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Foot and ankle complex injury prevention for adolescent basketball players

Holistic guidelines for trainers

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ABSTRACT

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The purpose of the thesis is to offer evidence-based holistic guidelines for physiotherapists, coaches, physical activity educators, or adolescent athletes themselves, taking into consideration psychomotor, socio-affective, and cognitive aims for a public lacking physiotherapeutical counselling on a greatly neglected body part in musculoskeletal prevention, the foot/ankle complex.

Theoretical knowledge for this work has been acquired through high quality literature such as books and research, prioritizing systematic literature reviews. A greatly practiced sport worldwide such as basketball allows up-to-date and high-quality findings, yet with the challenges of an underaged target group, that have been overcome by a great variety of studies in different perspectives and spectrums, associated with a fine biomechanical and relevant physiological analysis.

Furthermore, decisions have been taken to expand the guidelines to a holistic scope to increase the rate of actual application of these measures, help more athletes, and develop knowledge related to prevention beyond the common scope of training. Components such as exercise, nutrition, equipment, safety, objective measurements, and compliance have been outlined.

The findings highlighted the significance of promoting education for the athletes and the physical activity facilitator for a more personalized, effective, and durable prevention, regardless of the current recommendations.

Keywords: Basketball, adolescent, teenager, injury, prevention, primary, secondary, ankle, foot, complex, knee, soft-tissue, chronic, acute, equipment, footwear, insoles, orthotics, bracing, nutrition, hydration, compliance, participation, education, supervision, guidance, safety, assessments, guidelines, neuromuscular, training, workload, obesity, flat-foot, sprain, strain, contact, traumatic

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1 INTRODUCTION

1.1 Background, aims and objectives.

Homo sapiens has the foot as its only contact surface with the floor. It is a very complex piece of engineering containing 33 joints, 28 bones, 112 ligaments, and is controlled by 13 extrinsic muscles and 21 intrinsic muscles (Altchek et al., 2012, p. 11).
In fact, the foot can be separated into greater sub-sections working in synergy. The different parts are separated as the forefoot (including metatarsals and phalanges), the midfoot (including cuboid, navicular, and three cuneiforms), the ankle and hindfoot containing the ankle joint, and the subtalar joint (including the distal fibula, distal tibia, calcaneus, and talus). The foot contains three distinct arches, the transverse arch, the lateral longitudinal arch, and the most prominent and most studied: the medial longitudinal arch.
The foot's function is weight bearing, shock absorption/force dissipation, propelling the body away from the ground/force transmission, and adapting to uncertain surfaces (Altchek et al., 2012, p. 11).

Enhancing the participation of teenagers in physical activity (PA) is a global concern, and limiting the burden of injuries is a key factor in keeping them moving and becoming healthier adults. The foot/ankle complex is subject to many injuries in sport, particularly in basketball. Providing a tool to the coaches or the closest facilitator for PA is an opportunity to limit this burden. Millions of teenagers are playing basketball across the world, and the qualifications of their closest educators are various and informal (Dieffenback, 2020, section I.1). Nevertheless, giving them access to clear guidelines will help an immense number of adolescent athletes. As practice-based, the purpose of the thesis is to offer evidence-based holistic guidelines for physiotherapists, coaches, PA educators, or athletes themselves, taking into consideration psychomotoric,

socio-affective, and cognitive aims for a public lacking physiotherapeutical counselling on a greatly forgotten body part in musculoskeletal (MSK) prevention.

The research of information behind the thesis will allow the creation of guidelines for supervised and non-supervised actions towards individuals requiring high attention levels. Furthermore, an easy-to-follow format shall be proposed for an engaging, playful, and clear experience, promoting spreading, and sharing to possibly benefit the highest number of trainers and young athletes.

The thesis also aims to develop the question of knowledge, and raise awareness related to the foot/ankle complex.

The scope of athletes has been limited to teenagers, which describes semantically 13 to 19-year-old individuals who started puberty but are not adults yet. For resource management and limiting a psychosocial scope already broad, no selection of research aimed to specifically classify subcategories among teenagers such as male/female or ethnical differences. These subcategories may show statistical differences in injury incidence (Rose et al., 2008), thus the injury prevention guidelines remain greatly similar.

1.2 Methodology

The purely theoretical part about biomechanics analysis, anatomy, and traumatology could be found in highly reliable books found on “SAMK *Finna*” or websites such as “*Physiopedia*” or “*Merck Manual*”. These foundational findings about human inner capacities and physiological characteristics have been well studied for a long time, and the latest updates are not necessary at this point in science. The other side of the same coin concerns the finding of reliable information provided by researchers via different formats.

In the different paragraphs of this thesis, it was necessary to frame the topic with a research question. The research questions have been formulated following the PICO format (Physiopedia, 2022e).

For example, with the question: *In adolescents basketball players (P), does high footwear (I) compared to low footwear (C) improve injury prevention (O)?*

The research questions have been multiple to perform this thesis, following this protocol and enlarging the scope if necessary. After formulating the research questions, I created a search term using the Boolean operator “AND”, such as: “Adolescent AND basketball AND injury prevention AND foot”.

Systematic reviews have been chosen as often as possible because they are the pinnacle of reliability in the world of studies. If the findings were very specific and systematic reviews were unavailable, the level of reliability mechanically decreased, yet it remained at a high standard for the purpose of the thesis. From different databases (*PubMed, Science Direct, Research Gate,* and *Google Scholar*), the number of studies found was immense, so depending on the options available, I framed my search of articles from 2014 to 2024, which will only contribute to the validity of the literature review. In the case of finding a very accurate literature review corresponding to my research question, I could pick up articles older than 10 years old, as well when referencing secondary sources.

From this, I went through the article titles and abstracts to exclude the non-relevant articles and do another exclusion selection based on the complete text from the remaining articles. In the model of a PRISMA flow diagram usually used for the selection process of studies (Tempere University Library, 2022).

From the content of the included articles, I will extract the relevant information and data and summarize them among categories and/or themes that seem suitable and comprehensive to answer the different research questions regarding the injury prevention topic, such as equipment, nutrition, or exercises.

With the given PICO example, a conclusion will be drawn to have an overall picture of the impact of high footwear on injury prevention of the foot/ankle complex in adolescent basketball players. The important part is writing the report to ensure clarity, validity, rigor, reliability, and robustness of the data gathered to help the scientific community (Coughlan and Cronin, 2021, p. 79).

The choice of a practical thesis aims to produce strong statements based on a well-conducted searching methodology in order to provide a final product that would be reliable, usable, and pleasant for the best distribution, and use, possible to the target group.
Firstly, an anatomical and biomechanical reminder about the foot/ankle complex shall be reviewed for a better understanding and role of its components. Secondly, biomechanics will be challenged from the perspective of specific basketball movements. Thirdly, pathologies and definitions of prevention will be described for a better understanding of the aims. The fourth part is the core of the thesis, discussing the main components of injury prevention as a broad bio-psycho-social scope with training, equipment, nutrition, and safety of the target group and raising the question of participation in the practical implementation to the guidelines. Guidelines, which shall be described in the 5th part, followed by the developmental ideas, and finally the discussion.

2 ANATOMY OF THE FOOT/ANKLE COMPLEX

2.1 Passive structures

The structure of the foot/ankle complex can be divided into 3 distinct parts.
The *ankle and hindfoot* (forming the subtalar joint) contain the distal tibia, distal fibula, calcaneus, and talus.
The midfoot contains the navicular, cuboids, and cuneiforms (1-3).
The forefoot contains the metatarsals (1-5), the medial and lateral sesamoid bones on the plantar surface of the 1st metatarsal (Hallux), the proximal phalanx (1-5), the middle phalanx (2-5) and the distal phalanx (1-5).

Beside the bony structures, it is important to mention the ligaments and their functions due to their relevance in the traumatology of basketball (Table 1).

Table 1. Main ligaments relevant in foot traumatology in basketball (Agur & Dalley, 2020, p. 542-578)

Main ligaments	
Function	Names
Reinforce medially the ankle.	Medial (deltoid) ligament of ankle (deep and superficial fibers)
Strengthen posteriorly the ankle.	Posterior tibiofibular ligament. Posterior talofibular ligament.
Stabilize the ankle laterally (weakest)	Calcaneofibular ligament. Anterior inferior tibiofibular ligament. Anterior talofibular ligament. Posterior talofibular.
Prevent anterior displacement (strongest)	Posterior tibiotalar ligament (superficial and deep). Posterior talofibular ligament. Calcaneofibular ligament. Tibiocalcaneal ligament.

2.2 Active structures

The role of the muscles is important in the maintenance of the foot and ankle complex health in general. The anatomical reminder in Table 2, based on Agur & Dalley, aims to support further research and statements regarding basketball.

Table 2. Muscles related to the foot and ankle complex (Agur & Dalley, 2020, p. 542-578)

Anterior Muscles leg, ankle and foot	Origin/Insertion	Innervation	Function(s)
Tibialis anterior	O: Lateral condyle and superior half of lateral surface of tibia I: Medial and inferior surfaces of medial cuneiform and base of 1st metatarsal.	Deep fibular nerve (L4-L5)	Dorsiflexion of ankle joint. Inversion of foot.
Extensor hallucis longus	O: Middle part of anterior surface of fibula and interosseus membrane I: Dorsal aspect of base of distal phalanx of hallux (1)	Deep fibular nerve (L5-S1)	Extension of hallux (1). Dorsiflexion of ankle joint.
Extensor digitorum longus	O: lateral condyle of tibia and superior three fourths of anterior surface of interosseus membrane I: middle and distal phalanges of lateral 4 digits (2-5)	Deep fibular nerve (L5-S1)	Extension of lateral four digits (2-5). Dorsiflexion of ankle joint.

Fibularis tertius	O: inferior third of anterior surface of fibula and interosseus membrane I: Dorsum of base of 5th metatarsal.	Deep fibular nerve (L5-S1)	Dorsiflexion of ankle joint. Aids in eversion of the foot.
Lateral Muscles leg, ankle and foot	Origin/Insertion	Innervation	Function(s)
Fibularis longus	O: head and superior two thirds of lateral surface of fibula I: base of the 1st metatarsal and medial cuneiform.	Superficial fibular nerve (L5, S1, and S2).	Eversion of foot. Weak plantar flexion of ankle joint. **Reflexively resist inadverted inversion of foot.**
Fibularis brevis	O: Inferior two thirds of lateral surface of fibula. I: Dorsal surface of tuberosity on lateral side of base of 5th metatarsal	Superficial fibular nerve (L5, S1, and S2).	Eversion of foot. Weak plantar flexion of ankle joint. **Reflexively resist inadverted inversion of foot.**
Posterior superficial muscles of the leg, ankle and foot	Origin/Insertion	innervation	Function(s)
Gastrocnemius	*Lateral head* O: lateral aspect of lateral condyle of femur.	Tibial nerve (S1 and S2).	Plantar flexion of ankle joint when knee is extended.

	Medial head O: popliteal surface of femur, superior to medial condyle. I: Posterior surface of calcaneus via calcaneal tendon.		During walking raises heel and flexes knee joint.
Soleus	O: Posterior aspect of head of fibula, superior fourth of posterior surface of fibula, soleal line and medial border of tibia. I: Posterior surface of calcaneus via calcaneal tendon.	Tibial nerve (S1 and S2).	Plantar flexion of ankle joint (independent of knee position). Stabilizes leg on foot.
Plantaris	O: inferior end of lateral supracondylar line of femur and oblique popliteal ligament. I: I: Posterior surface of calcaneus via calcaneal tendon.	Tibial nerve (S1 and S2).	Weakly assits gastrocnemius in plantar flexion of ankle joint. Weakly assits gastrocnemius in knee flexion.
Posterior deep muscles of the leg, ankle and foot.	Origin/Insertion	innervation	Function(s)

Popliteus	O: lateral surface of lateral condyle of femur and lateral meniscus. I: posterior surface of tibia, superior to soleal line.	Tibial nerve (L4, L5, and S1).	Unlocks fully extended knee joint (laterally rotates femur 5°on planted tibia). Weak flexion of knee joint.
Flexor hallucis longus	O: Inferior two thirds of posterior surface of fibula and inferior part of interosseus membrane. I: base of distal phalanx of hallux (1)	Tibial nerve (L4, L5, and S1).	Flexion of hallux (1) at all joints. Plantar flexion of ankle joint. Supports medial longitudinal arch of foot.
Flexor digitorium longus	O: medial part of posterior surface of tibia inferior to soleal line, and by a broad tendon of fibula. I: Split in bases of distal phalanges of lateral 4 digits (2-4)	Tibial nerve (S2 and S3).	Flexion of lateral 4 digits (2-5). Plantar flexion of ankle joint. Supports longitudinal arches of foot.
Tibialis posterior	O: interosseus membrane, posterior surface of tibia inferior to soleal line	Tibial nerve (L4 and L5).	Plantar flexion of ankle joint. Inversion of foot.

	and posterior surface of fibula. I: Tuberosity of navicular, cuneiform, and cuboid and bases of metatarsals 2-4.		
1st layer of muscles of the sole of the foot	Origin/Insertion	innervation	Function(s)
Abductor hallucis	O: medial process of tuberosity of calcaneus, flexor retinaculum, and plantar aponeurosis. I: medial side of base of proximal phalanx of hallux (1).	Medial plantar nerve (L5, S1).	Abduction of hallux (1). Flexion of hallux (1).
Flexor digitorum brevis	O: medial process of tuberosity of calcaneus, plantar aponeurosis, and intermuscular septa. I: both sides of middle phalanges of lateral four digits (2-5).	Medial plantar nerve (L5, S1).	Flexion of lateral four digits (2-5). Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.

Abductor digiti minimi	O: medial and lateral processes of tuberosity of calcaneus, plantar aponeurosis, and intermuscular septa. I: lateral side of base of proximal phalanx of 5th digit	Lateral plantar nerve (S1-S3).	Abduction of 5th digit (5). Flexion of 5th digit (5). Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
2nd layer of muscles of the sole of the foot	Origin/Insertion	innervation	Function(s)
Quadratus plantae	O: medial surface and lateral margin of plantar surface of calcaneus. I: posterolateral margin of tendon of flexor digitorum longus.	Lateral plantar nerve (S1-S3).	Assists flexor digitorum longus in flexion of four lateral digits (2-5). Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
lumbricals	O: tendons of flexor digitorum longus.	*Medial one*: medial	Flexion of proximal phalanges.

	I: medial aspect of extensor expansion over lateral four digits (2-5).	plantar nerve (L5, S1). *Lateral three*: lateral plantar nerve (S1-S3).	Extension of middle and distal phalanges of lateral 4 digits (2-5). Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
3rd layer of muscles of the sole of the foot	Origin/Insertion	innervation	Function(s)
Flexor hallucis brevis	O: Plantar surfaces of cuboid and lateral cuneiforms I: both sides of base of proximal phalanx of first digit (1)	Medial plantar nerve (L5, S1).	Flexion of proximal phalanx of first digit (1). Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
Adductor hallucis	*Oblique head* O: bases of metatarsals.	Deep branch of lateral plantar nerve (S1-S3).	Adduction of first digit (1).

	Transverse head O: plantar ligaments of metatarsophalangeal joints. I: tendons of both heads attach to lateral side of base of proximal phalanx of first digit (1).		Assists n maintaining transverse arch of foot. Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
Flexor digiti minimi	O: Base of fifth metatarsal (5). I: Base of proximal phalanx of fifth digit (5).	Superficial branch of lateral plantar nerve (S1-S3).	Flexion of proximal phalanx of fifth digit (5), thereby assisting with its flexion. Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
4th layer of muscles of the sole of the foot	Origin/Insertion	innervation	Function(s)
3 Plantar interossei	O: plantar aspect of medial sides of shafts of metatarsals 3-5	Lateral plantar nerve (S1-S3).	Adduction of digits 3-5.

	I: medial sides of bases of proximal phalanges of third to fifth digits (3-5)		Flexion of metatarsophalangeal joint. Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.
4 Dorsal interossei	O: Adjacent sides of shafts of metatarsals 1-5. I: 1st: medial side of proximal phalanx of second digit (2). 2nd to 4th: lateral sides of second to fourth digits (2-4).	Lateral plantar nerve (S1-S3).	Abduction of digits 2-4. Flexion of metatarsophalangeal joints. Primary function of intrinsic muscles of the foot is to collectively **resist the forces that attempt to flatten the arches** of the foot.

2.3 Foot shapes

Feet have been classified into five dominant categories depending on their shapes and proportions. During examination, understanding the food shape can give information about loads and lever of arm affecting the foot (Altchek et

al., 2012, p. 47). Some factors predicting foot shape are purely genetics or related to ethnicity such as the growth of the toes. Thus, some other factors are environmental, such as Body Mass Index (BMI), frequency of participation in sport activity, or the shoes frequently used (Stankovic et al., 2018) when talking about angles, or proportions.

The Egyptian foot is the most common and has the specificity of having the great toe as the longest. The great toes are known to be subject to more arthritis (Cleveland Clinic, 2024), but it usually develops over 30 years of age and does not apply to the target group of the thesis.

The Greek foot (also called Morton's foot) has the specificity of having the second toe as the longest.

The Squared foot (also called Peasant's foot or Roman foot) has the specificity of having the greater toe and the second toe the same length.

The Simian foot has the specificity to have the great toe leaning laterally.

The Model's foot is a narrow foot with enhanced taper in metatarsal length from 1st to 5th rays (Altchek et al., 2012, p. 47).

These foot shapes are not described as pathological, like *pes cavus* or *pes planus* and only refer to anatomical specificities.

3 BIOMECHANICS OF THE FOOT/ANKLE COMPLEX

The foot biomechanics are extremely sophisticated, and up to 33 joints are mentioned in the literature. The focus will be held on the most important joints and complexes of joints. The biomechanics of the principal joints of the foot will be described from proximal to distal. The gait point of view is seen as the most functional for athletes and valid people in general. Moreover, the transfer to running is very similar when it comes to the foot and ankle's kinematics. The main differences are a shortening in gait cycle, the vertical forces increase up to 3x the body weight, the ROM of joints is increased by 50% (Appendix 1), and the phasic activity of the lower limb muscles is altered (ACSM TEAM, 2022). Firstly, the ankle and subtalar joint motion will be described; secondly,

the transverse tarsal joint; thirdly, the metatarsophalangeal joint (MTP joint); and a short description of specific conditions will be made.

In the gait, the closed chain motion is the most complex because the floor blocks the rotation of the foot. In this case, the dorsiflexion is done by the leg moving over the foot, and the internal rotation of the leg replaces the abduction of the foot when in open chain. In plantar flexion, the leg in moving backward away from the foot, and the leg describes an external rotation.

The open chain motions occur in a fixed talus and leg. The pronation results in dorsiflexion, abduction, and very slight eversion. The open chain supination results in plantar flexion, adduction, and again, a very slight inversion.

Regarding the angle of the ankle joint, we can conclude that the dominant motor actions are dorsiflexion and plantar flexion in the horizontal plan.

The subtalar joint joining the talus and calcaneus is working in a closed relationship with the ankle (tibiotalar joint) to form together the “ankle complex”. Open chain movement comes from the calcaneus, so the calcaneus and the rest of the foot shift about the talus and leg that are fixed. The open chain pronation results from dorsiflexion, abduction, and eversion of the foot. The open chain supination is in opposition, the result of plantar flexion, adduction, and inversion of the foot.

The closed chain is also, in this case, the most complex because the sagittal and transverse movements of the calcaneum are blocked by the ground. Therefore, all the inhibited motion of the calcaneus occurs equally and oppositely at the talus and the leg relative to the foot. But the motion of the calcaneum remains identical as in an open chain. Thus, in closed chain pronation, eversion of the calcaneus still occurs, but abduction and dorsiflexion are carried out by talar plantar flexion and adduction with internal rotation of the leg. In this position, it is worth mentioning that the morphological position of the foot is lower (arches included) and wider. Likewise, in the closed chain supination, the foot (arches included) is in a taller and thinner position, mostly because the

talus is not protruding medially anymore. In this pattern, inversion of the calcaneus will still occur, but adduction and plantar flexion are in fact talar dorsiflexion, and the abduction is seen as an external rotation of the leg above.

Regarding the angles of a freely moving subtalar joint, we distinguish an equally important motion in the frontal and horizontal planes. It is also regarded as the most important component responsible for the overpronation or oversupination of the foot (Giovinco, 2022).

The transverse tarsal articulation functions as one joint but is formed by the calcaneocuboid joint and the talonavicular joint. It allows the subtalar motion while the forefoot remains fixed in a closed-chain environment, like the stance phase of the gait with a sort of rotation. This joint becomes rigid in supination, and eversion “unlocks” the transverse tarsal articulation to allow a flexible midfoot in pronation.

The metatarsal phalangeal joint describes a “break” at last of the stance phase when the heel is elevated and the weight shifts evenly across the metatarsal heads. When the dorsiflexion of the toes occurs, the plantar aponeurosis gets under tension and therefore raises the longitudinal arch of the foot because it is “pulling” the distal metatarsals and the calcaneus towards each other. It is called the “windlass mechanism”. (ACSM Team, 2022.)

Clinical measurements of ROM provide a useful insight into the ankle and foot function during gait. As reported in the Appendix 1, the range is significantly relevant to be reported up to the hip. The relationship between hip and ankle/foot is immense, especially in a closed chain pattern. Which will impact numerous exercises used with athletes.
When the subtalar joint is everted, the tibia is internally rotated, which transmits through the knee an internal rotation of the hip. In contrast, when the subtalar joint is inverted, the tibia is externally rotated, which transmits through the knee an external rotation of the hip. Depending on the degree of disfunction, the overall gait and biomechanics of the whole lower limb can be impacted, and moreover, with athletes who must endure repetitive and intense efforts

throughout their careers. Not to mention here that, for instance, an externally rotated hip or a Trendelenburg case will impact the position of the foot through caudal direction and therefore affect the foot's ability to perform safely.

In a foot with normal medial longitudinal arch, the weight-bearing areas are at the forefoot the sesamoid bones of the 1st metatarsal, the head of the 2nd to 5th metatarsals, and at the hindfoot the tuberosity of the calcaneum (Agur & Dalley, 2020, p. 570). These weight-bearing areas can be different if the medial longitudinal arch is falling.

The fallen medial longitudinal arch is a condition called "flat foot" (pes planus). Whether it is genetic, acquired chronically, or traumatic, it is a result of the talus shifting inferomedially, producing the midfoot to unlock due to the eversion (Physiopedia, 2022b).

The condition of "hollow foot" (Pes cavus) describes a too high medial longitudinal arch. In this condition, cavus is defined by a varus hindfoot, a higher calcaneal pitch, a high-pitch midfoot, and the forefoot in plantar flexion and adduction. Causes are not all well understood but can be neurological, tumoral in the spinal cord, congenital, or structural due to a contracture of the plantar fascia, shortening of the Achilles tendon, or antagonist disbalance between weak dorsiflexors and overpowered plantar flexors (Physiopedia, 2022c). Also, for instance, the chain reaction from an abnormally internally rotated hip can affect all the way down and create a hollow foot.

The complexity of the foot makes its assessment difficult with one objective measurement. The triplanar mechanism, the different functions and structures must be considered when it comes to assessments. The alignment evaluation of the arches is an important component. A study among navy seals has shown that the risk of stress fractures was nearly twice as high with subjects having flat or hollow foot types compared to subjects having normal arches (Kaufman et al., 1999, p. 588). Even though an asymptomatic flat/hollow foot does not require treatment, it is in fact a risk factor for injuries that is not neglectable for athletes (Altchek et al., 2012, p. 47).

4 BASKETBALL MOVEMENTS

4.1 Jumping

Jumping has the aim of raising the center of mass (CM) of the individual; the whole body is involved in the process, but all forces are primarily transmitted through the feet (Chapman, 2008, p. 133–152), at least in basketball and most of the valid sports activities. The use of the arms may be gentler than the effort of the legs. Knowing that it is possible to jump with arms only (Chapman, 2008, p. 133–152). With that said, a basket may require a maximum height jump but also a controlled and moderate jump for shooting, for example. The acceleration shall be totally vertical or angular, depending on the task. The mechanical impulse generated from the ground will be transmitted efficiently on a court, with the softness of the chosen footwear as a bias.

Improving vertical jumps, whether initiated from a standing position or with a run-up using a bilateral leg take-off, can be achieved through broader speed-strength training approaches like jump squats. However, when an athlete is tasked with executing a jump using a run-up and a single-leg take-off, their ability to handle substantial stretch loads with significant eccentric demands becomes crucial and is rooted in their reactive strength. Therefore, it is essential to employ more targeted methods, such as plyometric training that emphasizes achieving maximum jump heights with minimal ground contact times. To enhance specificity and align with the coordination demands of jumping from a run-up with a single-leg take-off, the plyometric training should incorporate elements like single-leg landings and take-offs, with contact times of approximately 0.25 seconds. (Talpey et al., 2021, p. 6-7.)

The number of jumps during games (Appendix 3) represents a moderate risk of injury. These risks are mostly correlated with muscle damage, depending on the body temperature when they are performed, stretch loads, and eccentric constraints. Most of the risks for both chronic and acute injuries are in fact related to the landing following the freefall phase after a jump.

4.2 Landing

Landing is a component of stress on the foot/ankle complex in basketball. To prevent injury, it is crucial to maintain an equilibrium between the stress placed on the body and the capacity of musculoskeletal structures to handle the induced strain. Without adequate stress, there is a risk of muscle degeneration or atrophy, while subjecting the body to a singular excessive load can result in immediate injuries like fractures or sprains or contribute to long-term issues such as cartilage damage. Consistent loading can have beneficial outcomes, such as enhancing the critical limits of musculoskeletal components even in challenging nutritional and hormonal conditions, but it can also lead to negative effects like fatigue fractures, muscle soreness, or persistent pain. (Zatsiorsky, 2000, p. 523). The progressivity of the exposition to landing and the proportion of landing exercises must be increased in basketball for further resiliency during practices and games.

The surfaces of landing in sports play an important role in biomechanics. A hard landing surface is associated with higher degrees of joint flexion in general and more knee injuries (Zatsiorsky, 2000, p. 526). The flight time represents an opportunity for the athlete to plan the landing and therefore optimize his or her reaction-force, and a visually clear and predictable landing.

Within 0.1 seconds after landing, the reaction force can vary greatly between a “land and go” strategy, a “land and stop” strategy, a voluntarily reduced force in the “land and stop” strategy, and a “land and go” strategy under fatigue conditions (Zatsiorsky, 2000, p. 529). To reduce the impact forces, it is recommended to increase the landing time; however, in basketball, the overall effectiveness of the player would be reduced (Ortega et al., 2010); therefore, other strategies shall be used to improve prevention without compromising the performances.

Typically, individuals engaging in Land and Stop tasks commence contact with the landing surface employing a forefoot-heel landing pattern. Conversely, in Land and Go tasks, participants may employ various landing patterns, including forefoot-heel, flat foot, or heel-toe (Zatsiorsky, 2000, p. 531).

Hip and knee flexion in landing are affected by the velocity of the total body COM during touchdown, surface properties, or level of fatigue. However, most

of the dorsiflexion of the ankle is used by athletes during the landing phase (Zatsiorsky, 2000, p. 532).
In basketball, foot velocity and magnitudes of forces at the ankle vary greatly depending on the foot's angle in landing and the task required to follow (stop, go, or direction). Ultimately, preparing for initiating a subsequent task will increase the reaction force, especially at the ankle extensors/plantar flexors. Furthermore, the activity of the medial gastrocnemius is more important already prior to contact with the floor in preparation for a plantar flexion of the ankle (Zatsiorsky, 2000, p. 544). Mineta et al. added in 2021 that “A greater knee varus peak angle and pelvic internal rotation peak angle after single-leg landing are predictive factors for lateral ankle sprain.”

The landing exposition is a necessary risk and may be challenged by proprioceptive or visual issues. Training clear technical landing tasks must be part of the planning. In addition, performing exercises that allow a balanced loading experience between the structures involved (hip, knee and ankle) seems to be the preferred strategy to absorb and/or send back the total body momentum safely and efficiently. Ideally, individual joint angles and limitations may be assessed prior, during, and following landings. Furthermore, basketball involves different landing loads and angles that require a variety of expositions, and learning more than one landing strategy is key. (Zatsiorsky, 2000, p. 547.)

4.3 Running in different directions

Running biomechanics can be influenced by speed and direction regarding the angle of the joints, the ground contact time, muscle activity, or passive structure constraints. The gender may also impact the overall pattern due to the Q-angle, which is generally higher in women. The size of the individual will impact the lever of arms at the different stages of the gait or running pattern. (Zatsiorsky, 2000, p. 162.) Also, some athletes may have different stress zones during the support phase depending on if the strike is done by the rear-, mid-, or fore-foot. The style or position of the player on the court or the fatigue (Zatsiorsky, 2000, p. 178), the alternative pattern of acceleration/deceleration

pattern, may also impact the real-time biomechanical needs. Besides, gait/running pattern analysis are rarely conducted in a competition setting, and usually done on a treadmill, having also an impact on the results (Zatsiorsky, 2000, p. 162). These statements imply that it is more difficult to assess a clear and specific need for basketball players than for “basic” runners.

Nevertheless, if no reliable specific numbers can be provided, we can transfer our theoretical analysis of gait/running and propulsion overall to basketball, keeping in mind while programming that a wide variety of specific patterns are mostly found in short acceleration (Gabbett, 2016) and deceleration phases (Petway et al., 2020). Improving the frontal plane for lateral steps and change of direction drills for an effective transfer into the target activity is also crucial (Gamble, 2012, p. 75). The basic principle of overloading in different training variables (Gamble, 2012, p. 79) may help to postpone the point of fatigue and prevent further disturbance of the gait/running pattern.

5 FOOT/ANKLE COMPLEX MOST COMMON PATHOLOGIES AND PAINS

The foot and ankle ordinary pathologies and their management will be discussed. Several pathologies of the lower limb can be directly, or indirectly linked to the foot. In adolescence, specifically in a sport made of repetitive impacts such as basketball, the foot and ankle are subject to acute and chronic injuries. They include osseous injuries, soft tissue injuries, and cartilage injuries. In the Table 3 are some common disorders ranked by region of the foot.

Table 3. Common disorders ranked by region of the foot (Altchek et al., 2012, p. 51)

Posterior heel pain
Stress fracture
Bursitis
Haglund’s complex

Achilles tendon injuries
Os trigonum syndrome (posterior impingement)
Fracture of the posterior medial talar process
Plantar heel pain
Plantar fasciitis
Fracture of the plantar calcaneal spur
Midfoot pain
Lisfranc injuries
Stress fracture of cuboid or navicular
Distraction/fracture of the accessory navicular (os tibialis externa)
Posterior tibial tendon injuries
Distraction/fracture of the os peroneum
Peroneal tendon injuries
Also dorsal midfoot pain:
Os supranavicular injury
Dorsal ganglion
Forefoot pain
Stress fracture of metatarsals
Freiberg's infraction
Neuromas
Sesamoid fracture
Dislocation including turf toes including soft tissue injuries plantar to the metatarsal phalangeal joint of the greater toe.
Diffuse foot and ankle pain (best identified with conventional imaging)
From several injuries
Avulsion fracture of the anterior calcaneal process
Avulsion injury of the lateral aspect of the talus where the extensor digitorum brevis inserts
Fracture of the base of the tuberosity of the fifth metatarsal
Stress fracture of the fifth metatarsal distal to the tuberosity

A study of the epidemiology of pediatric basketball injuries presenting to emergency departments (meaning traumatic) over 6 years has been conducted by

Aaron J. Zynda et al. in 2022. “There was a significant increase in injury prevalence in adolescents (12- to 17-year-old categories: 238,678 injuries per year) when compared with childhood (7- to 11-year-old categories: 56,242 injuries per year)”. Ankle strain or sprain was the most common diagnosis with 17.7%, followed by finger injuries (12.1%), head injuries (9.4%), and knee strain/sprain with 4.5%. It is also mentioned that knee injuries are significantly more prevalent in female players compared to male players.
The earlier analysis of the biomechanics of the foot and the basketball constraints may lead to the following statement: numerous knee injuries can also be prevented by an optimized foot/ankle function, as mentioned by Aarts et al. in 2021: “Risk factors for knee injuries included ankle dorsiflexion with a range less than 36.5 degrees”.

All effects of acute traumatic injuries can be reduced, and recovery can be faster with a trained foot and healthy body pattern. For the ankle sprain “severe fatigue of the peroneus longus (also known as *fibularis longus* in paragraph 2.2 Active structures) is apparently the dominant cause of lack of foot stability, which was manifested by abnormal lateral deviations of the Center of Pressure (COP) during the stance phase. Under these conditions, ankle sprain injuries are likely to occur.” (Gefen, 2002, p. 1).
Furthermore, chronic injuries can be prevented efficiently, and specific exercises can prevent the non-exhaustive following list.

Chronic ankle instability is one common cause of osteochondral lesions of the ankle, and stability can be improved with exercises (Altchek et al., 2012, p. 125).

The foot shape matters when speaking about pathologies of the foot/ankle complex. Individuals born with flat feet, high arches, or toes in atypical position may experience instability around the toe joints, potentially leading to the development of Morton’s neuroma (Cleveland Clinic, 2022).

The foot's arch is in better position when the foot is supinated, but associated with inversion, the position of the ankle is in danger because of the exposure

and the lesser protection of the antero-lateral side of the ankle in case of shift. So, the foot shall be trained along with the ankle's strength and stability. The risk of tibial fracture is biomechanically related to a rigid high-arch foot not being able to absorb the forces or a flat foot leading to early muscle fatigue (Altchek et al., 2012, p. 254). Active range of motion has been shown to be more beneficial in cases of contusions, therefore, for prevention (Altchek et al., 2012, p. 257).

In the peroneus longus tendon, there is a zone of stress where a "wringing out" of the vascularity may occur and lead to disorders. These hypovascular zones are also where tears are most frequent. Specific exercise will help to ensure sufficient blood flow and limit these risks (Altchek et al., 2012, p. 141).

The posterior tibial tendon has a high injury risk in sport due to overuse (Altchek et al., 2012, 150). Overuse, in that matter, can be another term for a lack of training or preparation. The role of the posterior tibial muscle is to plantar flex the ankle joint and invert the foot (Agur & Dalley, 2020, p. 561), which are two functions that can be reinforced by training to make sure the specific sport activity does not exceed its inner capacities.

The Achilles tendon is known to respond very well to activity. It will thicken and stiffen with stimuli and atrophy and loosen with inactivity. The greater its diameter, the greater its resistance, but overuse also leads to increased degenerative enzymes. Spreading the tension throughout the rest of the chain, such as the foot or hip, will help reduce its labor during exercise and avoid overuse. Achilles tendon pathologies are also related to its surrounding structures, such as bursae. If repetitive efforts occur in a dorsiflexed position, the pressure is increased on the bursae surrounding the Achilles tendon. Furthermore, a difference in leg length of 5 mm may predispose an elite athlete to tendinopathy (Altchek et al., 2012, p. 161). To complete the needs to prevent a rupture, the statistics show in industrialized countries an increase in the rate of ruptures because of the decreasing of constant exercises and the increase of sudden "weekend warriors" exercises (Khan et al., 2005, p. 1). Regular strengthening of the plantar flexion along with flexibility exercises will contribute to reducing

this effect in situations like uphill running, known for being a risk factor, which translates into an eccentric load in a stretched position.
Polyfactorial with other risk factors such as the consumption of some medicines (off topic), “a reduced plantar flexor strength is a modifiable risk factor when treating patients with Achilles tendinopathy.” (Van der Vlist et al., 2018, p. 1).

A limited dorsiflexion leads to increased tension in the plantar fascia because of an enhanced pronation of the foot to compensate (Altchek et al., 2012, p. 220). In 90% of cases, the treatment for plantar fasciitis will include a specific stretching program along with medications, night splinting, and orthotics.
A study documents strength and flexibility deficits in the supporting musculature of the posterior calf and foot that are affected by plantar fasciitis. (Kibler et al., 1991, p. 1). The physiotherapeutic treatment for an os trigonum syndrome includes the stretching and strengthening of the lower leg muscles via isometric and eccentric exercises (Physiopedia, 2022d).
For Freiberg’s infraction, studies suggest a blending of a compromised vascularity, genetic predisposition, and changes in biomechanics. Again, major contributors can be changed by training (Talusan et al., 2014, p. 1).

All sports including some running involve tendonitis, tendinopathy, stress fractures and exertional compartment syndromes. Improper footwear, but also malalignment and specific muscle imbalances are great contributors to most of these issues. It is important to point out that most general leg pain for runners can be limited by using proper shoes (discussed in a further paragraph) and doing a specific training program.

6 PREVENTION

6.1 What is prevention?

The Merck Manual divides health prevention into primary, secondary, and tertiary prevention and aims to reduce the risks of diseases or burdens and their associated risk factors.
Primary prevention strives for preventing a disorder/disease/accident to occur. The most relevant tool in sports is “counselling to change high-risk behaviors”.
Secondary prevention strives for reducing the consequences of a developing condition that would be detected early. The most relevant tool in sports includes the assessment and evaluation of known potential risks in athletes.
Tertiary prevention strives for managing the complications of an existing, often chronic, condition.
The most relevant tool in sports includes rehabilitation from injuries, use of protective equipment, and control of known disorders like Sever’s disease (Physiopedia, 2024a) or pes planus (Physiopedia, 2022b).

6.2 Why to use prevention?

The financial effectiveness of health prevention is often discussed as a major benefit. Thus, it should not be the only motivation, and the true aim is to improve health overall at a reasonable price. (Weinstein, 1990.) Indeed, prevention is cost-effective but not free of money or resources.

In 2016, a systematic review by Ekegren et al. concluded that “for studies using objective measures, low physical activity levels and high levels of sedentary behaviors were found consistently after injury.” Those sedentary behaviors in adolescents may cause mental health issues (Hoare et al., 2016) and other psychosocial problems (Kuiper et al., 2018).

6.3 How to evaluate what to prevent?

Preventative measures in physical activity are typically guided by risk factors, which play a pivotal role. These factors, encompassing both extrinsic and intrinsic elements, have the potential to elevate the risk of injuries or accidents during physical activity in adolescents. Moreover, injuries and accidents may arise from the interplay of these factors. The identification of these risk factors is crucial for physiotherapists/coaches to contribute effectively to injury prevention efforts. Here is a risk factor evaluation in the Table 4 (can also be found in Appendix 2):

Table 4. Risk factors evaluation (Physiopedia, 2024b)

Extrinsic risk factors		Intrinsic risk factors	
Non-modifiable	Potentially modifiable	Non-modifiable	Potentially modifiable
Sport played (contact/no contact) Level of play (recreational/elite) Weather Position played Time of season/time of day	Rules Playing time Playing surface (type/condition) Equipment (protective/footwear)	Previous injury Age Gender	(Aerobe) fitness level Preparation sport-specific training Flexibility Strength Joint stability Biomechanics Balance/proprioception

			Psychologi-cal/social factors

Table 5. Example of a risk evaluation for an adolescent basketball player:

Extrinsic risk factors		Intrinsic risk factors	
Non-modifiable	Potentially modifiable	Non-modifiable	Potentially modifiable
Basketball no contact with others Recreational level Indoor Small forward High-school-Season 2 to 3 games/ week + 3 to 3 practices/week	Official rules Playing time can be reduced Official playing surface Additional equipment can be used (higher and softer sole footwear, ankle brace, knee pads, kinesiotaping…)	Numerous previous ankle sprains 15 years old Female	(Aerobe) fitness level top level Preparation sport-specific training can be improved Flexibility top level Strength can be improved Joint stability can be improved Biomechanics can be improved Balance/proprioception can be improved Psychologi-cal/social factors Nothing to report

An effective risk factor evaluation is ideally made individually but can be done for a group if the resources are lacking and if the intervention may not be individualized afterward. Based on this evaluation, it is possible to target with more precision the most important components to address and improve for the athlete or the coach/trainer/physiotherapist in charge.

7 EFFECT OF TRAINING OF THE FOOT/ANKLE COMPLEX ON HEALTH AND PERFORMANCE

7.1 Theory

When it comes to performance training for the lower limb, glutes, quadriceps, hamstrings, adductors, and sometimes the triceps surae are mentioned. But if we think about the whole muscle chain needed for an athlete to propel himself from the floor, the foot flexors are at the very beginning of that chain. The foot is often forgotten for different reasons, like the unmotivating repetitive aspect of its strengthening, or the small size and “invisible” development of its muscular components. An athlete with a tight core and powerful thighs could send about 700kg to the ankle and foot to support on an approach run (Reiss & Prévost, 2020, p. 255). The enormous ligamentous structure is in an extremely heavy constraints if the muscles are not working properly, which can lead to pain, sprains, or tears and greatly limit performance.
Studies have shown that strength training is showing great results in performance such as vertical jump, 50-meter run or 1-legged long jump (Hashimoto & Sakuraba, 2014, p. 1). But here is a quick overview of the different qualities a foot/ankle complex should have for an athlete to perform well and justify the implementation of the workout plan.

Anticipation and strength are important components as the weight goes rapidly from zero to more than 125% of the body weight across the foot in gait. But mobility is also an important component, depending on the conditions. For instance, the midfoot should be mobile to allow movement in the 1st interval of

gait, while it must be rigid in the 2nd interval and 3rd interval to allow an efficient transmission of energy. (ACSM Team, 2022).

Maximal dorsiflexion and strength of the hallux appear to have a great impact on the motion of the rest of the chain. Therefore, assessing the optimal functioning of the 1st MTP joint is a useful information through the dynamic function of the foot (Allan et al., 2020, p. 1).

Intrinsic muscle activation is high all the way through the gait, but also body weight is at its highest point when ankle rotation is most extreme. Which translates to a need for strength in a full ROM (Appendix 3).

The need for a 5° angle of ankle dorsiflexion appears to be limited in gait (Appendix 1). But a dorsiflexed ankle is more stable than in a plantar flexed position (Agur & Dalley, 2020, p. 573). Thus, it is important to have optimal dorsiflexion when implementing exercises like squats with athletes that require generating force and having maximum stability. Also, when it comes to uphill walking or running in another direction than a perfect straight line, more ROM will be required.

The expert in sports biomechanics, Tapani Keränen mentioned in a lecture that jumping work is not enough to strengthen the foot/ankle, but that it is necessary to gain isometric strength too (KIHU, 2022).

Starting with a destabilization of the foot on the ground causes a chain reaction up to the back. As mentioned earlier, a foot too everted causes medial rotation of the tibia, which causes tension in the knee (no rotation should occur while extended) and is transmitted to a medial rotation of the femur, which in turn tilts the pelvis anteriorly, leading to pelvic girdle instability and overlordosis, overkyphosis, back pain, and/or overall function disorder. The opposite statement is also true: working on pelvic girdle stability will ultimately contribute to a healthier foot.

That configuration often leads to a painful femoroacetabular impingement (FAI) and potential damage to the hip joint. Also, such a configuration leads to a weaker push-off during the gait and contributes to adding stress to the hip flexors (Altchek et al., 2012, p. 250).

To address these issues, among others, neuromuscular training has shown protective benefits among middle- and high-school age basketball players in the lower limb (Foss et al., 2018).

7.2 The health/performance paradox

There is a prevailing faith that a higher training load correlates with increased injury rates. However, one will also find evidence suggesting that training exerts a protective effect against injuries. For instance, team sport athletes who engaged in over 18 weeks of training before experiencing their initial injuries showed a decreased risk of subsequent injuries, and elevated chronic workloads have been proven to lower the risk of injury. Furthermore, in various sports, athletes with well-established physical attributes are associated with a diminished risk of injury. It is evident that for athletes to cultivate the necessary physical capacities that offer protection against injuries, they must be willing to undergo rigorous training. Lastly, there is evidence indicating that inadequate training may elevate the risk of injury. These findings collectively underscore that reducing workloads may not always be the most effective approach to safeguarding against injuries. (Gabbett, 2016.)

Yet, adverse events are dose related (Gabbett, 2016). For teenage basketball players, a systematic review in 2021 by Aarts et al. showed an overall injury rate ranging from 2.64 to 3.83 per 1000 hours of athletic exposure. The workload must be measured in a specific way to be usable in the assessment of the athlete's readiness.

In basketball, the main internal factors affecting workload can be related to the Rate of Perceived Exertion (RPE), Heart rate (HR) or soreness levels. Furthermore, individual well-being can be measured with various subjective questionnaires, often using a simple 5-, 7-, or 10-point Likert scale (Sullivan and Artino, 2013).

External factors in basketball may include: distance covered (measured with GPS), amount of jumps (measured with accelerometers), longer distance high-speed running (GPS+accelerometers), volume of training (can be measured in tons lifted per week and/or minutes played per week), and divided into frequency of training per week.

A valid overall workload calculation is RPE x minutes. The result is written as Arbitrary Units (AU), and 300-1000 units is a range of intensity (from lowest to highest) that may be found in a team sport per session.
This workload can be measured in an acute and chronic fashion.
The acute measurement is conventionally used for one week in team sports, and the chronic workload measurement is done over a three-to-six-week period.

For a long-term injury rate reduction, the ratio Acute:Chronic must be ideally between 0.8 and 1.3, which would translate to an athlete that sustained enough training and is ready to perform without being hit by fatigue or overtraining (Appendix 4).

After figuring out how the quantity of activity is regulated by the ratio Acute:Chronic workload, the other factor promoting performance and health is the progressivity of the implementation of the workload. Indeed, no more than a 10% increase in workload should occur weekly to maximize benefits over risks. Lastly, the prescription of relevant and appropriate training is another key component ensuring optimal health prevention. (Gambett, 2016.)

Despite these general rules, it is valuable to note that external factors of workload may affect athletes differently depending on their age, training experience (Rogalski et al., 2013), and injury history (Fulton et al., 2014). That’s why an individualized evaluation remains the best option, and a collection of data may help for further seasons to anticipate injuries on a case-by-case basis.

8 EFFECT OF ASSISTIVE DEVICES/PROTECTIVE EQUIPMENT FOR INJURY PREVENTION

8.1 General

“In a sports context, wearing knee and elbow pads could change the risk-taking behaviour of the athlete during training, which does not necessarily lead to a reduction in the incidence of injury and may even lead to other injuries.” (Van Tiggelen et al., 2013.) Thus, different equipment at different levels of prevention can be used in different sports, and it is necessary to open up the different measures separately before giving recommendations for their implementation, or not for teenage basketball players.

8.2 Bracing, taping and kinesiotaping

Ankle bracing and taping have been shown to be effective against chronic ankle instability (CAI), oftentimes found in people who have had one or several ankle sprains. In the case of secondary prevention, several studies conclude that they are beneficial, like Hiller and Beckenkamp in 2023.
Kinesiotaping may improve ankle inversion proprioception performance for athletes with and without CAI, and longer tape shows greater effects (Yu et al., 2021), but it does not improve foot cinematic (Kuni et al., 2016).
Ankle tape in general has shown effectiveness in proprioception whether it is applied by a physiotherapist specialized in sport and exercise or self-applied by a pre-elite athlete in the context of netball in a randomized controlled trial (RCT) in 2021.
A systematic review with meta-analysis concludes, however: “Taping can be considered by clinicians for preventing injury in non-injured athletes by restricting ankle plantarflexion at the beginning of landing. The results from our review do not support a strictly biomechanical mechanism of ankle sprain prevention by external supports, instead proprioception may be playing a role”. (Beckenkamp et al., 2021). With that said, it is important to remember that a reduced

dorsiflexion range may increase the risk of injury to the knee joint (Malliaras, Cook and Kent, 2006).

8.3 Orthotics and insoles

Insoles are commonly used in sports, but how do they help? These medically prescribed devices may reduce overall impact and the support medial longitudinal arch of the foot.
Insoles are devices made to cushion and absorb shocks, while foot orthosis are thought to redistribute pressure and aim to restore the natural function of the foot to relieve pain or improve biomechanics overall (Physiopedia, 2024c). Foot orthosis can be useful in cases of specific injuries or conditions as a secondary or third prevention, such as in medial tibial stress syndrom (Naderi et al., 2021) or in a painful flexible flat foot (Yurt et al., 2019). Thus, how about primary prevention? A systematic review is available to answer this question. Foot orthoses demonstrated effectiveness in preventing overall injuries and stress fractures, yet they did not prove to be effective in preventing soft-tissue injuries. On the other hand, shock-absorbing insoles were not found to avoid any type of injury. The quality of the trials included varied greatly, nonetheless it is a great start for further investigation. (Bonanno et al., 2017.)

8.4 Ideal footwear

In 2022a, a systematic review by Lam et al. about the “Effect of shoe modifications on biomechanical changes in basketball” concluded that a softer shoe cushion mitigates the impact better in passive or unanticipated landings. Furthermore, higher-collar shoes do improve ankle stability when cutting and jumping, a shoe with energy restitution properties (stiffer-bending forefoot, grippy traction material) improves jumping, cutting, and sprinting. In addition, athletes who know their shoe mass is lighter shall improve their performances in jumping and/or cutting tasks. Nevertheless, this factor is the least important compared to traction and forefoot stiffness (Worobets and Wannop, 2015).

Again in 2022b, Lam et al. reported results indicating that elevated collar height combined with orthoses with arch support seem to lower the likelihood of ankle sprains during landing, although they may potentially raise the load on neighboring joints, which concurs with other theories provided in this thesis.

9 HYDRATION, NUTRITION AND SUPPLEMENTATION OF YOUNG ATHLETES FOR INJURY PREVENTION

The fundamental principles of sports nutrition advised for adult athletes are equally applicable to younger athletes, with the difference that during growth and maturation, changes are perpetual and balance an evolving concept at a faster pace than for adults. Furthermore, teenagerhood is a critical time for food habits and body image development, and these components must be taken into account while counseling young athletes about their injury prevention nutrition.

Coping with elevated nutrient and energy needs during phases of rapid growth, coupled with managing shifts in body composition and variations in metabolic and hormonal levels, can be a considerable challenge for young athletes. Social and emotional factors, along with the stage of development and timing of maturation, significantly influence individuals' self-perception and their perspectives on sporting accomplishments. (Burke et al., 2021, section 18.)

9.1 Hydration

The lack of fluid intake shall reduce the overall performance, attention level and accelerate the fatigue process, increasing the risk of injury, especially during the landing maneuvers as mentioned in paragraph 4.2.

Water is better than sports drinks because of the associated risk of obesity and “sweat sodium losses are generally lower in young athletes compared to adults (Meyer et al., 2012, p. 4), so replenishment of electrolytes is less critical”.

To quantify the amount of water to drink, the athlete should not lose more than 2% of his pre-effort bodyweight to prevent dehydration. Surely, the temperature of other environmental features may increase or decrease the need for hydration.

9.2 Macronutrients

The overall energy intake is greatly evolving during the growth spirts and overall maturation of athletes. The energy restriction may have psychological and physiological consequences, especially at this stage of life, and is not recommended. On the other hand, overeating increases the risk of poor food behaviors and obesity. Yet the sum of Energy availability (equal to: Energy intake - Exercise energy expenditure) must be positive (Desbrow et al., 2014, p. 572). The fine line of balance is reached by monitoring the Body Mass Index and body composition, educating and supporting the young athletes in the search of well-being and a balanced relationship towards food for the rest of their life.
As spoken earlier, macronutrient intake for adolescents will follow similar rules than for adults and no specific supplement of macronutrients such as protein or carbohydrates is necessary for adolescent athletes as the requirements are met with food (Aerenhouts et al., 2011; Heaney et al., 2010). Nonetheless, those supplements may represent a practical option to ensure adequate intake in case of travel or quick and easy access to energy during a competitive event itself.

9.3 Micronutrients

Micronutrients are more likely to be lacking in youth athletes (Heaney et al., 2010). Iron deficiency in young athletes, especially female athletes, is common regardless of the sport (Roy et al., 2022; Shoemaker et al., 2020).
Calcium and D vitamin requirements for adolescents are highest during a growth spurt and should be addressed (Hecht et al., 2023).
Much like their adult counterparts, young athletes face an increased risk of vitamin D shortage if the sun exposure is limited, if they reside at latitudes

exceeding 35 degrees, engage in prolonged indoor training sessions, possess dark skin, or regularly use sunscreen or protective clothing (Burke et al., 2021, section 18). A poor relationship between D-vitamin intake and stress fracture injury has been directly found (Tenforde et al., 2010), but a systematic review and meta-analysis in 2019 by Yao et al., established that the combination of D-vitamin and calcium was a more promising strategy. Also, severe vitamin B12 deficiency was found in 7% of athletes, and 4% had severe folic acid deficiency (Ercan & Arslan, 2018).

In general, it is viewed as inappropriate to encourage young athletes to absorb dietary supplements for the purpose of performance enhancement. This perspective aligns with the stance of prominent sporting organizations and expert groups. It is important to note that this recommendation did not apply to the clinical use of dietary supplements, such as calcium, iron, and vitamin D, when administered under the appropriate guidance of qualified health professionals like physicians or sports dietitians. (Burke et al., 2021, section 18; Hecht et al., 2023.)

10 SAFETY

10.1 Autonomy

Supervised physical activity has shown overall to be more productive in physical capacity development than unsupervised physical activity (Fennell, 2016). But what about safety? Benefits of physical activity among all publics, including teenagers, have been shown to outweigh the risks (Physiopedia, 2024b). Specific physical activities, such as weightlifting with adolescents may contain well known risks related to improper guidance, inappropriate load (Faigenbaum and Myer, 2009) or poor proprioception (Physiopedia, 2024b).
Thus, improving the participation rate in unsupervised exercises, while still being guided, in addition to the supervised activity, can be for some athletes a

safe and efficient way to adapt and orient their workload to the demands of their sport. The quality of the guidance is a key component; education, training, and scientific updates from the coaches/physiotherapists are where the process all starts. The aim of the product of this thesis is to partly solve this equation.

10.2 Teenagerhood, maturity and specific biomechanical response

This phase of biological maturity may require attention when it comes to performance and the risks of overstimulation or disbalanced use of the musculoskeletal system.

In general, children exhibit a lower susceptibility to injury compared to adults when subjected to similar impact energy levels. Moreover, injuries sustained by children are less likely to result in permanent disabilities. The enhanced flexibility of the thorax, for instance, allows for greater deformation before rib fractures occur, thereby reducing the risk of associated internal injuries in children. Notably, advancements in automotive crash testing and evaluation have contributed to predicting the biomechanical responses of children and adolescents. This, in turn, has facilitated the development of safety guidelines based on the tolerance levels of immature orthopaedic tissues. Similar advancements have been observed in the realm of sports injuries, where comprehensive documentation of patterns and injury mechanisms exists. Children and adolescents, however, experience distinct injury patterns compared to adults, necessitating specialized treatments. Despite the well-described nature of these injury patterns, a complete understanding of the biomechanical mechanisms behind them remains elusive, posing challenges in diagnosis and treatment. (Winkelstein, 2012, p. 346). Which is one more reason for us to aim for prevention.

Thus, we know that specific conditions at growth plates such as Sever's disease may occur in athletic growing children and adolescents (usually earlier than the target group between 10-12 years old), directly due to repeated shear forces and impact pressure at the calcaneus growth plate (Physiopedia, 2024a). We can also put in parallel the loss of muscle force production in

dorsiflexion between roughly 10 and 12 years old (Winkelstein, 2012, p. 341). Later, main skeletal muscle strength increases significantly, and no growth plate issues are to be expected after puberty.

Biomechanical age can vary from biological age due to environmental adaptations such as physical activity (Winkelstein, 2012, p. 342). A relevant intervention will improve the biomechanics maturity of young athletes, regardless of genetic differences.

Lastly, according to G. Mascherini et al. in 2019, over a cohort of 1046 athletes, male and female, in Italy between 8 and 18 years-old, Caucasian, 16.2% were overfat, and 10.8% were obese with body fat percentage measurements. Body Mass Index measurements have shown 20.1% of overweight, and 3.5% of obese. With that said, abnormal skeletal alignment, impacting the healthy development of bone and cartilage, has been associated with obesity. Notably, a comparison of gait kinetics in obese children revealed significant differences when compared to their counterparts with a healthy BMI (Winkelstein, 2012, p. 347).

Growth may also be related to deconditioning. “In the absence of sufficient corresponding neuromuscular adaptation, musculoskeletal growth during maturation can influence the development of abnormal movement mechanics during certain activities” (Myer et al., 2014).

11 INCREASE PARTICIPATION RATE FOR PHYSICAL ACTIVITY

11.1 In general

There is a suggestion that most coaches primarily concentrate on psychomotor development, giving minimal consideration to cognitive or affective elements. To comprehend the comprehensive requirements of performers, coaches must extend their focus beyond the physical and mental aspects of sports performance, delving into the social and, potentially, spiritual dimensions of personal development. (Parker and Vinson, 2013, p. 140.)

Van Tiggelen et al. (2013), p. 649, added that “the Knowledge -Attitude -Practice path (KAP path) appears to be weak: having the knowledge is not a guarantee to modification of the attitude and subsequent behaviour of the individual.” They also highlight p. 650: “The sum of the efficacy and the efficiency of a preventive measure, together with good compliance and controlled risk-taking behaviour of the individual athlete, results in the effectiveness of prevention of sports injuries.”

A systematic review by Bogardus et al. identified the main barriers encountered to an effective implementation on the Anterior Cruciate Ligament (ACL) injury prevention program. These barriers include the motivation, the time demand, the skill requirements for the program facilitators, the compliance, and the cost (Bogardus et al., 2019).
The most difficult factor to overcome appears to be compliance (Van Tiggelen et al., 2013, p. 650). Studies reveal that injury prevention programs incorporating structural changes, such as regulations, enforcement processes, and environmental or product adjustments, were more successful than those relying on behavioral modifications (Lund and Aarø, 2004, p. 278).
In addition, it is commonly known that “successful maintenance of physical typically requires substantial support and supervision” (Mullen and Hall, 2016, p. 6).
Nevertheless, imagining a pattern relying only on supervision will ultimately enter into conflict with the barrier of *cost*. The monetary cost, and also the time resources of an adequate teacher/facilitator may be an issue. It is also crucial to understand the true role of the physical educator. Mosston and Ashworth described the paradigm of teaching physical activity through transfer of the decision-making to the mentee. Thus, the aim and role of the person in charge of physical education are to guide students through a series of teaching styles, from Command style (Mosston and Ashworth, 2008, p. 76) to Self-teaching style (Mosston and Ashworth, 2008, p. 290), to become autonomous and self-efficient.

11.2 In team sports

In team sports, compliance is also an issue. Moreover, compliance will affect adherence and the quality of execution. That is why it is crucial to have supervision and/or adequate guidance (Gamble, 2012, p. 183). Also in 2012, Gamble writes that a group setting intervention shows a better outcome than an individual intervention. To save time, enjoy the group training set-up, and have supervision, the injury prevention intervention may be included in the players warm-up before the actual training (Gamble, 2012, p. 184). The systematic review and meta-analysis of Ding et al. in 2022 supports this perspective. With that said, higher intensity, heavier loads, and deeper range of motion should be performed while being warmed up, not as a warm-up, and consequently could benefit from being performed separately.

Considering the socio-affective aim of physical activity, including specific drills that mimic game situations, often ball related, and the importance of “play” will be a great way to enhance the compliance rate. Although, if all athletes playing ball want to play, depending on the level and ambition of the athletes and also depending on their momentaneous perceived mindset, the coach/educator may evaluate the need to build a session plan that includes more or less fun factor. Indeed, higher level athlete who are performance oriented, shall show better adherence to a monotonous program than lower-level athletes driven more by the participation itself than the outcome, as written by Jones and Kingston in 2013.

12 HOLISTIC GUIDELINES AS END PRODUCT

The end-product is a PDF document, based on the findings of this thesis, at the destination of the coaches, physiotherapists, or other PA facilitators. The PDF will include bullet points related to strength, equipment, education, nutrition/hydration, and measurements as seen on the cover page (Appendix 6).

The document will also include a proposition of content to implement in a basketball practice, and another proposition of content for a separate injury prevention training session. The aim of the author was to offer flexible guidelines, offering the possibility for the instructor to adapt and modify the specific content while implementing the principle of injury prevention effectively. These strategical choices stem from the monotonous nature of injury prevention sessions and encourage the coach creativity and awareness of the need for personalization.

13 CONCLUSION

A holistic guide required a comprehensive overview of the injury prevention components, such as training, its associated safety and participation rate, but also equipment, nutrition at a micro- and macro-nutritional level, and hydration. An adolescent should have access to an effective injury prevention intervention to promote optimal bio-psycho-social development, if possible, in a cost-effective manner for society.
The different levels of prevention are covered by counseling, evaluation of risks, education, and the use of protective equipment. All evaluation and intervention are best done in a personalized manner but can also be done in a group if the resources are lacking. Case-by-case observation will make the difference as the playing level rises.

Neuromuscular training has been shown to be an effective measure to enhance both performance and injury prevention for athletes. The modalities must correlate to the demands of the sport in terms of motor actions, intensity, and diversity. Thus, if increasing the volume and intensity are necessary ove time, they still must be done in a controlled and strategic manner to keep the players injury-free. Evaluating the workload can be done in an objective (e.g., use of GPS) or subjective (e.g., use of RPE) manner. The acute:chronic workload formula and increasing the workload by 10% maximum per week are good

steps towards balance. Nevertheless, individualized evaluation remains the best option, and a collection of data may help for further seasons to anticipate injuries on a case-by-case basis. Some of the important intrinsic measurements of the athletes are the passive range of motion (PROM) of the ankle dorsiflexion, which should be equal or over 36,5° and the PROM of the 1st MTP dorsiflexion, which should be equal to or over 90°. An assessment of the individual maximal angle of the knee while landing in a game situation is challenging but valuable to give further individual guidance, especially on isometric exercises.

Despite some specific risks at the growth plates of growing individuals, a specific intervention may accelerate the biomechanical maturity of the athletes, and strength development activities can counteract the decline in motor skill and neuromuscular development in adolescents. The benefit/risk balance of training can be improved by proper guidance and the use of appropriate loads. Hence, educating and updating the coaches/physiotherapist/PA facilitators and adequately splitting the athletes' tasks between supervised and guided exercises are key components of maintaining a high level of safety.

Promoting autonomy to some extent has been shown to be an efficient developmental opportunity, but it raises the question of actual participation. Improving the adherence and quality of the execution of injury prevention is a key factor for the plan to show a positive outcome. For better compliance, but also cost efficiency and time management, it is relevant to include an injury prevention program in the warm-up at the beginning of a basketball session as a group. Specific drills, including the ball, are valuable for both psychomotor and socio-affective aims. It is also relevant to combine both supervised sessions and guided self-performed sessions. These guided sessions can be scheduled as a group by the coach as a structural modification of the schedule. The quality of the guidance and education provided to the coachee to comply is, yet again, a cornerstone for success.

Among the equipment available for the foot/ankle complex, these statements are rising regarding injury prevention. Taping is useful as a proprioceptive clue,

but not necessarily to limit the range of motion, especially of the dorsiflexion that increases the risk of knee injury. An athlete experiencing chronic ankle instability will benefit from using bracing or taping at the ankle. These pieces of equipment are also effective if they are applied by the athlete himself.
Arch support and high collars are shown to be effective but must be used with care if the athlete is known to be prone to knee injuries. Furthermore, better cushioning of the shoes does reduce the impact on post-fatigue and unanticipated landings.
With that said, the athlete's perception of comfort and adequate confidence regarding his equipment matters, and "the most appropriate means of achieving behavioural modification is to integrate it into the athlete's skills training rather than in a dictatorial fashion" (Van Tiggelen et al., 2013). Yet again, education is a key factor in self-care efficacy.

Young athletes possess distinct nutritional and hydration needs due to their daily engagement in training, competition, and the concurrent demands of growth and development. Drinking water over any other type of drink is the first component of successful hydration. In addition, the athlete should never lose more than 2% of his bodyweight in dehydration during an exposition to PA. When providing dietary education and recommendations for this demographic, the emphasis should be on fostering long-term health. Specifically, it is crucial to encourage developing athletes to align their eating patterns with daily exercise demands, ensuring a consistent intake of high-quality carbohydrates and protein throughout the day, particularly in the immediate post-training period, and adequate hydration, like for an adult athlete. Special attention should be paid to potential risks such as negative or low energy availability, and there should be a focus on meeting dietary requirements for calcium, vitamin D, iron, folic acid, and vitamin B12 given the susceptibility to deficiencies and elevated needs in young athletes. It is recommended to satisfy the nutrient needs of young athletes through food rather than relying on supplements. The utilization of dietary supplements by developing athletes does not replace by any means proper training and nutrition, but their use under guidance by dietary professionals associated with education may provide great results in injury prevention and overall development of adolescents towards nutrition. (Burke et al.,

2021, section 18.) Prevention of obesity is another key component of foot/ankle complex health in young athletes. Regular, formal or informal, educative and non-judgemental evaluation of the BMI and body composition can be performed in prevention.

14 DISCUSSION

Injury prevention is a broader topic than exercise measures alone and many components were discussed in this thesis. Fortunately, many studies have been conducted around risk of injury prediction, nutrition, and assistive/protective equipment to help preventive training to work throughout the different levels of prevention. Creating a product aiming to combine all the main recommendations in one, while giving flexibility to the PA facilitators to add on their creativity and the specificities of their athletes had not been done to my knowledge and shall be a useful tool wherever basketball is being played by adolescents.

Challenges regarding the research process were numerous, including some paywalls to have access to some articles, finding up-to-date specifically answered research questions, targeting adolescents, and the recent pandemic of SARS-CoV-2 that greatly impacted the world of sport, participation levels, and research. Indeed, while anatomy and physiology may explain a significant amount of decisions made regarding the adolescent public, it remains difficult to conduct some intervention and experiment with the durability of an intervention for two main reasons. The first one is ethical; with an underaged public, we cannot decently expect the same freedom scientifically as with a fully self-conscious adult and legally responsible adult. The second reason is that, by definition, the adolescent is evolving at a fast and inequal pace, which makes it extremely difficult, if not impossible, to contrast and reliably conclude over data gathered on long-term measures. With that said, no contradictory findings were found between physiology, biomechanics, and effective interventions.

The effectiveness of the various common pieces of equipment may have been a subject of interpretation and has been clarified reliably throughout the work.

The best intentions, honesty, professionalism, and rigor have been used to build up these up-to-date holistic guidelines, and there is no conflict of interest to be signaled. Nonetheless, “up to date” is another word for perishable, and what is described as strong statements today shall be questioned, enhanced, modified, and partially erased with hopefully new research and findings. In addition, holistic approach must be attached to the athlete-centered paradigm (Finnish association of physiotherapy, 2018, p. 8; Dieffenbach, 2020, section I.3). The greatest and most valid outcomes that emerged from this work were, after all, the importance of education and personalization in most of the measures.

Education has a central place for coaches, trainers, and other PA facilitators as they ensure the quality and reliability of the adolescent’s measure implementation. The role of the coach is to open and exploit the action potential of the individual kindly and selflessly towards a goal (Meulemans et al., 2013, p. 23; Barber, 1963, p. 672). Yet, limitations in the trainer’s expertise, conscious or unconscious, might be a terrible curse and play against the athlete. In addition, perpetually educating themselves means also staying up-to-date, providing a durable effect on the field, and expecting a greater outcome in a longer time frame.

In addition, a core competence of the coach is to educate the coachee (Dieffenbach, 2020, section I.5). Educating the coachee will enhance compliance, quality of measure implementation, and self-efficacy, and who knows, influence the next generation to educate the younger generation themselves. The positive circle of transmission must continue the endless route of science. Simultaneously taking benefits from our predecessors, hopefully this thesis participated in the generational effort of transmission.

Personalisation is also an ageless cornerstone of athlete tracking and counseling. The challenge is more significant in team sports, where it is valuable to implement measures in a group and where the attention of the coach is divided by the number of players. As mentioned in the development ideas below,

digitalization can provide a significant help in gathering data's efficiently and ensure the best use of the coach's energy for the promotion of an individual and qualitative guidance.
Nevertheless, the proposed guidelines shall fill a momentaneous gap of knowledge and encourage the professionals of sport to learn more about injury prevention for the best interest of their athletes and, in extension, the community.
As a future physiotherapist, the knowledge on the field of injury prevention has increased and the measure of the importance of the commitment to keep learning as a lifelong process is taken. Research skills and critical thinking to extract the most reliable and ethical results possible have been challenged for the best outcome. Moreover, from an academic research methodology, finding a clinical application and viable public product was a test without a safety net, requiring the development of problem-solving skills. As a conjecture of a research work, the nature of the broadcast information is inevitable a selective truth; nonetheless, the scientific community can rely on an ethical, transparent, and protocolary work.

14.1 Developmental ideas

14.1.1 Measurement of outcome in sport's club

As mentioned by the author of this thesis, several measurements are possible and necessary to assess the workload and other risk factors to help evaluate the risk of injury.
Based on "the conceptual model of injury causation" by Van Mechelen, step 1 is to "establish the extent of the injury problem", step 2 is to "establish the aetiology and mechanism of injury", step 3 is to "introduce preventive measures", and step 4 is to "assess the effectiveness by repeating the step 1" (Appendix 5) (Van Michelen, 1992, as cited in Van Tiggelen, 2013, p. 649). The developmental idea for the clubs is to monitor the occurrence of injuries and regularly reassess the outcome of the new measures. This process of relapse can be found in an action research cycle. Numerous advantages can arise from this

measure. It allows the next innovations to be truly contextual; it allows them to adapt to changes in environment, target group, and so on. It also allows a better compliance of the athletes understanding with facts their needs and how to improve (Coghlan & Brannick, 2014, p. 11), and it allows the durability of the intervention. In this case, continuing to implement injury prevention measures over time without forgetting the step 1.

14.1.2 Digitalization

The next suggestion aims to increase the accessibility of injury prevention measures by digitalizing the guidance towards injury prevention for young athletes. In that matter, digitalization would help with health promotion and the collection of feedback/data that would help the clubs and sport institutions to make decisions regarding their performance and protection policies for their young athletes. If a significant skepticism still exists towards this innovation, the SARS-COV-19 pandemic has helped its acceptance and translated into a massive increase of income for the companies selling wearable and fitness apps, which is still ongoing in 2024 (Ruth et al., 2022).

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APPENDIX 1

Table 6. Maximum values for ROM requirements for normal and running gait (Physiopedia, 2022a, Joint ROM during gait)

Maximum values for ROM requirements			
Joint	Motion	For normal gait	For running (gait+50%)
Hip	flexion	20°	30°
	hyperextension	20°	15°-30°
Knee	flexion	60°	90°
	extension	0° (full extension)	0° (full extension)
Ankle	dorsiflexion	5°	8°
	Plantarflexion	20°	30°
1st MTP	dorsiflexion	60°	90°

APPENDIX 2

Table 4. Risk factors evaluation (Physiopedia, 2024b)

Extrinsic risk factors		Intrinsic risk factors	
Non-modifiable	Potentially modifiable	Non-modifiable	Potentially modifiable
Sport played (contact/no contact) Level of play (recreational/elite) Weather Position played Time of season/time of day	Rules Playing time Playing surface (type/condition) Equipment (protective/footwear)	Previous injury Age Gender	(Aerobe) fitness level Preparation sport-specific training Flexibility Strength Joint stability Biomechanics Balance/proprioception Psychological/social factors

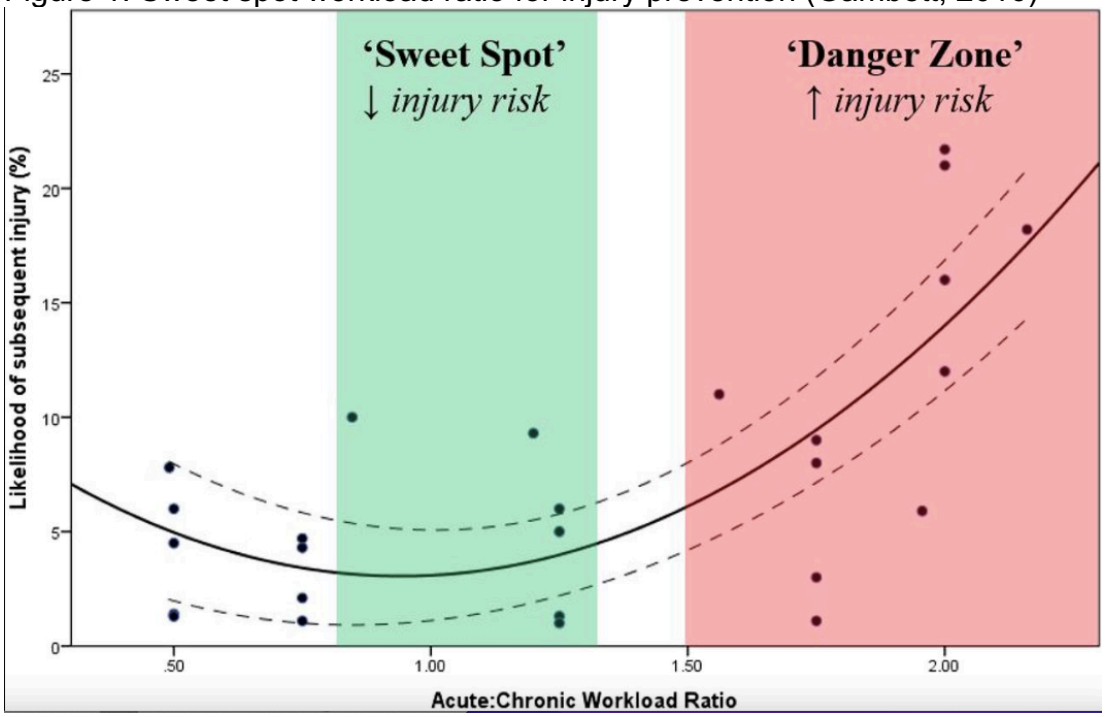
APPENDIX 3

Table 7. Jumps amount and types in basketball (Talpey et al., 2021, p. 4)

Jumps amount and types in basketball.		
146.8 ± 19.0 jumps per game for the whole basketball team.		
Double leg take-off 83%	Single leg take-off 17%	
Stationary approach 69%	Running approach 26%	1 step approach 5%

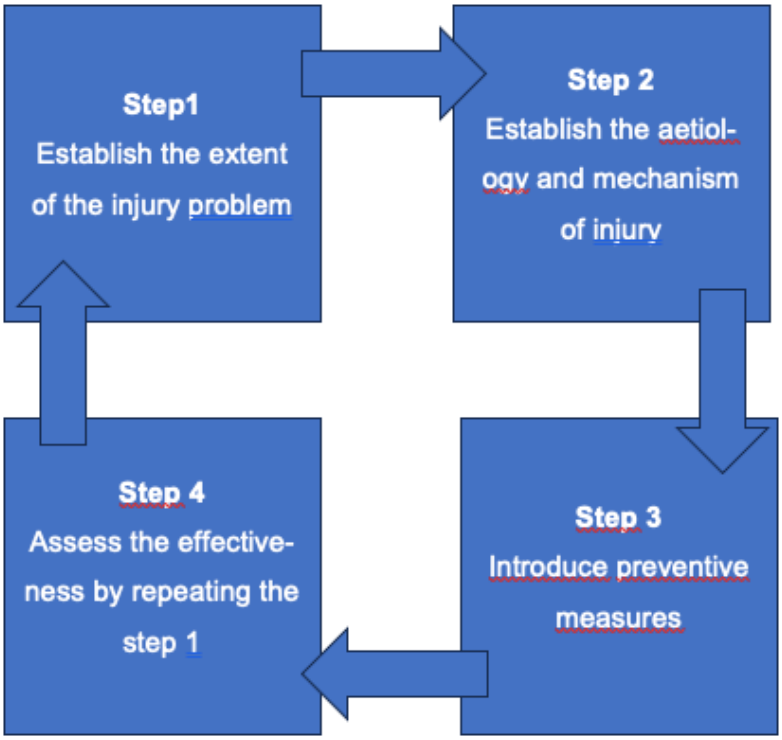
APPENDIX 4

Figure 1. Sweet spot workload ratio for injury prevention (Gambett, 2016)



APPENDIX 5

Figure 2. Conceptual model of injury causation (Van Michelen, 1992, as cited in Van Tiggelen, 2013, p. 649)



APPENDIX 6

Figure 3. Cover page of the guidelines for foot and ankle injury prevention for teenage basketball players