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Role of ankle dorsiflexion in sports performance and injury risk: A narrative review

Haifa Saleh Almansoof [1], Shibili Nuhmani [1*], Qassim Muaidi [1]

[1] Department of Physical Therapy, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, Dammam, SAUDI ARABIA
*Corresponding Author: snuhmani@iau.edu.sa

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ABSTRACT

The objective of this literature review is to understand the role of ankle dorsiflexion range of motion in sports performance and the risk of injuries. The ankle harmonizes the interaction between the body and the supporting surface through adjusting to the supporting surface and handling forces to contribute effectually to different functional activities. Ankle dorsiflexion is an essential construct in many sport-specific skills. Ankle dorsiflexion is associated with activation of brain areas involved in movement preparation, sensory integration, motor planning/execution, balance, and visuomotor coordination. Ankle dorsiflexion was associated with enhanced activation of deep core and quadriceps muscles. Decreased ankle dorsiflexion is linked to compensations and altered kinetics and kinematics that can potentially affect sports performance and increase the chances of sustaining injuries. It is vindicated to consider more focus on ankle dorsiflexion range of motion in research studies, sports-related pre-season screening, clinical examination, injury rehabilitation, and return-to-sports judgment.

Keywords: ankle dorsiflexion, sports performance, sports injuries, compensatory strategies, sport-specific skills

INTRODUCTION

The ankle joint is among the human body's most complex joints, and it consists of an osseous and soft tissue system that offers an inherent structure and function coordination. The ankle offers steady and effectual interactions between the body and the supporting surface while standing, walking, and in other functional activities. It adjusts simultaneously to various supporting surfaces, absorbs and transfers forces applied to it, and offers firm propulsion while walking. The ankle joint tolerates extensive body weight-related forces (compressive, shear, and rotatory) throughout daily functional activities. The human foot sole has various nerve endings (receptors) that can perceive the metatarsal and calcaneal viscoelastic changes, pressures, and distortions. Sensory information from those receptors is transferred to higher nervous system-level nuclei that command the muscles around the joints. These nuclei collect this information and transmit it as an instant reaction to the muscles to control the joints. Ankle dorsiflexion is a predominantly tibiotalar (talocrural) joint motion in the sagittal plane around the ankle axis of rotation that passes through the medial and lateral malleoli [1]. The ankle is intrinsically stable in weight-bearing due to the closed-packed position of the articular surfaces. Ankle dorsiflexion in a weight-bearing position causes the talocrural joint to be locked in a closed-packed position [2]. The weight-bearing ankle dorsiflexion makes the lower limb a more stable beam in the walking stance phase for efficient energy transfer. Ankle stability relies on its medial and lateral ligaments in a non-weight-bearing position [3]. The ankle plantar flexion is an unstable ankle position because it places the talus narrowest portion in the ankle mortise, reducing the talocrural joint bony stability [2, 3].

Active ankle dorsiflexion enables higher pelvic floor muscle maximal contraction in females [4], greater quadriceps activation and force production during a maximal isometric task in healthy individuals, and increased transverse abdominis activation in draw-in maneuver in healthy individuals. A greater range of ankle dorsiflexion and increased gastrocnemius-soleus complex extensibility were correlated with landing higher sagittal plane knee displacement and low ground reaction forces and loading rate [5-7] that may decrease the anterior cruciate ligament injury risk [7] and patellar tendon load in healthy and physically active individuals [5]. Open-chain dorsiflexion was significantly correlated with 50-meter all-styles swimming time in healthy female swimmers [8]. Weightlifters' performance and technique (in snatch and clean and jerk) efficacy were highly correlated with the ankle joint dorsiflexion ROM [9]. Greater gastrocnemius-soleus complex extensibility reduced frontal and horizontal plane knee loading throughout walking in male athletes [10]. The decreased ankle dorsiflexion ROM is associated with displacement of the ankle motion axis. The ankle motion axis displacement is related to soft tissue shortening around it [11]. Sprinting, jumping, and change-of-direction performance significantly affect the ankle dorsiflexion ROM throughout busy matches calendars in young soccer athletes. A systematic review concluded that there was moderate evidence regarding the correlation between ankle

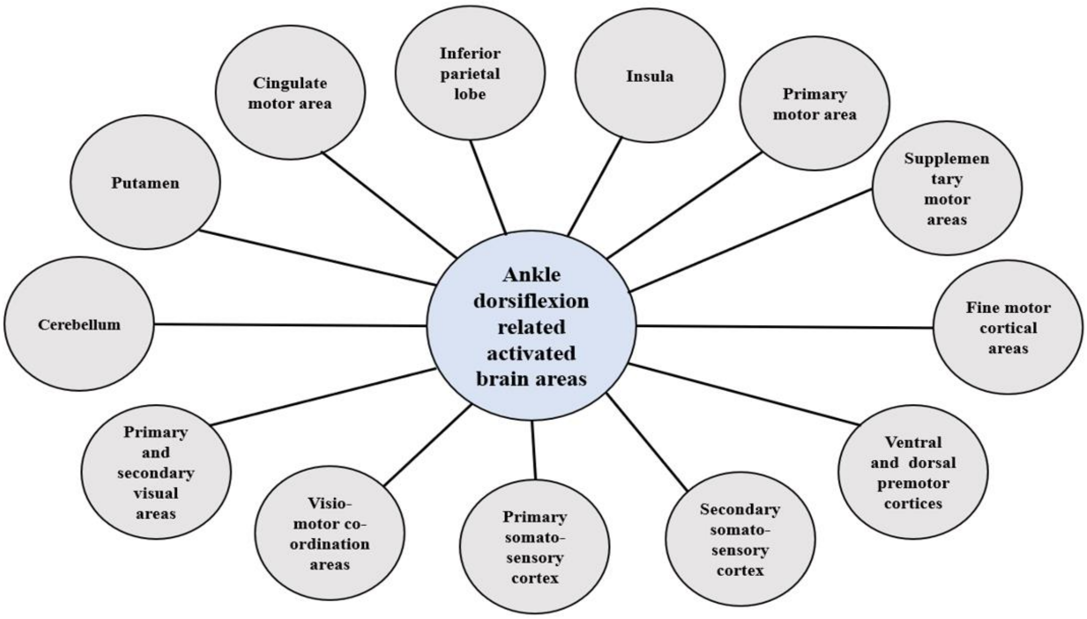

Figure 1. An outline of ankle dorsiflexion related activated brain areas (Source: Authors' own elaboration)

joint flexibility and musculoskeletal injury risk [12]. Decreased ankle dorsiflexion throughout the mid-stance to the push-off phase of the gait cycle results in greater forces on the forefoot and midfoot that can precipitate or exaggerate one or more of various pathologies like metatarsalgia and neuropathic ulceration [13]. Ankle dorsiflexion ROM of less than 10° showed lower limb and pelvic kinematics alterations while walking (i.e., short steps, pelvic ipsilateral rotation angle low peak, and low maximal flexion angles of the hip and knee in the stance phase)[14]. Male United States army rangers with ankle dorsiflexion ROM asymmetry ≥6.5^0 were more likely to suffer musculoskeletal injuries by four times and musculoskeletal overuse injuries by 5.1 times than rangers without asymmetry [15]. Therefore this study aims to understand the role of ankle dorsiflexion range of motion in sports performance and the risk of injuries.

ANKLE DORSIFLEXION & ACTIVATION OF NERVOUS SYSTEM IN HEALTHY INDIVIDUALS

Ankle Dorsiflexion & Brain Activation

In six young and healthy male volunteers (20-25 years old), using the functional MRI (fMRI), it was found that many cortices are involved in active ankle dorsiflexion, the primary motor areas in particular [16]. It massively excited the contra-lateral primary motor area (M1) and primary somatosensory cortex (SI), supplementary motor area (SMA) and cingulate motor area (CMA); bilateral ventral and dorsal premotor (PM) cortices, insula, and secondary somatosensory cortex (SII) [16]. Furthermore, it was found to activate sub-cortically in bilateral cerebellar lobules IV-V and VI and putamen [17]. The passive ankle dorsiflexion was found to have a similar to active ankle dorsiflexion activation pattern location but with limited activation extent and degree in SMA/CMAc, M1, SI, bilateral ventral, and dorsal PM, and cerebellum [17].

During fMRI, eight healthy right-handed adults moved their right ankle in dorsiflexion and plantarflexion when auditory cued. Findings concluded that ankle dorsiflexion activated significantly more regions in the right cerebellum, left primary motor cortex (M1), and bilateral supplementary motor area (SMA) [18]. The motor cortex is importantly engaged in gait variations as a reaction to barriers. Ankle active dorsiflexion excited additional areas in the right putamen. Greater motor representation and cortical resources of the active ankle dorsiflexion is probably because of the more demanding kinematic task [18] like the ankle dorsiflexion in heel strike and throughout the swing phase in walking [19] and the need for a synchronized neural network to comply with the monitored environmental challenges for precise placement of the foot [18]. Moreover, ankle dorsiflexion excited additional regions engaged in movement preparation (i.e., the inferior parietal lobe) and sensory integration cortex.Furthermore, the primary and secondary visual areas got activated by ankle dorsiflexion, which suggested that ankle dorsiflexion could be engaged in the sensory integration of vision [16]. Active ankle dorsiflexion produced marked excitement in motor planning/execution and visuomotor coordination brain areas [17]. In the walking push-off phase, the acceleration is offered by the plantarflexion that does not need fine-tuning with the environmental challenges for foot placement [18].

It was found that the dorsiflexed ankle could activate more cortical areas than the plantarflexed ankle, specifically the fine motor movements cortical areas as displayed by the functional MRI (fMRI) [16]. For the tibialis anterior agonist or antagonist action, the motor cortex can very precisely modify its activation, whereas the inhibition adjustment of the soleus is much weaker [20]. The tibialis anterior cortical inhibitory control is finely tuned to the functional-need-oriented role [20]. **Figure 1** outlines/summarizes the ankle dorsiflexion-related/associated activated brain areas.

ANKLE DORSIFLEXION & CORE STABILITY THROUGH IRRADIATION NEUROMUSCULAR FACILITATION

The abdominal draw-in maneuver recruits the transverse abdominal muscle and its deep musculofascial corset effect on the lumbopelvic region. Consequently, ankle dorsiflexion in healthy young adults can immediately increase the transverse abdominis' corset effect [21]. This study gives empirical proof showing that the abdominal draw-in maneuver combined with ankle dorsiflexion effectively improves transverse abdominal muscle activity and interrelated morphological changes [21].

Irradiation type of neuromuscular facilitation is the enhancing response (specifically selectively enhancing the neuromuscular response related to the number of active and selective recruited motor units) propagation and strength secondary to a stimulation and stimulus-prompted temporal or spatial summation. It is also possible that the irradiation may enhance the activity of transverse abdominal muscle selectively through the active dorsiflexion when combined with the abdominal draw-in maneuver, consequently enhancing lumbar spinal stability [21]. The decreased transverse abdominis activity was associated with low back pain occurrence and deterioration. Moreover, the lumbar spinal stability is a low back pain precipitating factor. Furthermore, it was revealed in a previous study that individuals with chronic mechanical low back pain had a significant reduction in the weight-bearing ankle dorsiflexion ROM when compared to normal individuals [22].

ANKLE DORSIFLEXION ROM & SPORTS

Ankle Dorsiflexion ROM & Adaptation to Sport

Practising sports significantly utilizes the musculoskeletal system, with the ankle being the primary joint engaged. The possible explanation for the excessive utilization of the ankle joint in many popular sports can be attributed to its anatomical and functional characteristics as the link between the leg and the foot. The ankle linkage role between the lower limb and the foot gives it a crucial biomechanical and postural role and an essential role in the precise performance of many sports skills. Practising sports can influence/alter the functional and structural integrity of the intra-articular and periarticular structures of the ankle [23].

When young and healthy judokas athletes were compared with football players regarding the weight-bearing closed-chain ankle dorsiflexion ROM (tested by weight-bearing lunge test), greater ranges were found in the judoka athletes. The possible explanation is that judokas athletes adapt better to the greater dorsiflexion variability imposed by judokas training than football players [24]. Competitive surfers' high performance substantiated the necessity of increased ankle dorsiflexion ROM, lower body power and strength, and landing ability with attenuated compressive forces [25]. In young healthy surfers, weight-bearing closed-chain ankle dorsiflexion ROM (measured by knee-to-wall weight-bearing lunge) was linked to the level of practice because it was higher in the national-level senior-elite surfers than the state-level junior-elite and recreational surfers [26].

Soccer practice negatively affects ankle joint mobility. Young soccer players were found to have a significant reduction in ankle dorsiflexion compared to all other sports. Soccer young male players may manifest a significantly decreased ankle joint mobility from the first few years of practicing sports activities, revealing an early harmful sports-related effect [27]. An inverse relationship between handgrip strength and ankle dorsiflexion ROM above the age of 13.3 years in soccer players can be due to the practice of soccer and the increase in muscle strength [27]. In this stage, the bone growth is faster than the growth of muscles and tendinous and causes a higher work demand for the incompletely developed muscles. Conversely, there was a positive correlation between ankle dorsiflexion ROM and handgrip strength in basketball, volleyball, and martial arts players above 13.3 years old [27].

Ankle dorsiflexion ROM in pre-season was greater than in mid-season and post-season in football players (i.e., progressive ankle dorsiflexion ROM reduction along a season indicates a progressive increase in the risk of injury throughout a season). Furthermore, approximately 30.0% of all football players in the post-season were found to have lower ankle dorsiflexion ROM degrees restriction than in the pre-season [28]. After the match, the acute effect of football performance caused an increase in ankle dorsiflexion ROM by 5.8% in the dominant ankle. However, this value was reduced by 2.7% after the match by 48 hours in both ankles, which may be linked to an inadequate recovery strategy [28]. Gastrocnemius–soleus muscle complex reduced muscular flexibility is one of the ankle dorsiflexion ROM limiting factors during functional activities [29]. It can occur as a reaction to altered or excessive muscle demands/loading throughout pre-season preparations [29], fascial repeated microtrauma in sports' collisions, and developing poor posture [30].

Ankle Dorsiflexion ROM & Wwalking, Running, & Sprinting

Ankle dorsiflexion ROM is crucial in daily activities like standing after sitting and in dynamic standing balance activities such as reaching [31]. There is a need for almost 10° of ankle dorsiflexion ROM for level surface walking, stair descending or kneeling. In the mid-stance phase of normal gait, more than 10^0 of ankle dorsiflexion ROM is needed to facilitate the tibia advancement over the foot to propel the body forwards [32]. In gait, decreased ankle dorsiflexion ROM may alter the lower-limb biomechanics that makes the lower limb more vulnerable to be affected with injury [7]. Decreased ankle dorsiflexion ROM may restrict the subtalar joint movement, preventing the ankle joint from getting a stable closed-pack position required in practicing walking and running. There is a need for almost $20\text{-}30^0$ of ankle dorsiflexion ROM to run or sprint. Increasing ankle dorsiflexion can help runners maintain the optimal position of the subtalar joint by decreasing the subtalar joint pronation degree and its consequences, which could elevate the injury risk.

Ankle Dorsiflexion ROM & On-Ice Skating Sprint

Ice-hockey on-ice skating sprint requires $20\text{-}30^0$ of ankle dorsiflexion ROM in young, healthy athletes. A 10-camera 3-D motion capture system was used to record joint kinematic differences throughout on-ice maximal skating sprint [33]. The on-ice maximal skating sprint was between ice hockey high-caliber skaters (age of 24.7±3.1 years) who played at the junior level or higher and ice hockey low-caliber skaters (age of 23.9±3.1 years) who played below junior level.

High-caliber ice hockey skaters performed the skating start significantly faster and with greater ankle dorsiflexion than low-caliber skaters, despite no lower-limb power differences (when tested using the long jump distances) [33]. Skate boot designers and manufacturers added an anterior hinge to the skate boot (the klapskate) to allow more ankle dorsiflexion ROM to assist in better skating speed performance.

Ankle dDorsiflexion ROM & Jumping

The ankle is a crucial joint to perform optimal vertical jumping. The energy needed for the impulse to execute a jump is generated and transferred by the bi-articular muscles (the mechanical energy is transferred in a proximal to distal sequence to the ankle joint that adapts its dorsiflexion motion). Then, the energy flows through the ankle joint that adapts its plantarflexion motion in the take-off phase, making 23.0% of the take-off velocity. The vertical jump is dependent on the force amount generated by the gastrocnemius muscle that aids (as a bi-articular muscle) in transferring the kinetic energy flow. It was suggested that improving the ankle dorsiflexion ROM improves the vertical jumping ability [34]. Individuals with gastrocnemius reduced muscular extensibility (lesser ankle dorsiflexion ROM) jumped with lesser height, the body center-of-mass vertical shift, and coordination than individuals with better gastrocnemius muscle extensibility (greater ankle dorsiflexion ROM) [35]. In young, healthy soccer players (age of 16.2±0.6 years old), the vertical jump performance tested with countermovement jump test was found to be correlated positively and significantly with weight-bearing closed-chain ankle dorsiflexion ROM (measured by knee-to-wall test) [36]. Greater ankle joint flexibility was found to result in enhanced performance of squat-jump tasks in post-pubertal female volleyball players [37].

Ankle Dorsiflexion ROM & Landing

In sports with multidirectional directional movements, the dorsiflexion ROM was found to influence direction changes and landing performance [38]. In basketball, maximal weight-bearing ankle dorsiflexion angle occurs when the knee is flexed at the jumping take-off phase [39]. In volleyball, the weight-bearing ankle dorsiflexion motion was linked with the highest force moment in landing [40]. In landing from a jump, the kinetic energy absorbance at the impact and after landing through the ankle dorsiflexion range was represented 37.0% to 50.0% of the total kinetic energy absorbed by the muscles involved in the task [41]. Furthermore, the major energy absorption by total muscle work in the stiff and soft landing was provided by the ankle plantar flexors with an average of 44.0%, knee extensors with 34.0%, and hip extensors with 22.0% [41]. Ankle dorsiflexion ROM restriction decreases the force-absorption ability along the lower limb during cutting, jumping, and landing, which causes higher ground reaction forces and higher frontal plane loading, mainly at the knee joint.

Ankle Dorsiflexion ROM & Squatting

A deeper back squatting activity is helpful in building strength in the lower limb [42] and developing jumping height [43]. Assessing ankle dorsiflexion ROM can be done in closed or open-chain positions with the knee flexed or extended. In young and physically active individuals, achieving back squat depth capacity was positively and significantly correlated with weight-bearing/loaded ankle dorsiflexion ROM (in closed-chain conditions using a goniometer smartphone app) with the knee flexed in the lunge test. It was found that in the lunge test, each additional 6.5^0 of ankle dorsiflexion ROM facilitated a 10.0% deeper back squat in young and physically active individuals [44]. In healthy young participants and while performing the single-leg squat activity, it was found that greater passive weight-bearing ankle dorsiflexion ROM with knee flexion was correlated with a better lower limb alignment (i.e., less thigh internal rotation during the single-leg squatting) [45]. In healthy and recreationally active young participants (18-30 years old), limited weight-bearing ankle dorsiflexion ROM with knee flexion predicted a lower functional movement screen™ (FMS™) composite score significantly [46]. A low FMS™ composite score was linked to the risk of injury in professional football [47] players. Furthermore, decreased weight-bearing ankle dorsiflexion ROM with knee flexion was significantly correlated with lower deep squatting activity performance [46]. The body's center-of-mass goes down throughout squatting or landing activities, imposing hip, knee, and ankle joint flexion [48]. Studies concluded that instead of accommodating limited ankle dorsiflexion ROM by imposing higher proximal joints' flexion excursions, athletes reveal a pattern of decreased flexion displacements along the lower limb [7, 49, 50].

Ankle Dorsiflexion ROM & Standing Dynamic Balance

In healthy adults (25.9±6.7 years old), the decreased weight-bearing ankle dorsiflexion ROM with knee flexion was correlated with reduced standing dynamic balance [51]. The decreased weight-bearing/loaded ankle dorsiflexion ROM with knee flexion on the weight-bearing lunge test explained a significant amount (28.0%) of the anterior reach distance variance in star excursion balance test [51].

Ankle Dorsiflexion ROM & Arm Swing

Kinematic data recorded via a three-dimensional Vicon motion analysis system showed significantly greater angles of ankle dorsiflexion ROM during the backward swing phase of the diagonal shot in the table tennis practice in professional healthy young (22.5±1.4 years old) [52]. Moreover, it was found that improving ankle dorsiflexion ROM is important to enhance the effectiveness of arm swing in vertical jumping, which is crucial for volleyball performance [37].

Therefore, the ankle dorsiflexion ROM is an essential construct in many sports activities, tasks, and skills performance. Sport activity-specific adequate ankle dorsiflexion ROM is necessary for competent sports activity performance. Inadequate/decreased ankle dorsiflexion ROM is linked to incompetent sports performance and increased risk of injury. The links between ankle dorsiflexion ROM and sports performance are summarized and presented in **Figure 2**.

ANKLE DORSIFLEXION ROM & INJURY PROVOCATIVE POSITIONS & COMPENSATORY MOVEMENT STRATEGIES

Ankle dorsiflexion ROM reduction/restriction is associated with injury risk through its contribution to develop compensatory movement strategies (CMSs) [53]. Dynamical Systems theory explains goal-directed movement from the viewpoint that numerous biomechanical degrees of freedom utilize various biomechanical patterns to accomplish a consistent result [53, 54].

The biomechanical patterns' variation is known as 'coordinative variability', and the pattern under use for a particular task can change markedly between individuals and within the individual [54]. Ankle dorsiflexion ROM restriction can be seen as a loss of degrees of freedom that impose one of

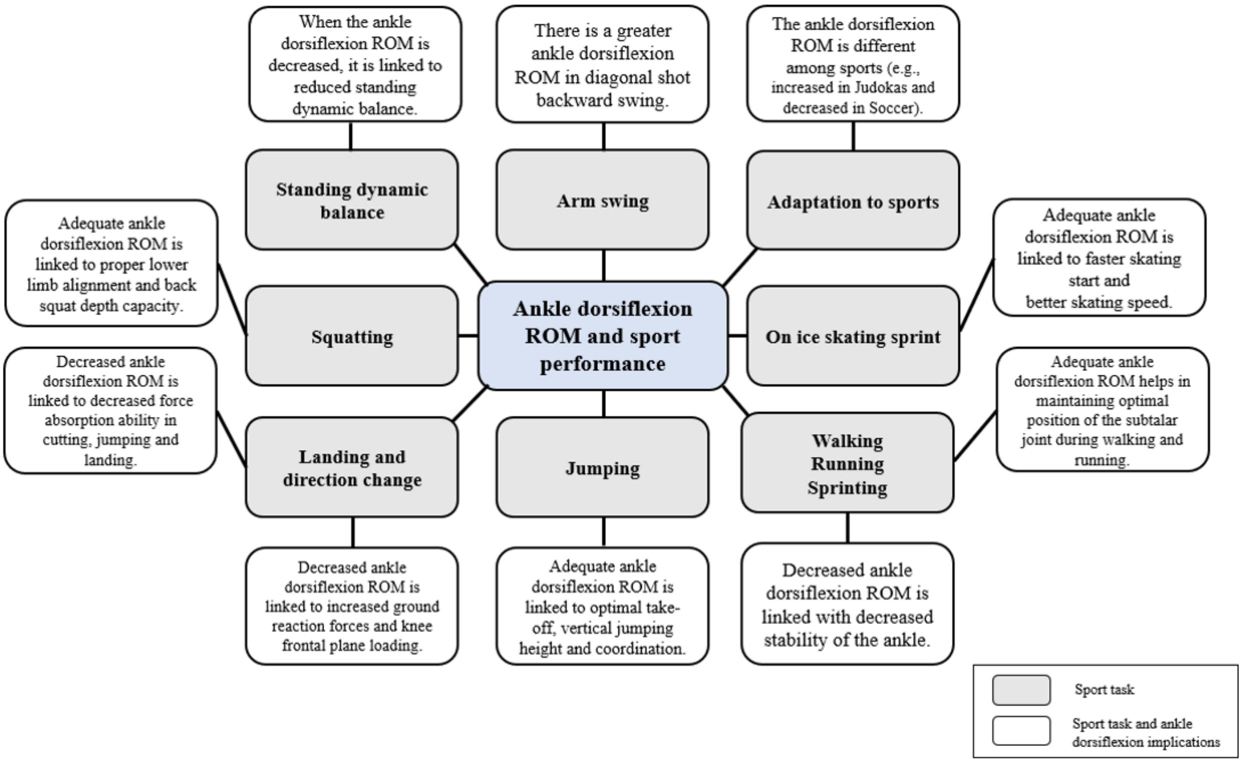

Figure 2. An illustration of summary of links between ankle dorsiflexion ROM & sports' performance (Source: Authors' own elaboration)

the compensatory (or alternative) movement strategies (or patterns) that are linked to various injuries/disorders [55].

In the lumbopelvic region and lower limb, CMSs are suggested as a sports injury risk factor for various types of sports [56]. Preventing these compensatory joint motions can be essential to avoid injury/damage. Normal muscle recruitment pattern observable changes happen when CMSs exist [57]. CMSs may happen due to mobility deficiency (somewhere in the lower limb) manifested as local motor control deficiencies affecting the stabilizing muscles activity [58]. The CMSs can help the athletes to execute the activity/skill by modifying its forces, but at the same time, such force modification can increase the lower limb risk of injury while performing this activity/skill [59].

Ankle Dorsiflexion ROM & Dynamic Valgus

Hip joint musculature recruitment patterns can be constrained by restricted mobility of the distal part(s) [58]. Decreased ankle dorsiflexion ROM is a factor that can participate in poor pelvic and hip quality of movement [60]. Decreased ankle dorsiflexion ROM may demand increased femoral internal rotation to allow more calcaneal eversion and, consequently, midfoot dorsiflexion as a compensatory movement strategy [58]. Individuals with decreased ankle dorsiflexion ROM have more activation of the hip adductors when compared with gluteal muscle activation. Decreased available ankle dorsiflexion can participate in creating a compensatory proximal motion made of hip adduction and pelvic drop in the contralateral side in healthy individuals and individuals suffering knee pain while performing a variety of single and double limb activities [60-62]. Decreased ankle dorsiflexion ROM can end up with observable compensatory frontal plane motions/displacements during weight-bearing functional activities like landing from a jump [49] and squatting [63]. The compensatory frontal-plane motions linked to deficits in ankle dorsiflexion ROM can be manifested as dynamic knee valgus [49, 50, 63].

In individuals who are free of any lower limb trauma history and active at a recreational level, decreased ankle dorsiflexion ROM while performing double-leg squat caused dynamic knee valgus, reduced the quadriceps activation, and enhanced the activation of the soleus. Reduced muscular flexibility in lateral gastrocnemius and soleus leads to knee reduced sagittal plane motion and enhanced frontal plane motion as compensation [63]. Accumulative imbalances can exist over time along the kinetic chain, putting the individual at higher risk to sustain overuse or overload knee injuries like anterior knee pain. Decreased ankle dorsiflexion ROM secondary to reduced flexibility of gastrocnemius [64] and soleus [65] is present in individuals with anterior knee pain, and it is a risk factor for developing it [63] because of a series of biomechanical compensations [65].

The decreased dorsiflexion while performing weight-bearing/loaded tasks decreases the capability to lower the body's center of mass, eliciting increased pronation in the subtalar joint and internal rotation in the tibia as compensation to get additional motion. Tibial increased internal rotation can lead to a consequent increase in the internal rotation of the femur and dynamic knee valgus knee alignment. It was found that individuals who have medial knee displacement during performing double-leg squatting (whom their patella passed medial to the great toe while squatting) have a decreased ankle dorsiflexion compared with those who squatted without the medial knee displacement (who sustained their knees over their toes while squatting) [66].

During the step-down task performed by university campus healthy women (age 18 years or older), a 3-D analysis of hip and knee kinematics revealed that the decreased ankle dorsiflexion ROM is linked to reduced knee flexion, greater hip adduction, and greater knee external rotation [50]. The observed faulty hip and knee kinematics (i.e., dynamic knee valgus) during functional activities have been linked with several overuse and overload injuries/disorders like ACL rupture [67], anterior knee pain [68], patellar instability/subluxation [69] and iliotibial band syndrome [70] in healthy young athletes and active individuals that can suggest that ankle dorsiflexion restriction may form a piece of the puzzle in these conditions' pathogenesis [50]. Furthermore, it was found that dynamic knee valgus (measured via high frontal knee projection angle) during a single-leg squat meant a 2.7 times higher possibility to be affected with acute lower limb injury and a 2.4 times higher chance of sustaining ankle injury within a year when compared with those with low frontal knee projection angles in basketball and floorball athletes (21 years old and under) [71].

Ankle Dorsiflexion ROM & Ground Reaction Forces

A negative correlation was found between ankle dorsiflexion ROM (mainly the ankle dorsiflexion ROM measured with knee extension) and ground reaction forces that can mean that inability to compensate for the reduced sagittal range may result in higher ground reaction forces Ankle dorsiflexion ROM restriction and the correlated reduction of flexion ROM in hip and knee (i.e., reduced joint excursion with resultant stiff-landing) may increase ground reaction forces or loading rates. Increased ground reaction forces and loading rates were correlated with various impairments/injuries/disorders in the lower limb like patellar tendinopathy, knee injury, tibial stress fracture in runners, and knee joint pain.

Throughout the normal landing and deceleration, the lower limb joints assist in the ground reaction forces absorption. The lower limb joints work synergistically and effectively in an accordion-like fashion to dampen the ground reaction forces. The gastrocnemius-soleus complex slows the speed of the ground reaction forces propagating to the knee during landing [72]. However, when the ankle dorsiflexion ROM is decreased, the forces acting on the joints of the lower limbs and their muscle stiffness change [73]. Gastrocnemius-soleus muscle stiffness was found to result in increased peak foot pronation, knee valgus and adduction moments, and ground reaction forces [74]. Consequently, the decreased ankle dorsiflexion ROM leads to increasing ground reaction forces, which magnifies the risk of injury in lower limbs [75]. Deficits in ankle dorsiflexion ROM are hamstring injury risk factors in healthy young soccer players. Horizontal force production during running/sprinting is highly linked to hamstring muscle activity. Therefore, the decreased ankle dorsiflexion may lead to magnified hamstring muscle mechanical loading and resultant strain injury.

Ankle Dorsiflexion ROM & Stiff Landing

Soft landing causes higher lower limb joint excursion, decreasing ground reaction forces and loading rate [76]. In young and healthy male athletes (22.1±3.9 years old) performing single-leg drop-jump landing while 3D kinematic data were collected, it was found that reduced weight-bearing ankle dorsiflexion ROM was linked to stiff-landing (specifically reduced knee flexion at initial contact) [77]. It was found that young and healthy recreational athletes with decreased weight-bearing ankle dorsiflexion ROM with knee flexion had the tendency to land with higher ankle plantar flexion and knee extension at initial contact and decreased ankle dorsiflexion and knee flexion at the maximum flexion point during bilateral drop-landing tasks of countermovement jump [59]. During the bilateral jump-landing task, ankle dorsiflexion ROM was found to be inversely correlated with peak vertical ground reaction force throughout a bilateral jump-landing activity [7]. The stiff-landing patterns have been linked to increased vertical ground reaction forces, compression forces, knee extensor moments, and anterior shear of the tibiofemoral joint [78]. The possible reason is that the limitation of ankle dorsiflexion ROM inhibits the knee flexion motion necessary for absorbing the shock during the landing phase [7]. Shock absorption (implying ground reaction force dissipation) is important to happen because a great posterior ground reaction force can lead to a great muscle force from the quadriceps that markedly draw the tibia anteriorly that excessively load the ACL and other knee passive structures [79].

Dynamic knee valgus [80] and stiff landings [81] were linked to a higher risk of getting lower limb non-contact injury. In a cohort study engaging healthy female basketball and floorball players (12-21 years old), it was found that stiff landings in vertical drop jump test (with lower knee flexion and higher peak vertical ground reaction force) were linked to ACLI increased risk [81]. While performing the football game, it was observed (using a systematic video analysis) in male football players affected with non-contact and indirect-contact ACLIs that the injured knee was straight at the initial ground contact and when sustained the ACL tear [82].

In the one-year prospective cohort study, it was found that in Swedish junior national level elite basketball players (14-20 years old) with weight-bearing ankle dorsiflexion with knee flexion was less than 36.5^0; there was an elevated risk (18.5% to 29.4%) of sustaining patellar tendinopathy within a year [39]. Basketball players with ankle dorsiflexion ROM greater than 36.5^0 had a low risk of developing patellar tendinopathy (1.8% to 2.1%). During performing dynamic sports activities, the reduced ankle dorsiflexion ROM reduces the ankle joint's energy absorption capacity. Consequently, the resultant abnormal compensation in the knee is manifested as an increased load on the patellar tendon, among other knee structures [39]. Specifically, limited ankle dorsiflexion ROM and its resultant increased foot pronation alignment can lead to excessive foot pronation and increased hip/femoral internal rotation [83] (internal rotation cutoff point of 40.76^0), which contribute to overloading the patellar tendon [84].

Ankle Dorsiflexion ROM & Knee Hyper-Extension in Walking

During forward progression in normal walking gait, it is essential that the ankle dorsiflexion ROM is enough to let the tibia move in the sagittal plane in an angular way over a stable foot during the single-leg step. The tibial angular forward movement can be limited because of a decreased ankle dorsiflexion that can trigger a compensatory movement strategy of altered gait kinetics and kinematics in the lower limbs. A significant and strog inverse correlation was observed between ankle dorsiflexion ROM peak angle and knee extension ROM peak angle (i.e., more ankle dorsiflexion restriction was correlated with more knee extension) during the walking terminal stance phase in healthy young individuals (21.7±2.2 of age).

Decreased ankle dorsiflexion ROM angle to less than 5^0 associated with knee hyperextension (i.e., knee increased sagittal plane loading) [85]. Knee hyperextension is one of the mechanisms of the non-contact ACLI.

Ankle Dorsiflexion ROM & Poor Anterior Reach Performance

In healthy and physically active individuals, the weight-bearing/loaded ankle dorsiflexion (evaluated by the weight-bearing lunge test) was correlated significantly with the Y-balance test anterior reach distance [86]. In collegiate athletes, it was found that the Y-balance test's poor anterior reach performance indicated an elevated possibility of a consequent ankle sprain injury [87]. The ankle can be decreased from reaching the required degrees of ankle dorsiflexion ROM by contractile tissues (i.e., the ankle plantar flexors) and other soft tissues that are non-contractile (i.e., ligament, joint capsule, and bone). Decreased ankle dorsiflexion ROM may affect subtalar joint motion and impede the ankle joint close-packed position required throughout walking and running, which can risk knee and ankle stability and postural stability [55].

Ankle Dorsiflexion ROM Restriction & Related Reduced Gastrocnemius-Soleus Complex Extensibility

Normal gastrocnemius muscular extensibility is necessary to minimize the risk of injury in the lower limb [88]. Limited ankle dorsiflexion ROM is associated with soleus and gastrocnemius reduced extensibility and tightness. Particularly gastrocnemius tightness is found to be a factor in lower-limb injuries and forefoot disorders such as hallux valgus, Achilles tendinopathy, stress fractures, metatarsalgia, plantar fasciitis/fasciopathy, ankle sprains [88, 89], patellar tendon injury [90] and ACLI [91].

The reduced muscular extensibility of gastrocnemius and its associated decreased ankle dorsiflexion ROM are correlated with a higher risk of developing plantar fasciopathy, which is the most prevalent running-related overuse disorder in runners. The possible reason is that the gastrocnemius reduced extensibility has an arch-flattening effect (the combination of hindfoot plantarflexion moments and forefoot dorsiflexion moments), causing passive longitudinal tension along the plantar fascia during the stance phase [92]. Limited ankle dorsiflexion can lead to excessive hindfoot valgus as a possible compensation during practicing functional tasks [93] with resultant foot pronation and excessive forces and pressures along with the mid and forefoot.Such repetitive stress is thought to lead to foot medial longitudinal arch mechanical breakdown via plantar fascia and surrounding ligamentous structures overstretch [93].

Reduced muscular extensibility of triceps surae and particularly the gastrocnemius portion can significantly be related to changes in knee function through restricting the ankle dorsiflexion ROM in functional activities. Decreased ankle dorsiflexion elevates the soleus and gastrocnemius tendons strain. In the walking and running gait cycle just before the toe-off, the soleus and gastrocnemius absorb the peak mechanical power [94]. However, force absorption that got taken over by the soleus and gastrocnemius increases when the ankle dorsiflexion is decreased. The sustainability of strain on the Achilles tendon can lead to tendinopathy, as concluded in previous studies when the decreased ankle dorsiflexion was linked with a 2.5 to 3.6 times greater Achilles' tendinopathy risk. Reduced ankle dorsiflexion ROM is among the Achilles tendinopathy significant risk factors in Nigerian football players. However, increased ankle dorsiflexion ROM was found (in a cohort study) to be a significant predictor of Achilles tendinopathy in male military individuals [95].

Ankle Dorsiflexion & Anterior Pelvic Tilt

Anterior pelvic tilting was found to be correlated with bilateral increased foot pronation/calcaneal-eversion [96] that can be secondary to decreased ankle dorsiflexion ROM [93]. Anterior pelvic tilt increases the risk of sustaining hamstring strain injury in sprinting late-swing phase in soccer players[97]. Therefore, decreased ankle dorsiflexion ROM can open opportunities for many lower-limb injuries (over-use/over-load injuries) to occur through its links with injury-provocative positions and compensatory movement strategies. Those links are summarized and illustrated in **Figure 3**.

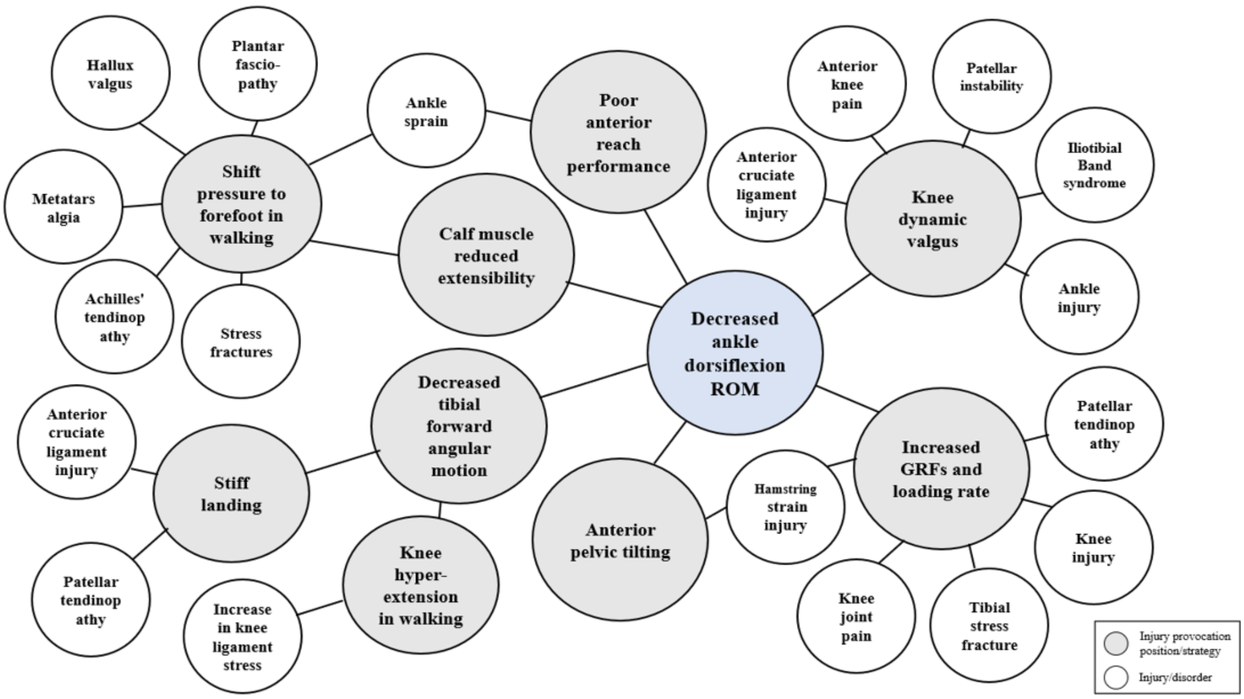

Figure 3. An illustration of summary of links between ankle dorsiflexion ROM restriction & injury provocative position & compensatory movement strategies (Source: Authors' own elaboration)

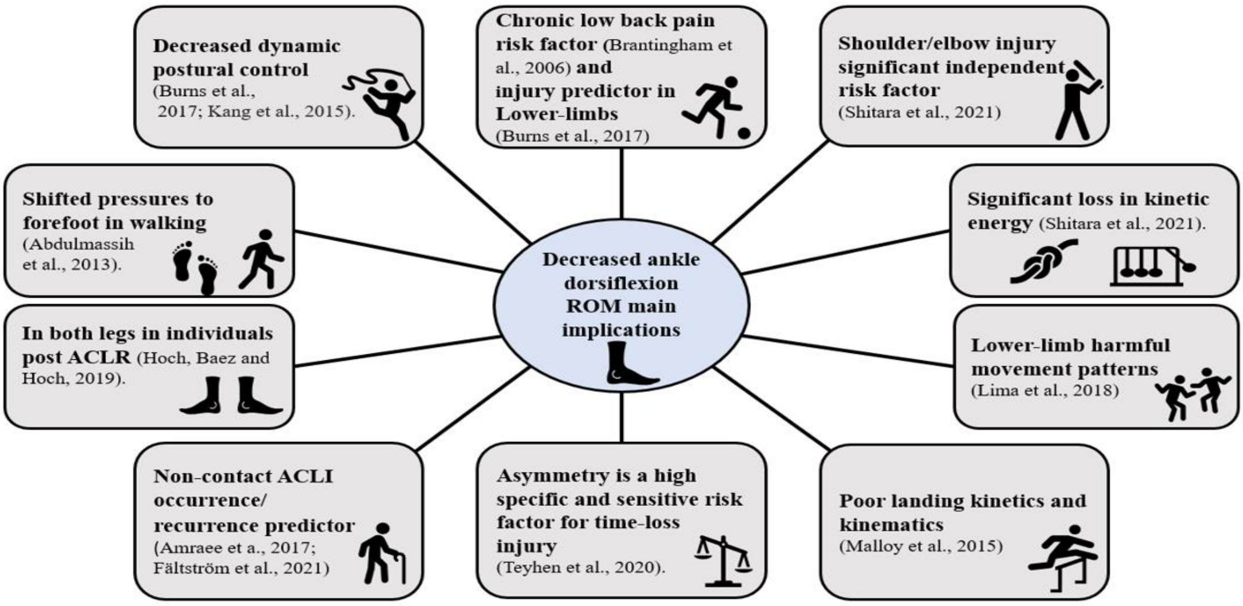

Figure 4. An illustration of decreased ankle dorsiflexion ROM important implications (Source: Authors' own elaboration)

In summary, the ankle dorsiflexion ROM has links with sports performance, injury prevention, and injury occurrence/recurrence. Important implications of decreased ankle dorsiflexion ROM, especially in what is related to shoulder/elbow injury, CLBP (chronic low back pain), non-contact ACLI, and post ACLR, are outlined and demonstrated in **Figure 4**.

CONCLUSIONS

Ankle dorsiflexion ROM influences sports performance and injury risk. These influences have multiple backgrounds. Ankle dorsiflexion is linked to activation of the brain area responsible for movement preparation, sensory integration cortex, motor planning/execution, and visuomotor coordination. It is also linked to increased activation of the deep core (transverse abdominis and pelvic floor) and quadriceps muscles. Ankle dorsiflexion is an essential construct in many sport-specific skills like squatting, jumping, landing, on-ice skating, sprinting, and arm swing. Decreased ankle dorsiflexion ROM contributes to developing compensatory movement strategies. The compensatory movement strategies could create the basis to elevate the risk of occurrence and recurrence of many sports injuries like an ankle sprain, anterior cruciate ligament, and plantar fasciopathy. Moreover, the ankle dorsiflexion influence on core muscles could contribute to the development of low back pain. Furthermore, the link between the ankle dorsiflexion and balance may precipitate sports-related injuries like falls and ankle sprain. Therefore, giving more attention to ankle dorsiflexion ROM in research studies, sports-related pre-season screening, clinical examination, rehabilitation, and return to sports judgment is justified.

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REFERENCES

1. Brockett CL, Chapman GJ. Biomechanics of the ankle. Orthop trauma. 2016;30(3):232-8. https://doi.org/10.1016/j.mporth.2016.04.015 PMid:27594929 PMCid:PMC4994968
2. McKeon JMM, Hoch MC. The ankle-joint complex: A kinesiologic approach to lateral ankle sprains. J Athl Train. 2019;54(6):589-602. https://doi.org/10.4085/1062-6050-472-17 PMid:31184957 PMCid:PMC6602390
3. Kiefer EA, Wikstrom EA, McDonald JD. Ankle dislocation without fracture: An on-field perspective. Clin J Sport Med. 2006;16(3):269-70. https://doi.org/10.1097/00042752-200605000-00014 PMid:16778550
4. Kannan P, Winser S, Goonetilleke R, Cheing G. Ankle positions potentially facilitating greater maximal contraction of pelvic floor muscles: A systematic review and meta-analysis. Disabil Rehabil. 2019;41(21):2483-91. https://doi.org/10.1080/09638288.2018.1468934 PMid:29733699
5. Martinez AF, Scattone Silva R, Paschoal BLF, Souza LLA, Serrão FV. Association of ankle dorsiflexion and landing forces in jumping athletes. Sports Health. 2022;14(6):932-7. https://doi.org/10.1177/19417381211063456 PMid:34961379 PMCid:PMC9631040
6. Schroeder LE, Tatarski RL, Weinhandl JT. Increased ankle range of motion reduces knee loads during landing in healthy adults. J Appl Biomech. 2021;37(4):333-42. https://doi.org/10.1123/jab.2020-0281 PMid:33931575
7. Fong CM, Blackburn JT, Norcross MF, McGrath M, Padua DA. Ankle-dorsiflexion range of motion and landing biomechanics. J Athl Train. 2011;46(1):5-10. https://doi.org/10.4085/1062-6050-46.1.5 PMid:21214345 PMCid:PMC3017488
8. Demirkan E, Ozkadi T, Can S, Alagoz I. Does ankle plantar and dorsiflexion affect fifty-meter swimming time in swimmers? Turk J Sport Exerc. 2021;23(3):353-8.
9. Kruszewski M, Kruszewski A, Tabęcki R, Mierzejewski B, Pągowski Ł. Range of motion in selected joints in relation to sports performance and technique effectiveness in weightlifting. Pol J Sport Tour. 2022;29(1):9-13. https://doi.org/10.2478/pjst-2022-0002

10. Rezazadeh F, Shojaeddin SS, Badicu G. Functional stretching decreases knee joint loading in male athletes with gastric-soleus tightness. J Men Health. 2021;17(3):145-52.
11. Daikuya S, Okayama Y. Physiotherapy for limitation of ankle dorsiflexion–New concept of classification and improvement strategies. J Bodyw Mov Ther. 2021;28:294-7. https://doi.org/10.1016/j.jbmt.2021.06.017 PMid:34776155
12. de la Motte SJ, Lisman P, Gribbin TC, Murphy K, Deuster PA. Systematic review of the association between physical fitness and musculoskeletal injury risk: Part 3-Flexibility, power, speed, balance, and agility. J Strength Cond Res. 2019;33(6):1723-35. https://doi.org/10.1519/JSC.0000000000002382 PMid:29239989
13. Abdulmassih S, Phisitkul P, Femino JE, Amendola A. Triceps surae contracture: Implications for foot and ankle surgery. J Am Acad Orthop Surg. 2013;21(7):398-407. https://doi.org/10.5435/JAAOS-21-07-398 PMid:23818027
14. Aquino MRC, Resende RA, Kirkwood RN, Souza TR, Fonseca ST, Ocarino JM. Spatial-temporal parameters, pelvic and lower limb movements during gait in individuals with reduced passive ankle dorsiflexion. Gait Posture. 2022;93:32-8. https://doi.org/10.1016/j.gaitpost.2022.01.010 PMid:35063755
15. Teyhen DS, Shaffer SW, Butler RJ, et al. What risk factors are associated with musculoskeletal injury in US army rangers? A prospective prognostic study. Clin Orthop Relat Res. 2015;473(9):2948-58. https://doi.org/10.1007/s11999-015-4342-6 PMid:26013150 PMCid:PMC4523518
16. Jiang T, Wu W, Wang X, Weng C, Wang Q, Guo Y. Activation of brain areas following ankle dorsiflexion versus plantar flexion: Functional magnetic resonance imaging verification. Neural Regen Res. 2012;7(7):501-5.
17. Francis S, Lin X, Aboushoushah S, et al. fMRI analysis of active, passive and electrically stimulated ankle dorsiflexion. Neuroimage. 2009;44(2):469-79. https://doi.org/10.1016/j.neuroimage.2008.09.017 PMid:18950717
18. Trinastic JP, Kautz SA, McGregor K, et al. An fMRI study of the differences in brain activity during active ankle dorsiflexion and plantarflexion. Brain Imaging Behav. 2010;4(2):121-31. https://doi.org/10.1007/s11682-010-9091-2 PMid:20502995
19. Capaday C. The special nature of human walking and its neural control. Trends Neurosci. 2002;25(7):370-6. https://doi.org/10.1016/S0166-2236(02)02173-2 PMid:12079766
20. Lauber B, Gollhofer A, Taube W. Differences in motor cortical control of the soleus and tibialis anterior. J Exp Biol. 2018;221(Pt 20):jeb174680. https://doi.org/10.1242/jeb.174680 PMid:30194250
21. Chon SC, Chang KY, You JS. Effect of the abdominal draw-in manoeuvre in combination with ankle dorsiflexion in strengthening the transverse abdominal muscle in healthy young adults: A preliminary, randomized, controlled study. Physiotherapy. 2010;96(2):130-6. https://doi.org/10.1016/j.physio.2009.09.007 PMid:20420959
22. Brantingham JW, Lee Gilbert J, Shaik J, Globe G. Sagittal plane blockage of the foot, ankle and hallux and foot alignment-prevalence and association with low back pain. J Chiropr Med. 2006;5(4):123-7. https://doi.org/10.1016/S0899-3467(07)60144-X PMid:19674683
23. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci. 2012;30(7):625-31. https://doi.org/10.1080/02640414.2012.665940 PMid:22394328
24. Liska D, Liptakova E, Baťalík L, Rutkowski S. The ankle joint dorsiflexion range of motion in the closed kinematic chain of judokas and football players-pilot study. Arch Budo. 2021;17:145-50.
25. Secomb JL, Farley ORL, Lundgren L, et al. Associations between the performance of scoring manoeuvres and lower-body strength and power in elite surfers. Int J Sports Sci Coach. 2015;10(5):911-8. https://doi.org/10.1260/1747-9541.10.5.911
26. Dowse RA, Secomb JL, Bruton M, Nimphius S. Ankle proprioception, range of motion and drop landing ability differentiates competitive and non-competitive surfers. J Sci Med Sport. 2021;24(6):609-13. https://doi.org/10.1016/j.jsams.2020.12.011 PMid:33414023
27. Francia P, Toni S, Iannone G, et al. How ankle joint mobility changes in young soccer players of different ages: A time series analysis. J Phys Educ Sport. 2021;21:2173-82.
28. Moreno-Pérez V, Soler A, Ansa A, et al. Acute and chronic effects of competition on ankle dorsiflexion ROM in professional football players. Eur J Sport Sci. 2020;20(1):51-60. https://doi.org/10.1080/17461391.2019.1611930 PMid:31072261
29. Araújo VL, Carvalhais VO, Souza TR, Ocarino JM, Gonçalves GG, Fonseca ST. Validity and reliability of clinical tests for assessing passive ankle stiffness. Rev Bras Fisioter. 2011;15(2):166-73. https://doi.org/10.1590/S1413-35552011000200013 PMid:21789368
30. You JY, Lee HM, Luo HJ, Leu CC, Cheng PG, Wu SK. Gastrocnemius tightness on joint angle and work of lower extremity during gait. Clinical Biomech (Bristol, Avon). 2009;24(9):744-50. https://doi.org/10.1016/j.clinbiomech.2009.07.002 PMid:19666202
31. Karas MA, Hoy DJ. Compensatory midfoot dorsiflexion in the individual with heelcord tightness: Implications for orthotic device designs. J Prosthet Orthot. 2002;14(2):82-93. https://doi.org/10.1097/00008526-200206000-00011
32. Norkin CC, White DJ. Measurement of joint motion: A guide to goniometry. F. A. Davis Company; 2016.
33. Renaud PJ, Robbins SM, Dixon PC, Shell JR, Turcotte RA, Pearsall DJ. Ice hockey skate starts: A comparison of high and low calibre skaters. Sports Eng. 2017;20(4):255-66. https://doi.org/10.1007/s12283-017-0227-0
34. Yun SJ, Kim MH, Weon JH, Kim Y, Jung SH, Kwon OY. Correlation between toe flexor strength and ankle dorsiflexion ROM during the countermovement jump. J Phys Ther Sci. 2016;28(8):2241-4. https://doi.org/10.1589/jpts.28.2241 PMid:27630405 PMCid:PMC5011569
35. Papaiakovou G. Kinematic and kinetic differences in the execution of vertical jumps between people with good and poor ankle joint dorsiflexion. J Sports Sci. 2013;31(16):1789-96. https://doi.org/10.1080/02640414.2013.803587 PMid:23879544
36. Godinho I, Pinheiro BN, Júnior LDS, et al. Effect of reduced ankle mobility on jumping performance in young athletes. Motricidade. 2019;15(2-3):46-51.

37. Panoutsakopoulos V, Kotzamanidou MC, Papaiakovou G, Kollias IA. The ankle joint range of motion and its effect on squat jump performance with and without arm swing in adolescent female volleyball players. J Funct Morphol Kinesiol. 2021;6(1):14. https://doi.org/10.3390/jfmk6010014 PMid:33546291 PMCid:PMC7931004
38. Gonzalo-Skok O, Serna J, Rhea MR, Marín PJ. Relationships between functional movement tests and performance tests in young elite male basketball players. Int J Sports Phys Ther. 2015;10(5):628-38.
39. Backman LJ, Danielson P. Low range of ankle dorsiflexion predisposes for patellar tendinopathy in junior elite basketball players: A 1-year prospective study. The Am J Sports Med. 2011;39(12):2626-33. https://doi.org/10.1177/0363546511420552 PMid:21917610
40. Richards DP, Ajemian SV, Wiley JP, Brunet JA, Zernicke RF. Relation between ankle joint dynamics and patellar tendinopathy in elite volleyball players. Clin J Sport Med. 2002;12(5):266-72. https://doi.org/10.1097/00042752-200209000-00002 PMid:12394197
41. Devita P, Skelly WA. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. Med Sci Sports Exerc. 1992;24(1):108-15. https://doi.org/10.1249/00005768-199201000-00018 PMid:1548984
42. Bloomquist K, Langberg H, Karlsen S, Madsgaard S, Boesen M, Raastad T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. Eur J Appl Physiol. 2013;113(8):2133-42. https://doi.org/10.1007/s00421-013-2642-7 PMid:23604798
43. Hartmann H, Wirth K, Klusemann M, Dalic J, Matuschek C, Schmidtbleicher D. Influence of squatting depth on jumping performance. J Strength Cond Res. 2012;26(12):3243-61. https://doi.org/10.1519/JSC.0b013e31824ede62 PMid:22344055
44. Gomes J, Neto T, Vaz JR, Schoenfeld BJ, Freitas SR. Is there a relationship between back squat depth, ankle flexibility, and Achilles tendon stiffness? Sports Biomech. 2022;21(7):782-95. https://doi.org/10.1080/14763141.2019.1690569 PMid:32022631
45. da Costa GV, de Castro MP, Sanchotene CG, Ribeiro DC, de Brito Fontana H, Ruschel C. Relationship between passive ankle dorsiflexion range, dynamic ankle dorsiflexion range and lower limb and trunk kinematics during the single-leg squat. Gait Posture. 2021;86:106-11. https://doi.org/10.1016/j.gaitpost.2021.03.015 PMid:33713896
46. Chimera NJ, Knoeller S, Cooper R, Kothe N, Smith C, Warren M. Prediction of functional movement screen™ performance from lower extremity range of motion and core tests. Int J Sports Phys Ther. 2017;12(2):173-81.
47. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen? N Am J Sports Phys Ther. 2007;2(3):147-58.
48. Taylor JB, Wright ES, Waxman JP, Schmitz RJ, Groves JD, Shultz SJ. Ankle dorsiflexion affects hip and knee biomechanics during landing. Sports Health. 2022;14(3):328-35. https://doi.org/10.1177/19417381211019683 PMid:34096370 PMCid:PMC9112706
49. Stanley LE, Harkey M, Luc-Harkey B, et al. Ankle Dorsiflexion displacement is associated with hip and knee kinematics in females following anterior cruciate ligament reconstruction. Res Sports Med. 2019;27(1):21-33. https://doi.org/10.1080/15438627.2018.1502180 PMid:30084269
50. Rabin A, Portnoy S, Kozol Z. The association of ankle dorsiflexion range of motion with hip and knee kinematics during the lateral step-down test. J Orthop Sports Phys Ther. 2016;46(11):1002-9. https://doi.org/10.2519/jospt.2016.6621 PMid:27686412
51. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. J Sci Med Sport. 2011;14(1):90-2. https://doi.org/10.1016/j.jsams.2010.08.001 PMid:20843744
52. He Y, Lv X, Zhou Z, Sun D, Baker JS, Gu Y. Comparing the kinematic characteristics of the lower limbs in table tennis: Differences between diagonal and straight shots using the forehand loop. J Sports Sci Med. 2020;19(3):522-8.
53. Davids K, Glazier P, Araújo D, Bartlett R. Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine. Sports Med. 2003;33(4):245-60. https://doi.org/10.2165/00007256-200333040-00001 PMid:12688825
54. Hamill J, Palmer C, Van Emmerik RE. Coordinative variability and overuse injury. Sports Med Arthrosc Rehabil Ther Technol. 2012;4(1):45. https://doi.org/10.1186/1758-2555-4-45 PMid:23186012 PMCid:PMC3536567
55. Mason-Mackay AR, Whatman C, Reid D. The effect of reduced ankle dorsiflexion on lower extremity mechanics during landing: A systematic review. J Sci Med Sport. 2017;20(5):451-8. https://doi.org/10.1016/j.jsams.2015.06.006 PMid:26117159
56. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. Am J Sports Med. 2005;33(4):492-501. https://doi.org/10.1177/0363546504269591 PMid:15722287
57. Mauntel TC, Begalle RL, Cram TR, et al. The effects of lower extremity muscle activation and passive range of motion on single leg squat performance. J Strength Cond Res. 2013;27(7):1813-23. https://doi.org/10.1519/JSC.0b013e318276b886 PMid:23096063
58. Howe LP. The acute effects of ankle mobilizations on lower extremity joint kinematics. J Bodyw Mov Ther. 2017;21(4):775-80. https://doi.org/10.1016/j.jbmt.2016.11.007 PMid:29037626
59. Howe LP, Bampouras TM, North J, Waldron M. Ankle dorsiflexion range of motion is associated with kinematic but not kinetic variables related to bilateral drop-landing performance at various drop heights. Hum Mov Sci. 2019;64:320-8. https://doi.org/10.1016/j.humov.2019.02.016 PMid:30836206
60. Lima YL, Ferreira V, de Paula Lima PO, Bezerra MA, de Oliveira RR, Almeida GPL. The association of ankle dorsiflexion and dynamic knee valgus: A systematic review and meta-analysis. Phys Ther Sport. 2018;29:61-9. https://doi.org/10.1016/j.ptsp.2017.07.003 PMid:28974358
61. Nakagawa TH, Petersen RS. Relationship of hip and ankle range of motion, trunk muscle endurance with knee valgus and dynamic balance in males. Phys Ther Sport. 2018;34:174-9. https://doi.org/10.1016/j.ptsp.2018.10.006 PMid:30347312
62. Rabin A, Kozol Z, Spitzer E, Finestone A. Ankle dorsiflexion among healthy men with different qualities of lower extremity movement. J Athl Train. 2014;49(5):617-23. https://doi.org/10.4085/1062-6050-49.3.14 PMid:25098656 PMCid:PMC4208865

63. Macrum E, Bell DR, Boling M, Lewek M, Padua D. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. J Sport Rehabil. 2012;21(2):144-50. https://doi.org/10.1123/jsr.21.2.144 PMid:22100617
64. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. Am J Sports Med. 2000;28(4):480-9. https://doi.org/10.1177/03635465000280040701 PMid: 10921638
65. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2005;35(12):793-801. https://doi.org/10.2519/jospt.2005.35.12.793 PMid:16848100
66. Bell DR, Padua DA, Clark MA. Muscle strength and flexibility characteristics of people displaying excessive medial knee displacement. Arch Phys Med Rehabil. 2008;89(7):1323-8. https://doi.org/10.1016/j.apmr.2007.11.048 PMid: 18586134
67. Malloy P, Morgan A, Meinerz C, Geiser C, Kipp K. The association of dorsiflexion flexibility on knee kinematics and kinetics during a drop vertical jump in healthy female athletes. Knee Surg Sports Traumatol Arthrosc. 2015; 23(12):3550-5. https://doi.org/10.1007/s00167-014-3222-z PMid:25112598 PMCid:PMC4977993
68. Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. Med Sci Sports Exerc. 2013;45(6):1120-4. https://doi.org/10.1249/MSS.0b013e31828249d2 PMid:23274607
69. Greiwe RM, Saifi C, Ahmad CS, Gardner TR. Anatomy and biomechanics of patellar instability. Oper Tech Sports Med. 2010;18(2):62-7. https://doi.org/10.1053/j.otsm.2009.12.014
70. Aderem J, Louw QA. Biomechanical risk factors associated with iliotibial band syndrome in runners: A systematic review. BMC Musculoskelet Disord. 2015;16:356. https://doi.org/10.1186/s12891-015-0808-7 PMid:26573859 PMCid:PMC4647699
71. Räisänen AM, Pasanen K, Krosshaug T, et al. Association between frontal plane knee control and lower extremity injuries: A prospective study on young team sport athletes. BMJ Open Sport Exerc Med. 2018;4(1):e000311. https://doi.org/10.1136/bmjsem-2017-000311 PMid: 29387448 PMCid:PMC5783037
72. Boden BP, Sheehan FT, Torg JS, Hewett TE. Noncontact anterior cruciate ligament injuries: Mechanisms and risk factors. J Am Acad Orthop Surg. 2010;18(9):520-7. https://doi.org/10.5435/00124635-201009000-00003 PMid: 20810933 PMCid:PMC3625971
73. Aali S, Rezazadeh F, Badicu G, Grosz WR. Effect of heel-first strike gait on knee and ankle mechanics. Medicina (Kaunas). 2021;57(7):657. https://doi.org/10.3390/medicina57070657 PMid:34206943 PMCid:PMC8304808
74. Kuhman DJ, Paquette MR, Peel SA, Melcher DA. Comparison of ankle kinematics and ground reaction forces between prospectively injured and uninjured collegiate cross country runners. Hum Mov Sci. 2016;47:9-15. https://doi.org/10.1016/j.humov.2016.01.013 PMid: 26827155
75. Norcross MF, Lewek MD, Padua DA, Shultz SJ, Weinhold PS, Blackburn JT. Lower extremity energy absorption and biomechanics during landing, part II: Frontal-plane energy analyses and interplanar relationships. J Athl Train. 2013; 48(6):757-63. https://doi.org/10.4085/1062-6050-48.4.10 PMid:23944381 PMCid:PMC3867086
76. Wang L-I. Lower extremity stiffness modulation: Effect of impact load of a landing task from different drop heights. Int Sport Med J. 2009;10(4):186-93.
77. Dowling B, McPherson AL, Paci JM. Weightbearing ankle dorsiflexion range of motion and sagittal plane kinematics during single leg drop jump landing in healthy male athletes. J Sports Med Phys Fitness. 2018;58(6):867-74. https://doi.org/10.23736/S0022-4707.17.07348-0 PMid: 28639442
78. Ameer MA, Muaidi QI. Relation between peak knee flexion angle and knee ankle kinetics in single-leg jump landing from running: A pilot study on male handball players to prevent ACL injury. Phys Sportsmed. 2017;45(3):337-43. https://doi.org/10.1080/00913847.2017.1344514 PMid: 28628348
79. Yu B, Garrett WE. Mechanisms of non-contact ACL injuries. Br J Sports Med. 2007;41 Suppl 1(Suppl 1):i47-51. https://doi.org/10.1136/bjsm.2007.037192 PMid:17646249 PMCid:PMC2465243
80. Koga H, Muneta T, Bahr R, Engebretsen L, Krosshaug T. ACL injury mechanisms: Lessons learned from video analysis. In: Musahl V, Karlsson J, Kuroda R, Zaffagnini S, editors. Rotatory knee instability. Springer; 2017. p. 27-36. https://doi.org/10.1007/978-3-319-32070-0_3
81. Leppänen M, Pasanen K, Kujala UM, et al. Stiff landings are associated with increased ACL injury risk in young female basketball and floorball players. Am J Sports Med. 2017;45(2):386-93. https://doi.org/10.1177/0363546516665810 PMid:27637264
82. Waldén M, Krosshaug T, Bjørneboe J, Andersen TE, Faul O, Hägglund M. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: A systematic video analysis of 39 cases. Br J Sports Med. 2015;49(22):1452-60. https://doi.org/10.1136/bjsports-2014-094573 PMid: 25907183 PMCid:PMC4680158
83. Souza TR, Pinto RZ, Trede RG, Kirkwood RN, Pertence AE, Fonseca ST. Late rearfoot eversion and lower-limb internal rotation caused by changes in the interaction between forefoot and support surface. J Am Podiatr Med Assoc. 2009;99(6):503-11. https://doi.org/10.7547/0990503 PMid: 19917736
84. Mendonça LD, Verhagen E, Bittencourt NF, Gonçalves GG, Ocarino JM, Fonseca ST. Factors associated with the presence of patellar tendon abnormalities in male athletes. J Sci Med Sport. 2016;19(5):389-94. https://doi.org/10.1016/j.jsams.2015.05.011 PMid:26087883
85. Ota S, Ueda M, Aimoto K, Suzuki Y, Sigward S. Acute influence of restricted ankle dorsiflexion angle on knee joint mechanics during gait. Knee. 2014;21(3):669-75. https://doi.org/10.1016/j.knee.2014.01.006 PMid:24530209
86. Kang MH, Lee DK, Park KH, Oh JS. Association of ankle kinematics and performance on the y-balance test with inclinometer measurements on the weight-bearing-lunge test. J Sport Rehabil. 2015;24(1):62-7. https://doi.org/10.1123/jsr.2013-0117 PMid:24458334

87. Hartley EM, Hoch MC, Boling MC. Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. J Sci Med Sport. 2018; 21(7):676-80. https://doi.org/10.1016/j.jsams.2017.10.014 PMid:29102301
88. Johanson M, Baer J, Hovermale H, Phouthavong P. Subtalar joint position during gastrocnemius stretching and ankle dorsiflexion range of motion. J Athl Train. 2008;43(2):172-8. https://doi.org/10.4085/1062-6050-43.2.172 PMid:18345342 PMCid:PMC2267329
89. Baumbach SF, Braunstein M, Seeliger F, Borgmann L, Böcker W, Polzer H. Ankle dorsiflexion: What is normal? Development of a decision pathway for diagnosing impaired ankle dorsiflexion and M. gastrocnemius tightness. Arch Orthop Trauma Surg. 2016;136(9):1203-11. https://doi.org/10.1007/s00402-016-2513-x PMid:27418341
90. Malliaras P, Cook JL, Kent P. Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. J Sci Med Sport. 2006;9(4):304-9. https://doi.org/10.1016/j.jsams.2006.03.015 PMid: 16672192
91. Hamilton M, Velasquez JR. Ankle flexibility and jump landing mechanics: Implications for ACL injury risk. Int J Athl Ther Train. 2011;16(6):14-6. https://doi.org/10.1123/ijatt.16.6.14
92. Pascual Huerta J. The effect of the gastrocnemius on the plantar fascia. Foot Ankle Clin. 2014;19(4):701-18. https://doi.org/10.1016/j.fcl.2014.08.011 PMid:25456717
93. DiGiovanni CW, Langer P. The role of isolated gastrocnemius and combined Achilles contractures in the flatfoot. Foot Ankle Clin. 2007;12(2):363-79, viii. https://doi.org/10.1016/j.fcl.2007.03.005 PMid:17561207
94. Sasaki K, Neptune RR. Differences in muscle function during walking and running at the same speed. J Biomech. 2006;39(11):2005-13. https://doi.org/10.1016/j.jbiomech.2005.06.019 PMid:16129444
95. Mahieu NN, Witvrouw E, Stevens V, Van Tiggelen D, Roget P. Intrinsic risk factors for the development of achilles tendon overuse injury: A prospective study. Am J Sports Med. 2006; 34(2):226-35. https://doi.org/10.1177/0363546505279918 PMid:16260469
96. Pinto RZ, Souza TR, Trede RG, Kirkwood RN, Figueiredo EM, Fonseca ST. Bilateral and unilateral increases in calcaneal eversion affect pelvic alignment in standing position. Man Ther 2008;13(6):513-9. https://doi.org/10.1016/j.math.2007.06.004 PMid:17910932
97. Alizadeh S, Mattes K. How anterior pelvic tilt affects the lower extremity kinematics during the late swing phase in soccer players while running: A time series analysis. Hum Mov Sci. 2019;66:459-66. https://doi.org/10.1016/j.humov.2019.06.001 PMid:31176257