattern is associated with increased loading at the ankle joint (Kuhman, et al., 2015). The mid-stance phase shows a higher ankle moment as opposed to rearfoot strikers (Bishop et al., 2006; Stearne et al., 2014). Furthermore, the ankle joint during forefoot strike patterns shows an 11 to 12 percent increase in contact force that is one and a half times the runner's body weight (Rooney & Derrick, 2013). An overall increased negative work and power are studied at the ankle joint during the stance phase. Furthermore, the forefoot strike pattern observes higher instantaneous ankle power absorption than a rearfoot strike pattern (Stearne et al., 2014). One study has observed increased rearfoot eversion with shod forefoot runners (Almeida et al., 2015).

Studies of the knee joint show increased flexion during initial contact (Yong et al., 2014) but decreased peak knee flexion excursion for natural shod forefoot runners (Almeida et al., 2015). Overall, there is decreased knee loading, frontal plane moment, and patellofemoral stress

(Kulmala et al., 2013). The patellofemoral stresses are decreased in short-term running with 10 to 13 percent lower stress per step, and long-term running with up to 13 percent lower stress per kilometer (Willson, Ratcliff, Meardon, & Willy, 2014). However, other studies observed an increased contact force by nearly 15 percent (Rooney & Derrick, 2013). Studies have realized an opposite relationship with regards to joint stiffness compared to rearfoot running: the knee is stiffer than the ankle. This relationship is thought to be from the inverse relationship of joint excursion between the knee and ankle (Butler, Crowell, & Davis, 2003).

The hip joint does not show conclusive significant findings on forefoot running with multiple studies. Hip joint moments and power were observed to be non-significant in one study (Stearne et al., 2014) and showed increased joint contact force by 12 percent in another study (Rooney & Derrick, 2013).

Common Injuries Linked to Strike Pattern

Common injuries for runners include back pain, hip pain, patellofemoral pain, plantar fasciitis, and medial tibial stress syndrome, Achilles tendinopathies, and iliotibial issues (Cheung & Davis, 2016; Daoud et al., 2012; Kuhman, Melcher, & Paquette, 2015; Stearne et al., 2014). The majority of injuries affect the lower extremity tendons (Mann et al., 2015). Rearfoot strike patterns have been confirmed to double the rates and slightly increase the severity of overuse injuries when compared to forefoot runners in some studies, but other studies have not been able to demonstrate a correlation. However, other factors do play a major role in injures as well, including gender, running distance, arch type, core strength, bone structure, and mileage per week (Daoud et al., 2012; Milner, Ferber, Pollard, Hamill, & Davis, 2006). The impact transient observed during rearfoot running has been thought to be associated with increases in tibial injuries and plantar fasciitis (Almonroeder, Willson, & Kernozek, 2013).

Rearfoot strike patterns have been attributed to increases in patellofemoral pain, linked with the increased knee extension moments. Some researchers have suggested landing training for runners to reduce chances of this injury. Symptoms decreased with landing training and shifting away from a rearfoot strike pattern (Cheung & Davis, 2016). Greater stride lengths have been observed to increase patellofemoral stresses. Due to the significant increases in patellofemoral stress during rearfoot running, some researchers believe this may indicate a reason to modify strike pattern away from the traditional rearfoot strike to shorten stride length and to aid in decreasing injury rates (Vannatta & Kernozek, 2015; Willson et al., 2014).

Previous incidence of medial tibial stress syndrome in females has demonstrated an increase in running-related loading variables. Observations in research include higher impact peaks and knee joint stiffness. As these loading variables relate heavily toward tibial stress, it can be assumed that reoccurrence is likely for tibial stress issues (Milner et al., 2006).

Due to the increase in ankle moments for a forefoot striker (Daoud et al., 2012), it is assumed that an increase in ankle injuries and Achilles tendinopathies may increase with this running pattern (Almonroeder et al., 2013; Mann et al., 2015). Greater impulses and loading rates are observed in the Achilles tendon while utilizing a forefoot strike pattern. Therefore, the forefoot strike pattern is thought to lead to an increase Achilles injuries for those with a previous history of Achilles issues (Almonroeder et al., 2013). Furthermore, forefoot running has been associated with increases in plantar pressure and loading (Vannatta & Kernozek, 2015).

Conclusion

Could the increase in the popularity of the forefoot strike pattern be due to the adoption of the strike utilized from elite runners from the recreational running population (Stearne et al., 2014)? Recreational runners demonstrate decreased mileage, velocities, and frequency of training compared to the elite runners (Daoud et al., 2012) Therefore, adoptions in running biomechanics from the elite group may be contraindicated. Future research needs to observe kinetic and kinematic data during running. There is little significant research to make a definite conclusion about the best running strike pattern (Almeida et al., 2015). A rearfoot strike pattern has been shown to increase the vertical ground reaction force at initial contact, producing the assumption in this pattern to increase running-related injuries. However, the forefoot strike pattern will increase gastrocnemius and soleus eccentric activation, leading to possible increase in Achilles running-related injuries. Both of these running effects can contribute to injury; and, therefore, make it difficult to ascertain the best foot strike pattern for a runner (Almeida et al., 2015; Almonroeder et al., 2013).

The ankle joint is the first joint to deal with the forces that are traveling up the body with every foot contact. Therefore, a foot strike pattern has most of its effects at the ankle joint (Rooney & Derrick, 2013). Moreover, the best foot strike pattern for runners may depend on gender or other uncontrollable factors (Phinyomark, Hettinga, Osis, & Ferber, 2014). There are many follow-up questions that need to be answered by further research. Are there significant results of kinetic data in the knee joint between strike patterns? Which strike pattern showed increased internal joint forces? In which plane of motion is the knee joint under most internal force during rearfoot and forefoot strike patterns?

Due to the lack of research and conclusions on a definitive type of strike pattern to decrease injuries, it seems that the answer may lie with individual preference based on personal deficiencies, previous injury, sex, footwear, available range of motion, body composition, training schedules, etc. (Daoud et al., 2012), and level of runner (Stearne et al., 2014). There does not seem to be a definite biomechanical supremacy of one foot strike pattern to another

(Stearne et al., 2014) due to the variation in biomechanical differences in runners (Daoud et al., 2012).

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