ŞEYDA ELİF ŞENER

MASTER THESIS

İSTANBUL-2020

T.C.

YEDİTEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF PHYSIOTHERAPY&REHABILITATION

The Evaluation of Running Biomechanics Among Runners.

ŞEYDA ELİF ŞENER

İSTANBUL- 2021

T.C.

YEDİTEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF PHYSIOTHERAPY&REHABILITATION

The Evaluation of Running Biomechanics Among Runners.

ŞEYDA ELİF ŞENER

SUPERVISOR

PROF. DR. FERYAL SUBAŞI

İSTANBUL- 2021

THESIS APPROVAL FORM

Institute : Yeditepe University Institute of Health Sciences

Programme : Sport Physiotheraphy

Title of the Thesis : The Evaluation of Running Biomechanics Among Runners

Owner of the Thesis : Şeyda Elif Şener

Examination Date : 30/04/2021

This study have approved as a Master Thesis in regard to content and quality by the Jury.

	Title, Name-Surname (Institution)
Chair of the Jury:	Prof. Dr. Habibe Serap İnal (İstinye University)
Supervisor:	Prof. Dr. Feryal Subaşı (Yeditepe University)
Member/Examiner:	Dr. Öğr.Üy.Ayça Aklar Çörekçi (Yeditepe University)

APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dateD 14.06.2021 and numbered 2021/06-01

Prof. Dr. Bayram YILMAZ

Director of Institute of Health Sciences

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

ŞEYDA ELİF ŞENER

DEDICATION

I would like to dedicate my thesis to my dear thesis advisor, Prof. Dr. Feryal Subaşı and I am truly thankfull to my parents , my mother Ayşe ŞENER and my father Yunus ŞENER, who are supportive and full of love.

ACKNOWLEDMENT

I would like to express my deepest appreciation to my dear Adviser Prof. Dr. Feryal Subaşı for her support, patience and precious time,

to esteemed Prof. Dr. Habibe Serap İnal and Dr. Ayça Aklar Çörekçi for their constructive feedback and opinions,

to dear Dr. Elif Üstün Develi for providing full support in putting this thesis in order despite her tight schedule,

to my dearest colleagues, PT Akademi team, my athletes, my coach and sports scientist friends, who have been generous enough to share ideas and offer help in not only taking the measurements for the study, but also interpretation thereof,

to dear Gülşah Başandaç, who has provided full support at all times and expanded my horizons,

to dear Mustafa Aydın, who urged me to start working in a faster and more energetic way thanks to his motivation speeches.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

FPI	Foot Posture Index
RA	Running Analysis
RE	Running Economy
RRI	Running Related Injuries
SJT	Squat Jump Test
STJ	Subtalar joint
TMT	Tarsometatarsal
TNJ	Talonavicular Joint
TRT	Treadmill Run Test
WBLT	Weight Bearing Lunge Test

ABSTRACT

ŞENER, ŞEYDA ELİF (2020) , The Evaluation of Running Biomechanics Among Runners, Yeditepe University, Institute of Health Sciences, Department of Sports Physiotherapy and Rehabilitation, Master Thesis, Istanbul

With the increasing awareness of maintaining a healthy lifestyle in modern life, running activity is becoming popular not only by professional but also amateur athletes. Considering that running, which increases cardiovascular endurance, can cause athletes to experience acute and chronic musculoskeletal injuries if done unconsciously, understanding running biomechanics for runners of all levels can contribute to the prevention of injuries and support the development of running performance. Therefore, the purpose of this study is; to measure running biomechanics and vertical jump parameters in amateur runners and to examine the relationship between these parameters. The study included 22 amateur runners (32.23 ± 6.43 years) who received running training and had a running training period according to their annual race goals. Foot posture index and footbalance sole analysis system of each runner's foot and ankle posture in stance position; Functional dorsiflexion angle of the ankle was measured with the Weight Bearing Lunge Test. Performance-related tests are performed by optojump system, Squat Jump Test, (Height) and running biomechanical parameters are Treadmill running test (contact time, contact phase, flight time, foot flat phase, propulsion phase, stride length, step length and height). measured. Before running and jumping measurements, each runner was given a standardized warm-up program (3 minutes of running up to 12 km / h) and mobility exercise. As a result of this study, there is no statistically significant relationship was found between positional stance parameters of the foot and biomechanical running parameters ($p > 0.05$). However, maximal vertical jump is higher in runners with a high foot dorsiflexion angle ($p < 0.05$). In addtion, no relationship was found between the height of the foot in running from the ground and the maximal vertical jump height. ($p > 0.05$). A negative correlation was found between contact time and contact phase, step length and stride length which are among the running parameters ($p < 0.05$). There is a positive correlation between height, contact phase and step length in running. ($p < 0.05$) In conclusion, while evaluating running biomechanics, we consider that dynamic performance measurements as well as static evaluations are valuable in evaluating running biomechanics and offering suggestions to improve running performance. For amateur runners of a certain level, reaction time drills based on the height, contact phase and duration of the foot from the ground, middle forefoot running press drills and horizontal jumps exercises, proprioception-balance exercises can be recommended to increase the step length and stride length that will affect the running performance. In addition, ankle mobility exercise and recommendations and suggestions can be given to increase the ability of the arch of the foot to adapt to movement can be made to increase vertical jumping performance in runners.

Key words: Running analysis, Runners, Amateur runner, Running biyomechanics, Run perpormance

ÖZET

ŞENER, ŞEYDA ELİF (2020) Koşucularda koşu biyomekaniği değerlendirmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü, Spor Fizyoterapisi, Yüksek Lisans Tezi, İstanbul 2020.

Modern yaşamda sağlıklı yaşam tarzının sürdürülmesi konusunda artan farkındalık ile koşu aktivitesi sadece profesyonel değil amatör sporcular tarafından da popüler hale gelmektedir. Kardiyovasküler dayanıklılığı arttıran koşu, bilinçsiz yapıldığı taktirde sporcuların akut ve kronik kas- iskelet sistemi yaralanmaları yaşamasına neden olabileceği göz önünde bulundurulduğunda her seviyeden koşucu için koşu biyomekaniğinin anlaşılması, yaralanmaların önlenmesine katkı sağlayabilir ve koşu performansının gelişimini destekleyebilir. Bu nedenle bu çalışmanın amacı; amatör koşucularda koşu biyomekaniği ve sıçrama parametrelerini ölçmek ve bu parametrelerin birbirleri arasındaki ilişkiyi incelemektir. Çalışmaya koşu eğitimi almış, yıllık yarış hedeflerine göre koşu antrenmanı periyotlaması olan, 22 amatör koşucu (32.23±6.43 yıl) dahil edilmiştir. Her bir koşucunun ayak- ayak bileği duruşu ayak postür indeksi ve footbalance taban analizi sistemiyle; ayak bileği fonksiyonel dorsifleksiyon açısı Weight Bearing Lunge Test ile ölçülmüştür. Performansa bağlı testler, optojump system aracılığıyla, maksimal dikey sıçrama yüksekliği testi, (Height) ve koşu biyomekanik parametreleri ise Treadmill koşu testi (temas süresi, temas fazı, uçuş süresi, flat fazı, itiş fazı, adım uzunluğu, adım genişliği ve yüksekliği) ile ölçülmüştür. Koşu ve sıçrama ölçümlerinden önce her koşucu standardize ısınma programı (12km/h e kadar 3 dakika koşu) ve mobilite egzersizi verilmiştir. Bu araştırmanın sonucunda, ayağın pozisyonel duruş parametreleri ve biyomekanik koşu parametreleri arasında istatistiksel olarak anlamlı bir ilişki bulunamamıştır($p>0,05$). Bununla birlikte ayak dorsifleksiyon açısı yüksek olan koşucularda maksimal vertikal sıçrama daha yüksektir ($p<0,05$). Koşudaki ayağın yerden yüksekliği ile maksimal vertikal sıçrama yüksekliği arasında herhangi bir ilişki bulunamamıştır. ($p>0,05$). Koşu parametrelerinden temas süresi ve temas fazında, adım uuznluğu ve adım genişliği arasında negatif korelasyon bulunmuştur ($p<0,05$). Koşudaki ayağın yerden yüksekliği ve temas fazı ile adım genişliği arasında pozitif korelasyon vardır. ($p<0,05$) Sonuç olarak, koşu biyomekaniğini değerlendirirken statik değerlendirmelerin yanında dinamik performans ölçümlerinin yapılmasının koşu biyomekaniğini değerlendirmede ve performansı geliştirecek öneri sunmada değerli olduğunu düşünmekteyiz. Belli bir

seviyedeki amatör koşucularda, koşu performansını etkileyecek adım uzunluğunu ve genişliğini arttırmak için ayağın yerden yüksekliğini, temas fazını ve süresini baz alan reaksiyon zaman drilleri, orta ön ayak koşu basış drilleri ve yatay düzlemde sıçrama egzersizleri, proprioception- denge egzersizleri önerilebilir. Bunlara ek olarak koşucularda dikey sıçrama performansını arttırmaya yönelik ayak bileği mobilite ve ayak tabanının harekete uyum yeteneğini arttıracak esneklik ve kuvvet egzersiz önerilerinde bulunulabilir.

Anahtar kelimeler: Koşu analizi, Koşucu, Amatör koşucu, Koşu biyomekaniği, Koşu performans

1. INTRODUCTION AND PURPOSE

1.1.The Evaluation of Running Biomechanics Among Runners.

Running can be described as a type of gait characterized by an aerial phase in which all feet are above the ground.[1] Moreover, running is a sport that may serve the prevention of chronic illnesses by improving aerobic endurance. Although running is known as a professional sport, it may become more popular among non-elite athletes due to increased awareness of the importance of aerobic endurance and maintaining a healthy lifestyle. On the other hand, the number of people engaged in these activities may face acute and chronic injuries related to running, which would be the risk to sustain this attitude. A thorough understanding of regular walking and running gait parameters is an important area for the physiotherapy profession to prevent and adequately manage these injuries.[2] Thus, assessment of running and running biomechanics may the best way to keep runners healthy for injury prevention and running performance development.[3] Also, improving performance in competitive runners is based on training and rehabilitation protocols that are rooted firmly in biomechanical principles. [2]

Gait cycle is divided in 2 main phases, the stance phase and the swing phase. The stance phase begins with footstrike, it is followed by midstance, and then finally take-off.[4] In each of these actions different muscle groups, bones, and joints are acting individually. When the foot strike begin, the muscles, tendons, bones, and joints of the foot and the lower leg work to absorb the impact of the landing. Swing phase of the running gait cycle will be examined, which occurs when the lower extremity swings through the air from take-off to footstrike. It is consisted of follow through, forward swing, and foot descent, ending with footstrike and it begins the stance phase again.

While assessing stride analysis, measures of gait characteristics like cadence, speed, step length, and stride length can be useful clinically. They can be measured simply with a stopwatch or in more complex ways with apparatus like an instrumented walkway.

The evaluation of the running biomechanics as an integral component, either for the injured runner or for screening for injury prevention is very important to complement a physical examination.[5] Appropriate running biomechanics includes synchronous movements of all of the components of the kinetic chain. Foot can adapt to uneven terrain and contribute as the link between the moveable surface and the remainder of kinetic chain. The importance of proprioception for being suitable postural control, and leverage for propulsion is irrefragable.[5]

Following the gait cycle, foot movement is simplified and can be affected by the compensatory movement of the muscles and joints in the lower extremity. Improper gait cycle can change the mechanics of lumbar motion and lower limb movements. Therefore, it may cause injury due to misalignment. It is necessary to understand the biomechanics of running gait along the entire kinetic chain.[2]

Biomechanical running analysis is significant both in injury prevention and also in detecting injured body mechanism to complement a physical examination and thorough history.[5] While some variables of interest will have an impact on running performance, the main focus of this analysis plan is to assign biomechanical factors related to common injuries in runners.[6] Several studies have been demonstrated as to the etiology of running related injury (RRI) including impact forces, foot pronation, foot strike pattern and hip muscle function. This has led to the dominance of biomechanical studies aimed at identifying specific factors specific to the features associated with the development of RRIs in individuals running environment.[7] In addition, several theories have been accepted as to the etiology of running related injury (RRI) including impact forces[8] , foot pronation[9] , foot strike pattern[10] and hip muscle function[11]

Running cycle is observed in real life with high resolution cameras, video recorders, force instruments, computer systems and other laboratory measuring devices. Dynamic electromyography, motion analysis, energy consumption measurements or systems , force plate recordings are defined for gait assesments systems that comprise stride characteristics.[12] Kinetic analysis is associated with force generation. Kinematics reflects the action itself and the effect of kinetics.[13]

Currently a treadmill should be preferred instead of other running devices for observation and monitorization. Because, they may lead some variation in the normal movement pattern. Also, in stance phase, running on treadmill provides a more safe gait to the runners, containing increased time spend [13,14] A recent review demonstrated that ground reaction forces, as measured by pressure-sensitive insoles in the shoes of female long-distance runners who were tested on a treadmill, were reproducible across different running velocities and stride frequencies. [14]

The following gait parameters were defined as the average of three walking trials: and walking speed, cycle time, step length, stance time, swing time, cadence, [15] [3] Biomechanical parameters measured with Treadmill Running Test which variables that depending on length are Stride Length (cm) Step Length (cm). Therefore, variables that depending on Time are flight time(ms), concact time(ms), contact phase(step/t), foot flat(s), propulsive plase(s), Pace (Steps/min.), Height(cm) and Stride angle(°). Hence, variables that depending on Speed are Speed (m/s),Average speed (m/s),Acceleration(m/s^2). [2,16]

Oxygen cost of running at a certain speed which is known as running economy has been accepted as the physiological criterion for 'efficient' performance and total distance has been defined as a critical element of running performance. There is a link between running mechanics and running energy costs. Various anthropometric dimensions and biomechanical factors can affect biomechanics. Also, contribute to a better economy for runners.

Kinematics and kinetics parameters of running may also be related to running economy. These parameters include low peak ground reaction forces; body centre of mass low vertical oscillation; stride length which is freely chosen over considerable training time; less range of motion but greater angular velocity of plantar flexion during toe-off; arm motion of smaller amplitude; faster rotation of shoulders in the transverse plane; more acute knee angle during swing; greater angular excursion of the hips and shoulders about the polar axis in the transverse plane; and effective exploitation of stored elastic energy.[3]

Activities such as running and jumping including biomechanical changes have been investigated in various scientific studies. These are often investigated plantarflexor loading, resulting in high loading to Achilles tendon. Another study involving biomechanical changes in achilles tendinopathies demonstrate that preventive and managing changes have been detected in runners with and without achilles tendinopathy of biomechanical changes.[17]

According to kinematic and kinetic analyses, barefoot runners, who strike the forefoot even on hard surfaces, produce smaller ground impact forces than shod rear-foot strikers. This difference primarily reduces the effective mass of the body by hitting the ground with a more plantarflexion foot during landing and more ankle compliance during impact. When people run barefoot or with using minimal shoes, the forefoot and midfoot strike walks were probably more common. This can protect the foot and lower limbs from some of the affected injuries currently experienced by the high runner percentage.[10]

Studies have shown that orthopedic factors affect walking and running biomechanics. In the presence of a problem, biomechanical running parameters also affect each other. [2,3,18]

Thus,the aim of the this study was to determine the relationship between biomechanical parameters of running and athletic performance among runners.

Ho: There is no relationship between running biomechanics parameters and athletic performance test parameters.

H1: There is relationship between running biomechanics parameters and athletic performance test parameters.

2. GENERAL INFORMATION

When an individual is performing work, foot support the body’s weight and play the important role of levers. The body weight normally falls on the center of the foot, and balance is maintained by the muscle activity of the foot. If the foot get deformed, the foot adapts to perform its functions under the conditions of disease or deformity[19]

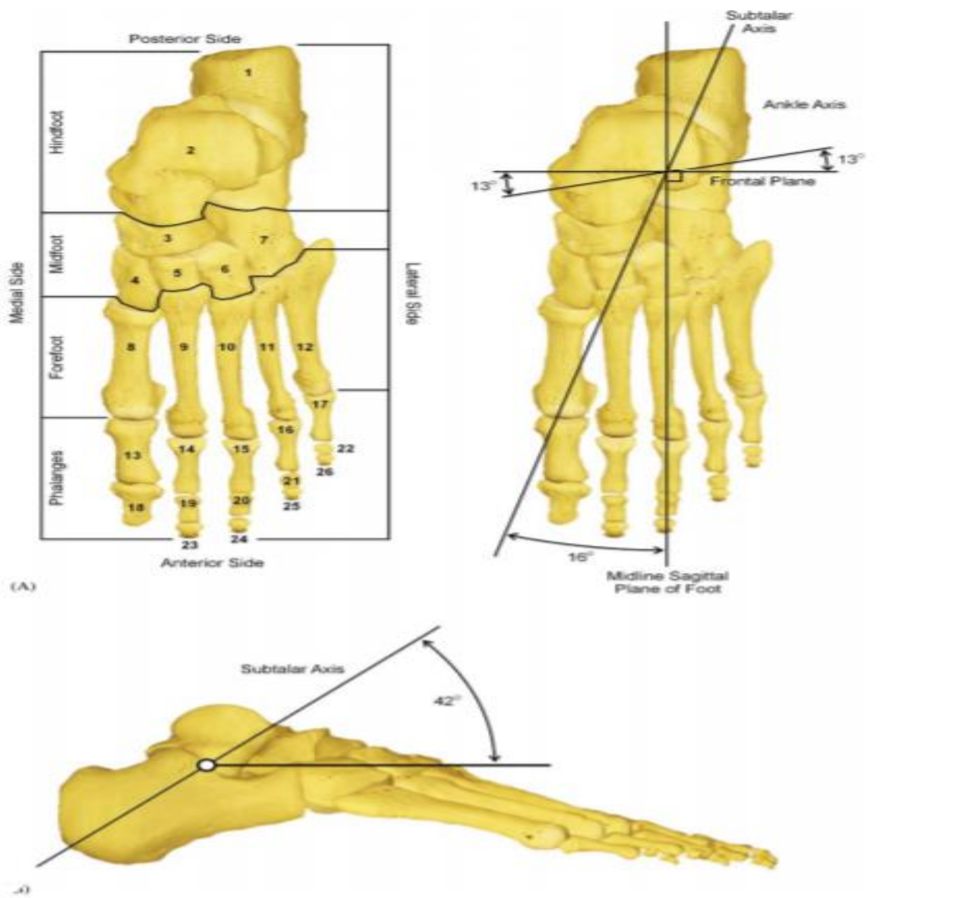
Although the two people do not share the same anatomy, strength, or proprioceptive qualities, there are many similarities to understand about the role of each individual's running cycle in the diagnosis and treatment of running-related injuries. This article is about the anatomy of the lower limbs which they relate to the ability to run, running gait cycle, and abnormal anatomy and biomechanics due to running injuries.

Anthropological and biomechanical research shows that the human foot has developed a unique design for support and propulsion. Theoretically, the arch and toes should play an important role, but many postural studies tend to focus on the simple hinge movement of the ankle joint. To investigate the role of the foot anatomy and the sensorimotor control of the posture,they measured the deformation of the foot arch and examined the effects of local perturbations applied to the toes (TOE) or 1st / 2nd metatarsals (MT) while standing. In the sitting position, loading and lifting 10 kg of weight on the knee lowered and lifted the foot arch from 1 to 1.5 mm. Less than 50% of this change can be explained by plantar surface skin tightening. During the silent posture, the arch probe and shank swing showed a significant correlation, which showed that when the tibia was bent forward, the arch of the foot was flattened and vice versa. Significant changes in the electromyogram (EMG) measurements of the tibialis anterior and gastrocnemius during the TOE and MT perturbations (shifting an appropriate part of the foot at 2.5 mm / s) and the root mean-square shin release (RMS) variability has increased significantly, these increases are greater in the case of MT. The slow return of RMS to the baseline (> 30 sec) suggests that a very small perturbation has changed the surface reference frame, which takes time to regenerate. These findings show that the foot is compatible in an active state and susceptible to minor deformations, rather than serving as a solid support base. As a result, the architecture and physiology of the foot contribute to the task of double-precision postural control with great precision. [20]

The foot opposes external resistance and is the end part of the lower kinetic chain. Normal arthrokinematic and proprioception in the foot and ankle affects the ability of the lower limb to weaken static and dynamic weight bearing forces. The lower limb must distribute and propagate pressure, pull, shear and rotational forces during stance phase. Insufficient distribution of these forces can lead to abnormal movement, resulting in excessive stress that can cause soft tissue and muscle breakdown. The most effective force reduction is achieved by the normal mechanics of the foot and ankle. [21]

2.1 Foot Structure

The foot is divided in four segments: the forefoot, the midfoot, the hindfoot and the phalanges. They are made of 26 bones (seven tarsals, ¢ve metatarsals, and 14 phalanges) and six joints (ankle, subtalar, midtarsal, tarsometatarsal, metatarsophalangeal (MTP) and interphalangeal (IP) joints).



Foot structure: (A) four segments: hindfoot (1, 2), midfoot (3–7), forefoot (8–12), phalanges (13–26). (B) ankle and subtalar axes. 1—calacaneum, 8—first metatarsal, 13—17—proximal phalanges, 2—talus, 9—second metatarsal, 18—distal phalange, 3—navicular, 10—third metatarsal, 19–22—middle phalanges and 4—medial cuneiform, 11—fourth metatarsal, 23–26—distal phalanges. 5—intermediate cuneiform, 12—fifth metatarsal, 6—lateral cuneiform, 7—cuboid.

Figüre 1: Joints of the foot bones [2]

The hindfoot consists of the talus and calcaneus. The three parts of the talus (body, neck and head) are guided to transmit the reactive forces from the ankle joint to the leg. It lies between the calcaneus and tibia and communicates thrust from one to the other. The calcaneus, provides a lever arm for insertion of the foot bone and is the largest and most rear leg gastrocnemius and soleus plantarfleksiyo strong forces applied as the Achilles tendon, one of the largest and strongest tendon in the body. Its structure enables the calcaneus to resist high tension, bending and compressive forces on a regular ground without being damaged.[21]

The midfoot is made up by the navicular, the cuboid and three cuneiforms. The navicular which is at the medial side of the cuboid, is articulated with the head of the talus in the anterior way. It is also the basis at the top of the medial longitudinal arch. The cuboid is articulated with the calcaneus in the proximal direction and with the fourth and fifth metatarsals in the distal direction. The three cuneiforms are convexly shaped while the plantar surface is concave and wedge shaped. In this way the apex of each bone points inferiorly. The cuneiforms are being articulated with the first, second and third metatarsals in the distal direction. The midfoots stability is contributed by ligaments and muscles. [21]

The forefoot is made of five metatarsals. They are all tapered distally and they all articulate with the proximal phalanges. The shortest and widest metatarsal is the first metatarsal. The forefoots base articulates with the medial cuneiform and is kind of cone shaped. Additionally the head of the first metatarsal articulates with two sesamoids on its plantar articular surface. The second metatarsal extends beyond the first proximal and refers to the medial and lateral cuneiform in a "key-like" configuration as well as with the intermediate cuneiform. This improves stability and makes the second ray the hardest and most stable part of the foot, which plays an important role in stabilizing the posture after hallux surgery. The third, fourth and fifth metatarsals’ base are broad and their dome-shaped heads are narrow in the shaft. The fifth has a prominent styloid, laterally and proximally at its base, on which the peroneus brevis tendon inserts. When the foot is inverted against the contracting peroneus brevis muscle, avulsion fracture of the styloid commonly occurs. [21]

Phalanges are made of digits. The big toe (hallux) is formed of two phalanges, all other toes contain three. The proximal and middle phalangeses heads tend to be trochlear shaped and allows for greater stability. Weight bearing and load distribution is contributed by the toes functionally. They also effect propulsion during the push-off phase of gait. [21]

2.2 Arches of the Foot

Human foot bones form three strong arches: two length ways and one across the foot. The foot bones are binded by ligaments together along with the tendons of foot muscles. This helps our foot bones to be hold firmly in the arched position but they still allow some give and springiness. During locomotion (especially in running), it is known that the foot arch is subjected to considerable deformations, resulting in elastic energy storage in the longitudinal foot arch for propulsion. From the biomechanical viewpoint, the foot has two important aims typically considered as a “functional unit”: to support the body weight and to serve as a lever to propel the body forward in walking and running.[20]

Pes planus (flat foot) is a condition in which the medial longitudinal arch is visibly lowered.1 Arch is made up of multiple ligaments, muscles and bony articulations which is described of the elevation of the foot. In the support and stabilization of arches Ligaments play the primary role, whereas secondary support is offered by the foot muscles during dynamic activities.[22,23] Between the arches of foot and lower limb biomechanics there is a functional link. The arch acts as a springy, flexible and elastic union between fore-foot and hind-foot. Tarsal coalition, ligamentous laxity, equinus foot deformity, tibial torsional defect, congenitally vertical talus, posterior tibial tendon dysfunction (PTTD), peroneal spastic flat foot post-traumatic flat foot and more have been recognized as risk factors contributing to flat foot. [22,23]

If the medial longitudinal arch is abnormally depressed it is referred to as flatfoot or pes planus[24]. Also ; within the sole are the lateral longitudinal arch, the medial longitudinal arch (MLA), and the transverse arch. Bone structures, ligaments, and the extrinsic and intrinsic muscles of the foot assists to control the MLA [19] The most common orthopedic issue seen in pediatrics seems to be flat foot. We all are born with flat foot and more than 30% of us have the deformity Calcaneovalgus foot. This condition is sometimes painful and sometimes not. In the ages of three to six the prevalence of flat foott is reduced and the fat mass in central arc disappears because of walking and activity of the child. Also the prevalence of flat foot is higher in boys than girls. [25] For the development of flat foot obesity is found to be rather conflicting risk factor.[24] Flatfoot can be flexible or rigid. Rigid flatfoot leads to great pain and has multiple etiologies and if often requires treatment. In the case of flexible flatfoot, the flat shape is because of weight bearing, but when the child stands on his or her tiptoes the arch can be reconstituted . Physiologic flatfoot is considered developmental and is often seen in children in the first decade of life. In children age is a predictive factor for flatfoot, and previous research has shown that with increasing age, flatfoot is likely to resolve. In addition, between ligamentous laxity as well as overweightness with flatfoot there is a significant association.

The presence of flatfoot has long been described as a foot abnormality that is often associated with pain and poor function. For this reason, for their children with flatfoot many parents are anxious to obtain prophylactic advice and treatment. Because there is no standard approach to its assessment or classification, clinicians often disagree about the management of flat foot , partly. To determine the prevalence of flatfoot in different countries different studies were conducted.[26] Also many other studies show that; to predispose people to PFPS lower-extremity malalignments, such as pes planus, genu valgum, and femoral anteversion, are thought. To increase the lateral tracking of the patella on the distal femur and thus create abnormal joint reaction forces to the articular cartilage on the retropatellar surface, hyperpronation of the foot and the subsequent increased internal rotation of the tibia and femur during gait are thought. [27] Although all 4 quadriceps muscles act to pull the patella superiorly when they concentrically contract, in controlling medial and lateral patellar motion, respectively the vastus medialis and vastus lateralis muscles have antagonist roles. [27]

2.3 Running Gait Cycle

The walking gait cycle differs from the running gait cycle. We can describe the gait cycle as the series of movements of the lower extremities between foot initial impact with the surface until it reconnects with the surface at the end of the cycle.1 To understand the gait cycle better, we examine the running gait cycle from the walking gait cycle and its differences. Gait cycle is divided in 2 main phases, the stance phase and the swing phase.[28,29]During the period of contact between the foot and the running or walking surface the stance phase occurs. In both walking and running these phases occur. When one lower extremity is in the stance phase, the other extremity will be in the swing phase. Running differs from walking because of an additional phase named float phase, which occurs twice during running. Between stance phase and the swing phase the float phase occurs, where both lower extremities are not in contact with the ground.[28 29]

Therefore, either 1 leg or no leg striking the ground throughout the gait cycle can be defined as running at any speed. There is a period of double stance during the walking cycle, [30] phase during the walking gait cycle in which both lower extremities are in contact with the walking surface.2 This occurs at the very beginning and very end of the stance phase when walking. This means that 1 or 2 legs are always in contact with the ground during stance phase during walking. When walking, stance phase occurs typically for about 60% of the gait cycle, and swing phase occurs for about 40% of the cycle.[28] When walking, in greater than 50% of the cycle of stance phase occurs, with swing phase consisting of the rest of the cycle.3 For running the opposite is valid, in which stance phase is less than 50% of the cycle.[2] For greater than 50% of the cycle the swing phase causes an overlap of swing phases between lower extremities, generating the characteristic float phase. When the velocity in running increases, the stance phase becomes even less of a percentage of the cycle. Therefore, in stance phase sprinters spend more small percentage of the gait cycle. In addition, during running compared to walking, step length and cadence are increased.[31] The distance from initial contact of 1 foot until the same foot makes contact with the running surface again forms the Stride length. The distance between initial contact of one foot and the subsequent initial contact of the opposite foot forms the step lenght. The number of steps taken during a certain amount of time is called cadence. When running cadence, stride, and step length increases, it also increases velocity and ground reaction forces.[31] This indicates for increased stresses through the lower extremities and risk for injury. between individual footstrikes walking has a wider basis and this is another difference. Between medial borders of the heels this is the distance. Comparing to running, walking has a greater base width of support which is approximately 1 inch. As the speed increases into a run, the base of support (Fig. 1. Swing and stance phases of running. Right leg in stance phase, left leg in swing phase. 188 Nicola & Jewison)narrows so that foot strike is more on the centerline of progression. In the transverse plane hip rotation reduces the up and down fall of the center of gravity.[2] In addition differences between walking and running are that running requires a greater range of motion of all lower limb joints. It also requires a big amount of muscle contraction, which has to be eccentric, than walking because of the higher impact forces.2,5 The foot and ankle movements progression, knee, hip, pelvis, torso, and upper body will be discussed in the running gait cycle regarding their role.[30]

Foto çek yandan cosmosda koşan arkadan koşan 27.kaynaktaki gibi; cümlede fotoğrafa göre Right Left değiştir. (Fig. 1. Swing and stance phases of running. Right leg in stance phase, left leg in swing phase. Fig. 2. Swing and stance phases of running. Right leg footstrike, end of float phase, beginning of swing phase left leg. Fig. 3. Swing and stance phases of running. Float phase of the running gait cycle.)

2.3.1 The Stance Phase

The stance phase begins with footstrike, it is followed by midstance, and then finally take-off.4 In each of these actions different muscle groups, bones, and joints are acting individually. When the foot strike begin, the muscles, tendons, bones, and joints of the foot and the lower leg work to absorb the impact of the landing.[18] During footstrike the landing is made easier by the actions of the subtalar joint, a multiplanar joint, which causes pronation of the foot. Additionally, the plantar fascia stretches so the foot can be allowed to expand and absorb the landing.[32] At the level of the talocrural ankle dorsiflexion occurs and is accompanied by the flexion of the knee, and hip motion, which are all involved in distributing the force of impact through the closed kinetic chain that occurs at footstrike. The energy is transferred by the rectus femoris and gastrocnemius from distal to proximal (ankle to knee to hip).[30] Throughout the foot and up the kinetic chain this helps to distribute the force of the landing, or shock attenuation,. During push off these muscle contractions drives backwards proximal to distal. Recent research has found by occasion that these kinematics and shock attenuation capability does not change with running-related fatigue of the lower extremity muscles.[33] When the stance phase progresses to midstance, in preparation for take-off the foot starts moving from pronation to supination. When the leg continues through the stance phase, the hamstring muscles shorten and contract.[30] This pulling motion is boosted by the contraction and push-off motion made by the gastrocnemius, soleus, and Achilles tendon, which cause plantar flexion of the ankle, and allow for take-off or toe-off. This makes the swing phase begin. We will discuss the footstrike in more detail before discussing the swing phase. Footstrike has different pattern types. Heel strike is one of the patterns. Most frequently, as the foot is in supination the lateral heel strikes the ground.

At heelstrike the calcaneus is in a slightly inverted position. In addition, when the heel strikes the ground first this occurs. Another form of footstrike is midfoot strike, which either in heel strike or forefoot strike can occur. During the running cycle runners who habitually run barefoot land on the forefoot.[10] On the opposite, runners who habitually use running shoes tend to land on their heels at footstrike. Pronators land on the outside of the heel. They finish mid to medial forefoot. Supinators will finish stance phase on the lateral forefoot. If they are forefoot strikers they may not even cause significant heel wear. Float phase of the running gait cycle. During the running gait cycle, when striking the ground the foot will absorb up to 3 times body weight.1,11 Running shoes are designed to cushion the foot and allow for neutralization of certain biomechanical differences in runners that we think they predispose injuries. Nevertheless, shoes inhibit some adaptive pronation during running gait, which likely protects runners from injury, new evidence suggests.[34] Shoes, which promote heel strike,[10] shows decreased metabolic and mechanical efficiency in running.13 Landing on the midfoot or forefoot during running, typically seen in barefoot runners,[10] helps expend impact forces to a greater extent than landing on the heel. Because the foot has a greater degree of plantarflexion at footstrike this occurs [10]as well as more pliable ankles.[10] On the opposite, running shoe heels ,allowing for ease of heelstrike, can reduce need for ankle dorsiflexion by 5 degrees. In the midfoot or forefoot the ankle is stiffer and unable to distribute impact forces as it would if the footstrike occurred during heelstrike.[10] This is because the impact forces cannot be converted into rotational energy on the kinetic chain through ankle dorsiflexion and knee flexion. Because of the way the impact forces are absorbed this implies as well that barefoot runners who do not adjust their footstrike to midfoot or forefoot strike from heelstrike, will have an increased risk of stress fracture injuries.[10] On the contrary to the effects of pronation, the degree of pronation observed in different runners does not affect ground reaction forces that the foot undergoes with running. [30]

2.3.2 Swing Phase

The swing phase of the running gait cycle examined, which occurs when the lower extremity swings through the air from take-off to footstrike. It is consisted of follow through, forward swing, and foot descent, ending with footstrike and it begins the stance phase again.4 While take-off occurs, the most active muscles are rectus femoris and anterior tibialis.3 During late swing phase the hamstrings and hip extensors are active.3 From late swing to the middle of the stance phase the hamstrings, gastrocsoleus complex, and hip extensors are active.3,15

Forward rotation of the ipsilateral pelvis and hip flexion made by the psoas and other pelvic muscles, along with the core to allow twisting of the pelvis are included in the float phase. During the middle of swing phase rectus femoris is active. During late swing phase the quadriceps begin to show activity.3 As the lower leg extends at the knee the hamstrings are lengthening and they are most vulnerable to injury at the terminal swing phase.15 The foot begins to descend to the running surface. At this time the stance phase is finished by the opposite leg. In both stance and swing phase it should be noted that, throughout the running gait cycle the adductors are active.[30]

2.4 The Kinetic Chain of Running

As mentioned, in the running cycle, the foot and ankle, knee, hip, pelvis, torso, and upper body has many significant roles .[30]

To understand the running cycle better, we have to have an understanding of the functional anatomy involved in the running gait. Here the lower extremity anatomy and the function of various aspects during the running cycle are being reviewed.

Various changes throughout the kinetic chain during the running gait cycle is lead to the actions of pronation and supination. The subtalar joint everts, the forefoot abducts, and the ankle (talocrural) joint dorsiflexes and internally rotates the tibia when pronation occurs. The knee follows in a flexed and valgus position. Hip flexion, adduction, and internal rotation is leaded by this. The ipsilateral pelvis rotates anteriorly when this occurs and it elevates to rotate forward on the side of pronation.[2]

Running biomechanics, particularly the joints of the foot and ankle, are determined by the lower limb anatomy. The rotation axis with each joint ensures that the joints have a dominant plane of motion perpendicular to that axis. For example, the talocrural joint's anatomy allows for an axis of rotation that mostly is in the frontal plane As a result, in the sagittal plane the talocrural joint has its predominant range of motion. In all planes with a predominant plane of motion each joint has its own moves. Triplanar movements that involve multiple joints of the foot and ankle are presumed ''pronation'' and ''supination''. Obligate motion in the entire lower limb kinetic chain causes pronation and supination of the foot and ankle. With the superior surface of the talus, the true ankle joint, also termed the talocrural joint, incorporates the articulation between the surface of the tibia and fibula. This joint primarily moves in the sagittal plane and allows dorsiflexion and plantarflexion. The talocrural joint axis travels primarily in the frontal plane with some posterior orientation from the medial to lateral side because the lateral malleolus is located posterior relative to the medial malleolus. Functionally, this results in talocrural joint movement in the transverse plane and very little movement in the anterior plane.[4]

As dorsiflexion occurs in the open kinetic chain, , external rotation of the tibia is accompanied. As with the stance phase of ambulation, in the closed kinetic chain, dorsiflexion causes pronation of the foot with internal rotation of the tibia [2] In the ankle joint the average range of motion is approximately 45, with up to 20 of dorsiflexion and 25 to 35 of plantarflexion[18] [2]

Effects of pronation and supination up the kinetic chain

	Pronation			Supination		
	Sagittal	Frontal	Transverse	Sagittal	Frontal	Transverse
Lumbosacral	Extension	Lat flexion same side	Protraction	Extension	Lat flexion opp side	Retraction
Pelvis	Anterior rotation	Translation and elevation, same side	Forward rot same side	Anterior rotation	Translation opp side; depression same side	Rear rot same side
Hip	Flexion	Adduction	Internal rotation	Extension	Abduction	External rotation
Knee	Flexion	Abduction	Internal rotation	Extension	Adduction	External rotation
Ankle	PF-DF		Internal rotation	DF-PF		External rotation
STJ	PF	Eversion	Adduction	DF	Inversion	Abduction
MTJ	DF	Inversion	Abduction	PF	Eversion	Adduction

Abbreviations: DF, dorsiflexion; Lat, lateral; MTJ, midtalar joint; Opp, opposite; PF, plantarflexion; rot, rotation; STJ, subtalar joint.

Figüre 2: Effects of pronation and supination up the kinetic chain[2]

Between the talus and calcaneus the subtalar joint (STJ), consists of three articular facets which are anterior, middle and posterior. These articulations are separate and function as a single joint by allowing the complex triplanar motions of pronation and supination. In the sagittal plane the axis of this joint runs downward, in the transverse plane posteriorly and laterally. The joint axis is oriented approximately 23 medial to the long axis of the foot in the transverse plane. In the range of 4 to 47, interindividual orientation changes occur.The joint axis is oriented In the sagittal plane, on average, 41 relative to the sole of the foot and runs posteriorly and distally from the dorsal aspect of the neck of the talus to the posterolateral corner of the calcaneus.[2] From 21 to 69 is the range of Interindividual variations Eversion and inversion as the joint axis becomes more horizontal, such as with a flat foot, occur to a greater extent than abduction and adduction. Also, as the axis approaches the sagittal plane, dorsiflexion and plantarflexion are allowed less [35]. Because of its configuration in relation to the remainder of the foot the STJ is analogous to an oblique hinge.[18] The foot is allowed to move in a complex, but predictable, manner in this way. Abduction and eversion of the foot along with hindfoot eversion is defined classically as pronation. Adduction and inversion of the foot along with hindfoot inversion is described classically as supination; however, multipl and multiplanar proximal joint movement will be caused by pronation and supination. Relative to the tibia the orientation of the STJ also results in a mitered hinge effect. Torque is transmitted proximally and results in internal or external rotation of the tibia which is developed by movement of the foot .[36] In weight bearing, between the degree of supination relative to tibial external rotation and pronation relative to tibial internal rotation there is a 1:1 relationship. [37] During normal ambulation the STJ has several functions. At the STJ, motion dictates control of plantar surface pressure and contact with the ground. As forces are transmitted through the STJ to the midfoot and forefoot, during gait stress dampening on the heel occurs. Also, during progression of gait triplanar motion about this joint axis results in either a flexible or rigid foot. Caused by ground reaction forces after foot strike STJ or calcaneal eversion, precipitates a cascade of events in the rest of the foot. The calcaneocuboid and talonavicular joints, the midfoot joints, allow eversion/ abduction and inversion/adduction of the forefoot. The midfoot joints, also collectively termed the transverse tarsal joint, have longitudinal axes that are similar to the STJ. Thus, these pair of joints also have been dubbed as the secondary STJ.

Their oblique axes are close to that of the talocrural joint. Mainly plantarflexion and dorsiflexion are also provided by them. When the hindfoot everts, the axes of these two separate joint components become parallel and allow pronation and increased movement within this two-jointed complex. When hindfoot inverts, supination takes place and the joint axes comes together, which causes this joint complex to ‘‘lock’’ into a rigid configuration.[38] As the foot progresses through the stance phase from initial contact to terminal stance this concept is important to consider. In reality, a flexible foot for shock absorption is needed for pronation, whereas a rigid foot for propulsion is needed for supination. The tarsometatarsal (TMT) joints are made of five rays. The first ray is made of the medial cuneiform and the first metatarsal. This joints motion is primarily a combination of dorsiflexion/inversion/ adduction and plantarflexion/eversion/abduction.The intermediate cuneiform and second metatarsal is included in the second ray. The second metatarsal is recessed and firmly mortised into the base of the first and third metatarsal–cuneiform joints. This bone as a result of the inherent stability as the foot progresses through the stance phase in preparation for propulsion is exposed to high stress.[18] The third and fourth rays are made up of the lateral cuneiform and third metatarsal along with the fourth metatarsal. Motion primarily to plantarflexion and dorsiflexion at these rays is limited. Some pronation and supination in relation to the cuboid is allowed by the fifth ray (fifth metatarsal). Created by the metatarsophalangeal joints, the metatarsal break is an important phenomenon. These joints extend about an oblique joint axis that extends from the head of the second metatarsal to the head of the fifth metatarsal[18] Flexion and extension is predominantly the motion at this joint. This axis allows the foot to become rigid as this joint is extending as the foot progresses through the stance phase just before toe-off. For efficient propulsion as the leg prepares to advance through the swing phase this supination results in an ideal rigid platform.[2] The anatomic uniqueness of the plantar fascia also helps to create the solid composition platform that is needed for propulsion. It is originated from the medial tubercle of the calcaneus. Its insertion is also around the metatarsal heads to the base of the proximal phalanges. It serves as a passive restraint and crosses the transverse tarsal and metatarsophalangeal joints. The Spanish windlass mechanism is formed at the metatarsophalangeal attachment. The plantar fascia tightens and pulls the calcaneus and metatarsal heads together when extension occurs at the metatarsophalangeal joint just before toe-off. The longitudinal arch of the foot is heightened by this and it forces the transverse tarsal joint into a forced flexion position, and thereby, creates a solid structural support. Besides that, to provide further stability of the foot the intrinsic foot muscles actively contract. Passive stability is also provided within the foots ligaments. Ligaments form two longitudinal arches (medial and lateral) and a transverse arch, along with muscular support and the unique bone architecture of the foot. The lateral ligaments are thinner than the medial foot ligaments. during ambulation hyperpronation is prevented by this design.

The arches of the foot, primarily on the calcaneus and the metatarsal heads, create weight-bearing points. Just before toe-off phase the sesamoid bones decrease force on the plantar surface of the first metatarsal head. The foot is allowed by the unique configuration of these arches to be mobile to adjust to the ground surface and rigid in preparation to push off the ground for the sake of propulsion.

Eccentric and concentric fashion is the way that the muscles of the lower leg and foot work. Muscle contraction while fibers are lengthening is eccentric work; muscle contraction while fibers are shortening is concentric work. In an eccentric fashion, the greatest amount of muscle work is done while running. To provide for joint control and shock absorption mostly eccentric contraction is involved in the pronation phase of gait. Mostly concentric contraction of various muscles involves the supination phase of gait, particularly the gluteals, to provide for acceleration and propulsion. Muscle fiber orientation often dictates a preferred plane even though muscles can work in all three planes. For example, the gluteus maximus has muscle fibers that are oriented in an oblique (transverse) fashion; therefore, this powerful muscle becomes an ideal leg external rotator (by way of concentric contraction) and controls leg internal rotation (by way of eccentric contraction). The gastrosoleus complex is another key muscle in running, commonly considered to be a pure plantarflexor. Because of its location in relation to the STJ axis still, this complex also contributes to the transverse plane motion of hindfoot inversion [39] As the foot progresses through the gait cycle this allows the gastrocnemius-soleus to contribute to supination.

2.4.1. Foot and Ankle

During the stance phase running requires the body to absorb continuous repeated impact forces which are initially absorbed by the foot and the ankle and then transferred up the kinetic chain. Up to 3 times the weight of the body is absorbed by the lower extremity that lands every time the foot plants onto the running surface during the running cycle, The foot has to act like a shock absorber, a lever arm to repulse the lower extremity ahead, and a balance board to keep the body in a straightforward motion, balancing to uneven running surfaces. During the stance phase the foot and ankle's ability to do this is facilitated by dorsiflexion, plantarflexion, pronation, and supination. In the mechanics of the foot and ankle during the running gait cycle the actions of pronation and supination play an integral role. At the subtalar joint which is between the talus and calcaneus these actions ocur.[40] The joint is an oblique tarsal joint. During stance phase running as the impact absorber during pronation and lever arm for propulsion during supination this allows the foot and ankle to function efficiently. Along which subtalar inversion and eversion ocur, the subtalar joint axis of the foot is followed by a 23° (4°– 47° interindividual variation) medially directed and 41° (21°–69°) superiorly directed posterior-to-anterior rotational axis. Through the complex range of motions this orientation allows it to move. During the running cycle abduction, adduction, inversion, and eversion motions allow pronation and supination of the foot. At footstrike the calcaneus is inverted about 6 to 8 degrees and through the rest of stance phase it moves to 6° to 8° of eversion.1 While running in shoes, low pronation is characterized in one study as 3° to 8.9° of eversion, middle pronation as 9° to 12.9°, and high pronation of 13° to 18°. In addition, on the medial posterior tibia and can be a predictor of a history of tibial stress fracture in runners. Eversion of up to about 11° can place abnormal stress. The foot is everted by the subtalar joint, causing pronation on impact. When pronation happens, the foot everts, the forefoot abducts, and the ankle dorsiflexes. As footstrike occurs the ankle begins dorsiflexion.[41] To allow the foot to pronate the tibia internally rotates.3 During footstrike to help absorb impact the plantar flexors of the ankle are eccentrically contracting.[31,42] For the purpose of impact absorption, pronation is also facilitated by dorsiflexion and pronation at footstrike.[2] During midstance phase of running the muscles of plantarflexion also control dorsiflexion.[43] Along with the quadriceps group of muscles, during the running cycle they are the main accelerators.[44] At footstrike the ankle joint is ideally at 90°. This progresses from neutral to 20°of dorsiflexion.[36]As the knee further flexes to absorb the impact of the stance phase this occurs during midstance. To accommodate for different running surfaces pronation allows for flexibility in the foot and ankle. Through the stance phase the foot is maximally pronated at about halfway.[45]. Pronation control is aided by the gastrocnemius and soleus.[2,12] In the ankle during the running cycle the tibialis anterior muscle has the highest sustained muscle activity and likely increases its susceptibility for injury.[43] To create propulsion at toe-off the stance phase ends with the foot supinating.[42] At the opposite, leading to a stiffer foot and ankle unit supination creates cross alignment of the tarsal joints and for better propulsion at toe-off during the running cycle a more efficient lever arm. The windlass mechanism of the plantar fascia facilitates this partially.[46] The posterior tibialis muscle also controls it.[42] The foot is inverted, the forefoot is adducted, and the ankle is plantarflexed when supination happens. Each individual has varying degrees of pronation and supination during footstrike and take-off because of varying degrees of hindfoot varus and valgus and forefoot varus valgus,

2.4.2 Knee

During pronation the knee is in valgus position and flexes, as mentioned.[2,28] When supination happens, it is in varus position and extends.[2,28] During the stance and swing phases it has 2 periods of flexion.[28,42] Knee flexion of 20° to 25° occurs at footstrike and continues to approximately 45° degrees at midstance.[30] Flexion at the beginning of stance phase tends as a shock absorber.[42] To resist knee flexion the quadriceps are active in an eccentric contraction after footstrike.[42] Within the foot the degree of pronation tends to impact the degree of knee valgus. As much as, within the stance phase, the greater the amount of pronation, the greater the amount of knee valgus is. During swing phase minimal power is generated by the muscles crossing the knee.[42] To prevent overflexion of the knee in early swing rectus femoris eccentrically contracts, and then to prevent overextension the hamstrings eccentrically contract during late swing. The primary function of extending the knee is made by the quadriceps muscle group. To extend the knee the vastus lateralis, the rectus femoris, the vastus intermedius, and vastus medialis all combine at the superior pole of the patella. During swing rectus femoris also contributes as a hip flexor. during late swing phase the quadriceps relax at full flexion and then to begin extension of the knee finally contract. The knee will extend to within 10° to 20° of full extension.[36] This allows maximum stride length and increases propulsion during swing phase by increasing the time spent in the air. Greater stride lengths increase ground reaction forces at impact, possibly interfering with coordination between the knee and ankle joints and increasing risk of injury [30].

2.4.3 Hip

To flex during swing and extend during stance phase is the movement of the hip during running gait. During stance phase the hip adducts and during swing phase it abducts. By propelling the thigh forward the psoas muscle begins swing phase. During the second half of the swing phase the power that the hamstrings and gluteus maximus generate occurs and the beginning of stance phase as well. This happens when the hamstrings and hip extensors are most active. Cocontraction stability of the stance leg during single leg support (stance phase) is provided by the abductors and adductors of the hip. When velocity increases the hip increases flexion range of motion. In swing phase at footstrike, the hip can be flexed up to 65° and extend to 11°.[47]The individual and speed of running relies on these maximum angles. In the middle of swing phase to “pull” the body forward the hamstrings and gluteus maximus extend the hip. The gluteus maximus mostly facilitates the hip to have a peak extension at toe-off.[47] The hip must extend in the late part of swing phase to plant the Fig. 6. Running knee joint ranges of motion. Knee flexion range of motion during running gait cycle. Among runners this can vary. In recreational runners the hip can go through a full range of about 40° from full flexion to full extension.[43] Hip flexion and extension arc can be as much as 60°. This is mainly occured in the sagittal plane of the body. [28]

Besides that, as velocity increases the amount of extension in the hip slightly decreases.17 In the course of the running gait cycle hip adductor muscles are active. This is unique from the walking gait cycle. They are only active in the walking gait cyle from swing phase to the middle of stance phase.18 Hip abduction-adduction arc can be as much as 15° [30]

2.4.4. Pelvis

The extremities are allowed to run by the pelvis, sacrum, and lumbar vertebrae which provide stability . During the running cycle the pelvis relies on symmetry to function. Rotational, anterior-posterior, and medio-lateral are the planes of motion of the pelvis.[48] Excessive anterior pelvic tilt, excessive lateral tilt, and asymmetric hip movement is included in pelvic biomechanical abnormalities that lead to the most injuries in runners. Excess strain placed on the hamstrings can be also leaded to by this abnormal pelvic orientation, which can increase rates of injury.[2,33] Abnormal pelvic mechanics can also contribute to injury. Ordinarilly, during running the range of motion of flexion and extension within the pelvis is between 5° and 7°.[47]During running than in walking anterior pelvic tilt is significantly greater, and helps to increase stride length.[49] During running there is a net 10° to 15° pelvic tilt, whereas standing it is about 10°.[47]

With increased velocities of running the degree of pelvic tilt minimally changes.[47] During the single leg stance phase ın the running cycle, to keep pelvic tilt stable the gluteus medius contracts.1 At footstrike, the pelvis is tilted posteriorly but still maintains a net anterior tilt approximately 10°. The pelvis begins to anteriorly tilt as stance phase begins. Immediately after toe-off maximum anterior tilt occurs and it is up to 20°.[47] Tight muscles that attach to the pelvis, weakened muscles, or a structural deformity can be caused by an abnormal pelvic mechanics and can influence running gait and lead to overuse injury.[30]

2.4.5. Thoracal Region

In the running gait cycle not just the lower extremity but the whole body plays a role. To allow for motion and limit injury through the running cycle, hip and lower extremity movement requires a stable and strong core muscle group. With supporting ligaments and muscles, the dynamic components of the upper torso consist of the ribs, sternum, and thoracic and lumbar vertebrae.[48] Absorption and distribution of the impact forces are done by the ‘’core’’ muscles. Body movements are allowed by the core muscles in a controlled and efficient manner. To stabilize the spine, pelvis, and kinetic chain there are[49] core muscles that work together. These consist of the abdominal muscles, paraspinal muscles, gluteal muscles, pelvic floor muscles, hip girdle muscles, and diaphragm.[50] During running these all work in unison to allow breathing and during the running cycle the twisting motion required. When running trunk flexion is between 3° and 13°.[47] During the running cycle, at footstrike the trunk is minimally flexed and during the running cycle is at its most erect position.[47] During the stance phase it begins flexion, until at the end of stance phase, when maximum flexion occurs. [47] After foot strike trunk ipsilateral tilt has been measured to range from 5° to 20° in coordination with pelvic downward tilt (toward contralateral side). In lateral tilt increasing speed accounted for up to 10° of increase. Meanwhile the pelvis rotates each stride, about the axis of the vertebrae the muscles of the thorax keep the spine and the abdomen stable.[30]

2.4.6. Upper Extremities

During the running gait cycle the arms play a role to balance and provide stability to the runner in motion. As a rule, during swing phase each arm movement is counter balanced by the opposite leg. During propulsion of the stance phase tHey have also been shown to effectively counterbalance vertical angular momentum.[44] The balance of the torso is aided by the arms as well. During running gait cycle arm movement stabilizes the body and helps the legs run with the most efficiency and least energy expenditure.31 Lastly, during the running cycle swinging arms assist in the generation of forward momentum.[2,41] The shoulder joint controls arm movement, and when strides are taken the movement of the legs requires a similar movement of the contralateral arm. Abduction of the arm from the body is caused by the deltoid muscle, which then allows the degrees of movement forward and backward, allowing arm swing about the ball and socket joint of the shoulder. During running cycle. Hip flexion, hip adduction, knee flexion, knee adduction, and ankle abduction have increased joint angles if arm swing is not sufficient [51] The pectoral muscles and teres muscles, which attach to the upper humerus, will act with each arm swing to counteract the pull of the deltoid, which actively helps with arm swing. For instance, to counter balance the body when the left leg swings forward, the right arm swings forward. It has been suggested that excessive crossover of the arms is an indicator for the lack of stability of lower body movement; though details of this lack of stability are not specified. From synchrony of arm and leg swings the efficiency of running benefits by minimizing twisting of the torso and pelvis. Because it allows maximum stride length for the running cycle, and it decreases torso and head rotation, this saves energy.[52]

2.5 Walking versus Running

Walking and running have series of pronation and supination. By increased velocity running is distinguished from walking, or distance travel per unit time, and the presence of an airborne or float phase. [29]If they observe a period of time when both foot are off the ground judges in race walking determine that participants are running illegally. There are two periods of float when neither foot is in contact with the ground during a running gait cycle. [29]

This results in decreased time in stance phase and increased

Differences between running and walking Increased velocity Increased ground reaction forces Float phase No double stance phase Decreased stance phase and increased swing phase Overlap of swing phase rather than stance phase Requires more range of motion of all lower limb joints Requires greater eccentric muscle contraction Initial contact varies, depending on speed Decreased center of gravity with increased speed Decreased base of support time in swing phase. Further reduction in stance phase occurs as velocity continues to increase, whereas swing phase duration increases. The forward momentum that is needed for running is produced by the swinging leg and arms, rather than the stance leg differently from walking. [41] Walkers also require less from their joints and muscles than runners. With hip flexion, knee flexion, and ankle dorsiflexion with running, a greater joint excursion has been noted.[30] With running other joints such as the joints of the lumbar spine and pelvis also likely go through a greater range of motion. Particularly in the sagittal plane increasing speed of running increases the amount of joint excursion.[30] With sprinting some investigators empirically noted a greater degree of transverse plane motion. Greater eccentric work is required to control this motion which are the muscles of the lower leg. Changes in running gait with increased velocity Running can be classified by speed. From 5 mph to 10 mph jogging, or submaximal running, can be defined as velocity.[37] As velocity increases characteristic changes in gait occur. When walking, in a sinusoidal curve in space during running the center of gravity of the body shifts; however, during running, the body maintains a forward lean throughout the gait cycle. To minimize lateral shift in center of gravity the line of progression from step to step is at or near the midline. The lower extremity joints increase their range of motion to decrease the vertical shift in center of gravity as speed is increased . Hence, faster runners require more flexibility and eccentric muscle strength than slower runners. using the terms: cadence, stride length, and step length, speed and length of gait can be described. The number of steps per unit time is equal to cadence (usually steps/min). The distance between successive initial contacts of the same foot is stride length. The distance from initial contact of one foot to initial contact of the opposite foot is step length. During running temporal and spatial variables generally are interrelated.

Increasing step lengths followed by increasing cadence increases velocity.[29] There is more time spent in float phase with elevation in velocity. Stride and step lengths are a function of leg length and total height and while velocity increases coincide with the ability to increase these lengths. The point of initial contact can change when running velocity increases. The lateral heel typically contacts the ground first during submaximal running. However the midfoot makes initial contact in sprinting. At impact this places the foot in slight plantarflexion. After initial contact as during submaximal running dorsiflexion still occurs directly, but during sprinting the heel does not touch the ground. Except for increased joint range of motion, the remainder of stance phase mimics submaximal running. The foot begins to plantarflex during sprinting during the terminal portion of swing phase, so that the midfoot can contact the ground. As well as stance phase duration in relation to swing phase, as velocity of running increases total gait cycle duration diminishes. As events of the gait cycle need to occur within a shorter period of time this results in increased velocity of lower extremity range of motion.[37] The higher eccentric contractions that occur to control joint motion will result in higher energy expenditure. Minimization of the vertical displacement of the body center of gravity is served by the increased range of motion in the lower extremity. As velocity increases to a sprint the end result is increased energy cost, which therefore limits the absolute running distance. Running efficiency or economy changes as velocity increases. Running economy has traditionally been measured by evaluating oxygen use at a certain rate. Speed is not only one parameter to determine the energy cost of running. We have also running biomechanics. An ideal model for economic running has not been found yet. Numerous factors may affect running efficiency, which are beyond the scope of this chapter. For a particular individual, to achieve the least energy expending pattern of running gait, training allows the body to biomechanically adapt over time.

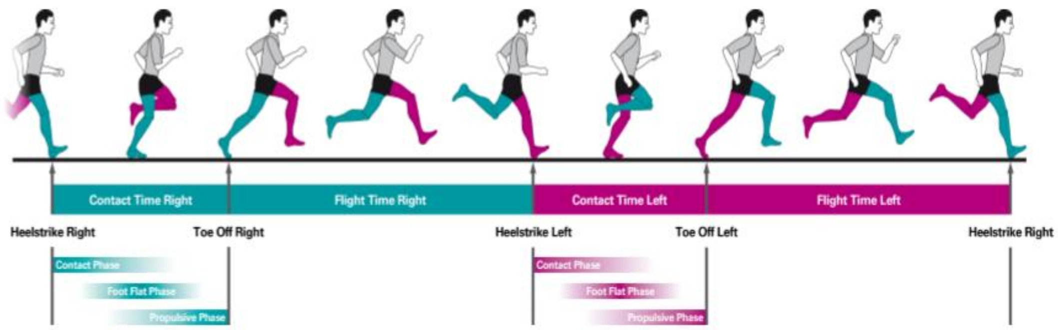


Figure 3: Running cycle phases [53]

2.6 Running Gait Analysis

Running gait analysis is done along a continuum from real time observational gait analysis to the use of high-resolution cameras and video recording devices as with walking gait; force plates; computer systems; and other laboratory measuring devices. Including motion analysis, dynamic electromyography, force plate recordings, energy cost measurements or energetics, and measurement of stride characteristics five gait measurement systems have been described[32] . Force production is related to kinetic analysis, whereas kinematics is the measure of movement itself and reflects the effect of the kinetics [54]. In a steady state outside of starting and stopping gait kinematic analysis is done best and it requires enough space for the subject to start, walk/run, and stop [55]. For continuous observation and monitoring, the use of a treadmill is needed but compared with nontreadmill running may cause variation in movement pattern. To use a more secure gait, runners are forced by Treadmill, including spending increased time in stance phase. As measured by pressure-sensitive insoles in the shoes of female long-distance runners who were tested on a treadmill, a recent review demonstrated that ground reaction forces, , were reproducible across different running velocities and stride frequencies. [14] Depending on the muscle that was tested EMG analyses across these differing running techniques varied.

2.6.1 Observational Gait Analysis

By all health care professionals observational gait analysis is used to some extent. It is the least expensive and easiest method of analysis. On stance, swing, and float phase the gait cycle is observed with gross focus sequentially. Stance and swing are subphases that are parts of the observations, including initial contact, loading response, midstance, and terminal stance for the stance phase, and preswing, initial swing, midswing, and terminal swing for the swing phase. From the frontal, sagittal, and transverse views observations are made and recorded. Reflective gait markers enhance the clinician’s ability to detect transverse plane abnormalities, particularly at the knee and ankle. After the gross inspection, in the frontal, transverse, and sagittal planes, analysis follows an anatomic sequence from foot and ankle to trunk. Deviations are determined by the observer from normal at each joint/anatomic region and each phase/subphase. Also observations of arm swing, spine rotation, and head and neck positioning are noted. Total limb function, as described by gait deviations at each joint/phase; and functional deterrents of effective weight acceptance or limb advancement [12] are the two areas which are summated from the observational findings. The ability to pronate or weight acceptance is evaluated starting at the foot and ankle and to observe obligate motions that occur proximally—the ‘‘bottom up’’ approach it progresses more cephalad. During the propulsion phases using a ‘‘top down’’ approach is used to assess the ability to supinate or limb advancement, and for proximal muscle contraction. The most common problem that is observed on empiric running analysis is excessive pronation. Such as the medial tibia, hyperpronation causes increased ground reaction forces in the medial aspect of the lower limb kinetic chain, although a physiologic amount of pronation is required. To control the excessive pronation, which may lead to tendonitis, muscles may need to work harder. Excessive internal rotation of the tibia and femur comes with excessive pronation. Patellofemoral maltracking is being leaded by this. Observed excessive supination is more rare and can lead to increased forces on the lateral direction of the kinetic chain. Pelvic abnormalities also are observed frequently in runners, such as excessive anterior and lateral tilt.

2.6.2 Motion Analysis

In general, motion analysis provides for quantitative description of body segments in gait without quantification of forces. The use of camera for still photography or a video recording device for filming rapid events like running is the simplest form of motion analysis. When they are imaged sequentially through a calibrated field of view, markers that are placed on the body segments allow for a more comprehensive analysis. Goniometers or electronically instrumented hinges were used to track limb motion initially[56] . Biaxial and triaxial systems were developed and are supplemented by a recorder that can provide immediate data on minimal and maximal arcs of motion and rates of change because of the changing center of knee joint motion. More sophisticated systems have been developed in which three-dimensional coordinates can be computed When two or more cameras/detectors detect the same marker by way of mathematical triangulation. To use clinically these systems are suitable and are functionally accurate [57]. Without long power cords infrared transmitters (active markers) and retroreflective markers (passive markers) can be used; this makes the analysis less cumbersome to set up and use. Measures, such as joint angle and velocity, are calculated once the computer program has calculated the motion of the limb segment. To allow for calculations of joint moments, powers, and mechanical energy motion analysis measures can be combined with force measures. In patient instrumentation, marker placements and data processing, there are pitfalls to be considered in motion analysis systems outside the scope of this text. [58]

2.6.3. Force Plate Analysis

During stance phase ground reaction forces are generated in the vertical, horizontal, and rotatory plane in conjunction with weight acceptance. With a force plate these forces—equal in intensity but opposite in direction to the forces experienced by the weight-bearing limb—can be measured. Ground reaction joint torques or moments can be calculated when the measured forces are combined with information on the joint center location. Typically, to avoid targeting for direct landing the plate is mounted in the floor in an inconspicuous manner, which can alter desirable natural gait mechanics. From force plate analyses vertical loads, horizontal shear, vector patterns, joint torques, and center of pressure determinations are the most useful data. Sagittal plane vectors and frontal plane vectors are included in vector analysis. Peak load is determined by gait velocity, or rate of limb loading[59] . During running peak vertical loads of 2.5 times body weight have been measured. [41]Variation in running style (eg, heel-toe or foot-flat styles) impact the shape of the ground reaction force patterns. [60]

2.6.4 Dynamic Electromyography

During active running or walking muscle activity timing and relative intensity are measured with surface or fine wire needle electrodes with dynamic EMG of multiple muscles. Dynamic EMG can be used to assess neuromuscular control of a runner in this way. To allow for recording, transmission of the myoelectric signal is done by way of cable or telemetry. A minimum significance level for signal activation must be defined so one can decide on the onset and cessation of active contraction accurately, although timing of muscle activation would seem to be a straightforward calculation. Of this minimum level, 5% is the definition of the maximal effort that is registered on manual muscle test of the muscle.[61] Especially with surface electrodes cross talk from other nearby muscles can limit the accuracy of single-muscle EMG quantification. Muscle activity is quantified by computer analysis. [32] Ultimately, integration, which consists of the collection of digitized, corrected signals over time, is carried out for short periods of time, consistent with the lower phases of the gait cycle.

2.7 Energetic Measurements of Gait

In gait energy expenditure is related to the alternating slowing and accelerating of body mass in conjunction with the raising and lowering center of gravity. [41] In normal and pathologic gait Global information on energy expenditure can be derived from measurements of metabolic energy expenditure and has been used to assess various pathologic gait patterns that are related to neuromuscular diseases and orthotic and prosthetic use.[62] Mechanical strength has been used as a global muscle effort descriptor, believed to be a good basis for energy expenditure for walking; however, some researchers have concluded that muscle effort shows no association with metabolic demand. To control the gravitational forces in a smooth, coordinated, and energy-efficient manner eccentric contraction is important, primarily during stance phase. In runners the swing energy expenditure may be higher than anticipated During human running the exact distribution of energy use among various muscles is not known but may shed some light on running efficiency. For the most economical running form there is no formula; however, the literature on biomechanics of running gait suggests that biomechanical factors, including anthropometric dimensions, gait pattern, kinematics, and kinetics, may be related to running economy.[32]

2.8 Stride Analysis

Measurements of gait characteristics such as cadence, speed, stride length and stride length can be clinically useful. They can be measured in more simple ways, with a stopwatch or apparatus such as an instrument gate. Including insole foot switches portable units, allow for more convenient, less expensive measures of gait characteristics. In conjunction with observational, qualitative measures these quantitative measures, can provide a quick and easy assessment that can be repeated while tracking recovery or rehabilitation.[2]

2.8.1 Optojump

OptoJump Next is an innovative analysis and measurement system that brings a new performance evaluation and optimization philosophy to the competitive sports in the world. OptoJump Next allows coaches, trainers, and researchers to continuously test and monitor athletes, taking basic parameters that characterize the level of an individual's performance and physical condition. This makes it possible to simply and instantly determine the capabilities or physical fitness of an athlete, creating a database that allows comparing values ,even months or years away, for that athlete or different athletes even for a while.[53]

It is an optical measurement system consisting of a transmitting and receiving bar.

Each of these contains 96 leds (1.0416cm resolution).

The leds on the transmitter bar constantly communicate with the leds on the receiver bar. The system detects any interruption in communication between the bars and calculates their duration.

Starting from these fundamental basic data, the dedicated software makes it possible to obtain a series of parameters connected to the athlete’s performance with the maximum accuracy and in real time.This is possible to measure flight and contact times during the performance of a series of jumps with an accuracy of 1/1000 of a second.

Moving mechanical parts absence ensures great reliability and accuracy. [16]

2.8.1.1 Single Meter on Treadmill

Gait and run analysis positioned on the side bars of a treadmill, OptoJump Next becomes a real portable lab for small spaces and with reduced costs. The system is compatible with the wide majority of treadmills and no synchronization is necessary to start and carry out a test.

Treadmill Running Test (TRT) Main Parameters Start type:

This can only be ‘Software command’ Stop type: this can only be ‘Software command’ or ‘End of time’ Test length: appears only if Stop type = ‘End of Time’ and specifies how many minutes:seconds the test must last (from 00:01” to 59’:59”) Treadmill speed: indicates the speed in km/h the treadmill is set at; the setting range is 0.1- 20.0 km/h with steps of Direction: Indicates, if the walking direction is 'Interface side' or 'Opposite side'. Therefore, if the interface drums are at the end of the treadmill choose 'Opposite Side', or vice versa.[53]

Figure 4: The placement of optojump system on treadmill [16]

2.8.1.2 Jump Test

A series of exercises like counter movement jump, squat jump, jumps on one leg, drop jump, continuous jumps, and protocols like ‘Drift' for dynamic stability, 'Single Leg Three Hops', '5 Dot Drill' for reactivity and endurance, to verify the stability and bending capacity of the knee are pre-configured. At the same time, the user can easily create customized tests or protocols.

Main Parameters Start type: Indicates if the start of the test must take place with a ‘status change’ (i.e. entering or exiting the bars) or with an ‘external impulse’ coming from the jack sockets (start button, signal light, etc.) Start: indicates if at the beginning of the test the athlete must be ‘inside the area’ of the bars or ‘outside the area’ Stop type: As for the start, the end of the test can take place because of a ‘status change’ or an ‘external impulse’, or (in the case of time tests) the end of the test time (e.g. a test “Jumps 15 seconds” will have the Stop type = ‘End of Time’). Finish: for the Stop type = ‘Status change’ it is necessary to specify if, at the end of the test, the athlete must be ‘inside the area’ of the bars or ‘outside the area’; in the other two Stop type cases this field does not appear Number of Jumps: appears only if the Stop type = ‘Status change’ and specifies how many times the athlete must jump (from 1 to 99) Test length: appears only if Stop type = ‘End of Time’ and specifies how many minutes:seconds the test must last (from 00:01 to 09:59) Secondary Parameters

Minimum contact time [ms]: allows to set a minimum contact time in milliseconds; if the contact time is shorter, it is considered incorrect; if the system registers a contact time shorter than this value, the time is added to the associated flight time (usually the previous one). This control can be enabled/disabled by inserting the value 0. Minimum flight time [ms]: allows to set a minimum flight time in milliseconds; if the flight time is lower, it is considered incorrect; if the system registers a flight time shorter than this value, the time is added to the associated contact time. This control can be enabled/disabled by inserting the value 0. Maximum flight time [ms]: allows to set a maximum flight time in milliseconds; if the flight time is higher, it is considered incorrect; if the system registers a flight time longer than this value, the time is not considered. Starting foot: if known, the foot with which the test starts ("right" or "left") can be indicated, otherwise leave as "not defined" Overload Weight [Kg]: is the value in Kg -or lb if the British unit of measurement is set- of a additional weight (e.g. of a lifting bar, kettlebell, etc.) if the athlete uses one during the jump test. Setting this parameter influences the calculation of Total [J] and Specific [J/Kg] Energy and Total [W] and Specific [W/Kg] Power. Overload % body weight: alternatively, a percentage of the athlete's body weight can be set. E.g. if an athlete weighs 70kg, entering 10% would be like defining an overload weight of 7kg in the previous field.

2.8.1.3 Quantity and Quality

Optojump Next goes beyond the acquisition of numerical data: thanks to small cameras that can be positioned as desired, it allows recording of the images of the tests performed, synchronising them perfectly with the events measured. This makes it possible to enjoy the advantages of cross-checking between data and images and also those deriving from more detailed video analysis through the exploitation of the possibilities offered by the dedicated utility.

The film sequences and all the other data are saved in the database. This makes it possible to consult them at any moment and, as with numerical data, to make comparisons between the performances of different athletes or of the same athlete at different moments. [16]

2.8.1.4 Validity and Reliability

Vertical jumping is one of the most common actions in various sports activities. It is therefore important to ensure that vertical jump height measurements made as part of the research or athlete support study have sufficient validity and reliability.[63]

In addition to valid and reliable isokinetic and isometric evaluations of lower limb muscle power and strength, vertical jumping performance , especially jumping height , is seen as an important functional parameter for athletic populations, especially in team sports.[63,64] Therefore, vertical jump height measurements made as part of a research or athlete support study should have sufficient validity (to what extent a tool measures what to measure) and reliability (consistency or stability of measurements).

In a study of Optojump's validity and reliability, they found that the use of Optojump photoelectric cells is legitimate for field-based assessments of the vertical jump height.[63]

2.9. Running Economy

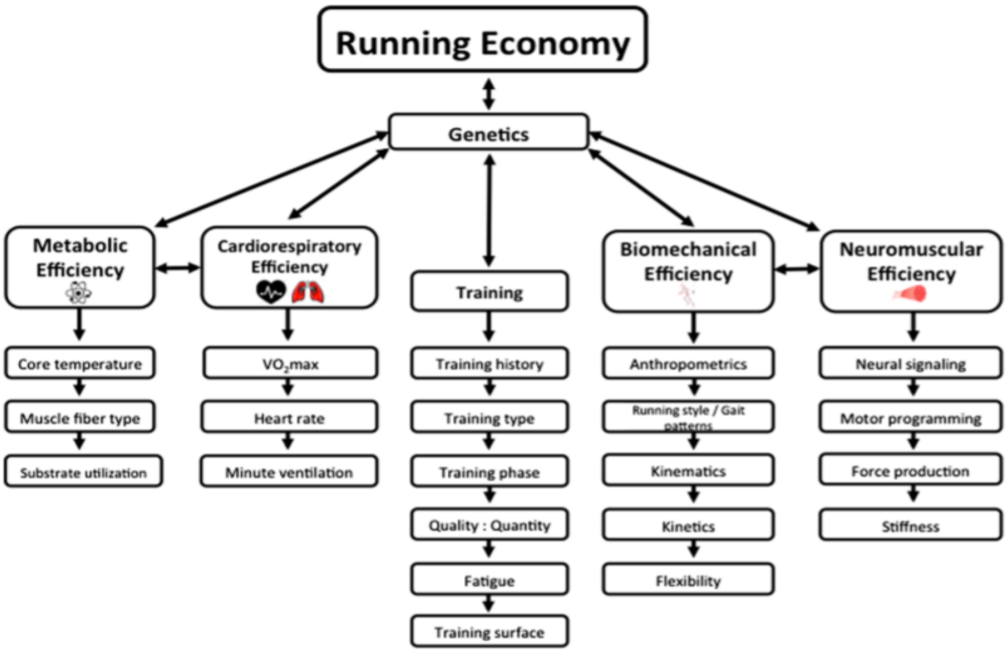
Running economy (RE) is a complex with multifactorial, metabolic, cardiorespiratory biomechanics and neuromuscular characteristics at the submaximal running level. Running economy factors can be explained by adaptation to training and other interventions. However, an economic change in an athlete may not be economical in another athlete because his physiological and biomechanical characters may not be the same.[65] Other description of RE is the amount of energy, often expressed as oxygen uptake, required to sustain running at a fixed submaximal speed, and is an important factor in determining long-distance running performance. [66]Representative running economy values for different caliber of runners running at various speeds are presented.[65]

In one review; training, environment, physiology, biomechanics and anthropometry can influence RE and also, affects biomechanicsand physiology. [66,67]

The steady-state oxygen consumption (VO2) at a given running velocity [68] reflects the energy demand of running at a constant submaximal speed. At the same steady-state speed, runners with good running economy use less oxygen than runners with poor economy [69] The running economy can vary by 30% in similar training runners with a vo2 max rating.[65] At the same time, the economy of running is very useful in predicting endurance running performance. [3,65,68]especially in homogenous VO2max athletes. [70,71] A simple concept is used when measuring running economy. There is a multifactorial measure that represents the combined functioning of the neuromuscular systems, metabolic, cardiopulmonary and biomechanical systems. [65]

Metabolic efficiency is the use of energy that provides optimal performance. [66] However, cardiopulmonary efficiency means to a reduced work output for the processes related to oxygen transport and utilization. Lastly, biomechanical and neuromuscular qualities refer to the interaction between the neural and musculoskeletal systems and their ability to transform power output into translocation and therefore performance [3].

With various types of efficiency the sophisticated concept of RE, that is, accounting for the work done and energy lost, may be understood by scientists, practitioners and coaches, nonetheless it has yet to be discussed in perfect detail in the literature. Genetic features are among the factors that affect running economy. However, there are a limited number of studies in this area that study specific genotypes. [72,73] . Furthermore, many of these factors are replaceable through various training modalities. Therefore RE is an important measure for athletes, coaches and practitioners to understand, quantify and attempt to enhance.



65

Figure 5: Factors affected runnig ecenomy[65]

Although there isn't any easily recognizable or universally applicable "effective" biomechanical model for all runners, it shows that runners have various anthropometric features, like a mass distribution closer to the torso and shorter Achilles moment arm have a tendency to have better RE.Neuromuscular effectivity can also play an necessary position in finding out RE,mainly among athletes with comparable physiological properties.Specifically,beginning of ground contact phase, the timing and amplitude of muscle activity can affect the economy by increasing leg stiffness and using saved elastic energy. Adjusting a given determinant can be more economical for one athlete, but the same adjustment for another athlete can be uneconomical due to differences in other physiological or biomechanical characteristics.Perhaps an extra promising avenue of research might also be to focus on the individual runner to best determine how athlete's structural and functional capabilities affect renewable energy, subsequent performance, and sensitivity to injury.[65]

2.9.1. Biomechanics and Running Economy

Running includes the conversion of muscle forces that are transferred through complicated motion patterns that make use of all the fundamental muscles and joints in the body [3].Current evidence suggests that multiple biomechanical characteristics may contribute to running economy; these consist of a range of anthropometric dimensions[6,74] [36]choose gait patterns and kinematic and kinetic elements [75]that have been proven to have an effect on biomechanical effectivity and relate to better running economy.

Other anthropometric features of the entire human body are also studied. It has been found that among elite male runners, foot length is negatively correlated with running economy. The width of the pelvis and shoulders may theoretically affect running economy [3] , but few studies have been conducted, and existing evidence shows that there is no correlation between pelvic width and running economy,or moderate negative correlation.The only posture features studied with respect to running economy are the torso angle or the forward leaning angle when running. When comparing long-distance runners grouped by running economy, one study [36]found that the most economical group had a slightly larger forward lean(5.9°) than the medium (3.3°) and smallest (2.4°) groups.

2.9.2. Body Mass

Various anthropometric features (such as height, Body mass , physique, and segmental mass distribution) may help explain individual and group differences and the potential impact on running economy. As we all know, the oxygen demand during running is not directly proportional to body weight [15,101], children's VO2 per kg body weight is higher than adults [71,76,77].Indeed, in running races from 800 meters to the marathon, even at the elite level, it is not uncommon for individual results to be as high as 25 kg and/or 30 cm. Several research[59,78] have proven light-weight guys to be no greater or much less cost-effective than their heavier counterparts.Other studies have shown that by increasing the weight of the trunk to artificially increase body weight during running, children[77,79 80]and adults[81] have lower VO2 per kilogram body weight.

These results support previous research[82,83] which reported that running barefoot or minimal footwear is more economical than standard shoes. However, it has been shown that shock absorption and other functions of the insole (in addition to weight) also have an important effect on running economy. [84] For example, when running in shoes with good shock absorption, the aerobic demand when running in a treadmill is reduced by about 2.8% compared to poor quality shock-absorbing shoes. [84]

2.9.3. Extremity Length

Although the mass distribution of the lower extremities has been shown to have an affect on running economy, there is no consensus on whether or not leg length is the factor that determines running economy.

Leg length leads to angular inertia and the metabolism of the moving leg during running [3,85]. Although some studies have focused on the relationship between leg length and stride [50,60], the effect of leg length on economy is only indirect survey. Humans and animals of different sizes consume roughly the same energy, and running has little effect on the environment; muscles and tendons do their work to lift and accelerate the body and extremities. Some work is recovered from tendon springs without the cost of metabolism, but no matter how much work the muscle does, it is necessary to activate the extremities and develop strength to support the body's weight.Kram 1990

In usual, middle- and long-distance runners have better running economy than sprinters[76] but the effect of leg length on these variations is unclear.

2.9.4. Achilles Tendon Moment Arm

The energy stored in the tendon depends on the mechanical properties of the tendon and the force that stretches the tendon (such as the length of the foot).The potential energy and kinetic energy removed from the human body in the first %50 of the standing phase are temporarily stored as elastic strain energy, and then return through elastic recoil in the second %50 [86].Therefore, for a given kinematic model, and thus a kinematic model, the tendon force is inversely proportional to the moment arm of the Achilles tendon[87] Since it is generally believed that the storage and reuse of elastic energy in tendons will greatly reduce the energy requirements during running[60] , previous studies have been able to establish average[88] , massive[87] and extraordinarily massive [65] The relationship between the change in running economy and the torque arm of the Achilles tendon, although the sample size is small, from 8 to 63 [65]

2.9.5. Running Style

Over time, runners will adopt the most economical way of running[89,90]

A wide variety of research exhibit that men and women have a tendency to freely pick their most good value gait sample While research have recognized small to reasonable relationships between biomechanical traits and stride size is one of the few gait variables that has been proven by using direct experimental proof to have an effect on financial system [60,71,91]

Therefore, it has been suggested that a high amount of training and many years of running experience are important for improving the working level. [92]

2.9.6. Stride Length and Stride Rate

As the length of the stride increases or decreases, the runner starts from the stride of his choice, and the next largest VO2 curve increases.[65] This primary curvilinear relationshipbetweenstride size and financial system has additional been proven for on foot [28]and racewalking.[93] The simple assumption in the back of this research seems to be that strides which are too lengthy will require sizable electricity at some point of propulsion, immoderate vertical oscillation of the core of mass, produce a foot strike function which creates giant braking forces and require joint tiers of action which invoke elevated interior friction and stiffness.[3]

Conversely, strides that are too quick would amplify inside work of contracting muscle tissue thru multiplied frequency and reciprocal movements, ensuing in expanded power expenditure and minimize.[3] Previous research has shown that VO2 was lowest at stride lengths close to the self-selected condition [91,94]

2.9.7. Vertical Oscillation

Studies evaluating the biomechanical traits of elite and good runners, located that elite distance runners have barely much less vertical oscillation and had higher running economy than good runners[65]

2.9.8 Footstrike Patterns

That the way the front foot strikes during running is more economical than the way the back foot does. However, previous studies using a habitual foot strike group found that there was no difference in running economy between foot strike methods[49,95]

While stride length, stride rate and different gait associated traits have been related with running economy, different kinematic and kinetic elements such as angular velocities of limb segments and joints [49,96,97]and floor response forces have additionally verified a relationship with running economy.[98]

2.9.9. Lower Body Kinematics

Comparison of elite and long-distance runners shows that the better economy of elite runners is greater with the maximum angle of the thighs during hip extension, the extension of the calf when stepping on the foot, and the knees during swing and toe separation The sharp angle is larger and is related to the soles of good runners. Compared with elite runners, the toes bend at an average of 10°[49,96]It turns out that running experimentally to increase knee flexion ("Groucho running") can increase the oxygen demand of running by up to 50% [99]

2.9.10. Upper Body Kinematics

Most research on running economy and running mechanics has focused on the kinematics of the lower extremities, and only a few studies [3,49,97] have considered the upper extremities. Anderson and Tseh [3] determined no relationship between running economy and ought to width, hip width, or ratio of shoulder:hip width.

Williams and Cavana[49] found that among elite male athletes, the shoulder: pelvis width and RE have a moderately negative correlation, which indicates that the reverse rotation of the shoulder and hips and the arm's Torque and force generated by exercise may affect running economy [100]

Tartaruga et al.[97] discovered no relationship between pace modifications of the wrists and shoulders or rotation of the hips and shoulders relative to the polar axis of the trunk and economy. Some results indicate that arm movements are less measured by the ankle offset measurement during the gait cycle, tending to reduce the upper and lower body offsets from the upper limb mass center in the lateral and horizontal directions, and are associated with better running economy .[96,97,100,101]

Therefore, there is a positive correlation between economy and shoulder rotation angular velocity and angular displacement of the hip and shoulder around the polar axis of the trunk and a negative correlation between economy and shoulder angular displacement in the sagittal plane has been previously described [101]

2.9.11. Kinetics / Ground Reaction Forces

Investigations associated to kinetics and running economy are confined and most work has centered on vertical floor response forces. Kram and Taylor [60] introduced a easy inverse relationship between aerobic demand throughout running and the time that the foot exerts force on the ground, and has nothing to do with body weight. This indicates that the energy demand during running is determined by the support cost. The time course of body weight and force production.Williams and Cavanagh [96] speculated that the running style of more economical runners has a recognizable dynamic pattern, which can be recognized by reducing unnecessary vertical movement [98]However, data collected from excellent male and female long-distance runners show that the correlation between ground reaction force and running economy is relatively low [49,96] which indicates that ground reaction force is unlikely to make one runner more economical than another. The determinants of the performance, and in fact, despite the low ground reaction force, some elite runners are still economical.Although due to the need to support body weight, vertical ground reaction forces have shown the need for metabolism during leisure and well-trained runners [98,102], horizontal reaction forces can also have a significant impact on running economy.

2.9.12. Neuromuscular Characteristics

In addition to metabolic, cardiorespiratory, and biomechanical factors, neuromuscular traits are additionally vital components of running economy. The interaction between the nervous system and the muscular system (ie, the neuromuscular system) is the basis of all exercises, and effectively transforms cardiopulmonary functions into effective mechanical mechanisms, and then into performance.[65]

Nerve signals and exercise programs, muscle strength generation and stiffness, muscle strength, shortened periods of stretching, calf stiffness and elastic energy storage are also neuromuscular characteristics of running economy.[65]

3. MATERIAL METODS

The sample of the study consist of 22 (Be between the ages of 20-43) 8 female 14 male amateur runners. Between January 2020 and February 2020, 28 randomly selected runners were evaluated for the study at PT_ Academy Athlete's Health and Performance Center. Therefore, 30 runners were included in the study. 8 runners exclude from the study.

Inclusion Criteria

- Consented to voluntarily participate in the study
- Be between the ages of 20-43
- Having totally minimum 6 hours / week training in the last 3 months

Exclusion Criteria

- To have undergone any orthopedic surgery involving the lower extremity in the last 6 months.
- Having any orthopedic problem diagnosed in the lower extremity (patellofemoral pain syndrome, lateral ankle sprains lliotibial band friction syndrome, tibial stress syndrome, plantar fasciitis, Achilles tendonitis and meniscal injuries) for the last 6 months.

The power analyze indicated to enroll 12 participants.

Participants included in the study on a voluntary basis. Informed consent form was obtained from each individual in writing by explaining the purpose and plan of the study.

The study protocol was approved by the Yeditepe University Ethical Committee at the date of 16.01.2020 and issue number was 1144 (Appendix 1). Participants involved in the 28 study on a voluntary basis. The aim and plan was explained and informed written consent was obtained from each runner. (Appendix 2).

3.1. Flowchart of Research

We planned to include 30 runners who satisfied to participate in our study. 8 runners were excluded from the study. 2 out of 8 paticipiants had younger age, another 3 paticipiants had weekly training hours. Also, 3 participinats had acute pain and any orthopedic problem diagnosed in the lower extremity. Finally, foot posture index, footbalance base line analysis , weight bearing lunge test and squat jump test assessments were performed on 22 participants. Before the running analysis, the warm-up program including mobility exercises and jogging was applied. Subsequently treadmill runnig test measurements were made.

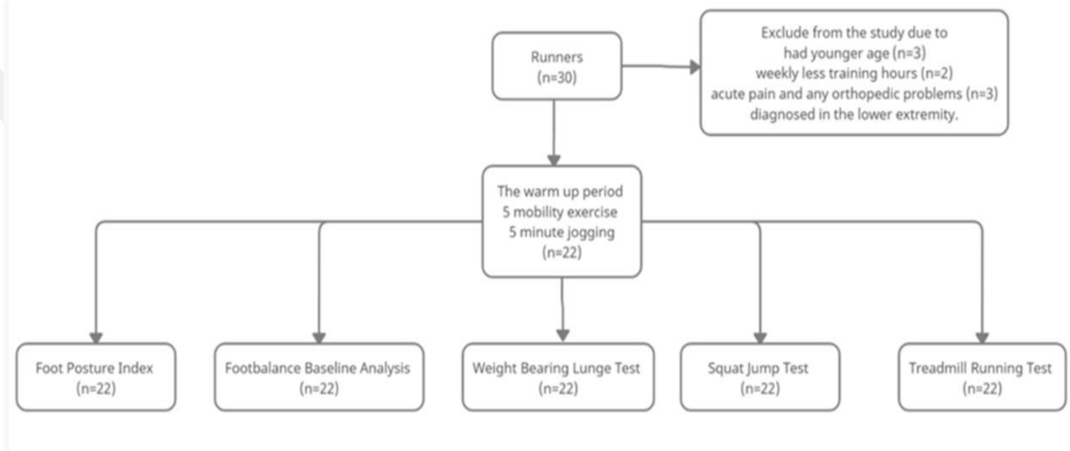


Figure 6: Flowchart of the study

3.2. Protocol

3.2.1. The Questinaire on Sociodemographic and Health Behavior Profile, Physical Features

The structured questionnaire prepared by researchers applied face to face interviews. The questionnaire included age, gender,occupation, education level, marital status, known diseases, drugs used, income level, smoking habits, dominant foot and hand, daily fluid consumption, sleep quality will be questioned. In addition, weekly training hours, past injury profiles and pain status evaluated.

3.2.2. Evaluation of Foot and Ankle Biomechanical Parameters

3.2.2.1 Foot Posture Index

Using set parameters and a basic scale, the FPI-6 is a novel form of rating foot posture. It is a clinical device used to measure the degree of pronation, neutrality or supination of a foot. It is a standing foot posture test and is thus not a substitute for gait testing where there is time and facilities. However, it is a more valid solution than many of the goniometric static weight and non-weight bearing interventions being used in clinics.[103]

The individual should stand with double limb support in their comfortable place of stance. The individual should be told to stand still, staring straight ahead, with their arms beside them. Before moving into a relaxed position, it might be useful to ask the subject to take several moves, marching on the spot. It is important to ensure that the patient should not swing through the test to attempt to see what is happening to himself, as this will have a direct effect on the position of the foot.In order for the test to be conducted, the participant would need to stand still for about two minutes in total. During the test, the assessor has to be able to walk around the patient and provide uninterrupted access to the posterior part of the leg and foot. If an observation will not be made (e.g. due to swelling of soft tissue), only skip it and show on the datasheet that the object has not been scored. Where there is real uncertainty about how high or low an item should score, the more conservative score is often used.

Table 1: Foot Posture Index Evaluation Parameters and Scoring

	-2	-1	0	+1	+2
Talar head palpation	Talar head palpable on lateral side/but not on medial side	Talar head palpable on lateral/slightly palpable on medial side	Talar head equally palpable on lateral and medial side	Talar head slightly palpable on lateral side/palpable on medial side	Talar head not palpable on lateral side/but palpable on medial side
Supra and infra lateral malleoli curvature (viewed from behind)	Curve below the malleolus either straight or convex	Curve below the malleolus concave, but flatter/more than the curve above the malleolus	Both infra and supra malleolar curves roughly equal	Curve below the malleolus more concave than curve above malleolus	Curve below the malleolus markedly more concave than curve above malleolus
Calcaneal frontal plane position (viewed from behind)	More than an estimated 5° inverted (varus)	Between vertical and an estimated 5° inverted (varus)	Vertical	Between vertical and an estimated 5° everted (valgus)	More than an estimated 5° everted (valgus)
Prominence in region of TNJ (viewed at an angle from inside	Area of TNJ markedly concave	Area of TNJ slightly, but definitely concave	Area of TNJ flat	Area of TNJ bulging slightly	Area of TNJ bulging markedly
Congruence of medial longitudinal arch (viewed from inside)	Arch high and acutely angled towards the posterior end of the medial arch	Arch moderately high and slightly acute posteriorly	Arch height normal and concentrically curved	Arch lowered with some flattening in the central position	Arch very low with severe flattening in the central portion - arch making ground contact
Abduction/adduction of forefoot on rearfoot (view from behind)	No lateral toes visible. Medial toes clearly visible	Medial toes clearly more visible than lateral	Medial and lateral toes equally visible	Lateral toes clearly more visible than medial	No medial toes visible. Lateral toes clearly visible.

Table 1: Foot Posture Index evaluation parameters and scoring

Features commensurate with an essentially neutral foot posture are scored as null, whereas a positive rating is given to pronated postures, and negative value is given to supinated features. The composite value provides an estimation of the average foot posture when the ratings are averaged. High positive aggregate values suggest a pronounced stance, a supinated overall foot posture is suggested by slightly negative aggregate values, whereas the final FPI aggregate score should be anywhere near zero for a neutral foot.[104]

3.2.2.2 FootBalance Baseline Analysis Evaluation

FootBalance Baseline Analysis evaluates posture of the foot base . The soles of the individual was grouped as pes planus pes cavus neutral and collapsed soles by using podoscope.(fig5) FootBalance FitPro software is used to draw the foot and ankle to adjust the individual's alignment for foot soles analysis. It classified as pronation over pronation supination and neutral (figure6) In addition, it evaluates the ankle supination and pronation in 3 different positions. These positions are upright, knee semiflexed and heel stance.(Figure7, Figure8, Figure 9)

Figure 7: Evaluation of foot sole type using Footbalance System (?)

Figure 8: Evaluation of foot posture during upright, knee semiflexed and heel stance position using Footbalance System

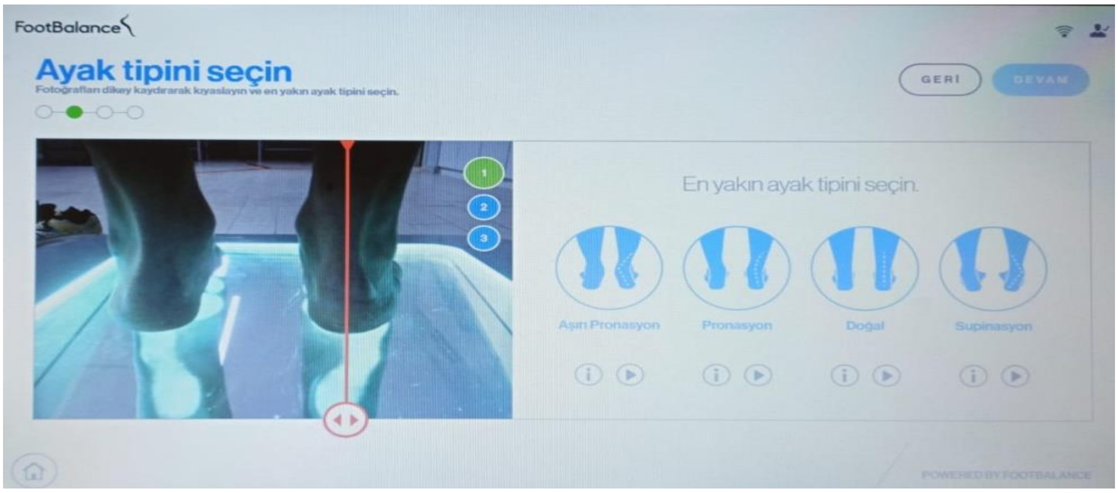


Figure 9: Evaluation of heel and ankle joint during upright posture

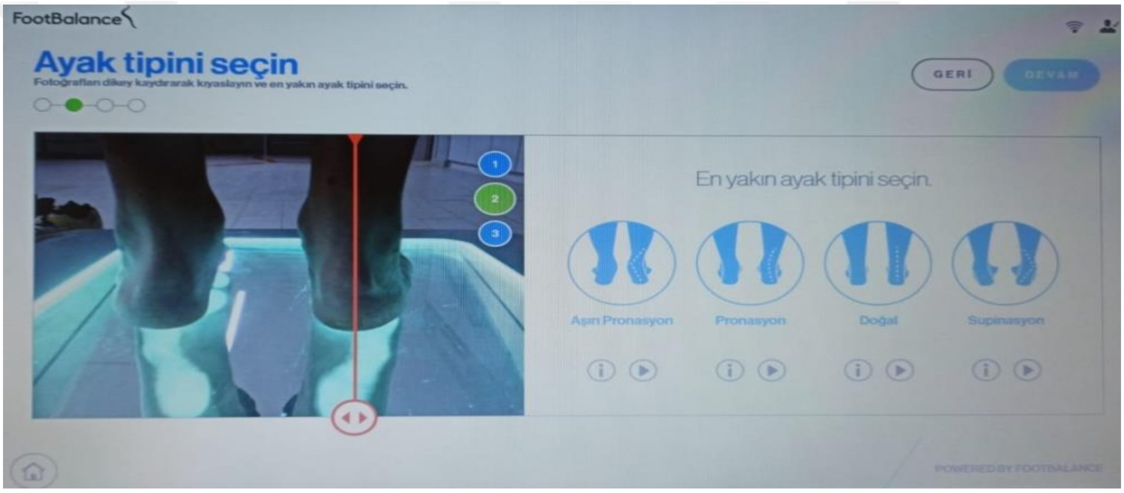


Figure 10: Evaluation of heel and ankle joint during knee semiflexed posture

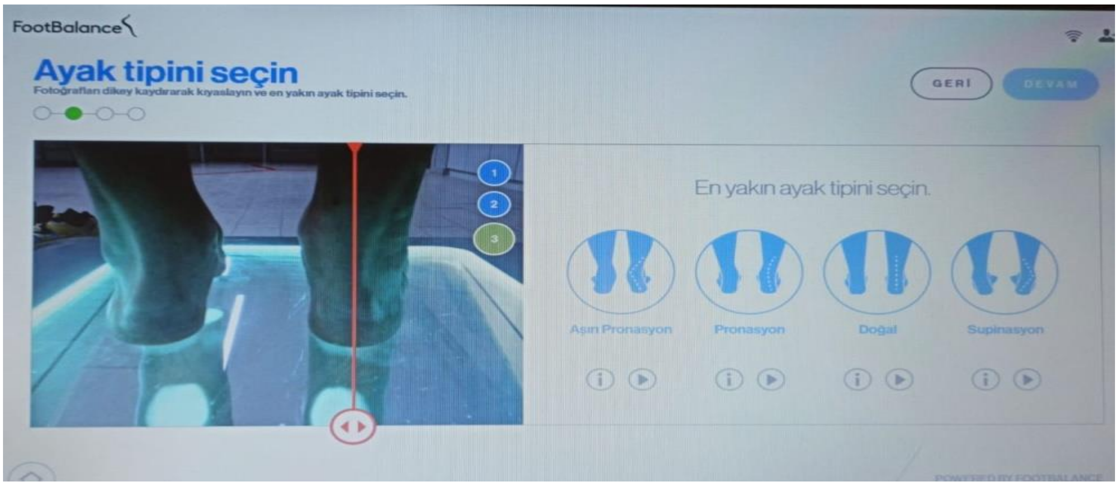


Figure 11: Evaluation of heel and ankle joint during heelstance posture

3.2.2.3 Weight Bearing Lunge Test - Spartanova

The Weight-bearing lunge test (WBLT) is used to assess the dorsiflexion range of movement (DROM) at the ankle joint.[105] Measurement was made with aninclinometer.

The subject is in forward straddle with both hands on a wall in front. Takes one leg backwards as far as possible while the knee is in full extension. The foot is located on the floor parallel to a tape-line, aligned perpendicular to the wall. In order to reduce the subtalar joint from pronation during the measuring process and thereby wrongly raise the importance of ankle joint dorsiflexion, the second toe and middle of the heel are positioned directly over the tape-line.

Physicaltherapist calibrate the inclinometer by placing it on the lower leg (on the anterior margin of the tibia, 10 cm distal from the tibial plateau), with the ankle in neutral position. Instruct addopt the forward straddle position and to In the posterior thigh, ındıvidual lean forward until optimum stretch is felt while keeping the knee completely extended and the heel in touch with the ground. To preserve balance and not limit the dorsiflexion of the posterior ankle, the front leg should stay in a stable position.

Physicaltherapist measure the ankle dorsiflexion range by placing the incinometer on the lower leg, on the anterior margin of the tibia, 10 cm distal from the tibial plateau

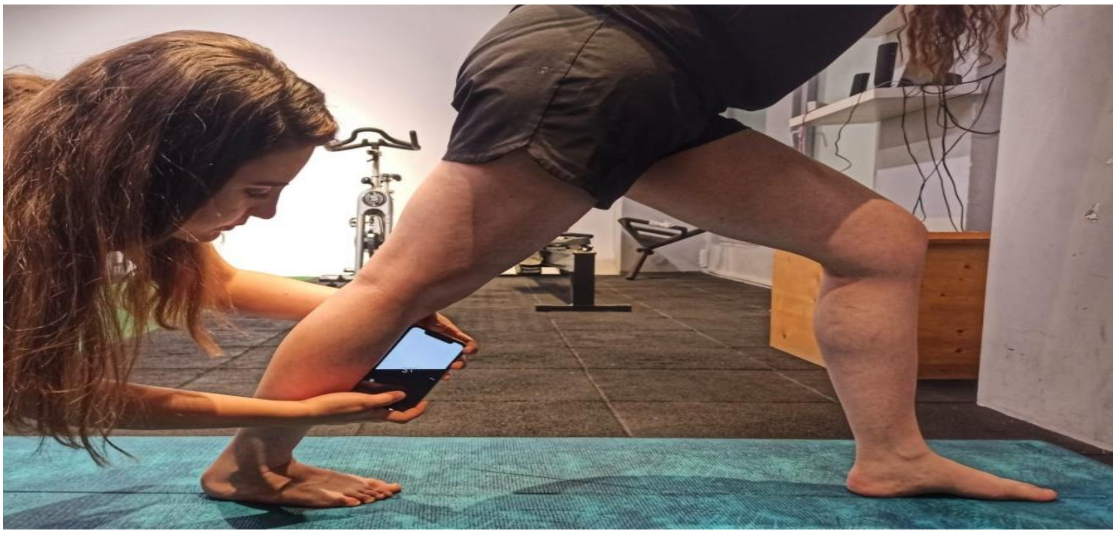


Figure 12: Measurement of weight bearing lunge test

3.2.3. Evaluation of Dynamic Biyomechanical Parameters

During running biomechanical parameters were determined using the optojump device on the treadmill. (h / p cosmos, treadmill system in sports and medicine) In addition, functional evaluations (squat jump) were performed using optojump sports performance device.

The following parameters will be determined:

Biomechanical parameters measured with Squat Jump Test are Height (cm). In addition, biomechanical parameters measured with Treadmil Running Test are that the variables that depending on length are Stride Length (cm) ,Step Length (cm). Furthermore, variables that depending on Time are flight time(ms), concact time(ms), contact phase(step/t), foot flat,(s), propulsive plase(s), Height(cm)

3.2.3.1 Squat Jump Test

Before the squat jump test, indiviual initially bounced 5 times consecutively to warm up.Beginning the test, the individial stood hands at the waist. The hip and knee were flexed at 45 degrees. With the sound of "jump!" individual made the maximum vertical jump without bowing.This test was repeated 3 times. The best result was obtained

Figure 13: Initial position of squat jump test

3.2.3.2 Treadmill Running Test

All participants performed pre- determined warm up programme which consist of 5 different mobility exercises and 5 minutes jogging . Mobility exercises prepared by the physiotherapist before the treadmill running analysis. These exercises are described below.

1. Dynamic streching exercise for anterior hip region.
2. Dynamic pigeon
3. Gastrosoleus pump
4. Extender
5. Half kneeling thoracic rotation

-Dynamic streching exercise for anterior hip region[106]:

While in the lunge position with the shoulders are on flexion during expiration physical therapist asked to move the hip forward and down.

Figure 14: Dynamic hip flexion mobilitiy exercise (Initial positon)

Figure 15: Dynamic hip flexion mobilitiy exercise (Final positon)

-Dynamic Pigeon:[107]

The individual prone extends to the ground on the elbows, with one hip in external rotation and the other in full hip extension. Tilting individuals' hips to the right and left while exhaling.

Figure 16: Initial positon of dynamic pigeon mobilitiy exercise

Figure 17: Final positon of dynamic pigeon mobilitiy exercise

Gastrosoleus pump:[108] (dynamic downwarddog stretching) ??

The individual's hands and foot are positioned on the ground, with the hip in the air, with trunk flexion. While exhaling , individual presses his right and left heels to the floor respectively.

Figure 18: Gastrosoleus pump mobility exercise

Extender:[109]

Indıvidual is in supine lying, one hip is extended and the other hip and knee are in fully flexed position and supports his bending leg under the femur with his hands. Also, makes active knee extension without changing the hip flexion angle.

Figure 19: Inıtıal positon of extender mobilitiy exercise

Figure 20: Final positon of extender mobilitiy exercise

Half kneeling thoracic rotation[110]:

The person is positioned near the wall, in the forward lunge position, the trunk in the neutral position, the shoulders 90 degrees flexed. While exhale, it makes trunk rotation and flexion movement on the shoulder near the wall.

Figure 21: Inıtıal positon of half kneeling thoracic rotation mobilitiy exercise

Figure 22: Mid-positon of Half kneeling thoracic rotation mobilitiy exercise

Figure 23: Final positon of Half kneeling thoracic rotation mobilitiy exercise

3.2.8. Runnig Analysis

Figure 24: Placement of optojump system on H/P Cosmos Treadmill

After the mobility warm-up exercises, The side bars of the optojump were fixed to the sides of the treadmill, parallel to each other by physicaltherapist. (fig. 22)

Individual stood single leg, hands on hips. Foot length measurement was taken by the optojump device. Afterthat, indıvidual began to run at speed of 7 km/h. The speed of the treadmill was gradually increased every minute starting from 7 km / h. The test was started when it reached a speed of 12 km / h. After 3 minutes, data acquisition was stopped and the test was terminated. The speed of the treadmill was again gradually reduced and the runner was allowed to cooldown.(fig. 23)

Figure 25: Running analysis with optojump system on H/P Cosmos Treadmill

Data Analaysis

IBM SPSS Statistics 22.0 program was used for statistical analysis while evaluating the findings obtained in the study.

While evaluating the study data, linear regression models were constructed to determine for treadmill running test (TRT) step lenght right and left. Multivariable analysis of the data suggested that treadmill running test (TRT) height right and left also, treadmill running test (TRT) contact phase are significant predictors of treadmill running test (TRT) step lenght right and left. The suitability of the parameters to the normal distribution was evaluated with the Kolmogorov-Smirnov test. While evaluating the study data, besides descriptive statistical methods (mean, standard deviation), Student t-test was used for comparing normally distributed parameters between two groups and Mann Whitney U test was used for comparisons of parameters that did not show a normal distribution in the comparison of quantitative data. Pearson's correlation analysis, Spearman's rho correlation analysis was used to examine the relationships between parameters that were not compatible with normal distribution. Significance was evaluated at the $p < 0.05$ level

4. RESULTS

The study was conducted with a total of 22 athletes (14 (63.6%) male and 8 (36.4%) female) between January 2020 and September 2020 dates**.**

Table 2: Distribution of General Features

		Min-Max	Mean±SD
Age (year)		20-43	32.23±6.43
BMI (kg/m^2)		18.36-25.95	22.18±2.55
Sleep (hour/day)		6-9	7.18±0.85
Traning (hour/week)		6.50-17.50	8.88±2.84
Water consumption (lt/day)		1.50-6.00	2.98±0.92
		n	**%**
Education Status	**University**	18	81.8
	Master	4	18.2
Dominant Leg	**Left**	4	18.2
	Right	18	81.8

The ages of the athletes were ranged from 20 to 43 years, with the mean of 32.23 ± 6.43 years.

The BMI distribution varied between 18.36 and 25.95 kg / m2, with an average of 22.18 ± 2.55 kg / m2.

When the daily sleep hours of the athletes were examined, it was found that it ranged between 6 and 9 hours, and the mean value was 7.18 ± 0.85 hours.

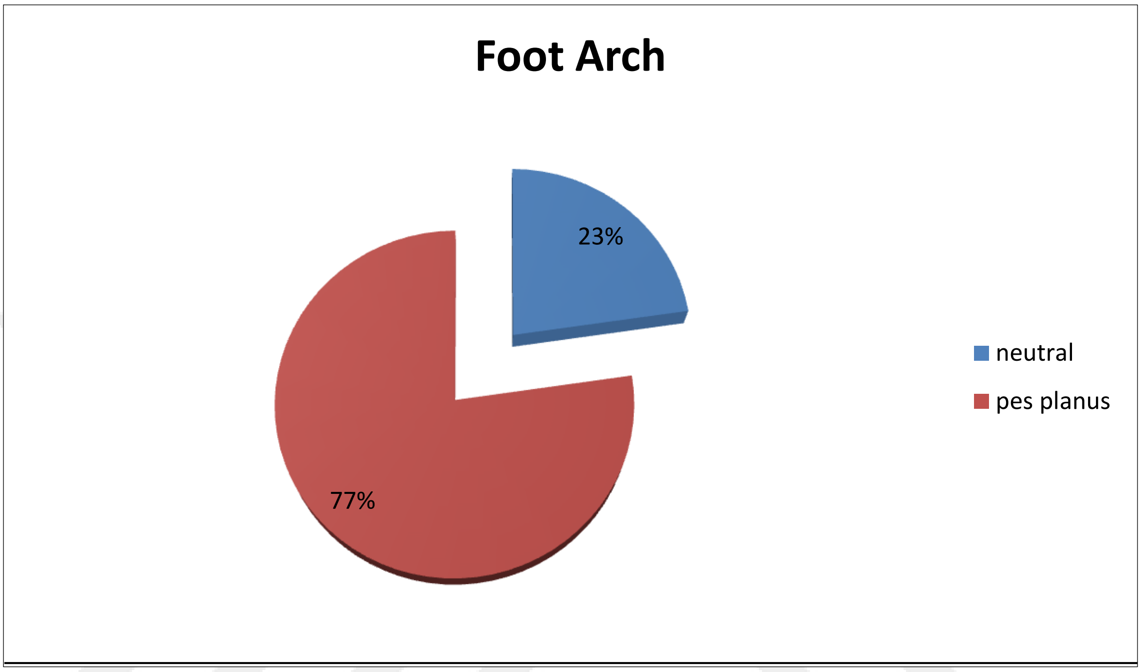
When the weekly training hours of the athletes were examined, it was found to be between 6.50 and 17.50 hours, with an mean value of 8.88 ± 2.84 hours.

The amount of water consumption varied between 1.5 liters and 6 liters per day, with an average of 2.98 ± 0.92. Eighteen (81.8%) of the athletes were university graduates, and 4 (18.2%) of them are graduate graduates.

Although 18.2% of the athletes had left dominant leg. (n=4), 81.8% have right leg dominant (n=18).

Footbalance (FB) Foot Arch Parameters

Graph 1: The Distribiton of Foot Arch



According to the foot arch analysis, 23% of the position of the foot of participants are neutral (n = 5) and 77% pes planus (n = 17).

Table 3: The Mean Value of Foot Posture Index Parameters in the Study Group

Parameters	N	Mean± SD	Minimum	Maximum
Total Left	22	3,36 ± 3,08	-1,00 /	8,00
Total Right	22	4,05 ±3,12	-1,00 /	10,00
Talar head palpation Left	22	1,55 ± 0,51	1,00 /	2,00
Talar head palpation Right	22	1,68 ± 0,48	1,00 /	2,00
Supra and infra lateral malleoli curvature Left	22	0.13±0.77	-1.00 /	2.00
Supra and infra lateral malleoli curvature Right	22	27.27±0.98	-1.00/	2.00
Calcaneal frontal plane position Left	22	0.31±0.94	-1.00 /	2.00
Calcaneal frontal plane position Right	22	0.40±0.90	-1.00 /	2.00
Prominence in region of TNJ Left	22	0.63±1.17	-2.00/	2.00
Prominence in region of TNJ Right	22	0.72±1.24	- 2.00/	2.00
Congruence of medial longitudinal arch Right	22	0.27±1.24	-2.00/	2.00
Congruence of medial longitudinal arch Left	22	0.22±1.15	-1.00/	2.00
Foot Posture Index Abduction/adduction of forefoot Left	22	0,50 ± 0,91	-1,00 /	2,00
Foot Posture Index Abduction/adduction of forefoot Right	22	0,68 ± 0,89	-1,00 /	2,00

When we examined the total Foot Posture Index, The mean value of foot posture ındex (FPI) total L is 3,36 ± 3,08in the study group. Also, median value is 3,00. The mean value of foot posture ındex (FPI) total R was 4,05 ±3,12in the study group. Also, median value is 4,00. Positive values stand out for both right and left foot.

Table 4: The Comparision of Treadmill Running Test Parameters (that depending on length) according to Foot Position Left

	Foot Position Left			
	Neutral	**Pronated**	**U**	**p**
Step Lenght Right(cm)	149.00±30.01	234.06±227.68	34.00	0.90
Step Lenght Left (cm)	114.00±24.67	295.67±376.48	31.5	0.71
Height Left (cm)	17.85±18.42	38.29±31.28	13.00	0.10
Height Right (cm)	23.82±29.43	52.41±102.04	19.00	0.25

Mann Whitney U Tes

Table 5: The Comparision of Treadmill Running Test Parameters (that depending on length) according to Foot Position Right

	Foot position Right		U	p
	Neutral	Pronated		
Step Lenght R(cm)	175.83±108.71	234.63±235.7	34.50	0.32
Step Lenght Left (cm)	172.16±76.00	304.06±396.31	38.00	0.49
Height Left (cm)	67.45±135.17	18.54±38.54	35.00	0.96
Height Right (cm)	73.90±141.17	35.01±65.28	38.00	0.96

Mann Whitney U Test

Treadmill Running Test Parameters that depending on lenght were compared according to foot position, Although the pronated foot position mean values were higher on both right and left sides, there was no statistically significant difference(Table 6 - 7).

Table 6: The Comparision of Treadmill Running Test Parameters (that depending on time) according to Foot Position Left

	Foot Position Left		t	p
	Neutral	Pronated		
Contact Phase Left (step/t)	30.47±12.85	31.81±7.69	-0.28	0.78
Contact Phase Right (step/t)	27.20±13.72	32.27±7.72	-1.03	0.31
Foot flat Left (sec.)	38.77±19.49	38.52±10.33	0.03	0.97
Foot flat Right (sec.)	42.62±20.24	37.57±10.49	0.73	0.47
Propulsive Phase Left (sec.)	30.67±6.80	20.67±8.00	0.23	0.87
Propulsive Phase Right (sec.)	30.17±6.65	30.15±8.99	0.04	0.99
Contact Time Left (msec.)	42.52±14.11	50.34±15.37	-0.93	-0.36
Contact Time Right (msec.)	41.92±13.56	49.66±15.12	-0.93	0.35
Step Lenght Right (cm)	149.00±30.01	234.06±227.68	-0.73	0.47
Step Lenght Left (cm)	144±24.67	305.52±385.66	-0.82	0.42
Flight Time Left (sec)	51.77±14.88	50.92±15.61	0.99	0.92
Flight Time Right (sec)	50.97±14.82	51.69±15.29	0,03	0,97

t: Student t test

Treadmill Running Test Parameters that depending on time were compared according to foot position. Although contact phase, contact time, step lenght of the pronation mean values were higher on left sides, there was no statistically significant difference.

The mean values of flight time and foot flat varied right and left side of neutral and pronated foot position.

Table 7: The Comparision of Treadmill Running Test Parameters (that depending on Speed) according to Foot Position Right .

	Foot position Right		**t**	**p**
	Neutral	**Pronated**		
Contact Phase Left(step/t)	32.03±11.57	31.39±7.46	0.15	0.87
Contact Phase Right (step/t)	33.90±11.76	30.39±7.82	0.81	0.42
Foot flat Left (sec.)	36.80±17.24	39.23±9.81	-0.42	0.67
Foot flat Rigt (sec.)	34.11±17.13	40.13±10.19	-1.02	0.31
Propulsive Phase Left (sec.)	31.11±8.67	29.38±7.49	0.46	0.64
Propulsive Phase Right (sec.)	31.96±8.68	29.48±8.58	0.60	0.55
Contact Time Left (msec.)	46.90±19.51	49.68±13.84	-0.37	0.7
Contact Time Right (msec.)	46.48±18.84	48.91±13.75	-0.33	0.74
Flight Time Left(sec)	57.23±14.10	49.54±15.49	1.02	0.30
Flight Time Right(sec)	57.63±14.66	50.20±15.04	1.02	0,31

Student t test

Treadmill Running Test Parameters that depending on time were compared according to foot position. Individuals whose right foot was pronated, foot flat and contact time mean values were found to be higher than neutral foot position. The contact phase, propulsive phase and flight time mean values were found to be higher in individuals with a neutral right foot. In addition, while the contact phase mean values were higher in neutral, contact time mean values were higher in pronation. However, no statistically significant difference was found.

Table 8: The Comparision of Treadmill Running Test Parameters (that depending on Speed) according to Foot Position Left.

	Foot position Left		t	p
	Neutral	Pronated		
SpeedL (m/s)	3.46±3.50	3.50±0.21	-0.36	0.72
SpeedR	3.46±0.06	3.49±0.18	-0.31	0.75

Student t test

Table 9: The Comparision of Treadmill Running Test Parameters (that depending on Speed) according to Foot Position Right.

	Foot position Right		t	p
	Neutral	Pronated		
Speed Left (m/s)	3.52±0.20	3.48±0.19	0.35	0.73
Speed Right (m/s)	3.49±0.18	3.48±0.17	0.103	0.919

Student t test

Treadmill Running Test Parameters that depending on speed were compared according to foot position. Mean values were close to each other according to the neutral and pronated foot position in the left and right feet. Mean values of neutral foot position in the left foot were less than pronated foot position .Also, mean values of neutral foot position in the right foot were higher than pronation. However, there were not statistically significant.

Table 10 :The Comparision of Weight Bearing Lunge Test Parameters Parameters according to Foot Position Left

	Foot Position Left		t	p
	Neutral	Pronated		
Weight Bearing Lunge Test Left (°)	40.50±5.19	46.00±6.82	-1.50	0.15
Weight Bearing Lunge Test Right (°)	41.00±3.74	45.50±6.03	-1.41	0.09

Student t test

Table 11:The Comparision of Weight Bearing Lunge Test Parameters Parameters according to Foot Position Right.

	Foot Position Right		t	p
	Neutral	Pronated		
Weight Bearing Lunge Test Left (°)	42.00±7.77	46.00±6.07	-1.27	0.21
Weight Bearing Lunge Test Right (°)	43.17±8.08	45.25±5.04	-0.73	0.47

Student t test

Weight Bearing Lunge Test Parameters that depending on speed were compared according to foot position. Although the mean values of pronated foot position in the left and right foot were higher, there was no statistically significant difference was found.

Table 12: Assesments about Treadmill Runnig Test (TRT) Step Length –Left (cm)

		Step Length –Left (cm)
Contact Time – Right(msec.)	***r***	-0.552
	p	0.008**
Contact Time – Left(msec.)	***r***	-0.546
	p	0.009**

r: Spearman's rho ***p<0.01*

While there was a statistically significant negative correlation at 55.2% (medium) level between Treadmill Running Test (TRT) Step Length -L and TRT Contact Time -R measurements (p <0.01). Also, there was a statistically significant negative correlation between the TRT Step Length –L and TRT Contact Time –L measurements at 54.6% (medium) level (p <0.01).

Graph 2 : Graphics about Treadmill Running Test (TRT) Step Length –L

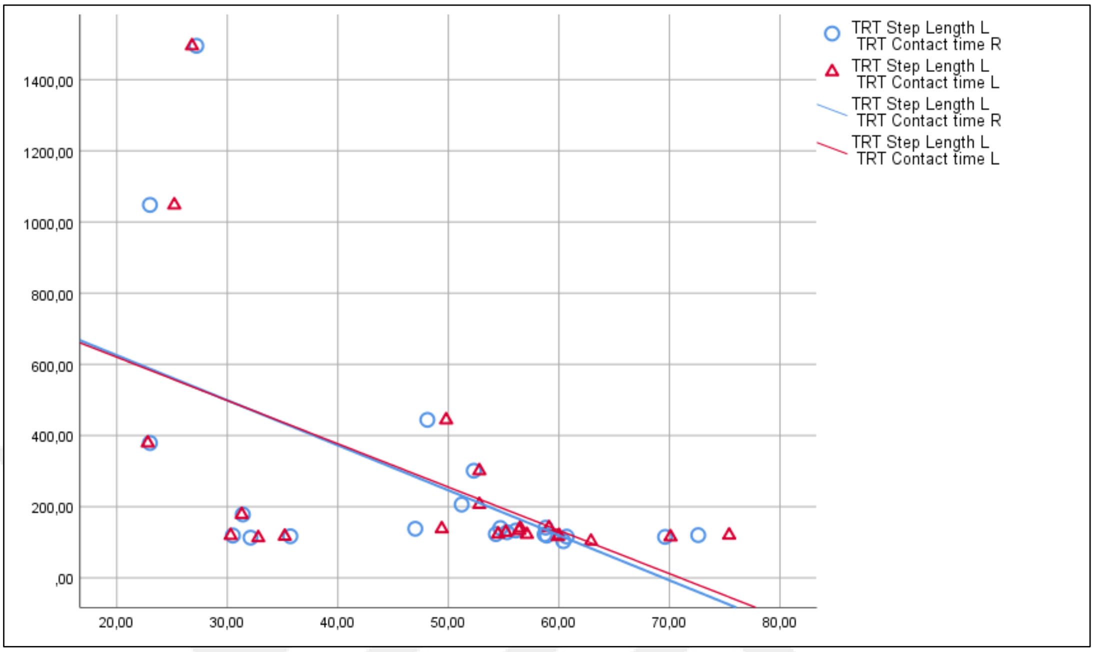


Table 13: Assesments about Treadmill Runnig Test (TRT) Step Length – Right(cm)

		Step Length –Right (cm)
Contact Time –Left (ms)	***r***	-0.574
	p	0.005**
Contact Time –Right (ms)	***r***	-0.583
	p	0.004**

r: Spearman's rho ***p<0.01*

There was a significant negative correlation between the Step Length -R and Contact Time -L measurements at the 57.4% (medium) level (p <0.01).In addition, there was a statistically significant negative correlation between the Step Length -R and Contact Time -R measurements at the 58.3% (medium) level (p <0.01).

Graph 3: Graphics about Treadmill Run Test (TRT) Step Length –R

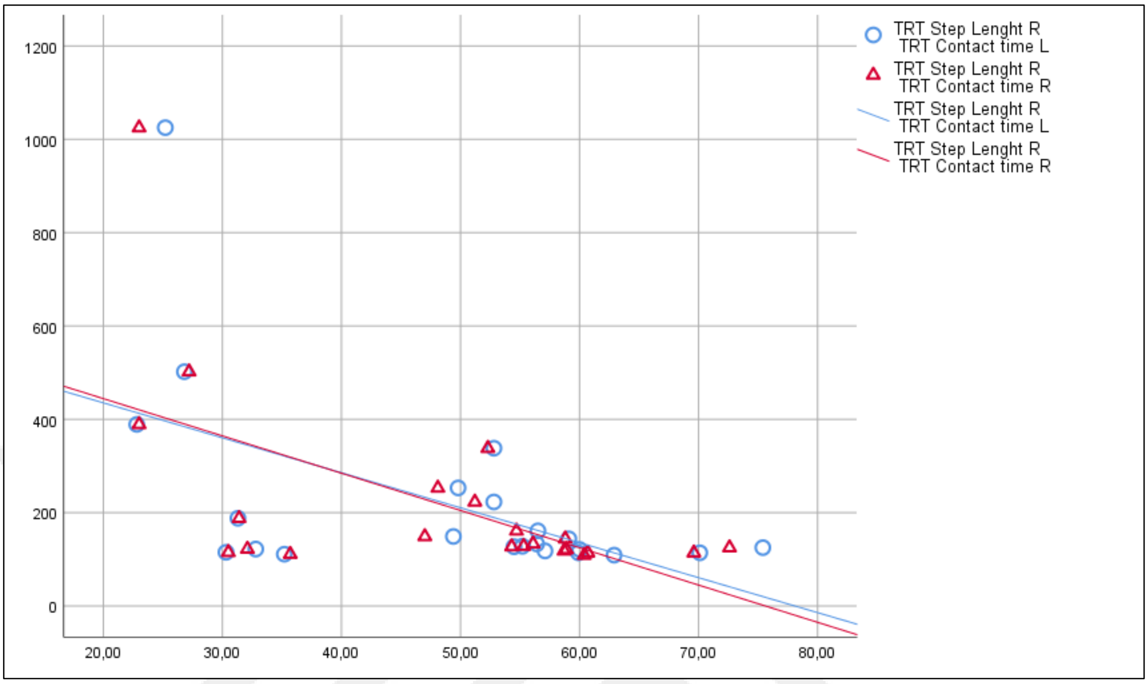


Table 14: Relationship between Treadmill Runnig Test (TRT) Stride Length (cm) and Treadmill Run Test (TRT) Contact Time(ms)

		Stride Length (cm)
Contact Time Left(ms)	***r***	-0.623
	p	0.002**
Contact Time Right (ms)	***r***	0.632
	p	0.002**

r: Spearman's rho *$**p<0.01$*

There was a statistically significant negative correlation between Treadmill Runnig Test (TRT) Stride Length and Treadmill Runnig Test (TRT) Contact Time-L at the 62.3% (good) level (p <0.01).Also, there was a statistically significant negative correlation between Treadmill Runnig Test (TRT) Stride Length and Treadmill Runnig Test (TRT) Contact Time-R at 63.2% (good) level (p <0.01). However, Treadmill Runnig Test (TRT) Contact Time Diff with TRT Stride Length. There was no statistically significant relationship between (p> 0.05).

Graph 4: Relationship between Treadmill Runnig Test (TRT)   Stride Length (cm) and TRT Contact Time(s)

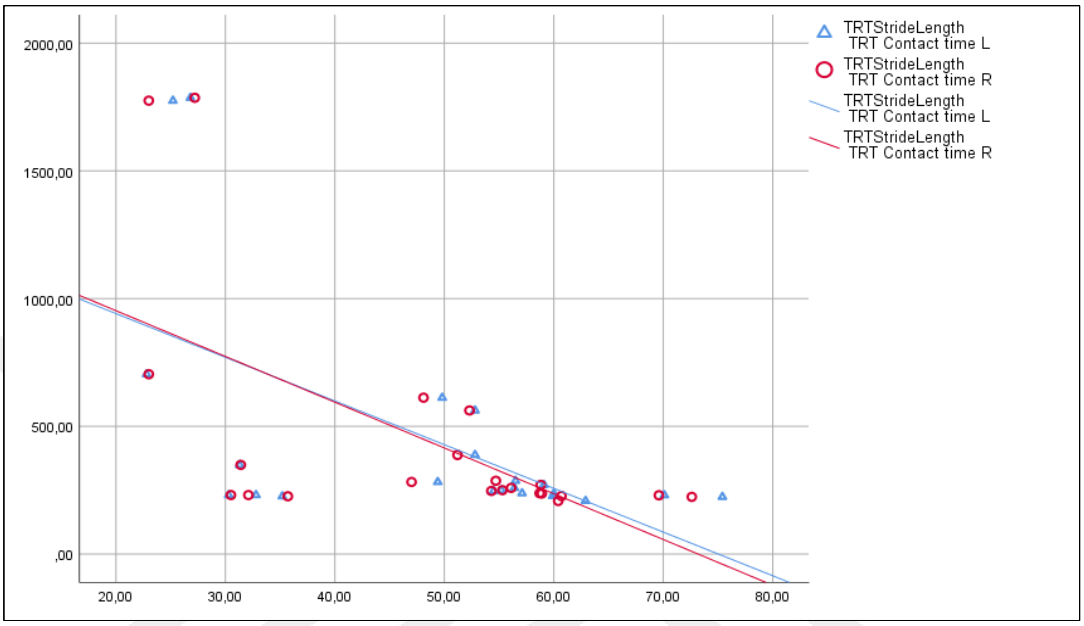


Table 15: Relationship between Treadmill Runnig Test (TRT) Contact Time(ms) Treadmill Run Test (TRT) Propulsive Phase (s)

		Contact Time –Left (ms)
Propulsive Phase –L (s)	***r***	-0.499
	p	0.018*
		Contact Time –Right (ms)
Propulsive Phase –R (s)	***r***	-0.494
	p	0.020*

r: Spearman's rho   **p<0.05*

Same side of the propulsive phase values and the contact phase values were related to each other. There was an inverse 49.9% (medium) significant correlation between TRT Contact Time –L and TRT Push Phase –L measurements ($p < 0.05$).Between the TRT Contact Time –R and the TRT Push Phase –R measurements, there is an inverse 49.4% (medium) significant relationship ($p < 0.05$).

Graph 5:Graphics of Relationship between Treadmill Runing Test (TRT) Contact Time (ms) Treadmill Run Test (TRT) Propulsive Phase (s)

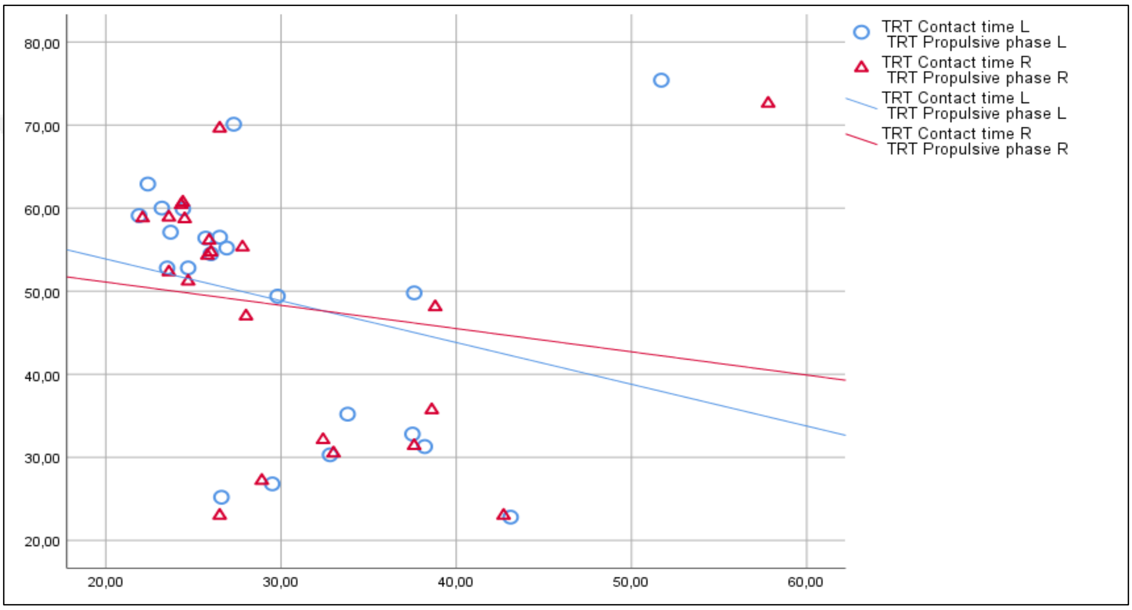


Table 16:Relationships between Treadmill Runnig Test (TRT) Height Difference (cm) and Squat Jump Test (SJT) Height (cm)

		TRT Height Difference (cm)
SJT Height (cm)	***r***	0.296
	p	1.193

r: Spearman's rho

There was no statistically significant relationship between the measurements of Squat Jump Test (SJT) Height measurements and Treadmill Runnig Test (TRT) Height Difference ($p > 0.05$)

Table 17:Relationship between Squat Jump Test (SJT) Height(cm) and Treadmill Running Test (TRT) Propulsive Phase

		Height (cm)
Propulsive Phase- L(s)	***r***	0.289
	p	0.204
Propulsive Phase- R (s)	***r***	0.340
	p	0.132

r: Pearson correlation coff.

There was no statistically significant relationship between SJT Height and TRT Propulsive Phase-L (p> 0.05). There is no statistically significant relationship between SJT Height and TRT Propulsive Phase-R (p> 0.05).

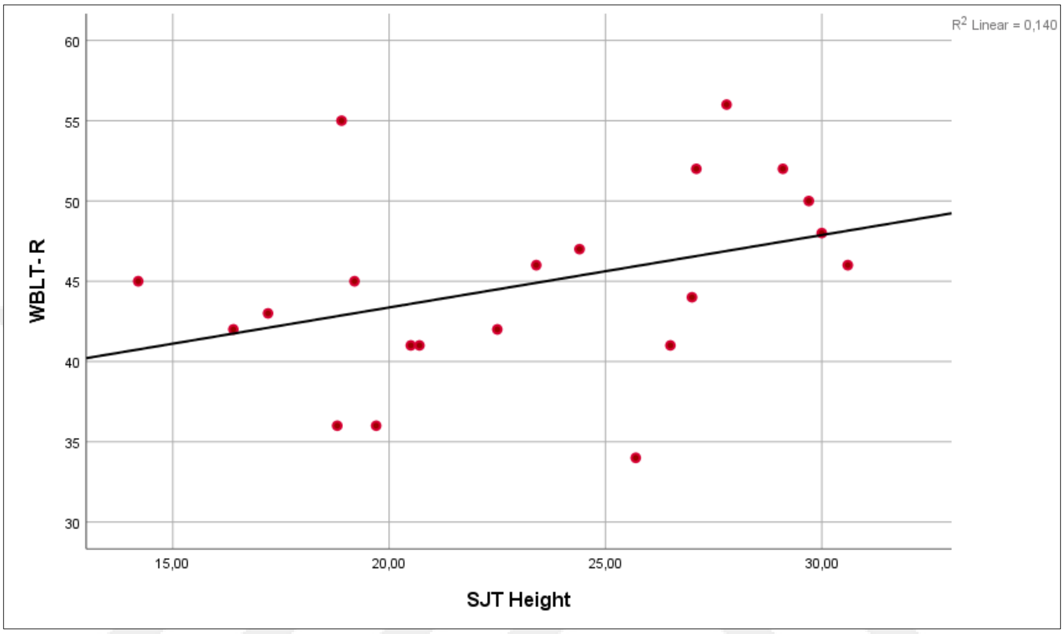
Table 18: Relationships between Weight Bearing Lunge Test (WBLT) and Squat Jump Test (SJT) Height

		Weight Bearing Lunge Test Left (°)	**Weight Bearing Lunge Test Right**(°)
Height(cm)	***r***	0.279	-0.447
	p	0.220	0.042*

r: Spearman's rho **p<0.05*

Weight Bearing Lunge Test Right and Squat Jump Test Height values were found to be statistically significant. (p <0.05)

Graph 6 : Graphics Relationships between Weight Bearing Lunge Test (WBLT) and Squat Jump Test (SJT) Height



While there was no significant correlation between Weight Bearing Lunge Test (WBLT) -L and Squat Jump Test (SJT) T Flight (p> 0.05), there was a significant relationship between Weight Bearing Lunge Test -R and Squat Jump Test T Flight to see 44.7% (middle) in the opposite direction (p <0.05).

Table 19: Relationships between Squat Jump Test (SJT) Height(cm) and Footbalance (FB) Foot Arch

		Squat Jump Test (SJT) Height
Foot Arch– Left	**Nötral (n=5)**	21.52±5.59
	Pesplanus (n=16)	23.86±4.79
	P	0.369
Foot Arch– Right	**Nötral (n=5)**	21.52±5.59
	Pesplanus (n=16)	23.86±4.79
	p	0.369

Student t test

There was no statistically significant difference between SJT Height measurements according to FB Base Type -L status (p> 0.05). There was no statistically significant difference between SJT Height measurements according to FB Base Type -R (p> 0.05).

Table 20: Predictors of Treadmill Running Test (TRT) Height- Right , Height – Left , Contact phase- Right parameters by linear regression analysis

Predictors	Standardized Coefficients (β)	Unstandardized Coefficients	±SEM	Significance(p)
Height (cm) Right	1.96	1.68	0.24	0.00
Height (cm) Left	-1.03	-0.98	0.27	0.03
Contact phase (step/t) Right	-0.11	-1.00	0.40	0.027
Constant	-	-	-	0.00

Dependent Variable: Treadmill Running Test Step Lenght Right

R= 0.98 R^2=0.97 Adjusted R^2=0.96 ±SEM: standart error of the mean

(adjusted model aldığım b.siz değişkenlerin, b.lı değişkeni açıklama düzeyi 1 e yakın olsun istenir.

The multiple linear regression analysis results showed that Treadmill Running Test (TRT) Height- Right , Height – Left , Contact phase- Right parameters were significantly related to Treadmill Running Test (TRT) Step Lenght Right parameters. Treadmill Running Test (TRT) Height- Right were associated positively with Treadmill Running Test Step Lenght Right (R = 0.98). (β = 1.96) Treadmill Running Test Height Left (β = -1.03) and Contact phase Right (β = -0.11) reduce negatively.

Table 21 : Predictors of Treadmill Running Test (TRT) Height- Right , Contact phase- Right parameters by linear regression analysis

Predictors	Standardized Coefficients (β)	Unstandardized Coefficients	±SEM	Significance(p)
Height (cm) Right	0.96	0.75	0.37	0.00
Contact phase (step/t) Right	-0.10	-0.85	0.50	0.03
Constant	-	149.11	12.50	0.00

Dependent Variable: Treadmill Running Test Step Lenght Left

R= 0.98 R^2=0.96 Adjusted R^2=0.96 ±SEM: standart error of the mean

The multiple linear regression analysis results showed that Treadmill Running Test (TRT) Height- Right , Contact phase- Right parameters were significantly related to Treadmill Running Test (TRT) Step Lenght Left parameters. Treadmill Running Test Height Right, which positively affected the Treadmill Running Test Step Lenght Left value, was found. (β = 1.96) Contact phase Right (β = -0.10) reduce negatively.

5. DISCUSSION

The findings of the study indicated that there was a negative correlation between stride length and step length in contact time and contact phase among amateur runners. In addition, there was a positive correlation between running height and contact phase and step lenght. Although the maximal vertical jump is higher in runners with a high ankle dorsiflexion angle, there was no statistically significant relationship between postural parameters of the foot and biomechanical running parameters. Moreover, no relationship was observed between the height of the foot in running from the ground and the maximal vertical jump height.

It is thought that evaluating dynamic parameters as well as static posture evaluations is of great importance to give suggestions that will improve performance for amateur runners. For amateur runners at a certain level, reaction time drills based on the height of the ground, contact phase and duration of the foot, midfoot- forefoot running drills and horizontal jumps exercises, proprioception-balance exercises can be recommended to increase the step length and stride lenght that will affect the running performance. In addition, ankle mobility exercise recommendations can be made to increase vertical jumping performance in runners.

In our study, while 76 percent of the participants had pes planus, there were no orthopedic injury with the lower extremities. Furthermore, the mean values were positive on both the left and right foot when we examined the total mean values of the participants in the foot posture index. Therefore, this suggested that the participants of foot postures were generally in pronation.

In the literature it was indicated that lower limb structural variations have also been suggested to contribute to mechanical deviations that bring runners at an increased risk of injury. Therefore, when exposed to the stress of athletic activities, the flatfoot results in irregular loading and rotational forces on the foot and lower extremity that contribute to injury.[111,112] The study showed that rigid orthotics intended to restrict the pronation of pes planus did not demonstrate that the medial lateral ground reaction forces on the foot were significantly changed.[113] Likewise, in our study, Treadmill Running Test Parameters that depending on lenght, time and speed were compared according to foot position, therewere no statistically significant difference. The impact absorber during pronation and the lever arm for propulsion during the stance phase. This makes it possible for the foot and ankle to work properly during supination.[4,33] It is considered that there may be other parameters besides foot position assessment that affect the foot flat phase during running. However, we could not found relationship between structural variations and injury among nonelite athles. It is thought that increasing the number of participants and prolonging the running test may improve the study.

In a study with 24 participants, the dorsiflexion angle was measured in individuals with pes planus and pes cavus. Weight Bearing Lunge angle in the pes cavus group was significantly less than the normal and pes planus groups. A strong, positive correlation was identified between tendo-Achilles length and foot type.[114] Similar to this study, the dorsiflexion angle was higher in individuals with pes planus in our study.

Two significant parameters that regulate horizontal acceleration were the stride length and stride speed in running.[115] Based on this, Treadmill Running Test step length and contact time analysis, It has been stated that the step length of individuals running increases as the foot contact with the ground decreases in our study.

In order to running speed to be high, braking ground reaction forces must be low, trust ground reaction forces must be increased. In order to achive this, the athlete must first reduced the braking ground reaction forces.[4] Although one leg that is in the swing phase, the step length increases during the runnig. At the same time, the other leg which is in the stance phase, the contact time and contact phase decreases. Similarly, stride length and contact time are inversely related to each other for both extremities. This state is often seen in individuals who have just started running because they do not have reached their professional running form yet. During running, it is thought that drill exercises and strength exercises that will reduce ground reaction foce will positively affect running performance.

According to the results of Treadmil Running Test contact time and propulsive phase measurements, when the contact time increases, propulsive phase decreases on the same side. In order to other reserches, as the foot's contact time with the ground increases, the effect of the push off phase decreases.[5] The reduced effect in the push off phase causes the runner to run a lesser distance in the horizontal and vertical plane.[4]

Hunter et al. reported that high vertical velocity increased flight distance and therefore step length. In this case, they concluded that the vertical speed at the moment of push-off is the kinematic parameter that causes a negative interaction between the step length and the step speed.[115] In our study, no relationship was found between the maximal vertical jump height and the height of the foot in flight during running. Similarly, no relationship was found between the maximal vertical jump height and the impulse phase in running.This is concluded that the maximal vertical jumping capacity will not affect the step length and stride lenght, Also, it is sufficient to raise the foot high enough to prevent foot contact with the ground in straight road runing.In addition, it suggests that the horizontal component of the propulsive phase during running is more important in moving front than the vertical component. All this suggests that maximal vertical jumping capacity alone will not support running performance and improvement. In this context, the major purpose in running is the Forward (sagittal) movement in the horizontal plane.

In a study investigating that effects of the reduction of ankle mobility on the jumping performance of young soccer athletes, through a validated jump platform valued and test, found that found that the ankle dorsiflexion angle affects the maximal vertical jump and the vertical jump is impaired by the ankles' mobility deficit. [116] In addition, our study demonstrated that as the ankle dorsiflexion flexibility increases, the maximal jump height in the frontal plane also increases as well. Ankle Joint mobility is considered to affect dynamic functional vertical jump strength in a positive way. Regularly made ankle mobility exercises is also considered to have a positive effect on jumping performance and running related ınjuries.

Chang et al. during level of walking foot arch height was gradually decreased in loading phase but suddenly increased in push-off phase, vertical jump and sprint start. Vertical jump and sprint start required significantly greater ranges of arch height change than level walking. The information obtained from this study enhanced our understanding of the changes of the human foot arch in static standing and dynamic athletic activities.[117] Similarly, ın our study, according to the Squat Jump Test Height and Foot Arch analysis results, suggested that the arch of the foot can not affect the jumping performance during standing, the arch of the sole of the foot can change functionally with dynamic movements, and the important thing is the ability of the foot arch to adapt to these functions. It is believed that flexibilty, mobility and strength exercises that will increase foot arch mobility will improve the ability of the foot to adapt to movement.

In running, the horizontal speed should be higher than the vertical speed. For this reason, the athlete should keep the horizontal speed as high as possible and the ground height of the center of gravity as low as possible in order to increase the speed.[4] While sprinters have a long pitch, vertical displacement of their center of gravity is less. The contact time and surface of their feet with the ground is less. [4] Likewise, in our study Treadmill Running Test height- right are associated positively with step lenght right (R = 0.98), (β = 1.96). Treadmill Running Test Height Left (β = -1.03) and contact phase right (β = -0.11) reduce negatively. Treadmill Running Test Height Right, which positively affected the step lenght left value, was found. (β = 1.96) contact phase right (β = -0.10) reduce negatively Height right positively affects TRT step Lenght right. Height left and contact phase right affect TRT step length right negatively. So, step length right increases as height right increases. Height left and contact phase decreases as they increase.

In conclusion, ıt is thought that the important to consider dynamic biomechanical parameters in addition to static posture evaluations such as foot posture and foot arch analysis in order to provide recommendations to improve performance and prevent injuries for Amateur Runners with have a spesific race schedule. In order to increase the step length and stride length that will affect running performance, reaction time drills based on the height, contact phase and contact time of the foot, midfoot- forefoot running drills and horizontal jogging- jumping exercises, proprioception-balance exercises can be recommended to amateur runners. In addition to these, ankle mobility and flexibility and strength exercises that can increase the ability of the foot arch to adapt to movement can be recommended to increase vertical jump performance and prevent injuries in runners

In future studies that will evaluate the relationship between running biomechanic parameters and jump height, it is thought that increasing the number of participants and prolonging the running test will contribute to reliability of the study.

It is thought that evaluating dynamic parameters as well as static posture evaluations may have great importance to give suggestions that will improve performance for amateur runners. For amateur runners at a certain level, reaction time drills based on the height of the ground, contact phase and duration of the foot, midfoot- forefoot running drills and horizontal jumps exercises, proprioception-balance exercises can be recommended to increase the step length and stride lenght that will affect the running performance. In addition, ankle mobility exercise recommendations can be made to increase vertical jumping performance in runners.

REFERENCES

1. Rubenson J, Heliams DB, Lloyd DG, Fournier PA. Gait selection in the ostrich: mechanical and metabolic characteristics of walking and running with and without an aerial phase. *Proceedings of the Royal Society of London. Series B: Biological Sciences.* 2004;271(1543):1091-1099.
2. Dugan SA, Bhat KP. Biomechanics and analysis of running gait. *Physical medicine and rehabilitation clinics.* 2005;16(3):603-621.
3. Anderson T. Biomechanics and running economy. *Sports Medicine.* 1996;22(2):76-89.
4. İnal S. Spor ve Egzersizde Vücut Biyomekaniği. *Spor ve Egzersizde Vücut Biyomekaniği*: Hipokrat Kitapevi 2017:225-237.
5. Souza RB. An evidence-based videotaped running biomechanics analysis. *Physical medicine and rehabilitation clinics.* 2016;27(1):217-236.
6. Johnston C, Taunton J, Lloyd-Smith D, McKenzie D. Preventing running injuries. Practical approach for family doctors. *Canadian Family Physician.* 2003;49(9):1101-1109.
7. Vannatta CN, Heinert BL, Kernozek TW. Biomechanical risk factors for running-related injury differ by sample population: A systematic review and meta-analysis. *Clinical biomechanics.* 2020;75.
8. Hreljac A. Impact and overuse injuries in runners. *Medicine & Science in Sports & Exercise.* 2004;36(5):845-849.
9. Davis IS. The re-emergence of the minimal running shoe. *journal of orthopaedic & sports physical therapy.* 2014;44(10):775-784.
10. Lieberman DE, Venkadesan M, Werbel WA, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature.* 2010;463(7280):531-535.
11. Barton CJ, Lack S, Malliaras P, Morrissey D. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. *British journal of sports medicine.* 2013;47(4):207-214.
12. Perry J, Davids JR. Gait analysis: normal and pathological function. *Journal of pediatric orthopaedics.* 1992;12(6):815.
13. Frigo C, Crenna P. Multichannel SEMG in clinical gait analysis: a review and state-of-the-art. *Clinical biomechanics.* 2009;24(3):236-245.
14. Karamanidis K, Arampatzis A, Brüggemann G-P. Reproducibility of electromyography and ground reaction force during various running techniques. *Gait & posture.* 2004;19(2):115-123.
15. Lienhard K, Schneider D, Maffiuletti NA. Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. *Medical engineering & physics.* 2013;35(4):500-504.
16. http://www.optojump.com/.
17. Sancho I, Malliaras P, Barton C, Willy RW, Morrissey D. Biomechanical alterations in individuals with Achilles tendinopathy during running and hopping: A systematic review with meta-analysis. *Gait & posture.* 2019;73:189-201.
18. Chan CW, Rudins A. Foot biomechanics during walking and running. Paper presented at: Mayo Clinic Proceedings1994.
19. Goo Y-M, Kim T-H, Lim J-Y. The effects of gluteus maximus and abductor hallucis strengthening exercises for four weeks on navicular drop and lower extremity muscle activity during gait with flatfoot. *Journal of physical therapy science.* 2016;28(3):911-915.
20. Wright WG, Ivanenko YP, Gurfinkel VS. Foot anatomy specialization for postural sensation and control. *Journal of neurophysiology.* 2012;107(5):1513-1521.

21. Abboud R. (i) Relevant foot biomechanics. *Current Orthopaedics.* 2002;16(3):165-179.

22. Ali M, Ullah MA, Amjad I. Prevalence of the flat foot in 6-10 years old school going children. *Rawal Medical Journal.* 2013;38(4):385-387.

23. Dowling A, Steele J, Baur L. Does obesity influence foot structure and plantar pressure patterns in prepubescent children? *International journal of obesity.* 2001;25(6):845-852.

24. Evans AM. The paediatric flat foot and general anthropometry in 140 Australian school children aged 7-10 years. *Journal of foot and ankle research.* 2011;4(1):12.

25. Kapandji IA. The physiology of the joint. *lower limb.* 1987;2.

26. Homayouni K, Karimian H, Naseri M, Mohasel N. Prevalence of flexible flatfoot among school-age girls. *Shiraz E-Medical Journal.* 2015;16(2).

27. Hertel J, Sloss BR, Earl JE. Effect of foot orthotics on quadriceps and gluteus medius electromyographic activity during selected exercises. *Archives of physical medicine and rehabilitation.* 2005;86(1):26-30.

28. Dicharry J. Kinematics and kinetics of gait: from lab to clinic. *Clinics in sports medicine.* 2010;29(3):347-364.

29. İnal H. Spor ve Egzersizde Vücut Biyomekaniği. *Papatya Yayınevi, İstanbul.* 2013.

30. Nicola TL, Jewison DJ. The anatomy and biomechanics of running. *Clinics in sports medicine.* 2012;31(2):187-201.

31. Ounpuu S. The biomechanics of walking and running. *Clinics in sports medicine.* 1994;13(4):843-863.

32. Perry J. Anatomy and biomechanics of the hindfoot. *Clinical orthopaedics and related research.* 1983(177):9-15.

33. Abt JP, Sell TC, Chu Y, Lovalekar M, Burdett RG, Lephart SM. Running kinematics and shock absorption do not change after brief exhaustive running. *The Journal of Strength & Conditioning Research.* 2011;25(6):1479-1485.

34. De Wit B, De Clercq D, Aerts P. Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of biomechanics.* 2000;33(3):269-278.

35. Oatis CA. Biomechanics of the foot and ankle under static conditions. *Physical therapy.* 1988;68(12):1815-1821.

36. Inman VT, Ralston HJ, Todd F. *Human walking.* Williams & Wilkins; 1981.

37. Mulligan E. Leg, ankle, and foot rehabilitation. *Physical rehabilitation of the injured athlete. 3rd edition. Philadelphia: WB Saunders.* 2004:329-376.

38. Elftman H. The transverse tarsal joint and its control. *Clinical Orthopaedics and Related Research®.* 1960;16:41-46.

39. Czerniecki JM. Foot and ankle biomechanics in walking and running. A review. *American journal of physical medicine & rehabilitation.* 1988;67(6):246-252.

40. Donatelli R. Normal biomechanics of the foot and ankle. *journal of orthopaedic & sports physical therapy.* 1985;7(3):91-95

41. Mann R. Biomechanics of running. *Running Injuries.* 1989:1-20.

42. Novacheck TF. The biomechanics of running. *Gait & posture.* 1998;7(1):77-95.

43. Reber L, Perry J, Pink M. Muscular control of the ankle in running. *The American journal of sports medicine.* 1993;21(6):805-810.

44. Hamner SR, Seth A, Delp SL. Muscle contributions to propulsion and support during running. *Journal of biomechanics.* 2010;43(14):2709-2716.

45. Sinning W, Forsyth H. Lower-limb actions while running at different velocities. *Medicine and science in sports.* 1970;2(1):28-34.

46. Hockenbury RT. Forefoot problems in athletes. *Medicine and science in sports and exercise.* 1999;31(7 Suppl):S448.

47. Schache AG, Bennell KL, Blanch PD, Wrigley TV. The coordinated movement of the lumbo–pelvic–hip complex during running: a literature review. *Gait & posture.* 1999;10(1):30-47.
48. Magee DJ, Manske RC. *Orthopedic physical assessment-E-Book.* Elsevier health sciences; 2020.
49. Williams K, Cavanagh P. Biomechanical correlates with running economy in elite distance runners. Paper presented at: proceedings of the North American Congress on Biomechanics1986.
50. Elliott B, Blanksby B. Optimal stride length considerations for male and female recreational runners. *British journal of sports medicine.* 1979;13(1):15.
51. Pohl MB, Mullineaux DR, Milner CE, Hamill J, Davis IS. Biomechanical predictors of retrospective tibial stress fractures in runners. *Journal of biomechanics.* 2008;41(6):1160-1165.
52. Pontzer H, Holloway JH, Raichlen DA, Lieberman DE. Control and function of arm swing in human walking and running. *Journal of Experimental Biology.* 2009;212(4):523-534.
53. optojump. user manual. manual version 1.12.1 , software version 1.12.
54. Esquenazi A. Clinical application of joint kinetic analysis in gait. *Physical Medicine and Rehabilitation.* 2002;16(2):201.
55. Chin M. Clinical Use of Gait Analysis for the Athlete. *Athletic Footwear and Orthoses in Sports Medicine*: Springer; 2017:55-65.
56. Finley FR, Karpovich PV. Electrogoniometric analysis of normal and pathological gaits. *Research Quarterly. American Association for Health, Physical Education and Recreation.* 1964;35(3):379-384.
57. Frigo C, Rabuffetti M, Kerrigan D, Deming L, Pedotti A. Functionally oriented and clinically feasible quantitative gait analysis method. *Medical and Biological Engineering and Computing.* 1998;36(2):179-185.
58. Della Croce U, Cappozzo A, Kerrigan DC. Pelvis and lower limb anatomical landmark calibration precision and its propagation to bone geometry and joint angles. *Medical & biological engineering & computing.* 1999;37(2):155-161.
59. SKINNER J, Hutsler R, Bergsteinova V, Buskirk E. Perception of effort during different types of exercise and under different environmental conditions. *Medicine and science in sports.* 1973;5(2):110-115.
60. Cavanagh PR, Kram R. Stride length in distance running: velocity, body dimensions, and added mass effects. *Med Sci Sports Exerc.* 1989;21(4):467-479.
61. Beasley W. Quantitative muscle testing: principles and applications to research and clinical services. *Archives of physical medicine and rehabilitation.* 1961;42:398.
62. Waters RL, RL W. ENERGETICS: APPLICATION TO THE STUDY AND MANAGEMENT OF LOCOMOTOR DISABILITIES. 1978.
63. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *The Journal of Strength & Conditioning Research.* 2011;25(2):556-560.
64. Ziv G, Lidor R. Vertical jump in female and male basketball players—A review of observational and experimental studies. *Journal of science and medicine in sport.* 2010;13(3):332-339.
65. Barnes KR, Kilding AE. Running economy: measurement, norms, and determining factors. *Sports medicine-open.* 2015;1(1):1-15.
66. Saunders PU, Pyne DB, Telford RD, Hawley JA. Reliability and variability of running economy in elite distance runners. *Medicine & Science in Sports & Exercise.* 2004;36(11):1972-1976.

67. Assumpção CdO, Lima LCR, Oliveira FBD, Greco CC, Denadai BS. Exercise-induced muscle damage and running economy in humans. *The Scientific World Journal.* 2013;2013.

68. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. *Sports Medicine.* 2004;34(7):465-485.

69. THOMAS DQ, Fernhall B, GRANAT H. Changes in running economy during a 5-km run in trained men and women runners. *The Journal of Strength & Conditioning Research.* 1999;13(2):162-167.

70. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. *Med Sci Sports Exerc.* 1980;12(5):357-360.

71. Morgan D, Baldini FD, Martin PE, Kohrt WM. Ten kilometer performance and predicted velocity at VO2max among well-trained male runners. *Medicine and science in sports and exercise.* 1989;21(1):78-83.

72. He Z, Hu Y, Feng L, et al. NRF2 genotype improves endurance capacity in response to training. *International journal of sports medicine.* 2007;28(09):717-721.

73. Rodas G, Calvo M, Estruch A, et al. Heritability of running economy: a study made on twin brothers. *European journal of applied physiology and occupational physiology.* 1998;77(6):511-516.

74. Pate RR, Macera CA, Bailey SP, Bartoli WP, Powell KE. Physiological, anthropometric, and training correlates of running economy. *Medicine and science in sports and exercise.* 1992;24(10):1128-1133.

75. Hoogkamer W, Kipp S, Spiering BA, Kram R. Altered running economy directly translates to altered distance-running performance. *Medicine & Science in Sports & Exercise.* 2016;48(11):2175-2180.

76. Daniels JT. A physiologist's view of running economy. *Medicine and science in sports and exercise.* 1985;17(3):332-338.

77. Thorstensson A. Effects of moderate external loading on the aerobic demand of submaximal running in men and 10 year-old boys. *European journal of applied physiology and occupational physiology.* 1986;55(6):569-574.

78. Davies C, Thompson M. Aerobic performance of female marathon and male ultramarathon athletes. *European journal of applied physiology and occupational physiology.* 1979;41(4):233-245.

79. Cooke C, McDonagh M, Nevill A, Davies C. Effects of load on oxygen intake in trained boys and men during treadmill running. *Journal of applied physiology.* 1991;71(4):1237-1244.

80. Davies C. Metabolic cost of exercise and physical performance in children with some observations on external loading. *European journal of applied physiology and occupational physiology.* 1980;45(2-3):95-102.

81. Abe D, Fukuoka Y, Muraki S, Yasukouchi A, Sakaguchi Y, Niihata S. Effects of load and gradient on energy cost of running. *Journal of physiological anthropology.* 2011;30(4):153-160.

82. Catlin M, Dressendorfer R. Effect of shoe weight on the energy-cost of running. Paper presented at: Medicine and science in sports and exercise1979.

83. Warne J, Warrington G. Four-week habituation to simulated barefoot running improves running economy when compared with shod running. *Scandinavian journal of medicine & science in sports.* 2014;24(3):563-568.

84. Frederick E. Physiological and ergonomics factors in running shoe design. *Applied ergonomics.* 1984;15(4):281-287.

85. Roberts TJ, Chen MS, Taylor CR. Energetics of bipedal running. II. Limb design and running mechanics. *Journal of Experimental Biology.* 1998;201(19):2753-2762.

86. Ker R, Bennett M, Bibby S, Kester R, Alexander RM. The spring in the arch of the human foot. *Nature.* 1987;325(6100):147-149.

87. Scholz MN, Bobbert MF, Van Soest A, Clark JR, van Heerden J. Running biomechanics: shorter heels, better economy. *Journal of Experimental Biology.* 2008;211(20):3266-3271.

88. Raichlen DA, Armstrong H, Lieberman DE. Calcaneus length determines running economy: implications for endurance running performance in modern humans and Neandertals. *Journal of Human Evolution.* 2011;60(3):299-308.

89. Nelson RC, Gregor RJ. Biomechanics of distance running: a longitudinal study. *Research Quarterly. American Alliance for Health, Physical Education and Recreation.* 1976;47(3):417-428.

90. Moore IS, Jones AM, Dixon SJ. Mechanisms for improved running economy in beginner runners. *Medicine & Science in Sports & Exercise.* 2012;44(9):1756-1763.

91. Hogberg P. How do stride length and stride frequency influence the energy-output during running? *Arbeitsphysiologie.* 1952;14:437-441.

92. Morgan D, Bransford DR, Costill DL, Daniels JT, Howley ET, Krahenbuhl GS. Variation in the aerobic demand of running among trained and untrained subjects. *Medicine and science in sports and exercise.* 1995;27(3):404-409.

93. Morgan D, Martin P. Effects of stride length alteration on racewalking economy. *Canadian journal of applied sport sciences. Journal canadien des sciences appliquees au sport.* 1986;11(4):211-217.

94. Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. *Medicine and science in sports and exercise.* 1982;14(1):30.

95. Di Michele R, Merni F. The concurrent effects of strike pattern and ground-contact time on running economy. *Journal of science and medicine in sport.* 2014;17(4):414-418.

96. Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. *Journal of applied physiology.* 1987;63(3):1236-1245.

97. Tartaruga MP, Brisswalter J, Peyré-Tartaruga LA, et al. The relationship between running economy and biomechanical variables in distance runners. *Research Quarterly for Exercise and Sport.* 2012;83(3):367-375.

98. Heise GD, Martin PE. Are variations in running economy in humans associated with ground reaction force characteristics? *European Journal of Applied Physiology.* 2001;84(5):438-442.

99. McMahon TA, Valiant G, Frederick EC. Groucho running. *Journal of applied physiology.* 1987;62(6):2326-2337.

100. Hinrichs RN. Upper extremity function in distance running. *Biomechanics of distance running.* 1990;4:107-133.

101. Anderson T, Tseh W. 955 RUNNING ECONOMY, ANTHROPOMETRIC DIMENSIONS AND KINEMATIC VARIABLES. *Medicine & Science in Sports & Exercise.* 1994;26(5):S170.

102. Kram R, Taylor CR. Energetics of running: a new perspective. *Nature.* 1990;346(6281):265-267.

103. Murley GS, Menz HB, Landorf KB. A protocol for classifying normal-and flat-arched foot posture for research studies using clinical and radiographic measurements. *Journal of foot and ankle research.* 2009;2(1):22.

104. Redmond AC, Crane YZ, Menz HB. Normative values for the foot posture index. *Journal of foot and ankle research.* 2008;1(1):6.

105. Powden CJ, Hoch JM, Hoch MC. Reliability and minimal detectable change of the weight-bearing lunge test: a systematic review. *Manual therapy.* 2015;20(4):524-532.

106. https://drjustinhildebrand.com/rehab-exercise/297-2/ JHB.

107. Sander S. Yoga Poses: Pigeon Pose (Kapotasana)| Tips, Benefits, and Follow-up Poses.

108. Mears SC, Wilson MR, Mannen EM, Tackett SA, Barnes CL. Position of the Hip in Yoga. *The Journal of arthroplasty.* 2018;33(7):2306-2311.

109. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British journal of sports medicine.* 2013;47(15):953-959.

110. https://theprehabguys.com/video-library/ Half Kneeling Thoracic Windmill – Closed B.

111. Wen DY. Risk factors for overuse injuries in runners. *Current sports medicine reports.* 2007;6(5):307-313.

112. Michelson JD, Durant D, McFarland E. The injury risk associated with pes planus in athletes. *Foot & ankle international.* 2002;23(7):629-633.

113. Miller CD, Laskowski ER, Suman VJ. Effect of corrective rearfoot orthotic devices on ground reaction forces during ambulation. Paper presented at: Mayo Clinic Proceedings1996.

114. Burns J, Crosbie J. Weight bearing ankle dorsiflexion range of motion in idiopathic pes cavus compared to normal and pes planus feet. *The Foot.* 2005;15(2):91-94.

115. Hunter I, Smith GA. Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. *European Journal of Applied Physiology.* 2007;100(6):653-661.

116. 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.

117. Chang Y-W, Hung W, Wu H-W, Chiu Y-C, Hsu H-C. Measurements of foot arch in standing, level walking, vertical jump and sprint start. *International Journal of Sport and Exercise Science.* 2010;2(2):31-38.