Abstract

Excessive pronation has been implicated in the development of numerous overuse injuries of the lower limb and is suggested to cause more proximal biomechanical dysfunction.   Functional foot orthoses (FFO) are frequently prescribed for lower limb injury associated with excessive foot pronation and have been demonstrated to have efficacy with specific conditions. However, the mechanism of action of FFO is largely unknown. Research investigating the kinematic and kinetic changes associated with FFO use is inconclusive. Furthermore these is a growing body of evidence suggesting that changes to muscle activity patterns in response to FFO may be responsible for their therapeutic effect. Additionally, current research suggests dysfunction of musculature of the lumbopelvic-hip complex is involved in lower extremity functional changes and is related to the development some pathologies traditionally attributed to excessive foot pronation.   Evidence of temporal coupling between the hip and the foot and changes in hip muscle activity associated with FFO use further suggest a relationship between proximal and distal lower limb function. The aim of this review is to discuss the association between foot and lumbopelvic-hip complex dysfunction and injury, assess the evidence for functional changes to lower limb and lumbopelvic-hip function with FFO use and finally to discuss the potential for changes to hip musculature activation with FFO use to influence distal mechanics and produce a therapeutic benefit.

Introduction

Abnormal foot function, particularly in relation to excessive or prolonged pronation, has traditionally been identified as a risk factor and possible aetiology for the development of lower limb overuse injury (1-3). Foot pronation has been proposed to propagate more proximal lower limb dysfunction and hence contribute to a wide range of lower limb injuries affecting the lower back, hip, knee, lower leg, ankle and foot (4, 5). This has lead to functional foot orthoses (FFO) being widely prescribed by podiatrists and other health professionals to treat pronation-related pathology under the assumption that they control foot pronation and restore normal foot and lower limb mechanics (6).

Evidence supports the effectiveness of FFO in the management of several lower limb pathologies (7-9), many of which are also associated with lumbopelvic-hip and particularly gluteus medius (GMed)dysfunction (10-12). The link between the lumbopelvic-hip complex and foot function is increasingly being investigated due to the presence of their concomitant dysfunction in the development of lower limb injury (5, 12-14) and the evidence that FFO appear to be effective in the management of these injuries (7, 8).

Research into the functional response of the lower limb to FFO is inconclusive. There is some evidence that small alterations to lower limb kinematics and kinetics occur (15), however, such functional change is frequently reported to be subject specific and inconsistent (16, 17). There is a growing body of literature indicating that muscle activity patterns are more significantly altered by FFO and may be responsible for their therapeutic effect (18).

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Just as abnormal foot pronation is thought to propagate proximal pathomechanics, dysfunction of the lumbopelvic-hip complex is proposed to influence the function of more distal structures of the lower limb (19) and may potentially play a role in foot motion (20). Interventions targeted at the musculature responsible for stability of the lumbopelvic-hip complex may have potential to alter lower limb mechanics and consequently reduce injury risk. Such proximal correction may play an integral role in producing therapeutic effects seen with FFO use.

The first aim of this review is to discuss the association between foot and lumbopelvic-hip complex dysfunction and injury. Secondly, the review will assess the evidence for functional changes to lower limb and lumbopelvic-hip function with FFO use. Finally, the potential for changes to hip musculature activation with FFO use to influence distal mechanics and produce a therapeutic benefit will be discussed.

Methods

The search strategy for this review consisted of an electronic database search of title and abstract. Databases included MEDLINE (1950 – 2011), Cinahl (1983 – 2011), EMBASE (1974 – 2011) and SPORT discus (1985 – 2011). Search terms used included foot posture, foot mechanics, lumbopelvic, hip, mechanics, kinetics, kinematics, muscle, injury, foot othoses and gait. No language restrictions were placed on the search. Titles and abstracts were then reviewed and included where relevant to the review topic in a non-systematic manner. Reference lists of included articles were searched for further relevant articles. All study types were included in order to review the theoretical

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concepts surrounding foot and lumbopelvic function and foot orthoses as well as empirical evidence. Exclusions were made from kinematic studies using 2-dimensional study methods and where ankle-foot orthoses were utilised. Only studies examining systemically healthy adults were considered in order to focus on musculoskeletal overuse injury.

Foot Function and Overuse Injury

The human foot has evolved as the foundation for upright standing and movement (21-23). In this role, the foot must support body mass, provide for postural balance, absorb shock, adapt to ground surfaces and transmit forces efficiently during gait and other bipedal activities. This is achieved via a complex series of mutually dependent movements of the joints of the foot (24). Significant movements occur at the talocrural , subtalar , talonavicular, calcaneocuboid and navicular-cuboid joints during the gait cycle (25-27). Recent investigations highlight the complexity and high individual variation of these tarsal movements (28). These articulations can, however, be summarised as the opposing triplanar movements of pronation and supination (29). Pronation, occurring at the beginning of the stance phase of gait, flattens the arches of the foot, increases the available motion of the forefoot and serves to absorb shock and allow the foot to adapt to ground surfaces (24). Towards the end of stance, supination of the foot raises the arch and decreases the available motion of the forefoot providing stability and facilitating efficient propulsive phase mechanics (24).

In clinical and research settings abnormal foot posture is typically characterised by a pronated or supinated foot type based on the position of the foot in static stance (30).

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Traditionally, these foot types were determined by deviation of the subtalar joint from the neutral position or observing the height of the arch (31). More recently developed methods, such as the Foot Posture Index , incorporate multiple joint positions across all anatomical planes (32). Given the natural variation in foot motion previously described, these may be a more accurate measure of foot type (32). However, no standard approach to measurement and classification of foot type has been adopted due to concerns over the reliability of these measures and their validity in reflecting dynamic motion (29).

Proposed interdependence of the musculoskeletal structures of the lower limbs indicates that function of the foot is related to that of proximal structures (5). Both extremes of foot type have been linked with lower limb injury. A supinated foot posture that displays little closed chain pronation has been reported as a risk factor for impact-related pathology (2) due to a reduced capacity to attenuate shock (24). Considerably more research has been performed on the relationship between pronated foot type and overuse injury. Pronated foot types have been associated with stress fractures (33), tibial stress fractures (1), medial tibial stress syndrome (34, 35), knee pain (3, 36), anterior cruciate ligament injury (37, 38) and low back pain (3). However, not all studies investigating this relationship have supported the connection between foot pronation and injury (2, 39, 40) and the reasons for such pathophysiological connections remain uncertain (41).

The proposed connection linking foot pronation aetiologically to injury involves the propagation of abnormal mechanics proximally. In theory, excessive pronation is coupled with excessive internal rotation of the tibia and femur (14, 42), a valgus knee position (42, 43) and anterior pelvic tilt (5). This positioning places stress on related

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musculoskeletal structures which predisposes to overuse injury via microtrauma incurred over many repetitions of the gait cycle (24).

Within the foot, abnormal pronation results in disruption of the midfoot which places extra strain on supporting structures of the arches such as the plantar fascia (44). Additionally, prolonged stance phase pronation causes instability of the forefoot that results in altered propulsive phase mechanics (44). Instability of the forefoot occurring with prolonged pronation is associated with first metatarsophalangeal joint dysfunction including a functional restriction of hallux dorsiflexion (functional hallux limitus) and an inefficient propulsive phase. Compensatory gait patterns including prolonged forefoot inversion, propulsive instability and postural perturbations are suggested to cause altered patterns of weight flow through the foot (45, 46).

At the lower leg and thigh there is evidence that a pronated foot type is associated with excessive internal limb rotation (47, 48) and delayed external tibial rotation (47) during running. This internal limb position is proposed to place the patella laterally on the femur, predisposing to patella maltracking and patellofemoral pain syndrome (14). In the frontal plane, eversion of the rearfoot has been associated with a valgus position of the knee (49). This is thought to create compression of the lateral knee compartment (14).

Foot posture has been suggested to affect more proximal structures with generalised excessive or prolonged foot pronation associated with transient functional shortening of the limb, increased internal rotation of the lower limb and a more anteriorly rotated pelvis position. The altered pelvis position is hypothesised to place increased strain on

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muscles of the pelvis and hip including iliopsoas, piriformis and gluteal musculature (Bird & Payne, 1999). There is subsequent narrowing of the greater sciatic notch and compression of the sciatic nerve due to anterior rotation of the pelvis potentially causing sagittal plane wedging of intervertebral discs (50, 51). Additionally, functional changes associated with excessive foot pronation are suggested to place significant strain of the sacroiliac and lumbosacral joints and to cause lumbosacral instability (51). Despite this strong theoretical basis linking foot function to biomechanical dysfunction of the lower limb and consequent injury, empirical support is still lacking. Current research investigating foot pronation and proximal kinematic function is summarised in Table 1.

Lumbopelvic Function and Overuse Injury

The role of instability and dysfunction of the lumbopelvic-hip complex in the development of overuse lower limb injury is becoming increasingly apparent (19). This complex consists of the musculoskeletal structures of the lumbar spine, pelvis and hip. Where musculature of this complex is dysfunctional in terms of flexibility, strength and neuromuscular activation, force distribution and transfer across joints is disturbed and structures are predisposed to injury (52). Deficits within this complex have been linked with low back pain (53, 54), patellofemoral pain syndrome (12), iliotibial band friction syndrome (11) and anterior cruciate ligament injury (10). In particular, alterations to neuromuscular activation of GMed has been related to pathology including ankle hypermobility (55), ankle injury (56), iliotibial band friction syndrome (11), patellofemoral pain syndrome (12, 43) and low back pain (57).

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Gluteus medius plays an essential role in the provision of hip and pelvic stability (52, 58, 59). The muscle produces and controls frontal and transverse plane movement at the hip joint and compresses the femoral head inside the acetabulum (52). GMed attaches proximally along the posterior iliac crest from the anterior superior iliac spine (ASIS) to the posterior superior iliac spine (PSIS) and unites distally into a strong tendon which inserts onto the anterosuperior aspect of the greater trochanter (58). Fibre orientation, functional electromyographic data and individual innervations from the superior gluteal nerve distinguish the GMed into three similar sized sections: anterior, middle and posterior. The anterior fibres (those closest to the ASIS) have a vertical orientation reaching from the ASIS to the attachment at the greater trochanter of the femur. The middle fibres run diagonally from the middle of the iliac crest to the insertion at the greater trochanter of the femur. The posterior section fibres run horizontally in line with the femoral neck (58). All fibres have capacity for abduction of the femur on the pelvis The anterior and middle segments have internal rotation capacity as the hip flexes and the middle and posterior fibres have external rotator moment arm in hip extension (11, 59).

There is growing evidence that dysfunction of proximal musculature has significant implications for distal limb functioning. Suggested biomechanical changes associated with lumbopelvic dysfunction include femoral adduction, internal femoral rotation and knee valgus (19). These changes have the capacity to produce a line of weight bearing falling medial to the subtalar joint and therefore could contribute to excessive or prolonged foot pronation. This may explain the injuries attributed to both excessive foot pronation and GMed dysfunction. Investigation of joint kinetics and power flow

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through the lower limb during gait supports this with evidence showing the dependence of knee and ankle moments on those of the hip (60) and a potential proximal power source for foot pronation (20).

Kinematically, dysfunction of hip abductors and external rotators (including GMed) leads to biomechanical positions that are proposed to be associated with foot pronation. These include reduced control of femoral adduction leading to frontal plane pelvic drop (61), internal hip rotation (13) and a valgus force at the knee during single leg stance (11) (Figures 1 and 2). This positioning and subsequent movement is proposed to produce tightness in the tensor fascia lata and iliotibial band predisposing to iliotibial band syndrome (11), anterior cruciate ligament injury (13), lateral patellar maltracking and increased lateral retropatellar contact pressure (12, 43). Further studies suggest that abnormal motor control patterns of GMed may predispose individuals to a number of lower limb overuse injuries. Nelson-Wong et al. (57) found that subjects who developed low back pain demonstrated co-contraction of left and right GMed. Bruno and Bagust (62) found that during prone hip extension individuals with low back pain had delayed onset of GMed activation. Additionally, it was shown that delayed latency of GMed activation is associated with a history of ankle sprain and hypermobility (55).

The Influence of Gender on Lower Limb Function

Females are more likely to experience anterior cruciate ligament injury, iliotibial band friction syndrome, tibial stress fractures (63), patellofemoral pain syndrome (64) and low back pain (54). This reported predisposition to injury is potentially due to structural

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and functional differences between the male and female hip and lower limb. Females have a wider pelvis, a greater valgus angulation of the femur (65) and a greater internally rotated hip position (66). It has been demonstrated that during dynamic activity females have significant differences in lower limb kinematics and kinetics when compared with their male counterparts. During running gait, females have been found to reach significantly greater knee valgus angle (67) and greater peak and velocity of hip adduction (65).

Several studies have linked gender to altered hip muscle activity. Leetun *et al*. (68) found that females have less hip abductor and external rotation strength than males, and that those with less abductor and external rotator strength were more likely to sustain an injury . Ireland *et al.* (12) found that weakness of hip abductors causes increased frontal plane hip motion and reduced control over knee motion. .

Single leg functional tasks require substantial neuromuscular control at the hip due to an increased external hip abduction moment and decreased base of support (19, 69). During such tasks females have been shown to perform poorly compared to males (70). The single leg squat is a common functional test to evaluate injury risk during dynamic function (19). Research suggests females demonstrate larger amount of knee valgus during single leg squats, beginning the squat in greater knee valgus, which was then maintained throughout the task (70). This has been suggested to be due to dysfunction of hip stabilising musculature allowing the femur to move into adduction which is accompanied by internal rotation and knee valgus (19).

Efficacy of Functional Foot Orthoses

Functional foot orthoses are commonly prescribed as an intervention for pronation related pathology (6) with an empirical basis for their use as a treatment modality in a number of pathological conditions. Uncontrolled longitudinal and retrospective studies have found evidence for improvement in pain, comfort, stability and mobility (9), symptom resolution and patient satisfaction (71) as well as improvement in the symptoms of specific injuries including patellofemoral pain syndrome, retropatella dysplasia and chondromalacia patellae (72), medial tibial stress syndrome (73), heel spur syndrome, plantar fasciitis (74) and low back pain (75).

Randomised clinical trials have shown FFO to be as effective in the treatment of knee osteoarthritis as knee bracing (76) and to be more effective than a flat insole in the treatment of patellofemoral pain syndrome (77) and painful pes cavus (78). A systematic review of the effect of custom moulded FFO on foot pain concluded there was evidence that they were effective in the treatment of pain associated with pes cavus, juvenile idiopathic arthritis and painful hallux valgus and rearfoot pain associated with rheumatoid arthritis (8). However, not all literature is supportive of the use of FFO as a treatment for lower limb injury (79, 80). A lack of high quality randomised controlled trials has been identified (8).

The Effect of Functional Foot Orthoses on Lower Limb Function

Traditionally, FFO have been prescribed to act as a passive restraint to excessive pronation (51). Subsequently, proximal posture and lower limb mechanics are optimised and stress to lower limb structures is reduced. More recent development of this theory

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takes into consideration other potential mechanisms including kinetic factors, impact forces and action on neuromuscular pathways (81, 82). However, these are largely theoretical considerations still requiring further empirical support (83).

Current literature on the influence of FFO on kinematic variables both statically and during functional tasks has shown some small alterations in foot and lower limb kinematics. Several studies have found a reduction in foot pronation movements with FFO intervention during walking and running (84-87). Additionally, peak rearfoot eversion has been shown to reduce by between 1.95^{o} and 2.3^{o} during gait with the use of FFO (15).

Potential for changes in function proximal to the foot is more inconclusive. FFO have been found to decrease peak tibial internal rotation (86, 88, 89) with reductions of between 1.33^{o} and 1.9^{o} reported (15). However, several investigations have reported a large intersubject variability in changes to tibial motion (16, 17) and there are few significant results on the kinematic alterations with FFO on structures further proximal to the tibia (90-93). This may be due, in part, to limitations in trials including small sample sizes, low statistical power, use of samples with heterogenous foot types and skin mounted markers which may not reflect underlying bony movement (94). Though it is possible that small changes may be significant for the development of pathology due to the repetitive nature of gait, lack of homogeneity of kinematic effect in the literature indicates that alterations to kinematics may not be the primary action of FFO in the treatment of injury.

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It has been suggested that alterations to joint moment and consequent reduction in loading of structures may be more relevant to the action of FFO in providing symptom relief than simple kinematics. Studies of alterations to joint moments with FFO have shown reduced rearfoot inversion moment (86, 91, 92, 95). This suggests that structures controlling this movement, including tibialis posterior, may be under less strain (95). At the knee, FFO have been demonstrated to increase internal moments of external rotation (86, 92, 95), flexion and extension moments (91) and abduction moments (95). To date, results of studies measuring kinetic changes have found only small alterations and the clinical significance of these changes is unclear. This is complicated by evidence to suggest that FFO can improve symptoms of knee pain without any significant biomechanical changes. Nester et al. (2003) found reductions in symptoms at the knee with FFO use without accompanying kinematic or kinetic changes. These results indicate that kinematic and kinetic changes are not the primary factors that produce relief from injury. It has also been suggested that changes to soft tissue function, particularly neuromuscular control of functional tasks, may be more significant as a mechanism for biomechanical changes responsible for injury relief (15, 93).

The contribution of sensory feedback provided by FFO to their mechanism of action has been recognised under neuromuscular theory (82). This theory proposes that FFO stimulate cutaneous mechanoreceptors, particularly the tibial nerve as it passes under the arch. Subsequent adjustments to intensity and timing of muscle activation are made in response to this biofeedback (82). This is supported by research that shows that during walking there is constant afferent feedback to the muscle in response to ground

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surface characteristics (96) and that location specific information is sent from each pedal nerve that elicits a distinct muscular response (97). This is demonstrated by evidence that stimulation of the tibial nerve provides afferent feedback that caused alterations to soleus activity continuously during locomotion (96).

In addition, FFO have been shown to alter muscular activity at various levels of the locomotor system (18). During walking gait, changes in the amplitude of several lower limb muscles have been found including increases in peroneus longus activity (98, 99) and decreases in tibialis posterior activity (99) with use of FFO. As tibialis posterior is a strong anti-pronation muscle and peroneus longus contributes to foot pronation these findings suggest alteration to muscle activity may play an important role in injury resolution (99). During running gait, increases in vastus lateralis and medialis , peroneus longus, biceps femoris and the medial gastrocnemius amplitude have been found (100), as well as increases in tibialis anterior activity and decrease in biceps femoris activity (101). Alterations to temporal parameters of muscle activation include a delay of medial gastrocnemius activity during running (100), an increase in tibialis anterior duration (102) and an earlier onset of erector spinae with forefoot wedging (103) during walking. Other results include an increase in vastus medialis and GMed amplitude during single leg squats, increase in vastus medialis activity during lateral step down and decrease in vastus lateralis activity during a maximum vertical jump (104). Whether these changes represent a more functional lower limb muscle activation pattern and if this has a positive effect on pathology remain uncertain (105).

The research indicates that substantial neuromuscular alterations are elicited by FFO (Table 2). However, the literature is lacking in investigations into the response of the

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lumbopelvic-hip musculature to FFO. Existing evidence has produced mixed results with respect to GMed activity. Hertel et al. (2005) found that orthoses increased GMed amplitude during single leg squats, however no changes during lateral step down or maximum vertical jump tasks. Conversely, Bird et al. (2003) found no changes in GMed onset or amplitude during walking with forefoot wedging, though this study was limited to forefoot wedging in the absence of footwear. Evidence for the potential of FFO to alter GMed activity may have implications for lower limb function. Neuromuscular treatment programs aimed at improving GMed activity has been shown to alter lower limb function towards a proposed ideal (106). If FFO increase GMed activity, this may produce such an optimization of function that acts to reduce injury risk.

Conclusion

Foot pronation is believed to contribute to the development of lower limb overuse injury (4). Reduced GMed activity and associated lumbopelvic-hip complex instability is also linked to the development of lower limb injury (12, 13). Significantly, many pathologies that have previously been attributed to excessive foot pronation and treated successfully with orthoses have also been linked to GMed weakness and also treated successfully with GMed strengthening programs (106). Evidence that females are more susceptible to such injury (63) and demonstrate a higher incidence of GMed related dysfunction (13) suggests that muscle strength at the hip may make an important contribution to lower limb function. Despite the fact that FFO are prescribed

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successfully to treat overuse injury attributed to both GMed dysfunction and foot pronation (7, 72) there is no conclusive evidence of the exact mechanism of action of this intervention. Identification of a coupling between the foot and the lumbopelvic-hip complex suggests that FFO may have an effect on more proximal structures (107), potentially altering lower limb muscle function and contributing to the therapeutic benefit of FFO. These factors, along with evidence for the neuromuscular effect of FFO (18), suggest that foot function and GMed function may be interrelated and that this relationship needs to be investigated further.

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Table 1: Summary of the evidence for the association between foot pronation and proximal kinematics during gait in adults

Paper	Subjects (control: pronated)	Activity	Foot posture measurement	Outcome measures	Findings associated with pronation
Dierks et al. (2008)	Forty (correlation study)	Running (treadmill)	Arch index	Knee motion – frontal plane	None
Houck, Tome and Nawoczenski (2008)	Twenty-one (7:14)	Walking	Forefoot varus exceeding 10° Rearfoot everted in static stance Navicular drop of 10°	Rearfoot motion – sagittal and frontal planes First metatarsal motion – sagittal plane First metatarsophalangeal joint motion – frontal plane	Greater rearfoot inversion at heel strike and 96% stance Greater rearfoot eversion at 28% stance Greater first metatarsal dorsiflexion
Hunt et al. (2000)	Nineteen males (correlation study)	Walking	Static rearfoot eversion Medial arch angle	Rearfoot motion – all planes	Greater maximum eversion
Hunt and Smith (2004)	Thirty-three males (18:15)	Walking	Clinician determined	Rearfoot motion – all planes	Greater rearfoot plantarflexion of the at 21% stance Less forefoot adduction at toe off Less overall transverse plane motion
McClay and Manal (1998)	Eighteen (9:9)	Running (treadmill)	Greater than 18° rearfoot eversion during running	Rearfoot motion – all planes Knee motion – all planes	Greater peak rearfoot eversion Greater everted position at heel strike and toe off Greater peak knee flexion Lower peak knee adduction and adduction excursion Greater rearfoot dorsiflexion, eversion Greater knee flexion velocity
Nawoczenski et al. (1998)	Twenty (10:10)	Running (treadmill)	Radiographic measurements	Rearfoot motion - frontal plane Tibial motion – transverse plane Coupling of rearfoot and tibial motion	Coupling ratio: greater frontal plane motion relative to tibial transverse plane motion
Nigg et al. (1993)	Thirty (correlation study)	Running	Arch height	Rearfoot motion - frontal plane Tibial motion – transverse plane Transfer of rearfoot motion to tibial motion	Less transfer of rearfoot eversion to internal tibial motion.
Williams et al. (2001)	Forty (20:20)	Running	Arch ratio	Rearfoot motion – frontal plane Tibial motion – transverse plane Knee motion– transverse and sagittal planes Coupling of rearfoot and tibial motion Coupling of rearfoot and knee motion	Greater rearfoot eversion excursion Greater rearfoot eversion velocity Greater peak knee flexion Coupling ratio: greater frontal plane motion relative to tibial transverse plane motion

Table 2: Summary of evidence for alteration to muscular activity with use of FFO during gait

| Paper	Participants	Activity	Control	Orthotic conditions	Muscles tested	Changes associated with orthotic use
Bird et al. (2003)	Thirteen Asymptomatic	Walking	Barefoot	Lateral forefoot wedge Medial forefoot wedge Heel lift	Erector spinae (at L3) GMed	Erector spinae: earlier onset with bilateral heel lifts and lateral forefoot wedge GMed:later onset with bilateral heel lifts and ipsilateral heel lift
Mundermann et al. (2006)	Twenty-one Pronated Asymptomatic	Running	Sham	Posted orthotic Moulded orthotic Posted and moulded orthotic	Tibialis anterior Peroneus longus Gastrocnemius Biceps femoris Vastus lateralis Rectus femoris Vastus medialis	All conditions produced a general increase in activity particularly for tibialis anterior, peroneus longus and biceps femoris
Murley and Bird (2006)	Fifteen Pronated Asymptomatic	Walking	Shoe only	Custom orthotic 0° inversion Custom orthotic 15° inversion Custom orthotic 30° inversion	Tibialis anterior Peroneus longus Gastrocnemius Soleus	None
Murley, Landorf and Menz (2010)	Thirty Pronated	Walking	Shoe only	Heat moulded orthotic Inverted custom orthotic	Tibialis posterior Tibialis anterior Peroneus longus Gastrocnemius	Tibialis posterior: decrease with heat moulded and custom orthoses Peroneus longus: increased with heat moulded orthoses
Nawoczenski and Ludewig (1999)	Twelve Pronated Symptomatic	Treadmill running	Shoe only	Custom foot orthotic	Vastus medialis Vastus lateralis Biceps femoris Tibialis anterior Gastrocnemius	Tibialis anterior: increase in activity Biceps femoris: decrease in activity
Stacoff et al. (2007)	Three Pronated History of injury	Walking	Sham	Posted orthotic Posted and moulded orthotic Proprioceptive device	Tibialis posterior	None
Tomaro and Burdett (1993)	Ten Pronated History of injury	Treadmill walking	Shoe only	Prefabricated orthotic	Tibialis anterior Peroneus longus Gastrocnemius	Tibialis anterior: increase in duration of activity following heel strike
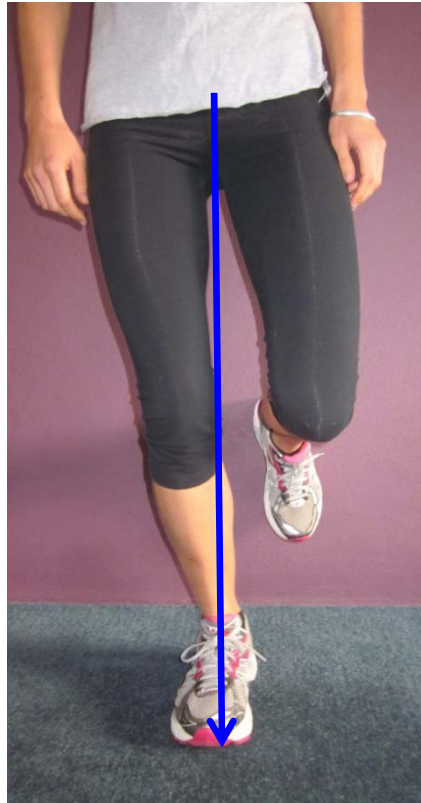
Figure 1: Single leg squat demonstrating adequate lumbopelvic-hip control and a line of weight bearing close to the subtalar joint axis.
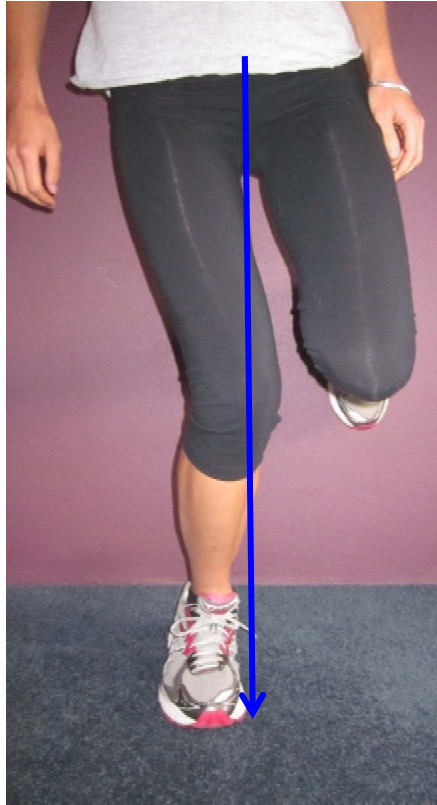
Figure 2: A single leg squat demonstrating dynamic knee valgus position, (associated with poor lumbopelvic-hip control), creating a more medially deviated line of weight bearing.