THE EFFECT OF TOE-IN/TOE-OUT VARIATION ON LOCOMOTION:

A COMPREHENSIVE REVIEW

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Abstract

Gait modifications can alter energy demands and cost of transport. Specifically, alterations in toe-in and toe-out alignment have been found to affect force production abilities during gait. However, the terminology used when describing alterations in toe-in/toe-out alignment is somewhat differential. The aims of this thesis were to conduct a literature review to define terminology associated with toe-in/toe-out gait as well as determine implications on force production, injury, disability, trainability, performance, and analyze possibilities for further investigations. Reference articles were collected from journal databases such as PubMed, Web of Science, Google Scholar, and SPORTDiscuss, by searching for studies related to intoeing gait, foot progression angle, and metatarsophalangeal joint during running. After reviewing the literature it was concluded that toe-in/toe-out modification could alter the gear ratio of the foot and result in a more mechanically advantageous gait pattern. Further inquiries are necessary to determine the exact parameters for degrees of intoeing and outtoeing that are beneficial, as well as its impact on performance during different phases of gait or movement patterns.

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Introduction

Anatomically modern humans have evolved over time to develop structures that lower energy demands and cost of transport during gait (Raichlen et al. 2011). Studying the anatomy and kinetic interactions between bones, ligaments and muscles of the foot and ankle is important when determining how force production is affected by changes in foot placement during gait. Examining the force production cascades and forefoot alignment factors associated with modern humans will allow investigators to understand the mechanisms of gross cost of transport and efficiency during altered gait patterns.

A clear understanding of the impact foot placement has on movement capabilities will provide researchers and clinicians with pertinent information about an individual's physical capabilities and clues in to ways to improve performance. This literature review aims to discover if foot placement and alignment can be used as a method of performance enhancement when considered as a dynamic variable throughout gait. In order to better understand the effect that the axis of push-off has on force production and performance during gaited motor skills, the terms associated with in-toeing and out-toeing gait must be comprehensively compared and differentiated before further investigations can be conducted. This literature review will analyze how these types of foot arrangement can be potentially beneficial to performance during gaited events as well as determining if altering foot placement throughout a walk, run, or sprint can impact performance capabilities.

Evolution and Anatomy

Energy expenditure during walking varies depending on an individual's body mass, lower limb length, lower limb proportions, and overall lower limb configuration or alignment (Zehr et al, Leardini et al. 1999). Although the proportions of the human foot have changed throughout evolution, researchers suggest the function of the foot has remained relatively unchanged, allowing comparisons of ancient and modern humans to be made (Bennett et al. 2016). Early humanoids such as Neanderthals and *Homo erectus* have been estimated to have approximately 9-14% higher gross cost of transport to cover any given distance versus modern humans (Hora and Vladimir 2014). The longer posterior pedal moment arm and shorter moment arms of the ground reaction force (GRF) at the knee and ankle of Neanderthals were the primary contributors to their less efficient gait pattern (Hora and Vladimir 2014, Raichlen et al. 2011).

Researchers have suggested that distance running played a fundamental role in the evolution of humans, belonging to the genus *Homo*, and specifically the only extant human species *Homo sapiens* (Raichlen et al. 2011). Neanderthals (H. *neanderthalensis*) had longer calcaneal tubers than the later *Homo erectus,* who have comparable calcaneus length to modern day humans. Similarly, other investigators have found correlations between long toe length and decreases in running economy in comparison to individuals with shorter toes (Rolian et al. 2008). Rolian found that an increase in average toe length of 20% resulted in twice the amount of flexor impulses and mechanical work, potentially increasing the total metabolic cost of completing the movement, and having overall negative effects on running economy. Shortened calcaneal tuber length or shorter toe lengths results in a shorter moment arms allowing for greater storage and release of force production. This has been shown to benefit economy during running, but does not have a similar impact on walking performance (Raichlen et al, Rolian et al. 2008). These evolutionary modifications of individual variances in anatomical foot characteristics result in altered resistance and moment arms, which can then impact force production and performance. This evidence suggests that intentional modifications of gait characteristics may also have the same performance changing effects.

In anatomically modern humans the ankle joint is formed by the interaction of the distal end of the tibia and fibula with the talus and the calcaneus. Ligaments on both sides of the ankle hold the bones together while tendons connect bones to muscles. As a biaxial joint the ankle performs four fundamental movements to change the orientation of the foot: dorsiflexion/plantar flexion in the sagittal plane, and eversion/inversion in the frontal plane (Behnke 2006). The foot can be divided into three primary sections; the hindfoot, midfoot, and forefoot. The hindfoot is composed of the talus and calcaneus, midfoot the tarsals, cuneiform bones, cuboid bone, and navicular bone, and the forefoot contains the five phalanges and metatarsals (Behnke 2006, Dimon and Qualer 2008). Dorsiflexion is accomplished by extrinsic muscles in the anterior compartment of the lower leg: tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius. The extrinsic muscles of the lateral compartment, peroneus longus and brevis allow for plantar flexion and eversion. In the superficial posterior compartment the gastrocnemius, soleus, and plantaris also perform plantar flexion of the ankle. Inversion and plantar flexion are performed by the muscles of the deep posterior compartment; tibialis posterior, flexor digitorum longus, and flexor hallucis longus (Behnke 2006, Dawe et al. 2011). The mechanisms involved in in-toeing and out-toeing are highly dependent on the network of muscles, tendons, ligaments, and bones of the hip, ankle, and foot. Altering one variable has the potential to cause variations in all other involved structures.

Term Evaluation

During gait, the forefoot can be angled in an inward, outward, or have a neutral orientation. Current literature describes this variable foot alignment using three terms; in-toeing and out-toeing, foot progression angle, and rotational foot placement. These terms are largely considered in the context of congenital deformity and in the clinical population as a static condition. However, it is also possible to examine toe-in/out as a modifiable variable during gait.

Toe-in/Toe-out: During gait initiation, the foot pushes off of the ground from the longest contact point, typically the second metatarsal bone, through one of two axes (Figure 1). An individual is said to have a toe-in position if their gait initiation occurs around the oblique axis, through the metatarsophalangeal joint of the second and fifth toe. Alternatively, the toe-out position occurs around the transverse axis, through the metatarsophalangeal joint of the first and second toe (Bojsen-Moller 1978).

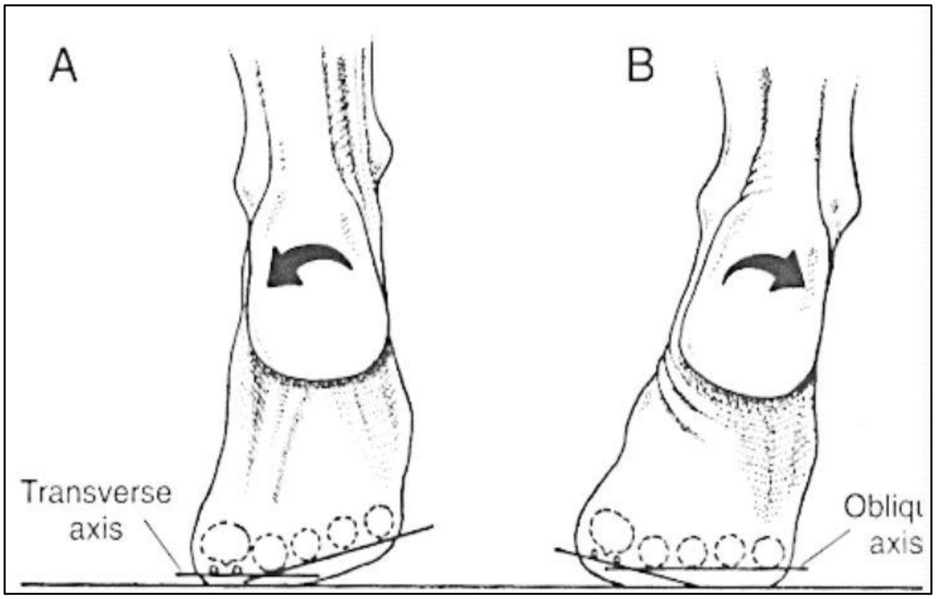

Figure 1: Transverse and Oblique Axes Through Metatarsophalangeal Joint of Second Metatarsal (Bojsen -Moller 1978)

Bojsen-Moller conducted their in-toe/out investigation by placing cadaver foot specimens in a holder meant to stimulate push off. The researchers manipulated the specimens into desired degrees of rotation in order to examine the effects of rotation about the oblique and transverse axis (Bojsen-Moller 1978). More commonly, 3-dimensional motion analysis systems such as VICON, (Oxford Metrics Ltd.) are used in conjunction with force plate measurements to determine toe-in/out angle (Erdemir et al).

Rotational Foot Placement: The term rotational foot placement is used to describe the orientation of the foot at the moment of push-off. An internally rotated foot is comparable to the oblique axis at the metatarsophalangeal (MTP) joint and an externally rotated foot is one that pushes-off from the transverse axis (Erdemir and Piazza 2002, Bojsen-Moller 1978).

Foot Progression Angle: In a clinical setting, in-toeing and out-toeing can also be caused by femoral anteversion and internal tibial torsion (Chang 1998, Jacobs 2010). The foot progression angle (FPA) or foot rotation angle is one of five clinical measurements that comprise the torsional profile. Thigh-foot angle, hip internal rotation, hip external rotation, and heel bisector line can also be analyzed to determine the cause of inward or outward foot rotation in a clinical population. The thigh foot angle is measured by determining the angular difference between the axis of the foot and axis of the thigh when an individual is prone with knees flexed at 90° (Fuchs and Staheli 1996). The FPA is measured while walking in a straight line, between the longitudinal axis of the foot (the long axis formed from the heel to the 2nd metatarsal) and an imaginary straight line extended out from the front of the foot (Cibulka et al. 2016)(Figure 2). Inward foot alignment is associated with a negative angular value and outward rotation with a positive angular value (Chang 1998, Almosnino et al. 2009).

The simplest measurement of foot progression angle can be determined from marking the foot placement of participants as they progress through their typical gait pattern. In early studies, participants would dust their feet with chalk and walk across a strip of paper. Their FPA would be determined by the degree in which the foot vector deviated from the midline axis of the walkway (Fuchs and Staheli 1996, Khan et al. 2017). More recently, motion sensor devices, such as the GAITRite system (CIR Systems Inc, Franklin NJ), are commonly utilized to identify footprints during gait by sensing and motion capturing a person’s heel, midfoot, and forefoot. The line of progression is measured in degrees from a line connecting two consecutive first contact points of the same foot (Cibulka et al. 2016, Fuchs and Staheli 1996, Schepers et al. 2010, Bowsher et al. 1995). More sophisticated means of foot progression determination can be made from foot-worn inertial sensors that utilizes an algorithm to calculate FPA for different walking speeds and foot angles (Huang et al. 2016, Rebula et al. 2013).

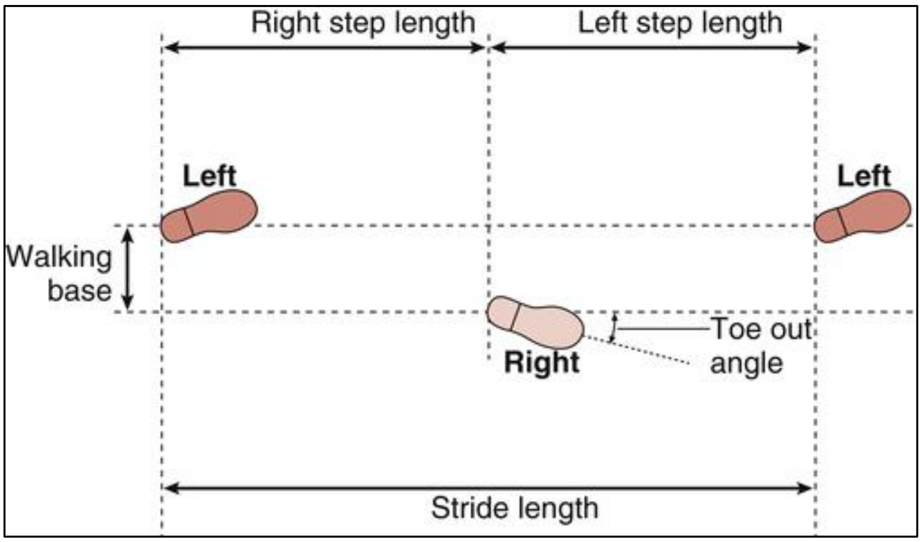

Figure 2. Foot progression angle measurement. (Whittle 2008)

The primary distinction between in-toeing/out-toeing and foot progression angle is the point of rotation. In-toeing/out-toeing is considered a variation about the metatarsophalangeal joint whereas FPA is generally caused by a torsion of the femur, tibia, or entire foot. When reviewing literature it is important to understand the point of reference used when describing foot placement, as in-toeing and out-toeing are commonly used as the term for both types of placement as outlined above.

Force Production

The relationship between the foot, toes, and ankle provides a mechanical setup similar to that of a geared bicycle (Carrier et al. 1994). Intentionally changing gait orientation and gear ratio can improve athlete performance and is trainable over time. As the only point in contact with the ground, the foot delivers body support for propulsion and impact absorption. The foot transmits ground reaction forces throughout the body in order for forward movement to occur. For example, the MTP joint dorsiflexes during the stance phase of gait and the joint absorbs on average 20.9 J during running and 47.8 J during sprinting (Stefanyshyn et al 1997). The primary phase of gait concerned with toe-in/out alignment is late stance, after heel off. A large amount of mechanical power is needed to lift up and push off the body into the swing phase of gait (Carrier et al. 1994, Erdemir and Piazza 2002, Ren et al. 2008). By moving the orientation of the feet and toes, the gear ratio of the ankle extensor muscles can be changed during gait. The gear ratio is the velocity ratio between the ankle extensor muscles and the point of application or center of force during the contact phase of step and is present during gait, regardless of whether or not there is a toe-in/out modification (Carrier et al. 1994). This concept of variable gearing allows athletes the ability to optimize force-velocity relationships throughout the gait cycle and stages of a movement or race.

Trained sprinters have been found to have naturally longer forefoot bones and shorter plantarflexor moment arm (pfMA) as compared to non-sprinters. This relationship reduces plantarflexor-shortening velocity and increases plantarflexor force during acceleration at the start of a sprint race (Baxter et al. 2012). Of course, an athlete cannot change the length of their foot bones in order to shorten their pfMA and velocity but other studies have found foot placement and orientation to have similar effects on plantarflexor forces. Regardless, foot proportions contribute to the ability to generate propulsive muscle forces and influence the gear ratio.

When analyzing the foot as a gear, the equation $R \times F_R = r \times F_m$ is used, where R is the ground reaction force moment arm, F_R is the ground reaction force, r is pfMA, and F_m is the plantar flexor muscle force (Carrier et al. 1994). The ground reaction force is the major contributor to joint moment during stance phase (Johnson and Buckley 2001). The proportion of r to R throughout each phase of gait determines gear ratio and is our primary point of interest (Figure 3). As the angle of the GRF changes, the proportion of r to R is affected. In Bojsen-Moller's study they found the ratio between the force arms of the triceps muscle for push-off of the oblique and transverse axis to be 1:1 but the ratio between the resistance arms averaged 5:6 (Bojsen-Moller 1978). During push-off with the transverse axis, toe-out, the medial sides of the feet are kept parallel and a longer resistance arm is formed, increasing the gear ratio. During push-off of the oblique axis, toe-in, the center of pressure under the foot is transferred from the heel to the lateral side of the ball of the foot and then on to the medial side and the big toe. This motion forms a shorter resistance arm with a lower gear ratio beneficial for isometric and slow angular motions (Bojsen-Moller 1978, Carrier et al. 1994, Erdemir and Piazza 2002).

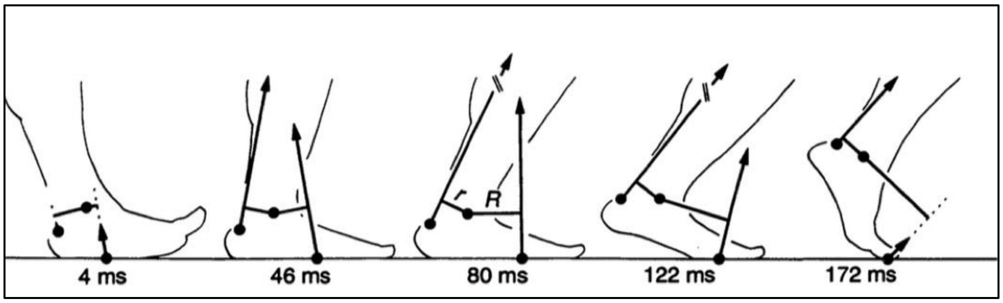

Figure 3. Depiction of ground force moment arm, R, and muscle force moment arm, r, during phases of foot support while running at a constant speed. (Carrier et al. 1994).

Movement of center of pressure from ankle to heel to forefoot during gait initiation also changes the lever arm of the foot and impacts the ground reaction force produced by the plantarflexor muscles (Carrier et al. 1994, Bojsen-Moller 1978). Generation of power occurs proximal to distal during stance at the hip, knee, and ankle, with the plantar flexors producing the greatest amount of peak power (Johsnon et al). While running at a constant speed, the center of force moves from under the arch of the foot just after landing to the tips of toes after lift off (Hennig et al. 1982). Push off generally starts in a low gear ratio and gradually changes to a high gear during gait (Bojsen-Moller 1978, Johnson and Buckley 2001).

Force production ability can be further influenced by altering the ankle complex by orientation of the foot or progression angle, which changes the dynamic rotation of the knee. Increased peak knee adduction moment (KAM) can result from a toe-in gait, while a toe-out gait decreases KAM and is commonly used as a compensatory mechanism (Wang et al. 1990, Lin et al 1996, Koblauch et al. 2013). In late stance, immediately before initiation, toe-out angle and low ankle inversion result in lower KAM (Andrews et al. 1996). At the same time, the gear ratio of the lever arm of the ground reaction force to the length of the heel increases, allowing plantarflexor muscle fibers to shorten more slowly and maintain force production (Carrier et al. 1994).

Bojsen-Moller and Carrier provide comparative results to support that toe-in/out would be beneficial during different gait patterns by optimizing muscles contractile performance. Bojsen-Moller's evidence suggests that a smaller gear ratio, toe-in, would be advantageous during stair climbing and start of acceleration during a sprint because of the shortened GRF moment arm and greater force production abilities. During Carrier's study, they also found that during accelerative running the gear ratio remained relatively low, less than 3, and maintained the muscles at a high power. However, other studies have shown a toe-out gait to increase GRF production without contributing to the horizontal force component moving an individual forward and would therefore have no benefit on performance capability (Simpson and Jiang 1999).

Active muscles that are stretched just before shortening are able to do more work during shortening (Cavagna et al. 1986). This means, that if a runner were to land at a low gear ratio and take off at a higher gear ratio, both the pre-stretch and subsequent shortening of the muscles could be optimized (Carrier et al. 1994). For example, during the first part of the contact phase of running step there is an increased stretch applied to the plantarflexor muscles and their gear ratio is <1. During mid-contact the gear ratio increases slightly to 2, and finally during late contact as GRF decreases and the velocity of the foot increases, the gear ratio increases to almost 4.

Therefore, the mechanical advantage of the muscles is relatively high during periods when the force exerted on the ground was the greatest and the muscle shortening velocity was the lowest (Carrier et al. 1994). If an individual can utilize these factors they would potentially have a more efficient gait pattern, acceleration ability, faster running speed, and increased jump height.

Impact on Movement Patterns

Movements such as walking, running, and sprinting can be differentiated by the contact time of the foot against the ground, as well as the value of force needed to propel the individual forward. As speed increases, the point of contact changes from the hindfoot to the forefoot (Novacheck 1998). Gait is measured using the gait cycle, the time in which one foot comes in contact with the ground until that same foot contacts the ground again (Figure 3). As the velocity of gait increases, the stance or push-off phase of the gait cycle decreases. The push-off phase of the gait cycle begins at the onset of plantar flexion about the talocrural joint and ends at toe-off from the MTP joint (Carrier et al. 1994, Neumman 2010). During push-off the ankle and foot act as a lever that propels the body forward with the center of rotation at the ankle (Erdemir and Piazza 2002). The MTP joint is one of the last anatomical features in contact with the ground during push-off phase of gait. Therefore, utilizing variations in foot placement may provide an individual with the ability to increase gait efficiency and performance.

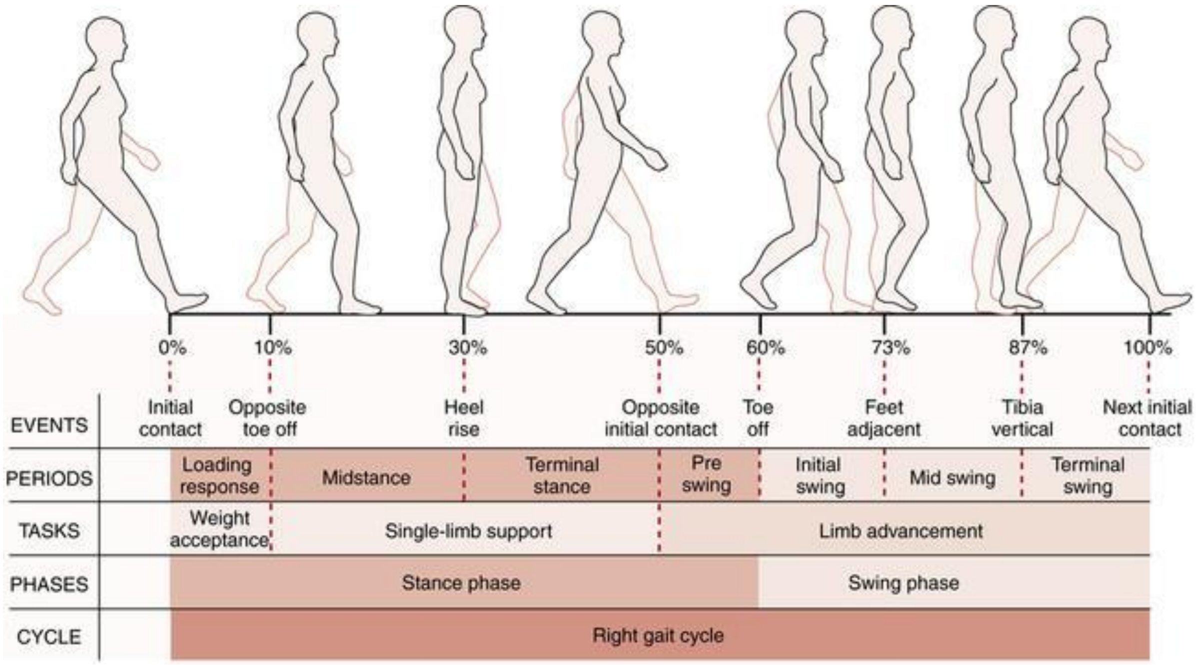

Figure 3. Phases of gait cycle. (Neumman 2010)

Modification of the foot rotation angle or toe-in/out during gait has been documented to occur naturally as a means of efficiently performing ambulation as well as artificially induced as part of an interventional program to improve performance (Almosnino et al. 2009). Modifying gait to an internally rotated foot position during walking minimizes the resistive moment that must be overcome by the ankle plantar flexors during the push-off phase of stance by reducing the moment arm of the GRF vector with respect to the talocrural joint axis (Erdemir and Piazza 2002). Alternatively, other investigators have found that adapting an externally rotated foot position decreases the KAM and unloads the medial compartment of the knee by shortening the moment arm of the GRF in relation to the knee joint center during the second half of stance (Andrews et al. 1996, Lynn and Costigan 2008, Teichtahl et al. 2006, Wang et al. 1990). A study performed by Almosnino et al. found that on average, the free moment

(FM) during walking tends to oppose inward rotation during early to mid stance. Outward rotation is opposed from mid stance until late state. Walking with internal foot rotation did not produce a statistically different FM than normal walking. However, external foot rotation peak FM and impulse were significantly greater than when walking with a normal foot rotation (Almosnino et al. 2009).

The relationship between foot angle modification between the clinical population and application in athletes remains largely unstudied. However, some studies have found asymptomatic individuals and moderate knee osteoarthritis to have similar major lower limb neuromuscular activation characteristics when walking with a 15° out-toed foot progression angle (Rutherford et al. 2010). Both groups showed a delayed recruitment of the gastrocnemius until late phase of stance and prolonged, heightened activity in the quadriceps throughout gait. Heightened quadriceps activity is an indication of higher metabolic cost associated with a toe-out gait modification during walking which may decrease endurance of the muscle during activity (Rutherford et al. 2010). The researchers noted that a longitudinal study would be necessary to see if these neuromuscular changes would diminish or remain the same with the adaptation of a long-term gait pattern modification.

A study performed by Fuchs and Staheli explored the relationship between sprinting ability and intoeing in high school sprinters through rotational profile characteristics. Their results showed that sprinters had significantly lower thigh-foot angles, +3°, than non-sprinters, +10°, and significantly more sprinters intoed during sprinting than control participants. No significant difference was found between the number of sprinters and controls (non-competitive sprinters) that sprinted neutral or sprinted out-toed nor was there a correlation between walking foot-progression angle and hip rotation. These findings suggest that low thigh-foot angles and sprinting intoed may allow for improved sprinting ability and efficiency and supported similar findings from previous studies (Fuchs and Staheli 1996, Staheli et al. 1985). However, the mechanism for enhanced sprinting ability with intoeing remains unclear. Fuchs and Staheli speculate that intoeing places the MTP joint perpendicular to the line of progression, allowing the toe flexors to act more efficiently in assisting the triceps surae, which includes the two heads of the gastrocnemius and soleus, for ankle push-off. Further studies are needed to support this hypothesis and determine the mechanism of potential benefits intoeing has on sprinting ability and economy.

Association with Injury and Disability

Alterations in toe-in/out are sometimes made artificially in order to cause changes in an individual's gait pattern. However, it could lead to negative outcomes without proper understanding of the mechanisms involved with gait modification. A deliberately modified intoeing gait has the potential to increase loads of the lateral aspect of the midfoot and forefoot by as much as 61% and 49% respectively while out-toeing can intensify the load on the medial aspect of the midfoot and forefoot by as much as 72% and 52% (Rosenbaum 2013, Simpson and Jiang 1999). These increased forces are one of the reasons researchers have looked at the relationship between injury and rotational foot placement and toe-in/out alignments and have found several beneficial as well as negative correlations.

Elevated free moment, FM, during gait has been shown by some researchers to be a predictor of the amount of torsional loading experienced during the push off phase of gait (Milner et al. 2006, Carter 1978). The free moment is the reaction to the force exerted by the foot on the ground acting about the vertical axis originating at the foot's center of pressure. Milner was able to use FM measurements to discriminate between healthy female runners and those with history of tibial stress fractures. Li and Umberger found that FM is especially sensitive to gait modifications in the transverse plane, such as stresses that may occur from altering rotational foot placement away from normal (Li et al. 2001, Umberger 2008). Therefore, the effect of toe-in/out placement on FM needs to be understood in order to prevent stress injuries.

Kinematic adaptations, including increasing toe-out angle, can be made as compensatory mechanisms to unload stresses on the knee in individuals with knee osteoarthritis and other knee conditions (Jenkyn et al. 2008, Andrews et al. 1996, Guo et al. 2007, Hurwitz et al. 2002, Lin et al, Wang et al. 1990). Decreasing adduction moment about the knee is especially relevant, as a high load on the medial knee compartment has been found to increase risk factors for osteoarthritic disease progression (Amin et al. 2004, Hurwitz et al. 2002, Miyazaki et al. 2002). Jenkyn found that a mean toe-out angle of 11.4° in patients with medial compartment knee osteoarthritis transforms a portion of the adduction moment into flexion moment in early stance. In those individuals with modified toe-out gait the frontal plane lever arm and adduction were reduced in early stance, and sagittal plane lever arm and flexion moment increased as compared to individuals with normal gait. Other researchers have found that landing in the toe-out position also decreases peak hip adduction, knee abduction, and internal rotation angles and may reduce the risk for ACL injury (Tran et al. 2016).

Jenkyn found no evidence for detrimental effects of toe-in angle position during takeoff from stance. However, studies by Tran et al. found that landing with both legs from a jump in a 30° toe-in position increased peak hip adduction, internal knee rotation moments, and peak knee abduction angles. Characteristically, these increased factors are associated with a valgus knee position and may contribute to biomechanical risks associated with ACL injuries and should be avoided (Tran et al. 2016). While this study used toe-in/out angles of 30° internal or external rotation respectively, angles of greater than 30° for either alignment have been categorized as "high risk" positions by the Landing Error Scoring System (LESS) a screening system for movement patterns during jumping tasks (Padua 2009). Adopting an internal or external rotation that is too dramatic will increase risk factors for injury, regardless of what potential benefits the alignment may have at a less severe degree of rotation.

Children with neuromuscular diseases have also been found to have altered foot pressure measurements caused by variations in their FPA. Neurologic disorders that impact foot progression angle are commonly distinguished from those that arise from a mechanical or anatomic variation in that they present gradually over a period of time during childhood (Chang 1988). In instances of pediatric anteversion during gait, altering support of the shoe has not shown evidence to improve the gait or change it to a more natural course. Instead, if FPA does not return to normal values by seven or eight years of age, surgical measures such as rotational osteotomy, tibial osteotomy, or Denis-Brown bar may be taken to correct the rotation (Chang 1988).

The FPA can also be a predictor of elevated regional plantar stresses and loads. For patients with diabetes mellitus and peripheral neuropathy, this could lead to an increased risk for dermal injuries such as pressure ulcers (Merriwether et al. 2016, Wu et al. 2014). Merriwether et al investigated the effects of static and dynamic predictor variables on FPA. They found that dynamic measures of external rotation during gait were strong predictors for FPA while static measures of joint position and joint mobility had no correlation to FPA. Dynamic measures accounted for 37% of foot progression angle variance out of the 15-45% variance FPA commonly accounts for in plantar stresses and loads (Merriwether et al. 2016). These findings were supported by Wu et al. who also found that gastrocnemius inflexibility, a common symptom of orthopedic and neurological conditions, results in a greater than normal toe-out foot progression angle and knee external rotation during the stance phase of gait and ultimately greater pfMA and medial GRF (Wu et al. 2014). Therefore cues targeting alterations in the thigh and shank may potentially allow individuals to alter gait patterns in order to decrease degree of external FPA, GRF, minimize risk of elevated plantar stresses, and chances of developing soft tissue injuries (Merriwether et al. 2016, Wu et al. 2014).

Conclusion

The findings of this literature review reveal there is strong evidence to suggest that modifying the axis of push-off through toe-in/out alignment or altering foot progression angle can change the gear ratio during movement and result in a more mechanically advantageous gait pattern to improve performance during locomotion. Previous research seems to suggest that toe-in forms a short resistance arm with low gear ratio that is optimal for slow angular motions. During toe-in a shorter GRF moment arm is formed and the plantarflexor muscles have greater force production abilities. Individuals tend to utilize a smaller gear ratio during the acceleration phase of running and short intense movements such as stair climbing. Adapting an intoed gait during these activities could result in a more efficient gait pattern. Alternatively, toe-out gait has been shown by researchers to form a higher gear ratio with longer resistance arm that decreases peak knee adduction moment and allows plantarflexor muscle fibers to shorten more slowly to maintain a more constant production of force.

Further studies are needed to determine concise parameters for degrees of internal or external rotation that will produce benefits as well as if those guidelines can be generalized to a population or should take into account an individual's unique anatomic and kinetic characteristics. Investigations into the effects of foot alignment during athletic performance such as sprinting, long distance running, and jumping should also be further researched. The majority of current literature is limited to clinical observations. Finally, a study that combines the use of intoeing and outtoeing during different phases of the gait cycle or phases of a run/sprint has yet to be conducted and may shed light on potential advantages of both forms of foot alignment.

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