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The Effect Of Gender And Weekly Running Distance On Running – Related Injury Patterns And Prevalence In Short, Middle And Long-Distance Runners.

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ABSTRACT

Background: Running-related injuries constitute a major health concern, especially with increases in recreational running and a growing number of distance running events. Literature broadly suggests that females could be at greater risk of sustaining traumas than males, but specific risk factors are unclear. Distance has also been shown to affect injury occurrence in runners, however to date, no protective threshold has been established in the amount of mileage per week.

Aim: To investigate the effects of gender and weekly distance on lower extremity injury prevalence in runners.

Methods: This research consisted of two studies. Study one was a retrospective cohort study, which was designed to investigate the prevalence of running-related injuries and establish trends in short, middle- and long-distance runners. Anonymised self-reported data related to running routine of 386 females and 614 males who attended a sports clinic for footwear prescription were sampled and analysed. The second study investigated 26 middle-distance runners (13 males and 13 females) in relation to their foot mobility, lower limb function and gait biomechanics through variety of static clinically recognised tests, such as Foot Posture Index, Windlass Mechanism, Supination Resistance and Single Leg Squat Tests and dynamic 2-dimensional video analysis.

Results: According to data in Study 1, both male and female runners in all distance groups were found to be at a very high risk of self -reported running-related traumas (80.5%-86.9%) and distance was not established as an injury risk factor ($p > 0.05$). Females had greater injury rates than males in each distance group, with the greatest difference observed in middle distance runners (females 91.5%, males 76.0%). Knee injuries were the most common traumas reported by each population, followed by the foot and shank. A significantly higher number of hip injuries were reported by females than males. According to data in Study 2, male middle-distance runners were found to suffer from knee (40%), shank (30%) and foot injuries (20%). In females, hip (33.3%), ankle (33.3%) and foot injuries (33.3%) were most common. Males and females also exhibited different characteristics in relation to foot mobility and knee motion pathway. Additionally, a positive relationship between injury occurrence and supination resistance was found in the left foot ($p < 0.05$).

Conclusion: Overall, all runners were found to be at a high injury risk, regardless of running distance, which was found not to be significant for injury prevalence. Females were found to be at a high, and significantly greater, risk of running-related issues compared to males, which was not explained by training habits. Although males and females showed similarity in patterns of injury, it was hypothesised that the underlying pathway of those injuries might differ between runners due to variety of internal factors associated with gender. Females had more pronated and flexible feet than males. Further research should focus on investigating how foot and lower limb mobility, body anatomy and hormonal status affects movement biomechanics in males and females to develop strategies to protect runners from running related issues through exercise, footwear recommendation and gait education.

CONTENT

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Chapter I: Background and Introduction

Running constitutes a basic form of human locomotion and is an inseparable component required for any sport (Stoggl and Wunsch, 2016). The fundamental physiological principle in running motion is to generate and maintain a constant energy production from both aerobic and anaerobic capacity and enable transfer of that kinetic energy into forward motion (Ristolainen *et al,* 2009).

Due to the affordability and accessibility, running has now become more popular than any other sport (Hespanhol Junior *et al,* 2015; Hulteen *et al,* 2017) and has been considered one of the most common forms of physical exercise undertaken recreationally by the global population in modern world (Hulteen *et al,* 2017; Andersen, 2019). One of the reasons for this phenomenon is the growing number of amateur and elite running events worldwide, such as 5 km, 10km, half – marathons, marathons as well as ultra-marathons, in the past few decades (Jungmalm *et al,* 2018). The term “runner” is an umbrella word to describe any individual engaging in running non-competitively, yet on a regular basis (Ramskov *et al,* 2016). The definition of a “recreational runner” has not been established either and has been used to define a wide spectrum of running populations. Statistical data from 2016 obtained by Stoggl and Wunsh, reported that, in the last forty years, millions of runners took part in marathons and half marathons and over 40,000 individuals crossed the finish line in each event. This was confirmed by Andersen (2019), who conducted a study based on marathon results obtained through surveys and questionnaires between 2008-2018, 456,700 individuals in the USA and 97,254 in the United Kingdom participated in marathons.

To date, the health benefits of regular exercise have been well documented in literature (Hespanhol Junior *et al,* 2015; Stoggl and Wunsch, 2016; Hulteen *et al,* 2017). Running itself has been linked with substantial improvements in general health, mainly through management of blood glucose levels and improvement in cholesterol metabolism and was also found to have a positive effect on biomedical indices of health related to cardiovascular disease (de Araujo *et al,* 2015). Hence, engaging in activities that involve running is often recommended by clinicians for physically inactive adults as a way of managing hypertension, type 2 diabetes mellitus, psychiatric, pulmonary and neurological diseases (Hulteen *et al,* 2017; Jungmalm *et al,* 2018).

Despite its advantageous effect on health, increased participation in running has also contributed to a significant rise in injury incidence amongst the world's population (Hespanhol Junior *et al,* 2013; Hulteen *et al*, 2017). Running-related injury (RRI) has been commonly defined as a musculoskeletal trauma which is associated with running and results in a restriction in running speed, distance and the duration and frequency for at least one week (van der Worp et al, 2015). In the last twenty years of research between 19 – 94% of runners were reported to suffer from running-related injuries annually (van Mechelen 1992; van Gent *et al,* 2007; Jungmalm *et al,* 2018). The injury prevalence, however, tended to vary between research over the years due to the variety of study methods, design and populations investigated. Additionally, this wide and vague percentage range of injury rates is also likely to be due to a lack of follow-up research and discrepancies in injury definitions, which in turn provided conflicting results in previously undertaken studies. It was noted, that the majority of previous studies were conducted on either recreational "novice", "half – marathon" or "marathon" runners only, depending on the type of running event they were training for or participating in at the time of data collection (Van Middlekoop *et al,* 2008; Bredeweg *et al*, 2012). Because of such classifications, most of these studies failed to account for the true running experience and running routine of investigated runners in relation to their weekly mileage, intensity of training and years of training (Hespanhol Junior *et al*, 2013). It could be argued that a "recreational" runner who is not training for an event could still cover weekly mileage above 50km and someone who was considered a "marathon" runner might have run sporadically in preparation for the event itself. Additionally, health and psychological status as well as social factors - injury, lack of time, commitment could also affect running schedule of those individuals (Francis *et al,* 2018). Typically, each event requires a specific training schedule which might also influence the intensity and frequency of running sessions undertaken by individuals at certain stages of their training plan- that could especially affect injury rates in novice runners, who have not yet developed a muscular adaptation to running and do not yet listen to their body (Van Middelkoop *et al,* 2008). It could be also argued, that acute and overuse injuries present themselves differently and depending on their severity (Lopes *et al*, 2012), individuals might have a certain attitude towards resting and seeking medical attention, depending on when and where the injury takes place - in training or during a running event itself (van der Poppel *et al*, 2014). As a result, there are significant constraints in injury data representation and the analysis of factors that had the strongest influence on the incidence of injuries in runners who were previously investigated.

Recent research in general provides more accurate and conclusive data on injury prevalence than earlier research due to improvements in methodology, more advanced technology as well as study designs (Hulteen *et al*, 2017; Mitani, 2017). A trend of high running-related injury incidence was also observed by Videbaek *et al,* (2015), whose systematic review and meta-analysis reported that the injury rate falls between 2.5 and 33.0 injuries per 1000 h of running in different studies.

Running-Related Injury Risk Factors

Several internal and external risk factors have been directly associated with predisposition and susceptibility to running-related injuries (Hespanhol Junior *et al*, 2015; Hulteen *et al,* 2017). Factors with the strongest relationship were identified as: previous injury, gender, running distance, as well as footwear and training errors (Lopes *et al*, 2012; Hespanhol Junior *et al,* 2015). General flexibility and muscular strength of runners have also been linked with increased injury risk (Stoggl and Wunsch, 2016). Interestingly, except for injury history, no consistent risk factor for running injuries has yet been identified.

To date, no information on 'high-risk populations' based on running distance is available and only a small number of studies have investigated runners with respect to injury trends combined with their weekly distance and running experience simultaneously (Gallo *et al,* 2012; Hespanhol Junior *et al,* 2015). No direct link was found between distance and predisposition to injury to a specific anatomical location. Hence, there is limited data available on injury trends based on mileage covered by runners on a weekly basis - short, middle and long distances - and in relation to a single session duration. It is unknown if, and how, running distance might affect injury prevalence and whether increased mileage affects trends in injury occurrence. Running distance was, however, previously linked to injury occurrence. This was mainly due to overuse often seen in long-distance and experienced runners (Kemler *et al,* 2018) as well as differences in training related characteristics, certain modality in running speed and frequency in short and longer-distance runners. Furthermore, Kuitenberg *et al,* (2015) in the first systematic review compared injury prevalence in different populations of runners and found out that the running distance and the injury risk followed a U-shaped pattern, suggesting that short-distance track runners and ultramarathon runners have the highest injury risk. This is thought to be caused by the increased speed and need for a higher force and energy demand of sprinting athletes rather than any other running population. In sprinting, the propulsion is highly dependent on gluteal activation and power obtained through the hips hence these structures are susceptible to a greater biomechanical load and therefore the majority of running injuries were found in the upper leg of individuals, followed by the hip and pelvis area (Kluitenberg *et al,* 2015). Interestingly, no other studies provided data on specific location and types of those injuries and whether those sites were different depending on running distance itself. It is believed, however, that due to significant differences in speed, intensity, running style as well as experience of different runners in certain populations, some might be predisposed to suffer from specific issues, such as Achilles tendinopathy, patellofemoral pain and plantar fasciitis (Dugan *et al,* 2005).

Thus, more research should focus on investigating whether injury sites are different in certain population of runners and interventions should be developed and applied to reduce associated risks. Another interesting observation was that no studies investigated runners who did not train for or participated in a specific event but were running regularly. Consequently, focus should be put on studying runners based on a specific "distance/mileage group" rather than according to the event they participate in, as training routine might not reflect true efforts of runners nor their weekly engagement in physical activity.

Overall, available data seem to support the general view that regardless of running experience and level of participation, runners in all age groups, running both shorter and longer distances are predisposed to sustaining variety of chronic injuries. It is therefore, thought to be due to a combination of anatomical, physiological and biomechanical factors which affect running performance and efficiency (Sinclaire 2015; Jungmalm *et al,* 2018).

To date, several studies to some extent have investigated the effect of biomechanics and abnormalities in motion pattern on running-related injury development (Daoud *et al*, 2012; Gallo *et al*, 2012; Suoza, 2016). It has been shown that maintaining an optimal physiological status during running is critical for delaying perceived fatigue (as indicated by aerobic capacity [VO2 max]) and inhibiting the development of compensatory movements within the gait cycle that could further affect number of parameters associated with running and thus lead to an injury (Stoggl and Wunsch, 2016). According to Hespanhol Junior *et al* (2015) increased running mileage and years in training have a strong effect on physiological capacity and biomechanics of individual's movement, as both were linked with improvements in cardiorespiratory capabilities (VO_2max) and perceived fatigue levels. The same study also suggested that experienced runners have a better physiological adaptation and increased oxygen delivery than novice runners, mostly due to significant rise in VO_2max, which was established after only a year of training (Hespanhol Junior *et al,* 2015).

According to running experience, injury rates in novice runners were set at 34.7%, compared to 26.3% in recreational runners and 29.9% in marathon runners (Hespanhol Junior *et al,* 2015) suggesting that the more experienced the runner, the lower the risk of developing a running-related injury. It was previously suggested that increased years in training allow runners to develop biomechanical adaptations over time to achieve the least energy-demanding style and technique of running (Dugan *et al,* 2005). Thus, it could be hypothesised that injury development pathways will differ in respect to length of running experience and certain body sites and locations – novice runners could be less susceptible to high stresses (overuse) but have a greater predisposition to developing acute traumas. To date, however, no studies considered running experience of runners as a separate risk factor in injury investigation.

As such, a more thorough investigation is needed to establish real-life and up-to-date injury prevalence amongst different populations of runners. Such investigations would allow the drawing of more reliable conclusions on current injury trends across specific populations and provide evidence relating to groups of runners covering short, middle and long distances separately, regardless of whether or not they are training for an event. Once a relationship between distance, motion mechanics and injury occurrence is established, an identification of injury development pathway could be determined for those runners and interventions applied.

The primary aim of the following study was, therefore, to investigate the injury trends based on the type of running individuals were engaged in – short, middle or long distances. Once patterns were determined, a further analysis of the relationship between foot anatomy and function of lower extremities on running-related injury development in runners was undertaken. To achieve this, the following research consists of two separate studies: Study 1 which focused on establishing existing injury patterns in runners based on their total weekly mileage and frequency of running sessions, and Study 2, which aimed to determine causes behind those injuries in relation to lower leg function, its flexibility, general running biomechanics and anatomical and functional characteristics related to the foot mobility of individuals.

Literature Review

Injuries constitute a tremendous problem for all-distance runners, regardless of whether they are engaged in running at a recreational or professional level. Running-related traumas are most commonly referred to as "overuse" injuries and occur when a "specific structure of the human body is exposed to a repetitive structural overloading, which exceeds that structures" optimal load capacity" (Hintermann and Nigg, 1998). Unfortunately, due to insufficient knowledge regarding physiological and biomechanical mechanisms that underlie injury development pathway and their complexity, only a small number of preventive interventions are currently available aiming to reduce their incidence within the society (Johnston *et al,* 2003; Aminaka *et al*, 2018). Furthermore, previous studies tried to investigate the multifactorial nature of injury development rather than study single pathways or variables within one of these mechanisms (Hulme and Finch, 2016). As such, it is still unknown which factors have the strongest effect on running-related injury rates. Since running is crucial for any athlete, performing both as a part of a team as well as individual sport there is a great need to fully understand the process of injury associated with running, human anatomy, training-specific factors (distance and intensity) as well as biomechanics of movement and their combined effects. This will then allow accurate conclusions to be drawn and enable development of interventions to reduce future occurrence of running-related injuries in both elite athletes as well as in the general population who run to increase their fitness levels.

Running Biomechanics - Gait Cycle

The gait cycle is the basic unit of measurement in walking and running motion (Stoggl and Wunsch, 2016). A single gait cycle describes the movement of one foot, from initial contact with the ground to when the same foot contacts the ground again (Gallo *et al*, 2012). Folland *et al*, (2017) described running motion as "free, unconstrained movement" that results from a variety of individual techniques and movement strategies that affect the overall lower limb kinematics. A single running gait cycle comprises of three main phases – stance, swing and float (flight) phase (Gallo *et al*, 2012). Stance phase refers to the time during which each foot is in contact with the ground and constitutes approximately 40% of a complete gait cycle (Stoggl and Wunsch, 2016; Kozinc and Sarabon, 2017). Swing phase describes the push-off, when the foot and the whole limb prepares to leave the ground, whilst the float phase describes the non-contact time of each foot with respect to the ground (Gallo *et al,* 2012). Within all three phases of the gait cycle, different muscles groups, ligaments and tissues within the foot, lower and upper leg activate at different times to enable motion to take place (Stoggl and Wunsh, 2016). Any abnormalities within the gait cycle, such as excessive pronation, supination, timing of movement and inefficient distribution of pressure might compromise the amount of forces and increase the overall load that the body is being exposed to which in turn leads to abnormal stress acting upon the body (Gallo *et al,* 2012). Furthermore, to achieve an appropriate and efficient motion forward, the movement of the kinetic chain on both sides of the human body needs to be synchronised (Dugan *et al,* 2005).

Lower Limb Biomechanics Within A Gait Cycle

Running biomechanics is largely determined by lower leg function, particularly the joints of the foot and ankle (Mitani, 2017). The foot itself constitutes a direct link between the ambulatory surface and the rest of the human body (Dugan *et al,* 2005). The main function of the foot is to absorb forces associated with initial contact and impact, adapt to an uneven terrain, ensure proprioception for appropriate position and balance as well as allow leverage for propulsion (Dugan *et al,* 2005). The subtalar joint (STJ) which is located between the talus and calcaneus, constitutes another important part required for motion. It has three distinct articular facets (anterior, middle and posterior) which are designed to allow motion in three different planes and enable the pronatory and supinatory movement of the foot to take place (Dugan *et al*, 2005*).* Pronation is simply the abduction and eversion of the foot and supination refers to adduction and inversion. Both result in multiplanar proximal movement of joints during each contact of the foot with the ground. To achieve it, a certain position of the ankle is required - during initial contact, it needs to be dorsiflexed (see *Figure 1*).

Figure 1. Ankle dorsiflexion.
Source: *https://www.flintrehab.com/2018/foot-drop-exercises/*

As dorsiflexion occurs, the tibia then rotates externally allowing the foot to progressively move through the ground to stance phase, when the weight bearing occurs, and the foot is in complete contact with the ground. At this point, pronation of the foot takes place and the tibia starts to internally rotate (Dugan *et al*, 2005).

During that stage ('mid-stance phase'), maximum flexion of the knee occurs the center of mass moves over the foot and leg, and the forces are being absorbed whilst the moving limb is being decelerated. After the 'mid-stance phase' the body enters propulsion which constitutes the last stage of contact of the foot with the ground (take – off) (*Figure 2*).

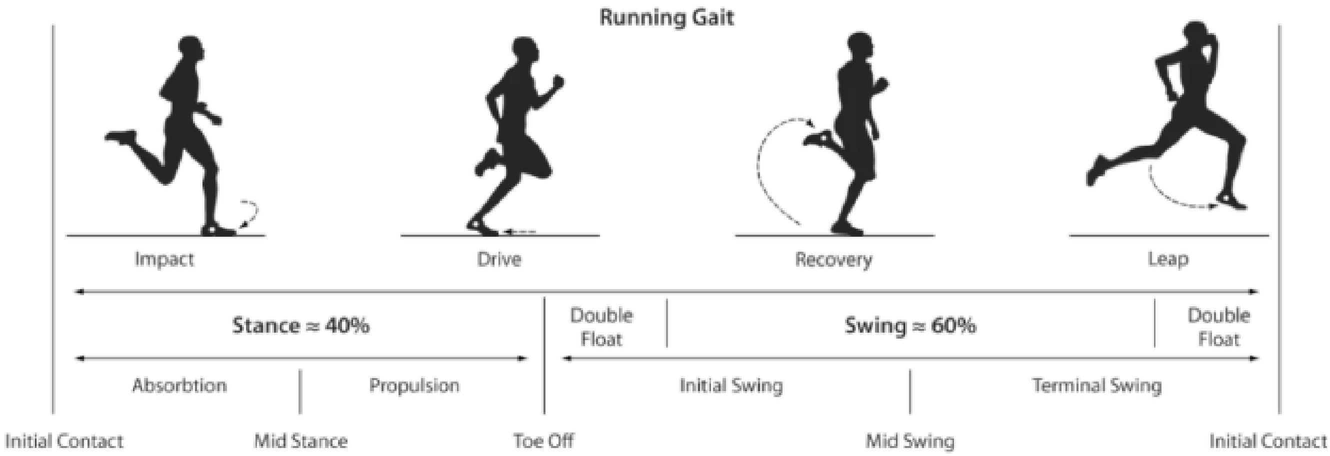


Figure 2. Running gait cycle
Source: https://www.kintec.net/blog/the-run-centre-4-point-run-analysis/

During that time, ankle plantar flexors generate increased vertical force through active flexion, pushing the foot off the ground surface (Kozinc and Sarabon, 2017). As soon as the heel is off the ground, the extension of the metatarsophalangeal occurs and the planta fascia is stretched, allowing for the transverse joint to flex and ensure enough stability as the foot leaves the ground. This action is referred to as a windlass mechanism (Dugan *et al*, 2005). Within the time the foot is on the ground, muscles of the foot and lower leg generate eccentric and concentric contraction aiming to lengthen and shorten the fibers respectively. Due to the nature of movement during running, the majority of muscle action requires eccentric work. Another important muscle is the gastrosoleus complex, the main function of which is to enable plantarflexion and promote supination as the foot travels through a gait cycle (Dugan *et al*, 2005).

Abnormal Mechanics And Injury Development

According to Nicola and Jewson (2012), any increase in motion or instability of the ankle in mid-stance phase of the gait cycle directly affects the knee position, which in turn increases the risk of sustaining a trauma in that area. This was in agreement with Mitani (2017) who also found a positive correlation between knee injury occurrence in runners and knee valgus, which constitutes an internal rotation of the knee in mid-stance phase of a gait cycle. This was explained by a greater tensile stress on the medial knee and compressive stress on the lateral knee as well as causation of uneven distribution of force on impact to the medial tibia and the knee. Nicola and Jewson (2012) also established a link between greater range of foot pronation and higher injury risk due to higher load exhibited on gastrocnemius, soleus and posterior muscles to compensate for greater internal rotation of the lower leg during single leg activity. Furthermore, a positive link between pronation movement of the ankle on development of plantar fasciitis, Achilles tendinopathy as well as fibular stress fractures was also established in other studies (Stoggl and Wunsch, 2016). This was in agreement with Souza (2016), who made the same observation and was able to associate knee internal rotation and ankle eversion velocities with higher injury rates in recreational male and female runners.

Intrinsic And Extrinsic Injury Risk Factors

It is generally proposed that injuries occur when the frequency, as well as the timing of impact forces exceeds the optimal loading the body is exposed and maximises physiological adaptation (Mitani, 2017). To date, it was found that the development and frequency of running – related injuries can be affected by a variety of intrinsic (gender, age, injury history) and extrinsic (training load, footwear, running distance) risk factors, which act upon the athletes in a non-random manner (van der Worp *et al*, 2015). Previously, inadequate distribution of forces, excessive pronation or supination and function of the foot and ankle have been associated with abnormal movement pattern which further causes excessive stress and results in breakdown of soft tissue and muscle (Chambon *et al*, 2014). Training load, running distance and training routine has also been positively associated with injury occurrence (Windt and Gabbett, 2016). To date, however, it is difficult to establish what role and to what extent the variety of intrinsic and extrinsic injury risk factors predispose runners to sustaining running-related traumas. Therefore, more research is necessary to determine the effect of specific factors on injury development and their mutual relationship on a runner.

Intrinsic factors: Previous Injury

Injury history has been extensively investigated and determined to be the strongest predictor of the occurrence of a new injury in all populations of runners to date (Molloy, 2016). It was found that following a trauma, runners adopted different biomechanical patterns and developed a compensatory mechanism aimed to protect the injured structure during running which resulted in exhibition of a greater load and stress on other musculoskeletal structures, both in the lower and upper leg (Dugan *et al,* 2005). According to research, also an incomplete recovery of previous trauma or inefficient rehabilitation from the earlier injury is strongly associated with predisposition to sustaining a secondary injury to the same structure (Hespanhol Junior *et al,* 2011; van der Worp *et al,* 2015). Healing time for different runners was also investigated previously and data suggested that depending on running experience and years of training, some individuals might recover quicker than others (Mitani, 2017). It was concluded that due to decreased running experience and hence running exposure, which protect from overuse traumas, type of injuries sustained by novice runners might also be less severe and be more. Hence, a novice runner might recover faster from an injury than a more experienced runner even (Linton and Valentin 2018). Experienced runners were also previously found to be older than novice runners and suggested to experience pain related to symptoms of early osteoarthritis (van Middlekoop *et al*, 2007). Furthermore, novice runners report less RRI injuries than more experienced runners, which might in turn promote their biomechanics and reduce the likelihood of developing compensatory running pathways. Compensatory mechanism often links to a greater dominance on one side of the body, more instability during single leg activity (midstance) as well as altered efficiency of the push off or landing patterns (Dallinga *et al*, 2014).

Gender

Gender has also been identified as a dominant variable in running-related injury predisposition. Taunton *et al.* (2002) concluded that, recreational female runners were twice more likely to get injured than men and suffer from iliotibial band friction syndrome, tibial stress fractures and patellofemoral pain syndrome. This was previously confirmed by Nicholl *et al* (1982) who established a strong positive association for overall lower extremity running injuries occurrence with female gender in marathon runners. It is important to mention, that in this particular study there were more females than male runners being investigated. The increased injury prevalence was linked to increased BMI (Body Mass Index) in injured females. Sinclair *et al* (2015) also explained this phenomenon by the presence of an increased knee abduction in women compared to males as well as an increased exposure to a higher patellofemoral load during the stance phase of their running cycle. Increased internal rotation of the femur was also found to affect inappropriate position of the patellofemoral joint and associated knee pain and hence contribute to increased injury risk. Research by Ferber *et al* (2003) suggested that the female population was also found to be at a higher risk of anterior cruciate ligament and patella associated injuries than males.

Sinclair *et al* (2015) also investigated shock attenuation in recreational runners and found out that females attenuated impact forces less efficiently than males. This was due to differences in anthropometrical parameters that mediated mechanical processes of shock wave transfer up through the body which increased their susceptibility to traumas (Mercer *et al,* 2003). Data also indicated that females tend to absorb more shock and energy in the hip joint than men in the first half of stance and were found to generate a greater amount of tibial external rotation within the majority of the stance phase of gait (Ferber *et al,* 2003; Mitani, 2017). As a result, the female population also exhibited higher vertical ground reaction forces and greater free vertical moments, which in turn might predispose them to greater stresses and loads whilst running.

Differences in anatomy associated with gender also seem to affect limb function in running. Alignment and range of motion of the lower limbs in males and females have been found to directly affect development of gender-specific injury trends and their frequency (Mitani, 2017). In this study, 64% of females and 46% of males had a history of lower limb sports injury. 34.4% of women and 20.8% of men had previous foot and ankle issues. The most prominent were knee injuries, which were found in 32.9% females and 24.7% of males. The gender-specificity in injury development was also confirmed by Ferber *et al* (2003). He studied both the sagittal and frontal planes and concluded that the majority of variations in limb mechanics are present in frontal plane analysis. Females were found to show increased adduction angle in the hip as well as greater abduction in knee position during stance phase than males. An increased foot pronation was also reported and proposed to occur as result of a slightly lower arch index in females than males. Furthermore, excessive pronation was found to exert a greater knee valgus and thus an increased internal rotation of the lower extremity in female runners (Mitani, 2017). According to Malinzak *et al* (2001) research also showed a lower peak knee flexion and reduced knee flexion in swing phase in females than males). Hence, females were found to be at increased risk of knee-related issues, especially ACL injuries, due to an increased internal rotation of the hip (Nguyen *et al*, 2008). These observations were, however not entirely in line with results obtained by Ferber *et al* (2003), who did not report any significant differences in knee joint movement, power or knee positions during the gait cycle in both genders. It is crucial to highlight that his study had a small sample size compared to other epidemiological studies. Hence, investigating only 40 recreational runners (20 males and 20 females) might have influenced the application of study results to the general population. Furthermore, the anthropometric model which was used in that study to determine kinetic variables was not specific to female gender. The analysis was also based on three-dimensional retro-reflective marker system, which required placing markers on a specific anatomical location manually for each subject. It could be argued that as the individuals were running, some markers could have misplaced.

Male recreational runners, on the other hand, have been found to suffer from more injuries to posterior muscles, such as hamstrings and calf issues, than women (Satterhwaite *et al,* 1999). A study by van Middelkoop *et al* (2007) undertaken during the Rotterdam Marathon on recreational male marathon runners confirmed this trend, outlining that males were more likely to injure the calf, knee and thigh regions. This could be explained by genetic, anatomical and functional differences between lower limb function in both genders, such as arch profile, overall body and muscle shape as well as range of motion in the foot an ankle (Ferber *et al,* 2003; Nguyen *et al*, 2008).

Due to the variety in injury anatomical locations across males and females it was concluded that a gender – dependent injury pathway associated with running exists (Boles and Ferguson, 2010; Buist *et al,* 2010; Mitani 2017). More thorough investigation should be designed to establish whether gender affects overall running biomechanics and to what extent does it affect injury rate of specific body sites.

Anthropometric Features: Q-Angle & Body Mass Index

As mentioned, previous observations on gender – specific injury patterns suggested that human anatomy influences susceptibility to running injuries, especially those related to the knee region. Increased Q-angle, described as the vector of pull exerted by the quadriceps muscles on the patella, which is commonly seen in the female population is positively associated with knee and iliotibial band (ITB) running-related injuries (Ellapen *et al*, 2013). This was found to be caused by a higher pull on the patella against the lateral femoral condyle which results in patellar subluxation and other patellofemoral disorders (Saragiotto *et al,* 2014). Additionally, the angle between the tibia and femur was found to further affect the amount of knee valgus in mid-stance in recreational male and female runners. Increased deviation of the Q-angle was previously suggested to predispose males and females to musculoskeletal knee injuries, mainly due to abnormal patella tracking and inefficiency in traction dealing with traction forces of the lateral patellar restraint (Ellapen *et al*, 2013).

More recent research undertaken by Mitani (2017) found no gender-related differences in participants with history of knee injuries. The same study, however, provided evidence that females might be at a higher injury risk overall due to their foot anatomy - a lower arch index was positively associated with running-related injury occurrence in recreational female runners investigated (Mitani, 2017). It was hypothesised that a decreased arch height index compromised the amount of shock absorbance during initial contact and increased the physical stress exerted on the whole leg as it travels over the running surface (Johnston *et al,* 2003). It was also argued that a lower arch height may contribute to increased range of pronation of the foot during mid-stance and thus increased tensile stress on the medial ankle joint, cause compensatory rotation in the tibia and compressive stress to be transmitted proximally through the whole limb (Williams *et al,* 2001).

Strength And Flexibility

Muscle strength, its contraction rate and joint flaccidity has also been found to affect running performance (Mitani, 2017). It was established that reduced muscle strength impaired the ability of a muscle to perform and resulted in slower than necessary activation, which in turn increases the joint flaccidity in runners (Mitani, 2017). According to Johnston *et al* (2003), runners might be at an increased risk of injuries in case of increased stiffness and weakness of quadriceps as well as gastrocnemius and soleus, which comprise the posterior chain of the lower leg.

The inflexibility often causes limitations in the range of motion in different joints, which also previously associated with incidence of running-related injuries. Kuitunen *et al* (2002), established two main types of flexibility: passive and active, which can be measured in different ways. Most commonly, tests assess stiffness of a certain muscle as well as range of motion available at a single joint or a group of joints (Kuitunen *et al,* 2002). Most of the existing data indicated that stiffer joints, due to significant limitations in flexion, directly influenced the quality and quantity of range of motion available to perform functional tasks and affected the chain of kinetic events associated with running (Davies Hammonds *et al,* 2002). Hence, a reduced range of motion in the lower leg was concluded to inhibit overall performance. Davies Hammonds *et al* (2012) suggested that a limited motion will lead to changes in running biomechanics and lead to development of compensatory mechanisms by individuals. Interestingly, joint hypermobility (a condition in which joints have a range of motion that is beyond normal limits) has also been linked with higher injury risks, as increased compliance was found to reduce and compromise the ability to absorb impact and utilise energy needed for further motion (Hintermann and Nigg, 1998). Dugan *et al* (2005) proposed that having an increased joint range of motion puts greater demand on tendons and muscles and requires more eccentric and concentric work to overcome the load and enable motion to take place. However, due to lack of appropriate investigation, it is unknown whether too much or too little flexibility may predispose to injuries more. Several studies tried to investigate the effects of joint flexibility and range of motion, but their outcomes provided conflicting data, mostly due to difficulty in validating tests and protocols for flexibility assessment in participants (Fukuchi *et al*, 2013). There is currently no test available that provides representative values of total body flexibility. Furthermore, flexibility is joint specific hence determining the range of motion of a few joints does not necessarily provide an indicator of flexibility in other joints. Overall, an increased stiffness of the limb was found to be protective on injuries in runners, due to better muscle activation (Stoggl and Wunsch, 2016). On the other hand, a greater range of movement in the plantar flexors has been previously linked with increased injury risk (James and Jones 1990). It was also established, that the state of fatigue will compromise the amount of leg stiffness over time. Hence, it was concluded over a prolonged period of running, the ability of the limb to withhold the force and energy demands will decrease (Stoggl and Wunsch, 2016). Previous research failed to find a direct association between increased ankle range of motion and lower limb injuries (van Mechelen, 1992). This was in agreement with Montgomery *et al* (1989) who established that stress fractures were more common in injured military recruits who had less range of motion in their ankle. Furthermore, quantifying the range of movement and distinguishing between active and passive joint motion needs further research and development of better methods of validation and assessment. Some of these tests were found not sensitive enough to be used as screening test or included both bias as well as errors in data collection (human error) and hence its interpretation.

Extrinsic Risk Factors: The Effect Of Running Distance On Injury Rates

According to previous studies, running distance was found to be the strongest external risk factor related to injuries, with previous injury history the greatest internal risk factor (de Araujo *et al*, 2015; Ramskov *et al*, 2016). It has been established that depending on the running distance, physiological and biomechanical demands vary significantly between short and long-distance runners, hence this constitutes an important modifiable variable (Molloy, 2016; Bertelsen *et al*, 2018). In the literature, inadequate rehabilitation of those injuries as well as poor training habits and inappropriate footwear were also linked with increased risk (Kluitenberg *et al,* 2015). Most research also agrees that in relation to individuals' running routine, training specific variables – such as distance, intensity and frequency – alongside movement biomechanics, play a key role in any running-related lower limb injury development (Gallo *et al*, 2012).

To date, distance has been quantified in different ways, though most of the time is referred to in terms of the total amount of mileage covered by an individual in a week (van Middelkoop *et al,* 2008; Hespanhol Junior *et al*, 2013). In that respect, it was established that a higher total weekly distance predisposed recreational runners to a variety of traumas, especially if they were beginner runners (de Araujo *et al,* 2014). This was confirmed by Hootman *et al,* (2002) who reported a higher incidence of injuries when running more than 32km per week, as well as Van Middelkoop *et al,* (2008) who found a positive relationship between running over 40km per week and the development of calf injury in male recreational marathoners. However, since no females have been recruited in this study, it is impossible to determine whether it was the distance itself or rather the effect of gender and human anatomy might have influenced the result of these variables. Earlier research by Macera *et al* from 2003 proposed that injury risk was 15% greater in runners whose weekly mileage exceeded 64+km while compared to a group that runs between 48-64km/week. This has not been confirmed by other research by Van Middelkoop *et al,* (2008) on marathon runners – this study provided evidence to support the view that an increased weekly distance (60km a week) was protective of injuries in runners who trained for a marathon. It was reported that 27% of individuals covering more mileage were injured, in comparison to 30.5% who ran between 0-40km per week. What is important, in neither of these studies a single session mileage and intensity was considered. Hence, it could be suggested that frequency of sessions per week, running intensity as well as distance per running session might be a factor that affects the likelihood of injury occurrence rather than the total distance covered. It could be also argued that some runners simply did not build up the strength and muscular adaptation to running and that could have affected the likelihood of developing an injury.

Compatible data were also reported by Nielsen, *et al,* (2014), who established a greater relative injury threshold among runners who were running longer distances and Grier *et al* (2012) in his study on military recruits. He reported that soldiers running more than 16 miles per week had 2.24 times greater injury risk when compared to soldiers who run 7 or less miles per week. It is important to highlight, however, that the training demand in military might not be comparable to a typical recreational runner. Often, they run carrying additional equipment, must meet specific requirements with regards to their fitness level and training volume, which to an extent might influence the effect of distance on injury occurrence.

Hence, it was concluded that even though distance is one of the most popular injury risk factors investigated in literature, to date, no real injury protective running distance threshold has been established, as it is highly dependent on running speed, intensity of running sessions and running frequency (Jungmalm, 2018; Dallinga *et al,* 2019). Huge variation in individuals running performance will also be directly linked with physiological status and fitness levels of investigated runners. Due to this fact, Kluitenberg *et al,* (2015), proposed a different approach in consideration of injury development and suggested that the relationship between running distance and injury risk follows a 'U-shaped' pattern. This implies that both short-distance track and ultramarathon runners tend to suffer from more injuries more than middle distance runners. The explanation for this phenomenon was that ultramarathon runners normally undergo more years of training than runners who cover shorter distances, so they might be at a greater risk of overuse injuries. The body tends to heal slower, so they might also be affected more by previous injury and predisposition to new traumas. Short distance track runners, in contrast, need to generate more explosive force and power so their muscle activation significantly exceeds requirements for a typical middle-distance runner, which in this study, was set to fall between 30-50 km per week.

To consider distance and its effect on injury as a risk factor, single running sessions and training volume should be investigated as modifiable variables. Depending on the frequency and intensity of short and long runs within a single week it can be argued that even though the overall distance is maintained the same, the running demands during those sessions would be different for individual runners. This could be explained by the effect of workload on injury and its role in developing fatigue state (Windr and Gabbett, 2016). Hunter and Smith (2007) argued that fatigue is multi-dimensional and affects the human body in several different ways. Hence, varieties in length of training sessions, speed and overall training load would put different demands on the runner's body and would require developing specific physiological and muscular adaptations, due to being exposed to higher amounts of load during a prolonged running session in comparison to shorter sessions. This is why an investigation is needed to determine injury patterns and pathways in more and less frequent short, middle- and long-distance runners. Interestingly, to the authors knowledge, no study to date has investigated distance as a risk factor using that categorisation approach.

In short and middle-distance populations of runners categorised based on total weekly mileage, increased mileage was found to be protective of injuries. Kemler *et al* (2011) reported recreational and novice runners (with less than a year of running history) to sustain more injuries per 1000h (8.78 injuries) than experienced runners, who ran 2+ years (4.24 injuries) and confirms the U-shaped pattern between running distance and injury proposed by Kluitenberg *et al* (2015). Fredericson and Misra (2007) reported that short distances are typically run by novice runners who have been found to be at a higher injury risk than more experienced runners. It was proposed that the smaller prevalence of running-related injuries could be due to greater running experience of those individuals, greater muscular strength as well as better adaptation to preferred movement pathway of the body (Nigg *et al,* 2015) compared to the short distance population (Taunton *et al,* 2002).

Unfortunately, due to the lack of data and specificity on the running experience and training specification of investigated runners in different distance groups it is unknown to what extent does it affect injury rates alone. More research is needed to examine the effect of distance modality on injury prevalence modality in novice and experienced runners as well as the effect of running experience in individuals running short, middle and long distances.

Running Intensity & Duration

To investigate an injury development pathway for a specific runner, his/her running mechanics, intensity of training as well as training routine must be considered (Heiderscheit, 2014). Running frequency and duration were also found to be significant to injury development, especially when a new training surface is being introduced (Macera, 2003). This is suggested to be where the greatest variability occurs amongst runners. Furthermore, it was argued that increased number of sessions per day on any surface, compared to the same amount of sessions weekly would rise the variability in running frequency and hence affect the associated injury predisposition (Molloy, 2016).

Currently, there is a lot of conflicting data on the effect of running speed and injury risk. It was found that faster runners generally need more flexibility and have a greater demand for eccentric muscle strength than slower runners (Dugan *et al,* 2005). This was explained by the fact that as speed increases, a rise in energy expenditure occurs. Simultaneously, lower limbs must increase their motion range to reduce the amount of vertical shift of the body's center of mass against the gravity (Dugan *et al,* 2005). To our knowledge, no studies established a direct association between running speed and specific injury trend. However, Nielsen *et al* (2014) argued that this could be due to the failure of accounting for varying running intensities during running sessions by researchers as they most commonly rely on self – selected speed of participants. He also concluded that sudden changes in total weekly mileage were directly correlated with knee pain (patellofemoral and patellar tendinopathy) as well as iliotibial band pain, whilst changes in the running speed and training intensity were more relevant to Achilles tendinopathy, calf (gastrocnemius) and plantar fascial pain in runners (Nielsen *et al,* 2014). This could be explained by a change in initial contact which occurs as a result of increase in speeds. In sprinting, midfoot striking was found to be more common than heel striking, which is typical for lower speeds. This change forces alteration of foot position on initial landing to a more plantar flexed, hence the posterior chain of the foot and lower limb is exposed to higher stress (Dugan *et al,* 2005). As such, it was suggested that short distance runners might be predisposed to different injuries than long distance runners as their average running speed varies and will typically be faster than in distance runners. This area, however, needs further research as there are many other risk factors directly associated with long distance running that could influence injury prevalence in this group of runners, mainly the effect of fatigue on preferred motion pathway, running surface and duration of physical activity (Dutto and Smith, 2002). Future studies must be designed in a way in which these variables can be measured and investigated separately.

Running-Related Injury Trends

Recent research reports the knee as the most commonly affected injury location in runners, especially in recreational groups and those running shorter distances, regardless of gender (de Araujo *et al,* 2015; Ellapen *et al,* 2013). In a systematic review, van Gent *et al,* (2007) identified the knee as a primary injured body site in all distance runners (up to 50%), followed by lower leg issues (9.0–32.2 % e.g. shin, Achilles tendon, calf, and heel), foot (5.7–39.3 %), and the upper leg traumas (3.4–38.1 % e.g. hamstrings, thigh, and quadriceps).

Similar patterns were established by van Poppel *et al* in 2014, who reported that short distance runners (who run 5km and 10km) commonly suffered from knee-related injuries (18.5%), followed by the calf (16.3%) and Achilles tendon issues. Individuals who were running 15km and 21km per week were also found to sustain similar a rate of knee injuries (19.7%), but much greater number of hip (15.2%) and thigh injuries (13.6%). Taunton *et al* (2003), however, was able to identify an increase in the prevalence of calf and foot traumas in middle distance runners who were participating in half marathon and marathon. Lower back and hip traumas were also reported by Saragiotto *et al* (2014) in middle distance runners and were associated with increased Q-angles and tightness in hip flexors. In short distance and novice runners, the primary injury site is the knee (Kluitenberg *et al,* 2015, van Poppel *et al,* 2014).

Due to the fact that no studies to date have investigated and directly compared populations of runners based on their distance category (short, middle and long), it is not possible to provide conclusions and generalisation on existing injury patterns in runners and identify key differences in injury occurrence amongst runners. Furthermore, differences in the sample sizes of investigated populations were observed, starting from 40 - 5000 individuals (Nielsen *et al,* 2013). It was noted, that the sample size depends highly on the type of data collections. Previous studies that recruited a big sample of participants normally based the data analysis on a self-reported injury questionnaire (>700). On the other hand, researchers who used both two- and three-dimensional analysis software very often designed smaller studies (<100) and were looking at a number of quantitative data and intrinsic risk factors (Gomez-Molina *et al*, 2017). It was also established, that there are significant differences in the equipment used for the data collection and analysis within studies. It is also worth mentioning, that the majority of previous studies recruited mixed gender recreational runners, with an uneven number of males and females (Mitani 2017; Ellapen *et al*, 2013). On the contrary, other research focused only on a certain gender (Van der Worp *et al* 2015; Van Middelkoop *et al*, 2007). To the authors knowledge not enough data is available on whether injury trends vary significantly in short, middle- and long-distance runners purely based on their weekly mileage.

Current Findings And Future Implications For Research

Even though running is a non-contact sport, it requires a great deal of submaximal and continuous activity, hence it leads to a high number of injuries. To date, several factors have been broadly associated with increased injury risk, especially in relation to running distance, gender and injury history. Some factors have also been suggested to be protective of injuries, such as running experience and certain biomechanical features (footstrike pattern, foot type). However, due to differences in study designs and inconsistency in injury definitions – which included both self-reported as well as medically diagnosed traumas, absence from training for a number of days as well as injuries that do not require rest from activity and recovery.

Furthermore, taking into consideration populations of runners examined in previous studies, which investigated both experienced, novice, professional as well as only individuals who participated in or completed a certain running event at the time of data collection, a more accurate analysis on injury incidence is necessary, as each year an increasing number of people engage in running events (Audickas, 2017; Hulteen *et al,* 2016). As mentioned previously, the main differences were in the data collection and population sizes. The majority of studies were undertaken during or after a particular running event (half marathon and full marathon). Conclusive data on the relationship between running experience, distance, gait biomechanics and injury trends should also be established. This could enable a reduction in associated injury risks and facilitate education of runners on how to recognise injury onset and prevent common traumas, in relation to technique, training intensity adaptation as well as consider appropriate footwear choice. Hence, it was concluded that a more controlled investigation is needed to determine current injury trends in comparable populations of short, middle- and long-distance runners, according to their running experience, distance and its potential effect on biomechanics. This will then establish any variations in injury risk and allow further investigation of underlying mechanisms and causation of running- related injuries with relation to foot anatomy and lower limb function.

The following study was designed to investigate the injury prevalence and patterns in short, middle- and long-distance runners and associated risk factors. The aim was to establish whether distance affects the likelihood of sustaining injury and whether the anatomical location of those injury differs. Both male and female runners were evaluated to determine if injury is gender specific.

CHAPTER II: Study 1 – The Investigation Of Running – Related Injury (RRI) Patterns In Male and Female Short, Middle- And Long-Distance Recreational Runners.

Background

Maintaining an active lifestyle has been previously shown to have a positive effect on a number of areas of human health, such as cardiovascular disease, mental wellbeing and reduction in obesity rates (Rasmussen *et al*, 2013*)*. To date, it is estimated that over 40 million runners is the USA and more than 50 million in Europe engage in running annually and the number of recreational runners falls between 12.5-25% in populations of developed countries (Vitez *et al, 2017*). Hence, it is safe to say that running is one of the most popular forms of exercise undertaken by individuals, regardless of their age, gender and nationality.

Furthermore, with increasing participation in running events by all types of runners, due to wide availability of places and entries, a high number of individuals experience traumas to lower extremities (Kluitenberg *et al*, 2015). It could be speculated that participation in a specific event (such as a half and full marathon) might have resulted in a greater number of runners increasing their running distances, frequency and intensity despite of their fitness levels and running abilities. Hence, increased prevalence of a variety of injuries, mainly to the lower extremities might be seen in recreational runners. It is, however, still unknown to what extent do those injuries occur as a result of abnormal biomechanics and/or compromised physiological status or poor training habits. To date, causes of running-related injuries (RRI) were proven to be multifactorial and several intrinsic and extrinsic risk factors have been associated with their occurrence (Saragiotto *et al*, 2014).

Unfortunately, even though a vast amount of research is available on injury prevalence in runners, there are also a lot of discrepancies and conflicting data on the causation, location and primary risk factors associated with running-related injuries. As in the case of runner types, this was concluded to be due to non-uniform definitions of injuries and cohorts studied. Differences in sizes and types of populations investigated (short *vs.* long distance, novice runners, etc.) also make it impossible to directly compare study findings to determine differing levels of risk. Another reason behind this might be associated with the fact that a lot of previous researchers focused on studying training variables separately from personal characteristics related to biomechanics of individuals (Ramskov *et al*, 2016; Gomez-Molina *et al,* 2017). Commonly, limited information is also available on the running experience of runners, their true running experience (volume) and a clear definition of populations of runners investigated. No definition is provided to determine who exactly are novice, recreational and professional runners and what is their running routine. A few studies investigated only male or female populations (van Middlekoop *et al,* 2008; Vitez *et al,* 2017) and some focused only on investigating females with regards to a certain injury occurrence (Ferber *et al,* 2003), such as Iliotibial Band (ITB) Syndrome and Anterior Cruciate Ligament (ACL) problems, further impeding the ability to apply findings to the general population.

In a systematic review of injury prevalence in runners by Gallo *et al* (2012) it was estimated that between 37% to 56% of recreational runners who train and participate regularly in distance running, defined as anything above the 5km mileage, sustain a running-related injury each year. This trend was confirmed by Nielsen *et al* (2013) who reported injury incidence as 27% in an observational prospective cohort study on novice runners with a one-year follow-up, as well as de Araujo *et al* (2015), whose study on amateur runners, reported injury prevalence of 14% to 50% per year. Injury rates were previously found to be even higher in individuals who were competing in a specific running event, such as a marathon, or just after they completed one. Data from the Rotterdam Marathon Study outlined that 18.2% of male participants sustained an injury during the marathon itself (Middelkoop *et al,* 2007). In the same study the one-year injury prevalence was reported as 54.8% and 15.6% of post marathon study male responders reported a new trauma. This was in agreement with results of a systematic review on the incidence of lower-limb injuries among long-distance runners provided earlier by van Gent *et al* (2007) who reported the incidence of lower-limb injuries to be between 26% to 92.4% in running populations across various studies.

Analysing the trends within different populations, it was observed that discrepancies exist in definitions of novice, amateur, marathon and half marathon runners in literature. The term "*amateur"* has previously been related to a runner who is running non-competitively, yet regularly, or habitually, purely for enjoyment and to maintain fitness (de Araujo *et al*, 2015). *Novice* has been used to describe a runner with less years of experience (Fokkema *et al*, 2018), but has also referred to the level and abilities of a certain runner (Kluitenberg *et al*, 2015). With regards to *marathon* and *half marathon* runners, this term was referred to both a runner who completed one of these events or one who was training in preparation for one (Fredericson and Misra, 2007; Small *et al,* 2017). No studies to date that we know of considered the actual distance of runners to describe the type of population they represent.

According to available data and evidence it was found that most of the running-related traumas in runners of all distances are in the knee and typically present themselves as patellofemoral pain and iliotibial band syndrome (Ferber *et al,* 2003; Souza, 2016;). Other locations of RRI were found to be in the shank (calf and shin pain), tibia (stress fractures) and foot and metatarsals (van Poppel *et al,* 2014; Souza, 2016).

Recently, there has been some evidence to show that injury location trends differ between certain populations of runners, especially in relation to distance covered. In a systematic review by Kluitenberg *et al,* (2015), sprinters were found to suffer from higher numbers of upper leg traumas and to have fewer knee injuries than runners who run longer distances. In the recreational population, knee issues were established to be the most common, with a prevalence of 26.3%, which is in consonance with the majority of studies undertaken in that population (Gallo *et al,* 2012). Novice, cross-country and marathon runners were more likely to suffer from lower-leg injuries – related to calf, shank and ankle, with injury occurrence of 34.7%, 30.3% and 29.9%, respectively. Interestingly, the 'marathon' population was found to have more foot-related issues (13.1%) than any other population studied in literature (Kluitenberg *et al,* 2015). Hence, more thorough research is needed to establish the direct effect of running distance on injury patterns.

The following research study was designed to investigate common traits and variables which might lead and predispose runners to specific injuries. It can be argued that in order to investigate mechanisms of injury development, distance should be considered separately as it has been previously shown to affect the ability to maintain optimal biomechanics and physiological status during prolonged periods of running.

What has been observed is that, to date, the majority of available studies categorised runners based on the event they were training for, rather than according to their weekly running mileage or focused on selecting populations that do not accurately capture the different extremes of running distance (by investigating only distance runners or only recreational or only shorter distances). In this study, the aim was to capture the entire running population from 5k runners to ultramarathon runners, through a representative sample of active runners. According to available data, no other study managed to cover this range. It was proposed that once runners can be classified in relation to the mileage, they are running weekly, it will be possible to further investigate to what extent injuries develop as a result of overuse and exposure to high, repetitive loads or personal/training factors.

Hence, the primary aim of this study was to determine the effect of weekly distance on injury prevalence and trends in short, middle- and long-distance recreational runners based on weekly distance covered.

Method

In order to establish injury patterns in a population of runners in relation to their weekly running distance, an analysis of historic running-related data of 1000 individuals (both males and females) was undertaken in the following study. The study was approved by the Kingston University faculty Ethics Committee. Data were retrospectively and anonymously sampled from a client database from a professional Sports Lab specialising in running gait analysis and prescription footwear. In this study, data from recreational runners, who *were engaging in running regularly for fun or maintain fitness levels but were not semi or professional athletes* were sampled and analysed.

Participants

A total of 1000 individuals, both males and females, were sampled in this study. All participants were between the ages of 18-55 years. Injured as well as non-injured individuals were included in the study. To obtain the most accurate data, only those whose main physical activity was running were included in the study. Hence, n=132 individuals from the 1132 complete forms obtained were excluded due to not meeting study criteria. Individuals who ran occasionally and/or were engaged primarily in other physical activities, such as contact sports (football, rugby, netball, etc.) or skiing and tennis, were excluded from the data collection as it aimed only to investigate injuries that developed as a result of running (accounting for 104 of the above exclusions). No information on whether participants were smokers or non-smokers or were suffering from any other underlying medical issues was provided in data collection for the study.

Data Collection

All participants had attended for footwear advice/evaluation consultation and biomechanical analysis unrelated to this study, which was performed by an experienced qualified run technician. The client forms, which were completed by each individual on the day of their appointment, were anonymously used in this study as a basic form of data collection aimed to determine population demographics, self-reported primary injury sites, weekly distance that each individual was covering in their training and associated running routine (APPENDIX I).

Data on gender, age, event participation, total weekly mileage, session duration and session frequency were collected. Both injured and non-injured participants attending the sports clinic between 2010-2011 were examined in the study. Only fully completed forms were used to provide most accurate observations, with incomplete or ambiguous responses excluded from the study. In the following study, 1256 forms were used, however, at this point 124 were excluded due to incomplete data.

For the purpose of the data analysis, **injury definition** for this specific study included any ***self-diagnosed running-related pain/discomfort that presented itself during or after a running session in any lower and upper part of the limb***. Both mild and severe traumas were studied, regardless of whether they resulted in any absence in training and having to rest. No information on whether the traumas required a medical intervention was obtained in the data collection.

Data Categorisation: Distance Groups

Following the data collection, before the analysis was undertaken, runners were categorised into a specific "**Runner Type Group**" – short, middle- and long-distance runners, based on the amount of weekly mileage and frequency of their running sessions they provided in the form.

Distance Group Specification

In this study, a total weekly mileage, session frequency as well as session duration was considered while assigning runners to a certain distance group.

Hence, for the purpose of this study, a **short distance** runner was defined as covering up to 29km/week, with a maximum of 8km per session. A **middle-distance** runner was covering between 30-40km/week with a minimum distance of 8km per single session and a **long-distance** runner any distance above 40+km/week. There was no requirement regarding the minimum or maximum distance and amount of sessions per week for this group. The reasoning behind the distance classification is to account for running exposure. It was found that some individuals covered increased amount of distance but only due to increased running frequency. It was argued that due to that fact a single session is still relatively short, and the injuries were less likely to be affected by increased demand associated with a run of a longer distance. Additionally, participants had been asked to mark any current area of pain on an anatomical diagram of a human model on the questionnaire and provide further information on the type of pain they were experiencing and/or specific diagnosis – if having been given by a medical professional. These data were then input into Excel and analysed to establish general running-related injury patterns and investigate factors that were directly predisposing runners to certain injuries with regards to their weekly distance. Within each type of running population, data on injury prevalence in both females and males were investigated both together and separately.

Statistical analysis

In this study, SPSS statistical Analysis Software was used to analyse the relationship between running-related injury and associated risk factors as well as establish the effect of gender on injury occurrence as well as location of RRI. A Chi-Square test was performed to establish whether variables in this study followed a hypothesized population distribution. The analysis was performed for all data and for each distance group. Significance was set at $p<0.05$.

Z-test analysis for each population group

In order to establish the strength of data and compare differences between population pairs, a z- test proportion analysis was performed using Excel. Z-test was used to determine the significance of differences between percentage values based on the different population sizes. Significance was accepted at $p<0.05$.

Results

Characteristics and training – related data of recreational runners

A total of 1000 individuals were sampled. Data relating to 387 females and 613 males were investigated. The majority of runners (42.3%) were in the 25-34 age group category, followed by 34.9% in the 35-44 age group and 15.1% in the 45-54 group. 43.6% of all participants reported running for general fitness, while 21.2% and 16.5% were training for marathon and a half marathon respectively. Only 9.3% and 1.4% of runners were training for a shorter distance race - 10km or 5km and less. The most popular running frequency of individuals was running 4 times per week (28.3%), followed by 3 times (24.7%). In relation to the time of each running session, 53.2% of individuals reported running between 45-60min. 21.4% and 21.1% reported running for 15-45min and 60-120min respectively (see *Table 9*).

Out of all runners, 339 (33.9%) females and 476 (47.6%) males were injured, accounting for a total of 81.5% of the whole population. The remaining 137 males and 48 females did not report any injury at the time the data were provided (18.5%). Data on injury status and frequency of individuals were also captured in the analysis. 55.5% had one injury at the time of their visit and 26% reported sustaining two or more traumas. At this point, no individuals were excluded.

Results For Specific Distance Groups

Within the whole population, runners were categorised into subgroups, based on their weekly distance, to *short* (n=660*), middle* (n=256) and *long-distance* (n=84) populations. Within these groups, 264 females and 396 males were in the short distance category. In middle distance group, 82 females and 174 males were reported. Lastly, 40 females and 44 males were found in long distance group.

It was found that in each running distance group investigated in this study most runners sustained injuries. Distance itself, has not been found to be significant for injury occurrence in this study (p>0.05). Difference in genders, however, and injury prevalence was found to be statistically significant for some of the population groups investigated. Of all short distance runners (both males and females) 81.2% reported injuries and the significance between gender difference was found to be statistically significant (p=0.008). A similar ratio was observed in middle distance runners, where 80.5% individuals sustained a running-related trauma and the significance for gender was established towards injury occurrence (p=0.003). There was no significance between the number of injured male and female runners in long distance population (p=0.304), even though the injury rate was the highest of all distance groups (86.9%) (*see Table 1).*

Table 1. The percentage (%) representation of injured vs. non-injured runners in each population group.

Population	All injured (%) n=815	All non-injured (%) n=185
Short distance (n=660)	81.2*	18.8
Middle distance (n=256)	80.5*	19.5
Long distance (n=84)	86.9	13.1

** refers to statistical significance with p< 0.05 obtained with Chi-Square analysis between distance group and injury occurrence*

Gender Specific Data For All Recreation Runners Investigated

Overall, in this study, gender was found to be statistically significant for injury occurrence ($p=0.039$) within the whole population of runners. No statistical significance was established for training-related factors, such as distance, event type, frequency, duration of running sessions as well as weekly distance ($p>0.05$). In relation to gender, it was established that out of all runners included in the study, 87.6% of females and 77.7% males sustained injuries. Females had significantly higher percentage of injury prevalence than males in both the short and middle-distance population groups studied ($p<0.05$; *Table 2*).

*Table 2. Injury incidence in male and female runners according to their weekly distance**

GENDER	DISTANCE		
	Short n= 660	***Middle n=256***	***Long n=84***
FEMALE	85.0%*	91.5%*	90.0%
MALE	77.8%*	76.0%*	82.2%

**the overall difference in injury incidence between all injured males and females in this study was significant, with p< 0.05*

Data outlined that for females, the highest percentage of injuries was observed in the middle-distance population (91.5%) and for males, in the long-distance runners (82.2%). In short distance runners, the difference between injured females and males was 7.2%. In long distance runners, the percentage difference between injury rates in male and female runners was similar and constituted 7.8%.

An important observation about injury rates in association with gender was made in the middle-distance population (*Table 2*). Even though injury prevalence in females was the highest for this distance group (91.5%), the prevalence in male middle distance runners was the lowest of all runner types (76.0%), resulting in a 15% difference between both genders (*Table 2).*

Injury Specific Data For Male and Female Recreation Runners Investigated

All injured female and male runners suffered primarily from injuries to similar body sites – the highest prevalence was for knee injuries (43.3% males; 42.2% females), followed by the foot (29.8% males: 29.6% females) and shank (20.4% males; 16.3% females). The prevalence of knee and foot injuries were similar across genders, in contrast to the areas of fewer injuries– in males, hip injuries had the lowest prevalence overall (4.6%), while in the female population the lowest rates of injuries were reported in the thigh (7.7%) (*Figure 3*).

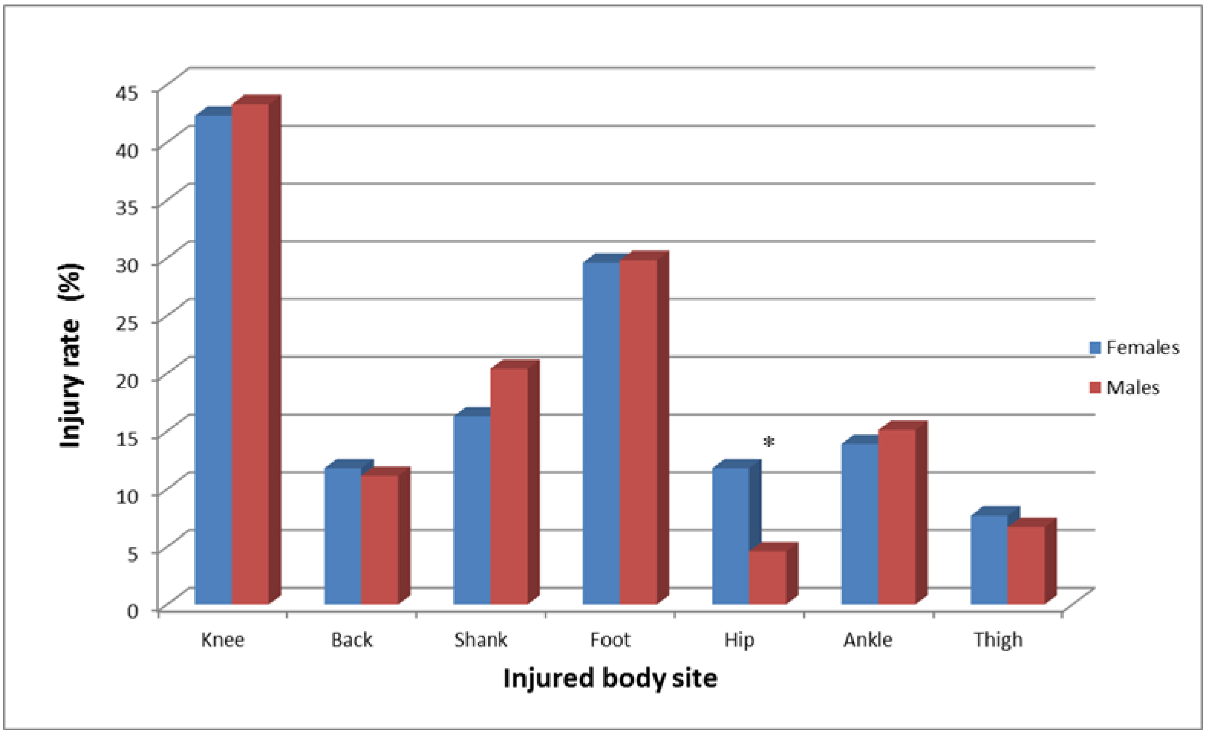


Figure 3. The injury prevalence (%) in relation to body site in male and female runners.

Statistical analysis determined significance of difference in injury rates between genders in only one investigated injury type. Differences in hip injuries were found to be significantly different in males and females ($p<0.05$) and constitute 7.2% difference between all injured males (4.6%) and females (11.8%).

Data analysis reported that the primary injury site in all distance groups regardless of gender was the knee (*Figure 4*). The percentage rates of those injuries remained almost identical in each population - in all short distance runners 42% of injuries were related to the knee, with a similar prevalence in long distance runners. In the middle-distance population, the rates were marginally higher, but not significantly so, at 45%. The second most prominent injury location for all distance groups in this study was the foot, with the prevalence of 30.6% in short distance runners; followed by 29.8% in the middle-distance population. The third most common body location exposed to traumas for short and middle-distance runners was the shank area – with 18.7% rate and 19.5% respectively. However, in long distance runners, ankle traumas were found to be the third most common injury (19.2%).

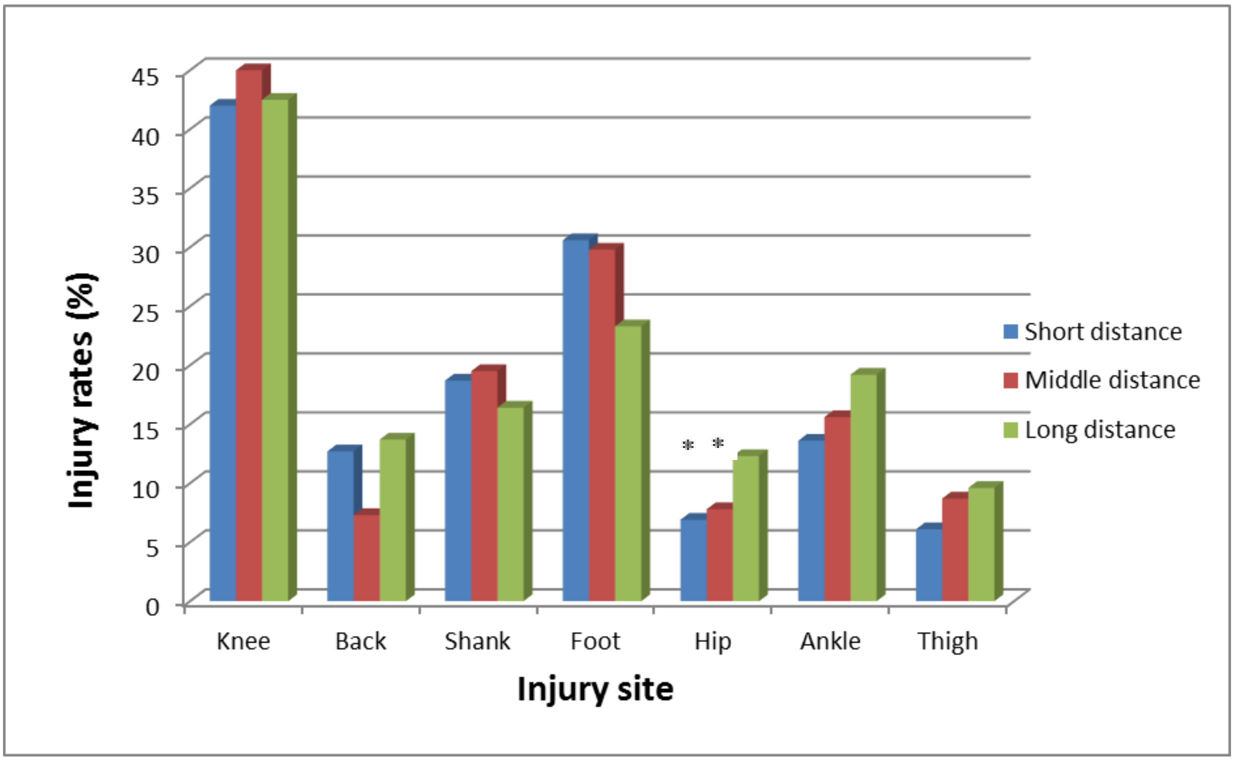


Figure 4. The injury prevalence (%) in relation to body site in all short (n=536), middle (n=205) and long-distance runners (n=73). indicates statistical significance (p<0.05)*

Single vs Multiple Injuries: All Populations

As a part of data collection, injured individuals were asked to provide information on the number of injuries they suffered from at the time of filling out client information. Although the majority of investigated runners were struggling with only one injury at the time, it was found that more runners suffered from a secondary injury (26 %) than were non-injured (18.5%) (*Table 3*).

In short distance runners, 167 individuals (25.3%) had multiple injuries which was more than the number of individuals who were non-injured (n=124, 18.8%) (*Table 4*). In middle distance population, 67 runners (26.4%) suffered from multiple injuries, compared to 48 (18.9%) who reported no injury (*Table 4*).

In long distance population, 30.9% of all runners in that group sustained two or more injuries and 14.1% were non-injured.

Table 3. The prevalence (%) of no, single and multiple injuries in the whole population of investigated runners as well as in relation to gender specifically.

Number of injuries	***Whole population***		***Males***		***Females***	
	N=1000	%	N=614	%	N= 386	%
None	185	18.5	137	22.3	48	12.4
One	555	55.5	328	53.5	227	58.7
Multiple (two or more)	260	26.0	148	24.1	112	28.9

Table 4. The prevalence (%) of no, single and multiple injuries in the short, middle- and long-distance population of runners.

Running population	***No injuries***		***Single injury***		***Multiple injuries***	
	N	%	N	%	N	%
Short	124	18.8	368	55.9	167	25.3
Middle	48	18.9	141	54.7	67	26.4
Long	12	14.1	47	55.0	25	30.9

Injury Prevalence And Trends In Different Population Of Runners

Short distance runners:

Due to the fact that several differences in injury prevalence and location were observed in all injured runners according to gender, female and male runners were considered separately for further analysis. As mentioned previously, data analysis for short distance runners indicated the knee as the area most susceptible to injuries both in female and male runners. Foot-related injuries followed by shank traumas were found to be also common for that population.

Table 5. The prevalence of injuries to a specific body location in male and female short distance runners.

INJURY SITE	FEMALES (%) n=227	MALES (%) n=309	DIFFERENCE (%)
KNEE	41.9	42.1	0.2
BACK	13.7	12.0	1.7
SHANK	15.9	20.7	4.8
FOOT	30.4	30.7	0.3
HIP	11.0	3.9	7.1*
ANKLE	11.0	15.5	4.5
THIGH	6.6	5.8	0.8

**statistical significance p<0.05*

The percentage rates of knee injuries were the highest for both male and female short distance runners and constituted 42.1% and 41.9% respectively (*Table 5*).

In the male population, the fewest injuries were reported in the hip (3.9%) and in the female population, thigh issues were least common (6.6%). The only significance was found in the difference in hip injury rates between males and females (7.1%) with a $p<0.05$.

Middle distance runners

Injury patterns in middle distance runners also indicated that knee-related traumas accounted for the majority of injuries in that population (*Table 6*), being 40.0% of all injuries in females and 48.4% in males, followed by foot issues (males 33.0%; males 27.7%) and injuries to the shank (F 17.3%; M 20.8%).

Table 6. The prevalence (%) of injuries to a specific lower-limb location in male and female middle-distance runners.

INJURY SITE	FEMALES (%) n=76	MALES (%) n=130	DIFFERENCE (%)
KNEE	40.0	48.4	8.4
BACK	8.0	6.9	2.9
SHANK	17.3	20.8	3.5
FOOT	33.3	27.7	5.6
HIP	12.0	5.4	6.6*
ANKLE	16.0	15.4	0.6
THIGH	10.1	7.7	2.8

**In middle distance population, the differences in hip injuries between genders were found to be significant (p<0.05).*

In contrast to short distance runners, even though knee injuries were most common for both genders, a great percentage difference in knee injury rates was observed for that population (8.4% discrepancy), indicating that men were more susceptible to injure that body site. No significance was established between the genders ($p>0.05$). Foot injuries were the second most common injury for both males and females, followed by shank traumas (*Figure 6*). The second highest difference in injury rates was in the hip, which is consistent with data for short distance runners. Statistical analysis established significance in gender and injury type within this population of runners for hip injuries ($p<0.05$) through Chi-Square Independence test and z-test.

Long distance runners

In long distance runners, the highest percentage of injuries was observed in the knee, both in males and females (*Table 7*). In the female population, in comparison to the short and middle-distance runners, the rate of those injuries was the highest of all (50%). In males, on the contrary, the prevalence of knee injuries was the smallest of all distance groups (35.1%). Simultaneously, this was the greatest difference in injury rates for specific body site observed in each population, although represented by relatively small population sizes and as such, not a significant difference. It was also noted that the second most common injury site in the female population was the ankle, followed by the shank, foot and hip (being 16.7% each). In males, foot-related issues were still the second most injured body site (29.7%), followed by back injuries. No statistical significance in the differences between gender was established for that population group ($p>0.05$) in relation to injury trends.

Table 7. The representation of injury prevalence (%) in male and female runners in relation to injured body site for long distance runners.

INJURY SITE	FEMALES (%)	MALES (%)	DIFFERENCE (%)
KNEE	50.0	35.1	14.9
BACK	8.3	18.9	10.6
SHANK	16.7	16.2	0.5
FOOT	16.7	29.7	13
HIP	16.7	8.1	8.6
ANKLE	27.8	10.8	17
THIGH	8.3	10.8	2.5

In this population, the greatest difference in injury rates between genders was found to be in the ankle (17%), followed by higher number of knee injuries in females (by 14.8%) and foot-related injuries, for which prevalence was higher for men (by 13%). The smallest difference in injury rates between genders was found in the shank (0.5%). The fewest injuries were reported in the back (8.3%) in female runners. In males, hip injuries were least common, which agrees with patterns observed in the short and middle-distance groups although was found not to be statistically significant for this population (p>0.05).

Personal And Training- Related Factors

Using the data provided through the questionnaire, a variety of training-related and personal factors and their effect on injury rates was investigated. These included genders, age, event participation, session duration, frequency of sessions and distance covered per week. For the whole population, out of all measured outcome, only gender was found to be significant with injury occurrence (p<0.05).

Age

According to the data, the prevalence of injuries in runners at different ages remained similar across all populations investigated in this study (*Table 8*). Age was found not to be a significant factor for injury occurrence in the whole population and each of distance group categories (p>0.05).

Table 8. The summary of data for age for the whole population and gender specifically (n=1000)

Age group (years)	***Whole population***		***Males***		***Females***	
	N=1000	%	N=613	%	N= 387	%
18-24	50	5.0	31	5.1	19	4.9
25-34	423	42.3	241	39.3	182	47.0
35-44	349	34.9	225	36.7	124	32
45-54	151	15.1	99	16.2	52	13.4
55+	27	2.7	17	2.8	10	2.6

Similarities were observed in age group trends data in the whole population as well as injured runners (*Table 8*). The vast number of injured individuals were in the 25-34 and 35-44 age groups. Data for each of the populations studied are shown in the *Table 8*.

Event participation

As a part of data collection in this study, individuals were asked to provide information on any event they were training for, with an aim of investigating whether event participation affects injury rates (APPENDIX II). Data was also recorded on individuals who were not training for anything at the time of data collection. In injured runners, depending on the population group studied, different trends in training were observed. The majority of injured runners within the short distance population were not training for a specific event but were running to 'maintain general fitness'. Injured middle distance runners were more likely to train for 'half' and 'full marathons'. In the long-distance population, 'half marathons', 'Ironmans' as well as 'ultramarathons' were the most popular events (APPENDIX II).

In this study, no significance between event type participation and injury occurrence were found ($p>0.05$).

Frequency of sessions

The characteristics of the whole population with regards to running frequency data were shown in APPENDIX II. It was concluded that the majority of runners ran 4 (28.7%) and 3 (24.7%) times per week (APPENDIX II). There were no differences in the most common frequencies in males and females. The vast number of male runners ran 4 (26.4%) and 3 (26.1%) times per week. Similar trend was reported for females – 31.3% and 22.5% ran 4 and 3 times per week.

No significance was established between frequency of sessions and injury occurrence for the whole population ($p>0.05$).

In APPENDIX II, session frequency data were also analysed and presented for each distance group. The majority of injured short distance male and female runners ran 3 times per week (32.4% and 18.9% respectively). In middle distance runners, the majority of injured runners ran 4 times per week (30.8% and 30.7%). In long distance group, highest number of injured female runners was reported running 5 times per week (50%). In males, the same frequency was reported in 24.3% of runners, followed by 18.3% who ran 4 times per week.

No significance was established between session frequency and injury occurrence in any of the populations of runners (*p>0.05).*

Distance

The effect of distance on injury occurrence and trends was the main aim of this in this study. Total weekly mileage covered by individuals was used to assess runners and categorise them to a certain population – short, middle and long. In this study, a short-distance runner covered between 5-29km/week, a middle-distance runner 30-40km/week and a long-distance runner 40+.

Table 9. Summary of weekly distance data for the whole population as well as males and female specifically.

Weekly distance (km)	***Whole population***		***Males***		***Females***	
	N=1000	%	N=613	%	N= 387	%
5-10	145	14.5	78	12.7	67	17.4
10-15	223	22.3	137	22.3	86	22.3
15-20	155	15.5	87	14.2	68	17.6
20-25	98	9.8	64	10.4	34	8.8
25-30	58	5.8	34	5.5	24	6.2
30-35	70	7.0	54	8.8	16	4.1
35-40	55	5.5	28	4.6	27	7.0
40+	195	19.5	131	21.4	64	16.6

In relation to the whole population characteristics (n=1000), it was found that the majority of runners covered total weekly distance of 10-15km (22.3%), followed by 15-20km (25.5%) and 5-10km (14.5%) (*Table 9*).

In male population, the same trend was observed, with 22.3% of runners running 10-15km per week, 14.2% 15-20km and 12.7% 5-10km. In females, the majority (22.3%) ran 10-15km/week, followed by 17.6% 15-20km and 17.4% 5-10% (*Table 11*).

As seen in *Table 9*, the majority of injured male and female short distance runners were found to cover between 5-30km per week, whilst in middle distance runners 30-40km per week was the most common distance. In long-distance runners, injured individuals were covering primarily 40+ km/week.

In each running distance population group, certain gender specific trends were apparent. Firstly, in short distance population the analysis indicated that men who ran 25-30 km/week were more likely to sustain an injury than those running any other distance. In middle distance runners, females who ran the distance of either 25-30 km/week or 35-40 km/week were at higher rates of injuries than men.

In this study, no significance between injury occurrence and weekly running distance was found. However, significance was established with regards to gender differences and injury trends in this study ($p<0.05$).

In relation to injury occurrence and trends, the data reported less knee injuries in males who run between 20km-40+ km/week – rates decreased from 48% to 35% (*Table 9*). Conversely, the female population was found to suffer from more ankle injuries when weekly distance increased from 5-30km/week to 40+km/week (from 11% vs 28%). Simultaneously, foot injury prevalence was found to increase in males who ran 40+ km/week rather than 30km-40km/week.

Discussion

The purpose of this study was to investigate the effect of weekly running distance and gender on injury trends in recreational runners and establish whether injury patterns changed in individuals with higher/lower mileage and if certain runners might be predisposed to sustaining traumas to a specific region. Additionally, an investigation of associated running-related training risk factors was undertaken, and a separate analysis was undertaken for male and female runners. It was hypothesised that increased weekly distance might increase the prevalence of injuries in runners as well as predispose individuals to traumas to different anatomical sites. This was explained by the perceived positive relationship between increased running exposure and overuse injuries.

In this study, distance itself was found not to be statistically significant for injury occurrence and differences in trends of those injuries (0>0.05). Gender, however, was found to affect injury occurrence and trends in short and middle-distance populations of runners ($p<0.05$). None of the other measured factors were found to be significant for injury occurrence. It could be argued, that due to differences in sizes of the populations in this study, the relationship might not have been reflected.

All recreational runners

This study confirms that the incidence of running-related injuries is high amongst all distance runners. Furthermore, data revealed that runners in this study were more likely to suffer from a secondary injury (26%) than be non-injured (18.5%). Results also indicated that the prevalence of running-related traumas in the long-distance population was the highest of all (86%), followed by short (81%) and middle-distance runners (80%). This trend confirms the U-shaped theory on injury predisposition in different running populations (Kluitenberg *et al,* 2015). This is significantly more than in other studies published to date, where prevalence of injuries to lower leg was found to range between 19.4% to 79.3% (van Gent *et al,* 2007; Gallo *et al,* 2012; Kluitenberg *et al,* 2015). This may have been affected by the fact that injury definition in this study included both mild and severe musculoskeletal traumas to lower limb and that they were self-diagnosed. Furthermore, the basis of data collection for this was information provided by individuals during their running assessment and consultation in a sports lab. Due to that fact, it is likely that the prevalence of injuries was higher than previously reported in literature (van Gent *et al*, 2007; Kluitenberg *et al*, 2015) as individuals might have been more likely to be injured as they were seeking help and recommendations with regards to footwear selection or pain management. It could be argued that some of the injuries reported by individuals might have constituted blisters and general muscle tightness or soreness. Nonetheless, capturing minor injuries is a strength of this study as those might lead to future injury, which might be significantly more severe. To date, no other study that we know of was investigating minor injuries as a way of predicting future injury locations. Mild injuries might not have affected the running engagement of individuals and thus, due to compromised healing process might contribute to developing new injuries or lead to more severity in current injury (Tonoli *et al*, 2010). No information was provided on whether the injury resulted in the absence in training.

Some authors previously investigating RRI, such as Malisoux *et al* (2014) and van Poppel *et al,* (2014) recruited participants whose injuries resulted in complete absence from running for at least a few days, required medical attention, or significant reduction in speed, duration and frequency (van Middelkoop *et al,* 2007). This in turn might have decreased the injury prevalence in those studies.

It is, however, important to highlight that in the current study the percentage difference in injury prevalence between all populations of runners was insignificant (6% difference, $p>0.05$). Thus, it can be concluded that regardless of weekly distance covered, all runners were at a relatively high, and similar, risk of sustaining injuries and running-related issues at some point as a result of engagement in running as their primary physical activity. Group comparisons may have been affected by differing numbers of runners, particularly when considering the low number of long-distance runners.

It was observed that in this study, the population sizes of different distance groups reflected on the trends in general population. Long distance runners and ultra-runners specifically, constituted the smallest population which was in agreement with Sheer and Murray (2014). The short distance runners, on the other hand, were the biggest, which was also previously reported in other studies. Those findings also implied that the majority of those individuals constitute novice runners, who are just at the beginning of their running journey (Kempler *et al,* 2018). Consequently, extensive research aimed to develop interventions to reduce injury prevalence in runners is essential.

Gender

Taking into account the results of this study it was proposed that gender has a greater effect on injury rates and associated trends than the distance itself. The extent of such differences in injury prevalence and its gender-specificity meant that further analysis focused on comparing trends in running- related traumas and data between males and females in short, middle- and long-distance runner populations was necessary.

Although overall there were more males (n=613) than females (n=387) in this study, a significant difference in injury occurrence was reported for both the short and middle-distance populations ($p<0.05$). Out of all participants involved in the study, females suffered from more injuries than males (87.6% *vs.* 77.7 % respectively), regardless of their weekly running distance. This has been surmised to be due to anatomical and structural diversity between males and females, as well as associated functional differences in running biomechanics (Francis *et* *al,* 2018). Sigward and Powers (2006) also argued that females generally exhibit altered neuromuscular control as a result from a greater Q-angle and increased dependence on quadriceps muscle activity to control landing. It could be hypothesized that due to the method of data collection and the nature of a sport lab environment and females could be more likely to only consider getting advice and assessment when injured, rather than for performance or general comfort purposes (Andrews and Chen, 2014).

Furthermore, it is worth mentioning that in each distance population studied, a higher number of males were reported (613 males vs 387 females). Only in the long-distance population, the males and female population size was similar (n=44, and n=40 respectively). Nonetheless, females were found at a greater percentage of injuries than males in each of the population groups studied.

This tendency is in agreement with the majority of previous studies that looked at running-related traumas in relation to gender, although the levels of injury rates were greater in this study than in others (Taunton *et al,* 2002; Tenforde *et al,* 2016). Such variability and changes could be primarily explained by anatomical, biological and biomechanical differences between genders. It was previously established that anthropomorphic parameters such as BMI, hormone levels and general flexibility (which were found to differ in males and females) might affect running gait and lead to abnormalities, which could potentially explain differences in injury trends (Dugan *et al*, 2005; Mitani, 2017). According to Nieves *et al,* (2010) genetics as well as nutritional deficiencies in calcium and vitamin D was also previously reported to affect injury risk in female runners.

Gender has previously also been associated with differences in movement biomechanics. Altered neuromuscular control which results from a greater Q-angle and greater activation of quadriceps muscles during initial contact has also been suggested to affect rates of injury (Nielsen *et al,* 2013). Furthermore, shock absorbance capabilities and fatigue levels have been previously found to affect running biomechanics in male and female runners. Sinclair (2015) provided evidence which suggests that males exhibited greater shock attenuation compared to females. In the study, women were also found to exhibit significantly greater patellofemoral loads than male runners. This was also seen in the current study, as knee injuries were the primary trauma location in female runners.

In this study, the aim was to determine if injury location varied in different populations of runners, categorized by distance. Some differences were observed in male and female runners.

Firstly, no significant difference in knee injury occurrence in males and females was established in this study ($p>0.05$), although the data were not able to distinguish between different types of knee injury and investigate whether these were gender specific. A significant difference, however, in injury prevalence was found in respect to hip injuries in both short and middle-distance population. In those distance groups, females reported significantly more hip-related traumas than males ($p<0.05$). Furthermore, even though no significance was established in the long-distance population it could be argued that this was due to a very small population size and the fact that there was a decrease in hip injuries in females, rather than increased in male runners. According to Heintjes *et al* (2005) evidence exist to support the view that female runners are more prone to incur hip injuries, whilst male runners are at an increased risk of sustaining hamstring or calf injuries. Hence, it was concluded that regardless of distance covered per week, women were more likely to sustain hip-related issues than males and this view was supported by the findings of the current research.

Knee Injuries

In this study, the most commonly injured body region was the knee, regardless of total weekly running distance and gender of runners. The main function of the knee during a gait cycle is allowing locomotion with minimal energy requirement from the muscles and providing stability, whilst accommodating for different terrains (Stoggl and Wunsch, 2016). The knee also helps in transmission, absorbance and redistribution of forces associated with braking and impact. Inefficient motion of the knee, as well as general weakness of the surrounding joints and tendons might lead to several traumas in runners, as they rely heavily on single leg activity (Dugan *et al,* 2005). Across all distance runners, knee injuries were found to be the most common issues in this study, regardless of gender and distance covered by study participants. This is in agreement with a number of previous studies on novice, marathon and long-distance runners, where knee injury prevalence percentage range was established to fall between 14%-50% (van Poppel *et al,* 2014, de Araujo *et al,* 2015; Kluitenberg *et al,* 2015). In this study, knee injury prevalence in all populations was at the upper end of that range and falls between 31.8% - 40+%. In long distance runners specifically, the knee injury prevalence was even broader across different studies and was reported as 7.2% - 50.0% (van Gent *et al,* 2007), compared to 31-42% here. The generally high rates of knee injury reported here could be influenced by sampling procedures/study design but are still indicative of the extent of the problem. This study suggests that distance does not affect rates of knee injuries, hence further investigation is needed to establish whether the predisposition is due to biomechanical pattern or rather anatomical and anthropomorphic factors.

No significant differences were observed between the rates of knee traumas in female and male runners in this study ($p>0.05$). In short and middle-distance runners, however, it was observed that males suffered from more knee injuries than females, which is not in agreement with previous studies, where female gender was positively associated with knee injuries (Mitani, 2017, Kluitenberg *et al*, 2015). Only one other study that is known of reported the same results (Taunton *et al*, 2002). This might have occurred due to an increased number of male participants in both population groups or have been affected by injury history of runners which was not sampled in this study in data collection hence was out of our control. The opposite observation was, however, made in the long-distance population in this study - knee injury prevalence was found to be higher in females (50%) than males (35%). The reason for such change could be that this population of runners was the smallest of all investigated populations (n=84), which could in turn have affected the representativeness of the data. Another reason could be that those injuries were gender specific or somehow related to the development of overuse injuries and running experience of the individuals investigated in this study. It has been established that as the distance increased, females could be less likely to maintain appropriate biomechanics, due to increased local muscle fatigue and reduced shock absorbance capabilities which might in turn affect single leg activity and balance, especially due to increased hip width and Q-angle (Ferber *et al*, 2003; Mitani, 2017). Another reason for such a phenomenon could be due to overuse related to years in training, although the length of experience related to running for individuals involved in this study is not known.

Overall, it can be concluded that distance does not predispose to knee injuries, however it is likely that the repetitive nature of running, associated impact forces as well as single leg strength might increase the likelihood of developing knee-related traumas (Ferber *et al*, 2003). Hence, further research is needed to establish what exactly is the knee injury development pathway associated with running and investigate whether the same factors cause knee injuries in males and females. It was concluded that a high prevalence of those injuries observed in this study highlights the extent of the problem and reinforces the need for future studies in all types of runners (short, middle and long distance). Unfortunately, due to the nature of data collected in this study, it was not possible to describe the type of injuries sustained by runners. Thus, there was no information available on whether the injury type, presentation and severity in this study. It can be argued, that even though rates of knee injuries were relatively similar, due to structural and anatomical differences between the sexes there might be a possibility that the mechanism of those injuries is different. Hence, diverse and unique interventions should be applied to decrease the risk of developing knee – related injuries in males and females. Females have previously been shown to have more knee valgus during the single leg weightbearing (stance) phase of running gait as well as increased pelvic rotation compared to males (Ferber *et al*, 2003). They have also been found to be more quadriceps dominated, which in turn might increase their risk of anterior knee problems, and predisposition to ACL and patellofemoral injuries in females (Messier *et al,* 2008).

Although not investigated in this research, it can by hypothesized that men are generally muscularly stronger than females, which might be protective of knee injuries when engaged in running. There is also evidence to prove that having greater muscular strength increases shock absorbing capabilities of the muscles surrounding the knee joint, hence resulting in lower knee joint loads (Messier *et al,* 2008). The same research also linked reduced hamstring flexibility with higher knee extension moments, which might increase the risk of knee injuries in females, who exhibit increased flexibility. According to Ferber *et al.* (2003) atypical foot and hip mechanics, which is commonly seen in female rather than male runners, also plays a role in development of knee – related issues, especially ITB, due to femoral and tibial attachments. This is why it is important to investigate the mechanisms of knee injuries – it seems that those traumas are often associated with a secondary injury to a different anatomical site and might occur as a compensatory movement pathway. Furthermore, due to an increased prevalence of multiple injuries in this study in runners of all distances it was argued that knee injury is more likely to develop in individuals.

Due to that fact, we conclude that muscular strength and optimal flexibility of the upper and lower leg is crucial in decreasing the likelihood of a variety of knee injuries in runners. Further research should focus on comparing to what extent each of these might contribute to injury occurrence and aim to identify factors which might contribute to increased susceptibility to movement abnormality in females and males separately.

Hip injuries

In all injured runners, hip traumas constituted 6%-16% injuries investigated in this study, which is in agreement with previous studies (van Poppel *et al*, 2014). The hip area is one of the most complex in the musculoskeletal system. It was established that loads equal to eight times body weight have been shown to act within the hip joint during simple jogging, with running potentially placing even greater demands (Anderson *et al*, 2001). During normal running, at a relatively low speed, propulsion is achieved mainly by the structures of the lower leg, but at higher speeds, the main power is generated at the hip in both males and females (Kluitenberg *et al*, 2015). This is caused by an increased demand on the upper muscles, resulting in a greater biomechanical load in these structures. This might explain the variations in injury regions in faster athletes (sprinting) and other populations of runners (Kluitenberg *et al*, 2015).

Due to significant differences ($p<0.05$) in prevalence of hip injury between males and females in short and middle-distance groups it was concluded that mechanisms of hip injury require further investigation. In this study, it was found that females were more likely to sustain hip -related injuries than men across all populations of runners, regardless of the distance they were running at. This suggests that distance is not the primary cause of such injuries and that there is an underlying reason which predisposes women to suffer from problems in that region more than men. It is important to study the mechanism of hip injuries as even though those traumas occur less commonly than other running- related traumas, they have been found to often be more severe and require more rehabilitation time (Anderson *et al.*, 2001). There is evidence to suggest, that abnormal motion or weakness in that area might also contribute to developing traumas to a different site, mainly the knee region (Dugan *et al*, 2005). The majority of injuries to the hip were previously found to occur due to overuse and mainly involved soft tissue traumas or primary joint bone pathologies (Geraci Jr *et al*, 2005). Hip and pelvis injuries were found to range between 3.3%-11.5% in studies of long-distance runners, as identified by a systemic review by Gent *et al.* (2007), which is in agreement with data obtained in this study. 8.1% of males in that population and 16.6% of females were suffering from hip related issues. Because of the dependency between hip and pelvis function, its biomechanics, and the fact that prevalence of hip issues seems to be gender specific, further research should investigate hip and pelvis movement in running in males and females and identify to what extend body shape, BMI and Q-angle and other functional factors affect the hip injury pathway. This is extremely important as some authors associate knee injuries with hip weakness and tightness (Ferber *et al*, 2003). Hence, more thorough analysis should be undertaken to investigate the influence of imbalance in the hip on injuries in the lower extremities and suggest strategies to minimise associated risks of traumas.

Foot injuries

In this research, the second most common injury site in short and middle-distance runners was the foot region, which was reported as 30.6% and 29.8% of all injuries, respectively. In long distance runners, foot injuries were less commonly reported (19%). According to the data, the degree to which males and females were susceptible to foot injuries was similar - being 30.7% and 30.4% respectively, in short distance population, and 27.7% and 33.3% in middle distance group. Although overall prevalence was lower in the long-distance runners, foot issues constituted the second most injured site in males (27.7%) and third in females (16.7%). Interestingly, the rate of foot injuries appeared to be greater in females who were running long distances. Although no significance was observed ($p>0.05$), it can be argued that since the long-distance population was the smallest of all studied in the following research (n=86), this trend should be investigated further in a larger cohort. To date, foot injuries have been linked with increased pronation, increase in navicular drop during midstance, as well as ankle eversion and inversion on initial contact (Nicola and Jewson, 2012). Females might be at a greater risk due to having a lower arch index and tendency to exhibit excessive pronation (Mitani, 2017; Dugan *et* al, 2005). It was also proposed that in a long-distance population, where the duration of a running session is prolonged and there is more repetitive load being applied onto the foot, and due to accompanying fatigue, male and female runners might be more prone to show abnormalities in foot motion pathway and hence be predisposed to foot-related issues (Dugan *et al,* 2005). In this study no information on the type of foot injuries were available. Previous research by Nicola and Jewson (2012) identified pain to metatarsal heads, the big toe or tension under the arches to be common in runners and this was found to be associated with abnormalities in push-off biomechanics. Foot movement has also been linked to pain and traumas higher up the kinetic chain (in knees and hips), hence it is crucial to reduce the prevalence of those traumas not only to minimise experienced pain and discomfort but also to manage other lower and upper limb injuries (Geraci *et al,* 2005). Taking into consideration the outcome of this study, where foot injuries constituted a high percentage of lower-extremity injuries, as well as the fact that a lot of runners suffered from multiple injuries evidence for a development of a secondary injury and its likelihood could be proposed.

Thus, it is important to highlight the need of wearing appropriate footwear, especially for runners who run longer distances. Insoles could also be considered in some cases to manage and improve abnormalities in foot movement and prevent from other injuries (Johnston *et al,* 2003). Due to the fact that the Sports Lab where the data was collected specialises in footwear recommendations, as well as manufacturing custom insoles, it could be argued that this might affect the representation of the population studied. It was hypothesised that individuals with foot-related issues and traumas might be more likely to seek advice from a footwear clinic, regardless of the severity of those problems. Some runners might be experiencing mild discomfort (blisters), yet still be willing to get advice and go through necessary testing and report those minor issues as injuries. Others might be experiencing more severe traumas which could affect their biomechanics up the kinetic chain. In this study, it was not possible to separate those injuries and assess their specific types and nature. Hence, more studies on foot injuries and associated mechanics in both injured and non-injured individuals should be conducted. More focus should also be put on investigating the influence of footwear design on foot function and gait biomechanics with an aim of reducing injury risk and managing the severity of existing traumas through motion control (where necessary) and shock absorbance properties.

Shank injuries

Due to discrepancies in injury diagnosis and the nature of self-reported information provided by study participants it was not possible to separate those injuries within the shank region. It was hypothesized that injuries to the lower extremities in this study mainly involved calves, posterior and anterior tibialis pain and medial-tibial stress syndrome. Most injuries in the shank were reported in middle distance runners (19.5%), followed by short distance (18.7%) and long-distance runners (16.4%), though this was found not to be statistically significant across different populations ($p>0.05$).

In relation to gender it was observed that the prevalence of shank injuries was almost identical for males and females in the long-distance population (16.2% *vs.* 16.7%). Mild, though not significant, changes in prevalence across gender was also observed in middle distance runners, where the percentage difference was the greater in males (20.7%) than females (15.9%) as well as male (20.8%) short distance runners than females (17.3%). This led to a conclusion that men have a greater proportion of injuries in the shank, especially whilst running shorter and middle distances. According to Nielsen *et al* (2014), a lot of studies highlighted the high prevalence of shank injuries in runners, although the systematic review found that those injuries were more evenly weighted between genders. This phenomenon was also confirmed by another study (Hendricks and Phillips 2013), in which shank, especially calf injuries, were found to be a significant issue for male runners, especially those running marathon distances. Females were previously found to be at an increased risk of medial-tibial stress syndrome than males (Newman *et al*, 2013). In this study, it was not possible to separate shank injuries into traumas to specific locations – calf, shin (medial-tibial stress syndrome) or injuries to the tibia itself, hence the significant limitation to the gender comparison of injury patterns. Due to that fact, in order to get a more relevant and detailed idea of the nature of shank injuries, future studies should focus on investigating the exact location, type and timing of pain that male and female runners are experiencing.

Study limitations

There are some limitations to this study. Firstly, data used for the analysis were based on runners who were recruited from the Sport Lab database, which might limit the generalisability of results. In this study, the aim was to investigate recreational runners, who were engaging in running regularly for enjoyment or to maintain fitness levels but were not semi or professional athletes. It can be argued that all runners who are not engaged in running on a professional level will be recreational runners, although some (depending on the involvement and commitment to training) might be more prone to injuries due to higher exposure to loads and overuse as they cover more mileage. It could be hypothesised, that based on volume and intensity of training as well as distances covered each week, some individuals will be more 'serious' recreational runners than others. There are discrepancies in the terrain runners run on most often – some will run on roads and trails, others on the treadmills. Thus, research should look at specific populations in relation to distance and investigate specificity of their running routine and running style. Unfortunately, assumptions were made in classifying individuals into runner types as no data were collected on the nature of running participation and performance level.

Secondly, bias might have occurred during data analysis as the injuries were self-reported by the study participants (Brenner and DeLamater, 2016). Prevalence and incidence of injuries might have been overreported as data collection was undertaken in a Sports Lab, to which individuals might have been referred to in order to manage or treat any ongoing injuries/issues. Additionally, providing inaccurate information on injury type and diagnosis might have taken place. The aim of this study was to investigate existing patterns rather than confirm diagnosis by health professionals. It was argued, that minor injuries and problems which did not require medical treatment might have been referred to as injuries which would increase the injury prevalence in certain lower-limb areas. In this study, data on injury duration and whether they required any absence in physical activity were not collected. Hence, there was also no information provided on the severity of injuries that participants were suffering from.

Thirdly, the data that was analysed was originally collected in 2010-2011 which means that the results of the study might not reflect the current injury trends in running populations when this paper was published and the scope of the problem in modern society. Taking into account societal changes as well as increased popularity of running in recent years it was argued that the injury trends should remain similar, if not even higher.
This study, however, illustrates the necessity for running- related research and investigation. A vast number of individuals are at an increased risk of injuries and potentially not able to commit and engage in physical activity as a result, which might in turn affect their fitness levels and general health (obesity risks, mental wellbeing, etc.) (Middelkoop *et al*, 2007). This might in turn affect the amount of people needing to start using the health services and require medical attention. Future studies should also provide a better definition and distinction between recreational, novice and experience runners to enable more reliable comparisons between studies.

Lastly, there were differences in the numbers of participants in each of the population groups in this study, which might have affected the power of the data, hence this might not accurately reflect overall trends. The long-distance population was the smallest, with a total number of 84 runners. The short distance population group was the biggest, with 660 runners considered and the total number of middle-distance runners was 387. This was due to the distribution of the client base in Profeet Sports Lab, where the data was collected. It could be argued that this trend in population sizes reflects the general pattern and distribution in relation to running engagement of recreational runners. It was previously established that the majority of recreational runners, especially novice, on a weekly basis cover shorter distance (Kluitenberg *et al*, 2015). This was also seen in this study, where short distance population was the biggest (66%). Middle distances are generally becoming more popular, especially in runners who are training for a middle-distance event, such as half marathon, marathon, triathlon. Ultra-distance population is still very small and even despite the growing number of ultramarathon events each year. This was reflected by findings in this study (8.4%). It could be argued that this trend is mainly due to the fact that vast number of individuals struggle to meet training requirement of an ultra-distance running as not only an increase in frequencies but also running distance per single session is required (Scheer and Murray, 2014).

Conclusion

Running-related injuries constitute a great deal of injuries sustained by individuals in recreational sport. Most injuries occur in the knee, foot and shank. In this study, prevalence of running-related injuries for all runners was found to be extremely high, varying between 80%-86% in short, middle- and long-distance runners, regardless of gender. These rates pose a concern to modern society, in which increasing numbers of individuals participate in running events each year. It was proposed that the accumulation of injuries will contribute to increased cost of treatment as well as significant amount of time off running and inability to maintain a healthy lifestyle. Hence, an evidence-based prevention program is necessary to reduce injury occurrence in short, middle- and long-distance runners. Even though this study did not find any evidence that weekly running distance directly predisposed runners to certain injuries, it was concluded that females had a greater risk of injuries and that some traumas might be gender specific. For instance, hip-related traumas were found to be higher in females in all population groups. Due to this, it can be hypothesised that there might be differences in the underlying biomechanical pathway behind hip injuries between genders.

Future research should focus on designing large prospective cohort studies to establish to what extent gender affects injury development and running biomechanics through certain anatomical (foot shape, Q-angle) and functional features (knee valgus, pelvic movement, overall flexibility).

CHAPTER III – STUDY 2: The Effect Of Foot Mobility And Lower Extremity Function On Running Gait And Running-Related Injury Occurrence In Male and Female Middle-Distance Runners.

Background

There is a vast amount of research currently available on running-related injury prevalence in male and female distance runners. So far, what is known for sure is that running-related injuries (RRI) are multifactorial, and their prevalence is influenced by a variety of internal and external risk factors (Saragiotto *et al*, 2014). It was previously established that due to action as a kinetic chain, different joints and segments in the lower and upper limb influence one another during running motion and play an important role in injury development and pain management in runners (Dufour *et al* 2017). Due to the fact that the foot is the part of the body that makes initial contact with the ground and serves as a shock absorber of impact and ground reaction forces (GRF), it was found that its shock-absorbing capability can be greatly inhibited. Thus, the shock travels up the kinetic chain and affect other body parts, leading to potential problems in the knee and hip due to increased load and stress (Geraci *et al* 2005).
The link between the lumbopelvic–hip complex and foot function is increasingly being investigated. According to Barwick *et al* (2012) there is a significant association between foot pain, knee and hip pain. Foot pronation has been previously found to propagate more proximal lower limb dysfunction and hence contribute to a wide range of lower limb injuries affecting the lower back, hip, knee, lower leg, ankle and foot (Geraci *et al*, 2005; Mitani, 2017). Interestingly, just as increased foot instability thought to alter proximal pathomechanics, the dysfunction of the lumbopelvic–hip complex was suggested to affect the function of more distal structures of the lower limb and potentially play a role in foot motion (Barwick *et al*, 2012).Previous evidence suggest that females have an increase susceptibility to hip injuries than males and generally demonstrated a higher incidence of gluteus medius related dysfunction (Ireland, 1999), which was also confirmed in Study 1 of this paper.

Folland *et al* (2017) previously described running motion as a relatively free movement. Nigg *et al* (2017), however, provided evidence which suggested that over time, runners develop a highly specific “preferred motion path” with regards to their movement. What this means is that in order to achieve motion with minimal energy demand, a certain preference in direction and pathway of joint angles and segment markers during a given movement is displayed by an individual (heel-toe, forefoot running, etc.). As such, it could be concluded that to a degree, people might be designed to move in a certain way. To support this view, Nigg *et al* (2017) carried out a study to investigate the effect of change in footwear interventions on motion. The results of that study showed that running shoes only marginally affected kinematics of lower limb, thus confirming the '*preferred motion path'* hypothesis (Nigg *et al,* 2017). Due to that fact, it could be argued that a specific focus should be put on investigating the function of the foot, lower leg and overall mechanics. To date, both personal characteristics and training-related factors, such as age, hormonal and physiological status, body composition as well as biomechanical parameters related to running motion have been associated with injury (Kluitenberg *et al,* 2015; Kozinc and Sarabon *et al,* 2017). Unfortunately, despite extensive knowledge and data on physiological processes involved in running performance and training habits, their mutual relationship and effect on movement patterns and injury occurrence in runners is still fairly unclear (Nielsen *et al,* 2013; Gomez-Molina *et al,* 2017). According to data from the initial study undertaken as a part of this research, over 81-86% of male and female runners, regardless of their training distance, sustained an injury. To date, various studies established that a great amount of those runners experience traumas to lower extremities, rather than anywhere else in the body, with knee injuries being the most common issues (van Gent *et al,* 2007; Kluitenberg *et al,* 2015). This was observed regardless of the gender, age and years of running experience of investigated runners and was confirmed by the results of Study 1 in this research. There is data available on the effect of total weekly distance on injury trends (Molloy, 2016; Vitez *et al,* 2017). Research, however, tried to determine the effect of distance on injury patterns not as a single and independent variable, but rather as a modifiable training variation. Due to that fact, the majority of study results remain controversial and suggest that distance modulation can be both protective of injuries, as well as serve as a risk factor. It was also noted that distance was often investigated mainly based on the total weekly mileage and not as mileage of a single running session combined with its frequency per week. Hence, the initial study of this research (Study 1) was undertaken to investigate trends and injury prevalence in different population of runners, taking into account variations in training routine and distance modalities.

In Study 1, which is presented in Chapter II of this thesis, the research focus was put on determining injury prevalence and trends in short, middle- and long-distance runners with the aim of identifying populations at a highest injury risk. What was found was that distance was not a primary risk factor in injury occurrence in recreational runners studied. Gender, on the other hand, was found to be statistically significant for injury occurrence and trends ($p<0.05$) in the whole population, as well as for specific populations of runners. This lead to conclude that to an extent, gender might predispose some runners to an increased injury prevalence. In that study, data reported that female runners were at a greater risk of running-related injuries overall than males in each distance group investigated – short ($p<0.05$), middle ($p<0.05$) and long ($p>0.05$). Interestingly, a 15% difference in injury prevalence between male and female in middle-distance population was observed, which was the highest of all investigated group. Hence, it was concluded that a separate study focused at the predisposition to injury occurrence and trends in middle-distance runners should be designed to investigate gender-related characteristics with regards to anatomy, biomechanics and personal characteristics of individuals. It could be suggested that this group might present specific training-related features, such as increased running experience, frequency or intensity, which would allow them to develop a more consistent gait. It was proposed that the outcome of such an investigation would allow establishing whether there is a significant difference between gender of runners, their training-related factors as well as biomechanical traits, such as range of motion of the ankle and knee and flexibility in the lower extremities. It was argued that even though there is fair amount of evidence to suggest differing injury risk for recreational runners, a limited amount of studies directly compare in a 'high risk' population group, where the difference between injury rates with regards to gender is the greatest (as identified by Study 1 in Chapter II). Due to that fact it was concluded that previous methods and assessments used to determine whether there might be underlying anatomical differences might not be effective enough and more specific functional tests (both manual and automatic), potentially separate for males and females, which comprise of both static and dynamic tests should introduced in running injury research.

Furthermore, it was noted that very few studies investigated foot mechanics and associated injury risk. Most of time, only movement of the foot was taken into account, rather than its anatomy and flexibility (Ferber *et al,* 2003; Mitani *et al,* 2017). Due to conflicting data on the effect of pronation and supination on injury prevalence it was suggested that a more thorough foot assessment would be useful in determining the type and characteristic of the foot in motion (Dugan *et al* 2005). It was argued that more functional tests should be used in relation to the foot and ankle to study injury occurrence in runners as most studies that consider gait neglect fundamental differences in foot structure. Hence, for the requirement of this study, foot motion and mobility were considered separately with regards to rearfoot, forefoot and midfoot segments to establish whether differences in motion range and its activation existed.

The aim of this study was to investigate foot mobility (through assessing 1st metatarsal flexion and associated windlass mechanism, Foot Posture Index (FPI) and supination resistance), motion range in the ankle and overall limb alignment (in relation to foot, knee and hip) to establish their relationship with injury occurrence in male and female runners. It was hypothesised that foot and ankle mobility would affect running biomechanics of individuals which in turn might predispose runners to developing certain injuries.

Method

To investigate injury occurrence in middle distance runners (covering between 30-40+km/week as defined in Study 1, with a minimum of 3 running sessions per week, with an aim to avoid 'casual runners') in relation to several associated personal and training-related factors in both genders, this study included male and female participants. The equipment used for this part of the study was Precore Treadmill (TRM700-16) serial no; AZCAF20170011, Contemplas TEMPLO 8.2 and Kinovea 0.8.15 Sport Analysis Software. Two-dimensional gait video recording and performing necessary analysis of participants from posterior (back) and anterior (front) view.

For this study (Study 2) **injury definition** was **any *chronic, acute, intermittent or occasional pain/discomfort that presented itself during or after a running session in any lower and upper part of the leg***. Only traumas that did not result in complete absence in training for longer than three days were investigated. Information on whether the injuries required medical intervention before the testing commenced was obtained in data collection. Specification on the body site injured (left/right) and the nature of pain for each, as described by individuals in the running-related injury questionnaire which was provided as a part of data collection, was also obtained.

Data Collection

The majority of participants for this study were approached in the Sports Lab during their consultation with a running technician. Because middle-distance runners were the target population, the main requirement for participation in this study was a weekly distance of 30-40km, a minimum of three running sessions per week with a minimum distance of 8km per single running session. Such requirement allowed to recruit participants whose running routine and training involved prolonged period of running session duration, frequency and intensity, as well as covering a greater weekly mileage than short distance runners, whose injuries might not develop from running exposure. Once participants volunteered for the study, they were sent a study information sheet as well as informed consent form (APPENDIX III). Participants were also asked to fill out a running and injury-related questionnaire to make sure they matched the research criteria as well as to gain more information on their running-related routine (APPENDIX IV). The running and injury-related questionnaire had been divided into two parts – Part One included a range of questions on personal characteristics (age, gender, height, weight, shoe size, training routine, footwear worn, running experience, etc). Part Two was injury specific and designed to gain information on the nature, type and severity of any ongoing injuries and issues that were running-related. All data collected for this study were kept anonymous. Only fully completed questionnaires were used for the analysis to provide the most accurate observations for this study. Once the questionnaires were returned, a practical testing session was scheduled with each individual to perform manual foot examination and collect additional static (Foot Posture Index - FPI-6, Windlass Mechanism test, Supination Resistance test, Single Leg Squat test – SLS- and ankle dorsiflexion test) and dynamic data (video analysis of running gait).

Participants

A total of 26 individuals, 13 males (34$\pm$9 years old) and 13 females (28$\pm$5 years old) who were middle-distance runners were recruited in this study and constituted both injured and non-injured individuals. There was no requirement of training for any running event during data collection. All participants were healthy, active and confident in running on a treadmill at a self-selected speed. Individuals were between the ages of 18-45 years and were running recreationally. No information on whether participants were smokers or non-smokers was obtained.

As a part of data collection participants were asked about any underlying, ongoing medical issues that could affect their health and fitness, what their running experience was as well as to provide detailed information about the type, severity and specification of any current and previous injuries (or traumas experienced in the past six months). Runners were informed that if they felt unable to complete the study due to injury or personal reasons, they could withdraw at any time.

Exclusion criteria

Individuals who did not fill out the questionnaire fully, provided contradictive injury data or did not elaborate on their training routine were excluded in the study. In this study, only 2 individuals were excluded. One person did not provide complete information about their training routine, the other sustained an injury before the practical testing was performed, thus was excluded to reduce bias and the effect of the compensatory preferred motion pathway on current running gait and thus study results. For this particular study, the additional criteria of injury duration were added to injury definition to minimise the effect of the trauma on other measure data necessary for this part of research. Hence, if the injury was severe enough to result in absence in training (more than three days), they were not included in the study.

Once the participants gave their consent to participate in the study and their questionnaires were returned, within 2 weeks' time they were invited to come for a practical testing session in the Sports Lab.

Data Analysis

Baseline Measurements: Static testing

During the practical testing session, initially, a static assessment was undertaken to assess range of motion of the foot and ankle of each participant through a variety of clinically recognised tests. This included a Foot Posture Index (FPI-6) test (Redmond, *et al* 2006), Windlass mechanism test (Bolgla and Malone, 2004), Supination test (Kirby, 1992) and Ankle Dorsiflexion test (Bennell *et al*, 1998). Additionally, to track the motion of each knee, a single leg squat (SLS) test (Liebenson 2002) was performed and recorded.

Foot Posture Index (FPI-6)

The FPI-6 is a popular method of rating foot posture using a specific set of criteria related to static foot motion and a simple scale (-12 to +12) (Redmond *et al,* 2006). It is a clinical tool used to quantify the degree to which a foot is pronated, neutral or supinated, based on the sum of reference values collected during the test, referring to both rearfoot and forefoot of each foot. A variety of factors in transverse, frontal and sagittal planes are analysed and given a specific value. A sum of all those factors gives an indication of the foot type: normal = 0 to +5; pronated = +6 to +9, highly pronated 10+ to +12; supinated = -1 to -4, and highly supinated -5 to -12 (APPENDIX V). In order quantify the overall value of FPI-6, Additionally, a User Guide And Manual (Redmond, 2005) was used to provide the most accurate data.

Windlass test & 1^{st} metatarsal stiffness

The windlass mechanism test allows for a direct stretch on the plantar aponeurosis which can be effective in examining dysfunction of the plantar fascia, which is located on the bottom of the foot (Dugan *et al,* 2005). The windlass describes the manner which plantar fascia supports the foot during weight-bearing activities (Sinclair *et al*. 2014). This provides information on the biomechanical stresses placed on the plantar fascia and is crucial for the determination of an effective propulsion and likelihood of appropriate activation of the plantar flexors during motion.

To perform the test, force is applied to the 1^{st} metatarsal (great toe) of each foot to achieve maximum toe flexion. This should then allow to achieve a motion response in the arch of that foot and a significant increase the arch profile whilst the subject is standing (Dugan *et al* 2005). The less force is needed, the more responsiveness in the 1^{st} metatarsal is observed. This, combined with the efficient and elastic action of the arch, indicates good mobility in the 1^{st} metatarsal and that a windlass response is efficient. As this assessment is a very subjective, clinical tool for toe range of motion measurement as it fully relies on individual effort, experience and skills of the tester, for the need of this study, a practical training by a podiatrist was provided before the testing commenced.

Supination resistance test

The supination resistance test is a technique introduced and used by Kirby in 1992 that enables to establish a subjective measure of the amount of force (kg) needed to supinate the foot. The test requires placing one or two fingers under the medial posterior part of the arch of the foot (around the talonavicular joint) and supinating the participants' foot while simultaneously raising the arch of the foot and then making an estimate of how hard or easy it was. For this study, a scale of 1-3 (1 – easy, 2 – normal, 3 – hard) was used. It was proposed that the less force is needed, the more flexible and responsive the foot is. As before, due to the fact that this clinical test was subjective, a practical training by a podiatrist was provided.

Ankle Dorsiflexion test

This specific test has been used numerous times in research to determine ankle mobility (Bennell *et al*, 1998). This method utilises the knee-to-wall principle, in which the participant performs a weight-bearing lunge. The participant places the test foot on a tape measure perpendicular to the wall and lunges forward so the knee touches the wall. Then, the foot is moved away from the wall until the knee can only make slight contact with the wall while the foot remains flat on the ground. Finally, the distance of the front of the foot (2^{nd} metatarsal) to the wall is measured (cm) to assess the ability to dorsiflex each ankle. The greatest the distance the foot can travel from the wall without the movement of the heel of the ground, the better the dorsiflexion is of that foot.

Single Leg Squat (SLS) test

The Single leg squat test is a method developed from an exercise into a functional clinical test by Liebenson in 2002. It was created to examine the function of the lower extremity kinetic chain, mainly the motion of the hip and knee. The Single leg squat test is a clinical test conducted in the position of single limb stance. The aim of this test is to measure the deviation (expressed in degrees) of the knee position from a neutral during a maximum knee flexion. For the purpose of this study, a video recording of each participant as they squatted from a standing position to a max of knee flexion, and then returned to the start position. Participants were assessed and analysed with regards to their standing frontal plane knee position (varus/valgus) in anatomical position as well as single leg stance (upright), peak valgus knee position, which constituted the greatest valgus angle exhibited during the single-leg squat (Claiborne *et al*, 2006). Lastly, the change in the amount of frontal plane knee deviation during the SLS was established (peak knee valgus minus standing frontal plane knee position).

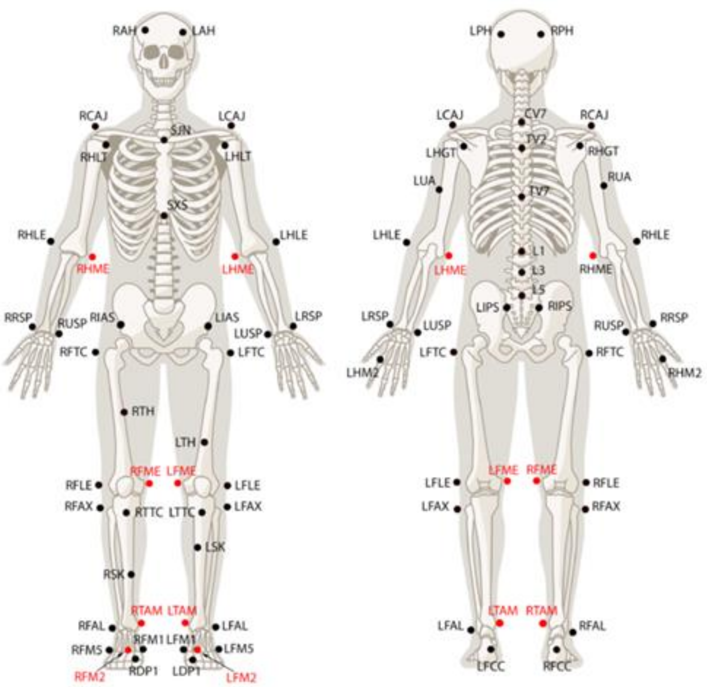
Dynamic testing

The equipment used for this part of the study was Precore Treadmill (TRM700-16), Contemplas and Kinovea 0.8.15 Sport Analysis Softwares, to enable two-dimensional gait video recording and performing necessary analysis of participants from posterior (back) and anterior (front) view.

As a part of dynamic testing, individuals were recorded running on a Precore Treadmill (TRM700-16) at a self-selected speed (average speed 12$\pm$2km/h for males and 11$\pm$2km/h for females) which was their average training pace (as outlined in questionnaires) for the duration of 5 min (at a 0-degree incline). Then, a qualitative video analysis of running gait was performed using two high-speed cameras. Recording was undertaken nonsynchronously (30Hz) in frontal (anterior and posterior) plane. Individuals were asked to run barefoot, whilst each side view was recorded for the duration of 1 min. Video analysis was later undertaken in slow-motion using Kinovea 0.8.15 Sport Analysis Software.

Sixteen red markers were placed onto participants in specific locations on each leg before the running test was undertaken. This was necessary for identification of angles and movement of the hips, knees and feet during gait cycle and to collect data from for the single leg squat test. The markers were placed on: Left Iliac Anterior Spine (LIAS), Right Iliac Anterior Spine (RIAS), Left Iliac Posterior Spine (LIPS), Right Iliac Posterior Spine (RIPS), Left Femur Lateral Epicondyle (LFLE), Right Femur Lateral Epicondyle (RFLE), Left Femur Medial Epicondyle (LFME), Right Femur Medial Epicondyle (RFME), Left Tibial Tubercle (LTTC), Right Tibial Tubercle (RTTC), Left Fibula Ankle Lateral (LFAL), Right Fibula Ankle Lateral (RFAL), Left Talus Ankle Medial (LTAM), Right Talus Ankle Medial (RTAM), Left Foot Second Metatarsal (LFM2), Right Foot Second Metatarsal (RFM2). These markes were used to quantify bilateral hip drop, knee motion as well as foot movement during dynamic testing (midstance) and for SLS test of each individual (*see Figure 7)*.

Additionally, a black line was drawn at the back of both heels of each participant (crossing through the middle of subtalar joint, in the middle of calcaneus bone) to allow for a visualisation and assessment of rearfoot movement during each running cycle when the foot was in contact with the ground (*Figure 8*).



Source: Leardini, A., Biagi, F., Merlo, A., Belvedere, C., Benedetti, M.G., 2011. Multi-segment trunk kinematics during locomotion and elementary exercises. Clin. Biomech. 26, 562-571.

Retrieved from: http://niederlande-infos.info/84865-supination-and-pronation.htm

Figure 7. Representation of marker placement data used in this study.

Figure 8. Center of the calcaneus

In the table below, the exact description of the marker placement in relation to a specific anatomical site was provided (*Table 10*).

Table 10. The description of the locations of each marker placed on each individual and used for static and dynamic analysis.

Description	Body Region	Anatomical Site
LIAS (PSISl)	Pelvis	Left Iliac Anterior Spine
RIAS (PSIS)	Pelvis	Right Iliac Anterior Spine
LIPS (ASIS)	Pelvis	Left Iliac Posterior Spine
RIPS (ASIS)		Right Iliac Posterior Spine
LFLE (LE)	Upper Leg	Left Femur Lateral Epicondyle
RFLE (LE)		Right Femur Lateral Epicondyle
LFME* (ME)	Upper Leg	Left Femur Medial Epicondyle
RFME* (ME)		Right Femur Medial Epicondyle
LTTC (TT)	Lower Leg	Left Tibial Tubercle
RTTC (TT)		Right Tibial Tubercle
LFAL(LM)	Lower Leg/Foot	Left Fibula Ankle Lateral
RFAL		Right Fibula Ankle Lateral
LTAM* (MM)	Lower Leg/Foot	Left Talus Ankle Medial
RTAM*(MM)		Right Talus Ankle Medial
LFM2* (SM)	Foot	Left Foot Second Metatarsal
RFM2*		Right Foot Second Metatarsal

Source: Leardini, A., Sawacha, Z., Paolini, G., Ingrosso, S., Nativo, R., Benedetti, M.G., 2007. A new anatomically based protocol for gait analysis in children. Gait Posture 26. 560-571.
Leardini, A., Biagi, F., Merlo, A., Belvedere, C., Benedetti, M.G., 2011. Multi-segment trunk kinematics during locomotion and elementary exercises. Clin. Biomech. 26, 562-571.

Statistical analysis

SPSS Analytical Software was used to perform descriptive and qualitative statistics on the collected data to establish the type and prevalence of injuries in runners according to different personal characteristics (height, weight, age) and running-related variables investigated in this study. Independent sample t-tests was used for the normally distributed variables (height, weight, BMI, shoes size, running experience). A Chi – square independence test was used to analyse the significance ($p<0.05$) between genders and injury occurrence as well as the association between injury likelihood and measured categorical risk factors. Analysis was carried out for the whole middle-distance population as well as for injured runners only (with respect to both genders).

Results

Whole population

Complete data were obtained from 26 individuals (height 172±9 cm, mass 67.79±10.62 kg, BMI 22.66±2.67 kg.m^2) of which 13 were males and 13 were females. Of the 26 individuals, 19 were injured, 10 males and 9 females. The remaining 7 were free from any known lower and upper extremity injuries. The characteristics of the middle-distance population is shown in *Table 11*.

Table 11. Summary of descriptive statistics on personal characteristics of the whole middle-distance population.

Personal characteristics	N	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	26	158.0	185.0	172.8	8.3
Weight (kg)	26	51.0	85.0	67.9	10.2
BMI	26	19.4	27.1	22.4	2.1
Shoe size (UK)	26	5.0	12.0	7.9	1.9

Table 12. Summary of descriptive statistics on personal characteristics of the males and females in middle-distance population.

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Height (cm)	male	13	179.0	5.4	1.5
	female	13	166.6	5.6	1.5
Weight (kg)	male	13	74.1	5.9	1.6
	female	13	61.6	9.8	2.7
BMI	male	13	23.2	1.4	0.4
	female	13	21.5	2.3	0.7
Shoe size (UK)	male	13	9.4	1.3	0.4
	female	13	6.3	1.2	0.3

Statistical analysis revealed that internal factors such as height, weight, BMI and shoe size of runners were not significant for injury occurrence ($p>0.05$) or gender (*Table 12)*. Additionally, in injured population, no significance in the difference between those factors and gender was established ($p>0.05$) (*Table 13*).

Table 13. Summary of descriptive statistics on personal characteristics of the males and females in injured population.

	Gender	***N***	***Mean***	***Std. Deviation***	***Std. Error Mean***
Height (cm)	male	10	179.9	4.3	1.3
	female	9	165.1	5.7	1.9
Weight (kg)	male	10	74.7	6.4	2.0
	female	9	60.1	9.1	3.0
BMI	male	10	23.2	1.6	0.5
	female	9	22.1	3.5	1.2
Shoe size (UK)	male	10	9.5	1.2	0.4
	female	9	6.3	1.3	0.4

Current injuries

At the time of data collection, 73% of individuals reported injuries (n=19). Overall, of all middle-distance runners, 76.9 % of males suffered from an injury, compared to 69.2% of females (*Table 14*). The difference in injury occurrence was found to be statistically non-significant ($p>0.05$).

Table 14. The percentage representation of the presence of current injuries in middle-distance runners according to gender.

Current injuries	***Males n=13***		***Females n=13***		***Total n=26***
Yes	10	76.9%	9	69.2%	19
No	3	23.1%	4	30.8%	7

The majority of those injuries were found to be in the lower extremities (*Table 15*), with 26.3% of participants suffering from traumas specifically to the foot and 21.1% to the knee and ankle, respectively. Of all injured runners, 15.8% of injuries were sustained in the shank region and the hip. Statistical significance was established between gender and injury type in this study ($p=0.025$). In order to establish the injury region where the significance was, a further analysis was performed. According to the data, the hip and knee injuries were statistically different between genders (p= 0.04 and p = 0.03, respectively).

Table 15. The summary of injury prevalence in injured middle-distance runners and trends in injured males and females specifically.

	All runners N=19		***Males n=10***		***Females n=9***	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*
Foot	5	26.3	2	20	3	33.3
Ankle	4	21.1	1	10	3	33.3
Knee	4	21.1	4	40*	0	0
Shank	3	15.8	3	30	0	0
Hip	3	15.8	0	0	3	33.3*

Men were found to have the highest prevalence of knee traumas (40%) and foot injuries (20%) followed by shank issues (30%). Only one male reported calf problems specifically (5.6%), and the other two reported shin injuries. In females, conversely, the biggest issues reported were hip (33.3%), ankle and foot injuries (33.3%). No knee or shank injuries were reported in the female population.

Internal Injury Risk Factors

Age

A total of 13 males and 13 females underwent data collection. Of all middle-distance runners, 34.6% were between the age of 31-35 years, followed by 26.9% aged 25-30 years old (*Table 16*). Only 11.1% of runners were below the age of 25 years or above the age of 41 years. In the injured population, a greater percentage of runners were between the age of 31-35 years (42.1%), followed by 25-30 years (21.1%) and 36-40 years old (21.1%). There was no significance between the age and injury risk in this study for middle-distance runners (p>0.05).

Table 16. The summary of the age data for the whole population as well as injured males and females.

Age group (years)	***Whole population***		***Injured population***			
			Males		*Females*	
	N=26	%	N=13	%	N=13	%
18-24	3	11.5	2	15.4	1	7.7
25-30	7	26.9	2	15.4	5	38.5
31-35	9	34.6	4	30.8	5	38.5
36-40	4	15.4	2	15.4	2	15.4
41-45	3	11.5	3	23.1	0	0

Previous trauma & injury risk

With regards to injury history, it was established that 88.5% of all investigated runners (both injured and non-injured) had suffered from at least one running-related injury in the past (*Table 14*). Comparing data on gender, 92% of all females involved reported having previous injuries compared to 84% of males. In the injured population, 94.7% of runners have previously sustained a running-related injury which consisted of all injured females (100%) and 90% of injured males reporting a history of injury/injuries (*Table 17*).

No statistical significance was established (p>0.05) for this variable as with injury occurrence.

Table 17. The summary of injury history incidence injuries middle-distance runners and according to gender.

	All runners		***Injured Males***		***Injured Females***	
Injury history	***Frequency***	***(%)***	***Frequency***	***(%)***	***Frequency***	***(%)***
Yes	23	88.5	9	90	9	100
No	3	11.5	1	10	0	0

For injured males, the mean value of ankle dorsiflexion was greater in right rather than left feet. The mean value of left ankle dorsiflexion was 8.1±2.69cm, whilst on the right, it constituted 8.85±3.14cm. Similarly, in injured females, the mean value of left ankle dorsiflexion test was 8.06±3.26cm, whilst on the right, it constituted 8.28±3.13cm. *p-values* established by the Independent Sample T – test were not significant ($p>0.05$).

Ankle range of motion (static)

Studying the data for all runners, it was identified that the average ankle dorsiflexion values varied marginally between left and right body side and the trend remained the same when comparing injured males and females (*Table 18*). The mean of left ankle dorsiflexion for the whole population was 8.42±3.27cm, and 8.63±3.23cm on the right.

Table 18. Results from the ankle dorsiflexion test (cm) in all runners, specifically with respect to gender and body side.

	Gender	***N***	***Mean***	***Std. Deviation***	***Std. Error Mean***	***P value***
Ankle Dorsiflexion Left	male	13	8.08	2.907	.806	.264
	female	13	8.77	3.691	1.024	
Ankle Dorsiflexion Right	male	13	8.46	3.031	.841	.528
	female	13	8.81	3.539	.981	

Table 19. Results from the ankle dorsiflexion test (cm) in injured runners only, specifically for gender and body side.

	Gender	***N***	***Mean***	***Std. Deviation***	***Std. Error Mean***	***P value***
Ankle Dorsiflexion Left	male	10	8.1000	2.68535	.84918	.128
	female	9	8.0556	3.26386	1.08795	
Ankle Dorsiflexion Right	male	10	8.8500	3.13626	.99177	.837
	female	9	8.2778	3.13360	1.04453	

External Injury Risk Factors

Running experience & injury type risk

Within the study, 34.6% of runners had over 9 years of running experience, followed by 3-5 years (30.8%) and 6-8 years (23.1%). Novice runners, with an engagement in running of 1-2 years constituted the smallest percentage of the studied population (11.5%) (*Table 20*).

Running experience was found to be statistically non-significant for injury occurrence and type in this population (p>0.05).

Table 20. Summary of running experience of all injured middle-distance runners and according to their gender.

	All runners (n=26)		*Injured Male runners (n=10)*		*Injured Female runners (n=9)*	
Years	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*
1-2	3	11.5	1	10	1	11.1
3-5	8	30.8	3	30	4	44.4
6-8	6	23.1	2	20	2	22.2
9+	9	34.6	4	40	2	22.2

Distance

The most popular running distance run by the middle-distance population in this study (n=20) was 30-40km/week (76.9%). The second most common distance was 40-50km/week which was reported in 11.5% of individuals (n=3) (*Table 21*).

Table 21. Summary of preferred total weekly distance in all middle-distance runners.

Total Weekly distance (km)	***All middle-distance runners***				***All injured***			
	males	%	females	%	males	%	females	%
30-40	8	30.8	12	46.2	5	26	9	47.4
40-50	2	7.7	1	3.8	2	10.5	0	0
50-60	2	7.7	0	0	2	10.5	0	0
75	1	3.8	0	0	1	5.3	0	0

Of all injured middle-distance runners, 73.7% ran between 30-40km per week (n=14). An equal number of individuals (n=2) covered between 40-50km/week (10.5%) and 50-60km/week (10.5%). Only one individual ran 75km/week.

All injured females (100%) were found to run 30-40km/week exclusively. In males, 50% ran 30-40km/week and the remaining 40% were running 40-50km/week (20%) and 50-60km/week (20%) respectively. Increased weekly distance was not found to be significant for injury occurrence ($p>0.05$).

Event participation and training versus injury risk

According to the data, 30.8% of middle-distance runners participated regularly in multiple (more than one per year) running events during which they were covering the distance of at least 21km (half, full marathons and triathlons) (*Table 22*). 15.4% of all runners were training only for a single event: half marathon, a marathon and a triathlon event, respectively. The least number of participants were training for an ultra-distance event (i.e. above 42km) or anything below 21km distance (3.8%, respectively). Only two individuals (7%) had not been in training for any particular event during the study.

Table 22. The characteristics of the whole and injured population with respect to event participation. Data were represented for male and female runners.

	Whole middle-distance population				***Injured population***			
	males	%	females	%	males	%	females	%
None	1	7.7	1	7.7	1	10	1	11.1
Half-marathon	0	0	4	30.8	0	0	3	33.3
Marathon	2	15.4	2	15.4	2	20	0	0
Triathlon	4	30.8	0	0	2	20	0	0
Ironman	1	7.7	0	0	0	0	0	0
10k	1	7.7	0	0	1	10	0	0
Ultramarathon	1	7.7	0	0	1	10	0	0

21km of running (Multiple events)	3	23.1	5	38.5	3	30	4	44.4
>42km of running (Multiple events)	0	0	1	7.7	0	0	1	111

Within the injured population, the trend was similar in terms of event participation – in both males and females, events with 21km of running were the most popular (30% and 44.44%, respectively). Half marathon races were the second most common races in injured females (33.3%) and males (15.8%). No significance was found between the event type and injury prevalence ($p>0.05$)

Running frequency & injury risk

The majority of all middle-distance runners ran two (61.5%) and three (30.8%) short runs per week, regardless of an injury. Of all runners apart from three individuals, 88.5%, ran only one long (10+km) run per week. According to data, 0 individuals (both males and females) run more frequently than that (*Table 23*).

Table 23. The characteristic of male and female runners for both whole population as well as injured population specifically in respect to running frequency.

Frequency of sessions per week	***Whole middle-distance population***				***Injured population***			
	males	**%**	**females**	**%**	**males**	**%**	**females**	**%**
1	6	46.2	5	38.5	4	40	3	33.3
2	4	30.8	6	46.2	3	30	4	44.4
3	3	23.1	2	15.4	3	30	2	22.2

In the injured population, an equal number of individuals were running once and twice a week (36.8%) (*Table 23)*. The remaining 26.3% of injured runners ran 3 times per week. Of injured males, 50% were found to run two, followed by 40% who ran 3 short runs per week. Of injured females, 66% ran two short runs per week. All nine females (100%) did only one long run, compared to 80% of males. The remaining 20% did either three or four long runs per week.

None of the runners ran more than 3 times per week. The frequency of running sessions was not statistically significant for injury occurrence (p>0.05).

Static tests data analysis

Static data analysis aimed to establish and compare foot characteristics to assess the mobility and range of motion statically and investigate the relationship with injury occurrence. This part of data analysis also involved testing and identification of knee motion pathway (determined in angles) during a single leg squat on each leg. Data for right (R) and left (L) sides were shown separately. This was due to the fact that current injuries were all single injuries that presented on a specific side. It was proposed that analysing left and right side of the body separately for each individual would be more beneficial for studying the overall associations between injury and associated risk factors.

Foot Posture Index

As seen in *Table 24*, the majority of feet studied in this investigation (n=52) were neutral (38.5%) or pronated (28.8%). Overall, the lowest occurrences were highly pronated or highly supinated feet (9.6% each). In relation to body side, it was observed that an equal number of runners had neutral feet types on the left- and right-hand side, followed by pronated feet (L 34.6%; R 23.1%) and supinated type feet (13.5%). There was no significance between FPI and gender in this study (p>0.05).

Table 24. Results of the Foot Posture Index test for all middle-distance runners, regardless of gender.

	Right		***Left***		***Total***	
Foot type	***N=26***	***%***	***N=26***	***%***	***N=52***	***%***
Highly pronated	3	11.5	2	7.7	5	9.6
Pronated	6	23.1	9	34.6	15	28.8
Neutral	10	38.5	10	38.5	20	38.5
Supinated	5	19.2	2	7.7	7	13.5
Highly supinated	2	7.7	3	11.5	5	9.6

As mentioned previously, data for this study were collected separately for each body side (left and right) to account for the differences between types and nature of limb characteristics and further investigate risk factors associated with injuries to a specific location on a particular side. However, a symmetry comparison was also performed to establish if runners were more or less likely to present the same characteristics between feet and body sides. With regards to FPI, it was found that in 61.5% of all runners investigated in this study the foot type on one-side corresponded with the nature of the other foot (*Table 24*). Asymmetry (where the characteristics between feet were reported) for the FPI data was observed in 38.5% of individuals in the whole middle-distance population.

Table 25. Symmetry data in all runners.

Symmetry	***Frequency (n=26)***	***%***
Yes	16	61.5
No	10	38.5

Within the injured population, regardless of the gender and body site, a greater number of injured runners had pronated and highly pronated feet (R 36.9%, L 40.6%) than neutral feet (R36.8%, L31.6%) (*Table 26*). The least common for this population were highly supinated and highly pronated feet, which were reported in only a few feet (17.3%; n= 9).

A separate FPI analysis was performed for the injured population to account for gender differences (*Table 26*). What was found is that 50% of injured males in this study had a neutral right foot, followed by highly pronated and supinated feet (20% respectively). On the left side, more males had a pronated (40%) and a neutral foot (30%). With respect to females, 33.3% of runners had a pronated right foot, followed by 22.2% with neutral and highly supinated right foot. On the left, 33.3% of females had either pronated or a neutral foot, where 22.2% were found to have a highly supinated left foot.

Table 26. Foot Posture Index results for injured male and female runners.

	Injured Males				***Injured Females***			
Foot type	**Right**		**Left**		**Right**		**Left**	
Highly pronated	2	20%	1	10%	1	11.1%	1	11.1%
Pronated	1	10%	4	40%	3	33.3%	3	33.3%
Neutral	5	50%	3	30%	2	22.2%	3	33.3%
Supinated	2	20%	2	20%	1	11.1%	0	0%
Highly supinated	0	0%	0	0%	2	22.2%	2	22.2%

Symmetry

Furthermore, it was established that in the injured population, the majority of runners were symmetrical in respect to their foot type characteristics according to the FFI-6 results. This suggested that 66.6% of females and 60% of males had the same type feet on the right and left side in this study (*Table 27*).

Table 27. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency N=19***	***%***	***Injured Males N=10***	***%***	***Injured Females N=9***	***%***
Yes	12	63	6	60	6	66.6
No	7	36	4	40	3	33.3

Windlass Mechanism

The data showed that majority of feet investigated in this population of runners presented with a delayed windlass (42.3%), followed by no windlass action (32.7%) (*Table 28*). Only 7.7% of all middle-distance runners had hypermobile feet. Differences in percentages were recorded between each body side – in right feet, 38.5% of all runners had no windlass action, followed by 26.9% of participants with a delayed response. On the left, the trend was the opposite – delayed windlass was present in 57% of individuals, followed by 26.9% with no action. The least common windlass type in all runners was hypermobile and mobile (7.7%-11.5%). No significance was found in differences in windlass mechanism types and gender ($p>0.05$).

Table 28. Windlass mechanism test results for all middle-distance runners.

Body side	**Right**		**Left**		**Both feet (total)**	
Windlass mechanism type	**N=26**	**%**	**N=26**	**%**	**N=52**	**%**
No action (stiff)	10	38.5	7	26.9	17	32.7
Delayed	7	26.9	15	57.7	22	42.3
Normal	4	15.4	2	7.7	6	11.6
Mobile	3	11.5	2	7.7	5	9.6
Hypermobile	2	7.7	0	0	2	3.8

Symmetry

Symmetry data was also analysed for windlass mechanism test. In 65.4% of all runners, symmetry between left and right foot was recorded.

Table 29. Symmetry data for all runners.

Symmetry	***Frequency (n=26)***	***%***
Yes	17	65.4
No	9	34.6

According to the data, the majority of injured runners (*Table 28*), 68.4% (R) and 89.5% (L), had a limited windlass (both stiff and delayed). Only 10.5% (R) and 5.3% (L) had a normal windlass mechanism. The least common characteristics was a mobile and hypermobile windlass mechanism which was found in only 21.1% (R) and 5.3% (L) of the whole injured population.

Table 30. Results of the Windlass mechanism test in injured middle-distance runners according to gender.

Body side	**Right**				**Left**			
Windlass mechanism	***Injured males***	***%***	***Injured females***	***%***	***Injured males***	***%***	***Injured females***	***%***
No windlass (Stiff- rigid toe)	3	30	3	33.3	3	30	2	22.2
Delayed	4	40	3	33.3	6	60	6	66.6
Normal	1	10	1	11.1	1	10	0	0
Mobile	2	20	1	11.1	0	0	1	11.1
Hypermobile	0	0	1	11.1	0	0	0	0

Data indicated that in both injured male and female groups, no windlass or a delayed windlass mechanism was most common (*Table 30*). This was reported in 70% (R) and 90% (L) of males (n=7 and n=9 respectively) and 69.9% (R) and 88.8% (L) of females (n=6 and n=9 respectively). Mobile and hypermobile windlass mechanism was uncommon for both genders (n=1 female and n=0 males).

Similarly, as for the whole middle-distance population, symmetry data were collected for injured males and females. 77.7% of injured females and 60% of males were found to have the same type of windlass mechanism in both feet (*Table 31*).

Table 31. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency n=19***	***%***	***Injured Males n=10***	***%***	***Injured Females n=9***	***%***
Yes	13	68.4	6	60	7	77.7
No	6	31.6	4	40	2	22.2

Supination resistance test

According to the results of statistical analysis, supination resistance response was found significant for gender in this study, but only on the left foot (p=0.04) when the data for both left and right feet were combined (p=0.02). No significance was established for supination response and injury occurrence (p>0.05). Overall, data indicated that the majority of all middle-distance runners exhibited a hard response to the supination test (*Table 32*). This was recorded for 48.1% of studied feet (both left and right). In 36.5% of all feet investigated in this study, a normal response to supination was observed, compared to 15.4% where the response was characterized as easy. With regards to the body side, a harder supination was seen in right feet (53.9%), compared to 42.4% in the left. In 30.8% of individuals (R) and 42.3% (L) a normal response was recorded. Easy response in supination was the least common in the whole middle-distance population with a prevalence of 15.4% respectively in the right and left foot.

Table 32. The frequency and percentage representation of different supination characteristics for all injured runners.

Supination resistance	**RIGHT**		**LEFT**		**TOTAL**	
	Frequency n=26	***%***	***Frequency n=26***	***%***	***Frequency n=52***	***%***
Easy	4	15.4	4	15.4	8	15.4
Normal	8	30.8	11	42.3	19	36.5
Hard	14	53.9	11	42.3	25	48.1

Symmetry data (*Table 33)* revealed that 65.4% of all runners had the same type of supination response to the test on each foot. Only 34.6% were found to have asymmetry between the body sides.

Table 33. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency (n=26)***	***%***
Yes	17	65.4
No	9	34.6

To investigate whether differences existed in relation to gender, trends in injured male and female runners were compared (*Table 32*).

Table 34. The frequency and percentage representation of the supination test results according to gender of runners.

Supination response	**Right**				**Left**			
	Injured males	***%***	***Injured females***	***%***	***Injured males***	***%***	***Injured females***	***%***
Easy	1	10	2	22.2	0	0	4	44.4
Normal	4	40	1	11.1	5	50	1	11.1
Hard	5	50	6	66.6	5	50	4	44.4

Analysing the injured population it was observed that differences in trends of data were seen in the female population. In left feet, 44.4% of injured female runners response to supination resistance test was either equally likely to be hard or easy to perform. Only 11.1% of females presented with a neutral response on the left side. In the right foot, 66.6% of females had a hard supination response. Males were found to be more likely to have either hard (50%) or normal (40%) supination response in the right foot. In left feet, only normal and hard supination was reported (50%, respectively).

With regards to symmetry (*Table 35*), it was established that 73.7% of all injured runners were symmetrical between left and right, and both feet presented with the same or similar characteristics in the supination resistance test. This was observed in both males and females, with rates of 70% and 77.7% respectively, and was statistically non-significant.

Table 35. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency n=19***	%	***Injured males n=10***	%	***Injured females n=9***	%
Yes	14	73.7	7	70	7	77.7
No	5	26.3	3	30	2	22.2

Single leg squat test

In order to investigate the characteristics and trends of knee movement in middle-distance runners, static single leg squat test was performed. Below, a summary table was presented to illustrate the results (*Table 36*).

It was noted that in 50% of all knees (of all runners) evaluated, a valgus motion was detected. The second most common trend was a neutral position, followed by 15.5% of varus. Data illustrated no significant difference ($p>0.05$) between the body sides – a greater prevalence of knee valgus was observed in the left knee (69.2%) than the right (30.8%) in the whole middle-distant population. In relation to the right knee, in the majority of runners (53.8%), a neutral position was recorded.

Table 36. Summary of the trends in knee movement during a single squat test in all investigated runners, with respect to each body side and the total knees investigated (n=52) (APPENDIX VI).

	RIGHT		**LEFT**		**BOTH KNEES (TOTAL)**	
Knee motion pathway	***Frequency N=26***	***%***	***Frequency N=26***	***%***	***Frequency N=52***	***%***
Varus	4	15.4	2	7.7	8	15.5
Valgus	8	30.8	18	69.2	26	50
Neutral	14	53.8	6	23.1	20	38.5

Analysing the symmetry of runners, it was found that 57.7% of all runners were asymmetrical and exhibited differences between knee motion on each body side (*Table 37*).

Table 37. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency n=26***	***%***
Yes	11	42.3
No	15	57.7

To investigate this further, detailed analysis was undertaken on the injured population (*Table 38*). According to the data, the trends in knee motion varied in relation to body side between genders: on the right side, 55.5% of females had a neutral knee position, followed by a valgus knee motion (33.3%). On the left, however, 77.7% of women presented with a valgus knee, and only 11.1% had a neutral and varus knee motion pathway. In males, trends were similar.

On the right side, 70% of males had a neutral knee position and 20% had knee valgus and 10% knee varus. On the left side, 70% of individuals had a knee valgus, followed by 20% with a neutral and 10% with varus knee motion pathway.

Table 38. Summary of trends in knee motion pathway in injured male and female runners.

	Right				**Left**			
Knee motion pattern	***Males n=10***	***%***	***Females n=9***	***%***	***Males n=10***	***%***	***Females n=9***	***%***
Varus	1	10	1	11.1	1	10	1	11.1
Valgus	2	20	3	33.3	7	70	7	77.7
Neutral	7	70	5	55.5	2	20	1	11.1

Interestingly, comparing the symmetry data between the genders, a greater similarity was observed than in the whole middle-distance population where 52.6% of all injured runners were symmetrical, whilst remaining 47.4% were asymmetrical. However, it was established that men were equally likely to be both asymmetrical and symmetrical, whilst 55.6% of females were symmetrical in their knee motion (*Table 39*). No statistical significance was established for that injury risk factor in relation to injury occurrence or with gender ($p>0.05$).

Table 39. Symmetry data in all injured runners and in respect to gender.

Symmetry	***Frequency n=19***	***%***	***Males n=10***	***%***	***Females n=9***	***%***
Yes	10	52.6	5	50	5	55.6
No	9	47.4	5	50	4	44.4

Dynamic testing data analysis

Dynamic testing was designed to assess and quantify the amount of hip drop (both left and right), as well as each knee and feet movement during a dynamic gait cycle, when the body is exposed to additional external forces and work.

All Injured Runners

In all injured runners, the average value of hip drop and deviation from a horizontal was greater on the left side (8.12 degrees), compared to right (7.84 degrees; *Table 40*). The mean value of knee deviation from a neutral position was, however, greater on the right side (8.14 degrees). Similarly, right foot was found to deviate more from a neutral position during a gait cycle (3.22 degrees) than the left (-0.28 degrees). None of these data were found to be statistically significant to injury prevalence (p>0.05).

Table 40. The summary of statistical analysis performed on injured middle-distance runners

Parameters (degrees)	***N***	***Minimum***	***Maximum***	***Mean***	***Std. Deviation***
Right hip drop	26	5.2	11.7	7.8	1.8
Left hip drop	26	3.6	15.0	8.1	3.1
Right knee deviation	26	9.3	4.0	8.1	3.6
Left knee deviation	26	8.0	7.6	7.6	5.2
Right foot deviation	26	-5.3	10.8	3.2	4.1
Left foot deviation	26	-8.7	9.0	-.3	5.3

Injured Males & Females

In all injured male runners, the average value of hip drop was greater on the left side (8.12degrees), than the right (8.1 degrees) (*Table 41*). The mean value of knee deviation was, however, greater on the left side (7.8 degrees) rather than right (7.2 degrees). Similarly, right foot was found to deviate more from a neutral position (180 degrees) during a gait cycle (3.27 degrees) than the left (-2.0 degrees). No statistical significance to injury prevalence was established (p>0.05).

In all injured female runners, the average value of hip drop was greater on the left side (8.09 degrees), compared to the right (7.6 degrees) (*Table 41*). The mean value of knee deviation was also greater on the right side (8.7 degrees) than left (7.4 degrees). Similarly, right foot was found to deviate more from a neutral position during a gait cycle (3.2 degrees) than the left (1.7

degrees). In this study, an increased number of current injuries were found in females on the left side of the body.

Analysing male and female data from the dynamic analysis no significant differences between genders were established in hip drop, knee pattern as well as foot pronation/supination.

Table 41. The summary of statistical analysis performed on all injured male and female middle-distance runners.

Parameters (degrees)	***Gender***	***N***	***Mean (degrees)***	***Std. Deviation***	***Std. Error Mean***
Right hip drop	male	10	8.1	2.4	0.8
	female	9	7.6	0.8	0.3
Left hip drop	male	10	8.1	3.6	1.1
	female	9	8.1	2.6	0.9
Right knee deviation	male	10	7.6	2.8	0.9
	female	9	8.7	4.4	1.5
Left knee deviation	male	10	7.8	5.5	1.8
	female	9	7.4	5.1	1.7
Right foot deviation	male	10	3.3	4.5	1.4
	female	9	3.2	3.8	1.3
Left foot deviation	male	10	-2.0	6.5	2.1

Discussion

This study investigated injury prevalence and trends in male and female middle-distance runners, who ran between 30-40km per week. The aim of this research was to investigate the effect of foot mobility, lower limb function and running-related factors and their relationship with injury occurrence. Data revealed that the trends in injury type varies between males and females ($p<0.05$). Foot type was also found to be different, although not statistically significant ($p>0.05$).

The justification for this research in looking at the middle-distance population specifically was due to the outcome of Study 1 (Chapter II). That part of the study was undertaken prior to this study and was aimed to identify populations at a highest injury risk in relation to distance: short, middle- and long-distance runners. The findings indicated that a 15% difference in injury prevalence between middle distance male and female runners exists -where males (76%) were found to have a significantly lower injury risk than females (92%; $p=0.003$).

Gender effect

This study aimed to establish if foot mobility and function of the lower and upper extremity was gender specific and whether males and females were predisposed to sustaining the same, or different, traumas as a result of running. Data from two recent studies on recreational runners provided evidence for a predisposition of female runners to chronic injuries when compared to males (Sinclair *et al.* 2015; Mitani 2017). This was thought to be due to differences in biomechanics as well as anatomical variances. The findings of those studies indicated that variability exist in foot mobility as well as static movement pattern of the foot, ankle and knee between males and females. Females were found to show greater knee abduction and internal knee rotation than males as well as to have a greater active hip internal rotation (Sinclair *et al* 2015).

Personal characteristics and injury trends

According to literature, the main reason for the differences in increased predisposition in females to lower limb injuries, mainly to the knee area, might be due to an increased Q-angle and decreased muscular strength, especially during single leg activity which is crucial for maintaining running motion (Dugan *et al*, 2005; Mitani 2017). According to Sigward and Powers (2006) a greater Q-angle in females compromises the neuromuscular control, which in turn leads to overreliance on the activation of quadriceps during initial contact and affects the overall body position. This was confirmed by the data reported, however, what was observed is that only the males suffered from knee injury itself. Females, on the other hand, presented with hip, foot and ankle injuries. Some differences were observed in flexibility (foot) and joint range of motion. Thus, it was hypothesized that that those differences, potentially affected by gender, through its effect on body anatomy and joint flexibility, would influence the movement biomechanics of individuals and injury development pathways resulting in specific injuries. This was due to previously established varieties in foot shapes and arch profiles, established in males and females (Williams *et al,* 2001) overall body physique as well as muscle dominance and lower extremity mechanics during running (Ferber *et al,* 2003).

Main findings of Study 2

In the current study, 73.1% of middle-distance runners suffered from a running-related injury. It was found that males suffered primarily to injuries to the knee (40%), shank (30%) and foot region (30%). All of those injuries were single injuries. In females, the most commonly injured body site was hip (33.3%), ankle (33.3%) and foot (33.3%). No difference in injury prevalence was found. Furthermore, no knee and shank injuries were recorded for females.

Furthermore, the majority of all investigated runners had sustained previous injuries (88.5%). Interestingly, no significant differences were observed between the types of those injuries - it was established that the most previous traumas sustained by all runners constituted multiple injuries in the lower leg (42.1%) and multiple upper leg injuries (21.1%). The rest of the injuries were found to be single injuries to the foot (15.8%) and ankle (10.5%). Only 5.3% of the injured population had suffered from a previous injury to the knee and thigh.

Only some trends in previous injuries were similar between genders, where 44.4% of females and 40% of males reported a history of multiple lower leg injuries. In males, however, other common traumas were multiple upper leg injuries (20%) and ankle injuries (20%). Of the females, 22.2% reported a history of multiple upper leg injuries and single foot injuries. None, however, suffered from any ankle or knee injuries historically. According to the literature, previous injury was often linked with the occurrence of new traumas (van der Worp *et al,* 2015). It was concluded that depending on the severity of the primary injury as well as the efficiency of rehabilitation, runners might be at an increased risk of sustaining traumas to the same or surrounding structures (Fonseca *et al,* 2015). This was previously associated with incomplete recovery and the development of compensatory mechanisms which led to more stress and overloading to other parts of the lower extremity (Van Middelkoop *et al,* 2008). The presence of previous injuries has been found to be an injury risk factor particularly for distance runners, especially those training for a marathon (Middelkoop *et al,* 2008). In this study, no statistical significance was established between previous injury and current injury (p>0.05), although it could be argued, that this was due to the small population size (n=26) as well as the fact that previous injuries were extremely common in the studied population (96%). All injured runners, apart from one, recruited had reported at least one previous injury. An interesting finding was that in all middle-distance runners, the majority of old injuries were either on both sides (52.6%) or just the left side (36.8%). With regards to injured population, it was established that all runners reported old injuries to be on both sides of the body. To be specific, 40% of males reported traumas were on both sides of the body at the time, and 40% only on the left side. Only 20% of injuries were to the right side. In females, 66.7% of previous traumas were to both sides, followed by 33.3% only to the left side. No females had injuries to the right side of their body.

Studying the patterns of new injuries, it was established that similarities between males and females in injury trends were uncommon, which confirmed the initial hypothesis and the existence of gender – specificity. In males, the majority of current injuries were in the knee (40%), ankle (30%) and the shank (30%). In females, hip (33.3%), foot (33.3%) and ankle (33.3%) injuries were most common. Interestingly, males were also shown to have more current injuries to the left side (60%). In females, the opposite trend was observed with 44.4% of injured on the left and 55.6% on the right side. It could be argued, that history of injuries on a particular body side might be increase the likelihood of developing injuries on the same side, especially in males (Middelkoop *et al*, 2008). Biomechanical and structural characteristics of injured runners have been found to resulted in alteration of the preferred motion pathway (Nigg *et al,* 2015) and developing compensatory mechanisms designed to protect injured structure. Often, incomplete healing and premature return to sport increases the chances of secondary injury (Middlelkoop *et al*, 2008). The nature of new injury might also depend on the severity of previous injury – all females apart from one had an injury to the soft tissue (88.9%). Males also suffered mainly from soft tissue traumas (50%), followed by joint (20%) problems. This is in agreement with Francis (2018) and van der Worp *et al,* (2015), who found that male and female runners were more likely to suffer from musculoskeletal injuries, mainly due to overuse and overloading associated with running longer distances.

No significance (p>0.05) in data between old injury side and predisposition to a new trauma on the same side was established, although it could be argued that a pattern could be observed.

Unfortunately, the injured population was relatively small (n=19) which might not have reflected the importance of this finding. It could also be argued, that depending of the timing of those previous injuries, their effect on compensatory gait and movement development by runners might be greater to protect injured structures. Thus, reinforced dominance and reliance on the opposite side to injury with regards to force and weight distribution might be observed. Here, the majority of injuries were found on the left side. This was associated with increased number of previous injuries to the same side. It could be argued that due to primary injury, those runners were weaker on the left side and might have adopted a running style where they relied on the right side more as a consequence. No information or data was collected on limb dominance in individuals. Furthermore, due to a greater number of individuals with a previous injury in this study (96%) it was concluded that establishment of whether the current motion biomechanics reflects true movement patterns of runners or whether it changed over the years is impossible. Hence, it is unknow if the running style that was captured on the video camera and lower limb test results are completely reliable in determining their effect on new injuries. It was argued that runners they might have already adopted a different running technique as a result of those previous injuries.

Foot mobility

A variety of static and dynamic tests were used to assess the nature and characteristics of the feet of investigated runners. To determine their foot mobility, data from the FPI-6, supination resistance, as well as windlass mechanism tests were used. The results of each of those tests provided information on forefoot and midfoot movement which was then used to make assumptions on the overall foot flexibility. To our knowledge, no other study used the same protocol in determining foot mobility. Those tests were, however, previously used independently to provide foot characteristics and investigate their associations with injury occurrence.

To assess the flexibility in the forefoot the windlass mechanism test was used, whilst the supination resistance test was used to provide midfoot characteristics. Since FFI is a foot type measure which depends on series of variables which assess both the forefoot, midfoot and the rearfoot it was used to provide additional knowledge and information about foot characteristics and overall mobility. For the requirements of this study it was proposed that increased foot mobility might affect the ability of that foot to generate power during the propulsive phase as well as influence the amount of pronation/supination movement during a single leg activity. If more work is required by muscles and tendons to allow motion to happen, an overload will occur and might lead to future injury in the kinetic chain.

Foot Posture Index (FPI)

Overall, more females than males presented with greater flexibility in their feet in the midfoot (FFI), which was determined by the amount of pronation. Forefoot mobility was assessed separately, using the windlass mechanism test. The majority of injured runners had a limited range of motion in the 1st metatarsal and thus a delayed or no windlass mechanism (*Table 28*). Previously, windlass mechanism was found to be crucial for efficient push off and plantar flexor activation as foot leaves the ground. The supination test served to provide data on the stiffness of the foot in the midfoot as external force is being applied. In this respect, the majority of injured runners' feet scored "hard" in terms of the test result.

Regardless of the gender and body site, injured middle-distance runners had more pronated and highly pronated feet (42.1%) than neutral (34.2%) or supinated feet (23.7%). The least common for the injured middle-distance population were highly supinated feet, which were reported in only a few runners (between 7.1%-10.7%) (*Table 26*). This finding is in agreement with other studies that previously looked at injury occurrence and excessive foot pronation (Ferber *et al*, 2003; Mitani 2017). According to literature, injured runners were also found to have a decreased arch profile and exhibited more pronation than non-injured populations (Molloy, 2016). Arch profile type was one of the factors assessed here as a part of FFI-6 test and supports those findings. Furthermore, Nielsen *et al* (2013) concluded that pronated feet seemed to be at increased risk to injury when compared to neutral feet, whilst supinated feet were observed to be at a very similar risk of injury to neutral feet after 50km and 100km of running. The majority of injured runners had a pronated foot type (as indicated by the FFI test). Interestingly, most of those runners also exhibited no or a delayed windlass mechanism which might affect the ability of the foot to flex through the great toe. Hence, more investigation should focus on evaluating the prevalence of injuries in respect to foot types as well as the association between foot anatomy and its motion. Data exist in the literature on the relationships between foot shapes, arch index height and the effect of excessive pronation and supination (Nigg 2001). Limited windlass has previously been associated with the development of plantar fasciitis as well as injuries to plantar flexors (Kozinc and Sarabon, 2017). Furthermore, according to Mitani, (2017) and Molloy (2016) arch types affect the movement of the foot, as well as its ability to shock absorb forces. It was stated that a low arch foot is more likely to pronate than a high arched foot, which were common in feet that supinated (Dugan *et al,* 2005). Pronation and supination have previously been associated with the development of compensatory rotations in the tibia and thus were positively linked to foot, ankle, knee and hip injuries in runners (Nigg 2001). Thus, it could be concluded that foot anatomy itself might be a risk factor for injuries. To date, no threshold for pronation or supination range protective of injuries was established, mainly due to the fact that both movements were previously identified as a normal phenomenon that accompany motion (Johnston *et al,* 2003). According to Nielsen, *et al* (2014), individuals who exhibited highly pronated foot movement were not more likely to be injured than those without excessive pronation. However, it could be argued that quantifying pronation in respect to mild, moderate and excessive is needed to establish whether a certain range might be linked with increased injury risk to certain anatomical sites, such as knee and ankle movement. In order to achieve that, new methods and protocols would have to be developed to investigate the passive and active range of motion of the foot and joints. The response to supination resistance was found to be statistically significant for gender. Differences in windlass mechanism outcomes and FPI could also be noted. More research should focus on developing assessment tests with higher reliability and validity of the data, especially in relation to force measures and range of motion. Both in the windlass mechanism and supination resistance tests a scale was used to determine the difficulty of motion and limitation of movement of joints. In order to achieve the best data possible, those tests need to be improved so that they can be used as a clinical tool and help medical professionals screen patients in respect to injury susceptibility.

A gender-specific investigation in foot mobility was also undertaken. Overall, data revealed that injured males and females show mild differences in their foot types. Males were found in general to have more neutral or supinated feet (70%), whilst females had more pronated feet (50%). This is in agreement with other studies on gender (Sinclair *et al,* 2015; Mitani, 2017). Mitani, (2017) and Ferber *et al* (2003) suggested that increased foot pronation is more likely to be found in female runner than males and was found to induce knee valgus and result in greater internal rotation of the lower leg in female than male runners. Here, it was proposed that pronated feet would also be more flexible than neutral and supinated feet and this might in turn affect the structure of the foot as a supporting base for the single leg activity as well as inhibit motion control and hence compromise the efficiency of the push off. The results obtained in this research confirmed this hypothesis, although it was found through variety of performed tests, rather than considering the mobility of the foot as a one unit, forefoot, midfoot and rearfoot must be considered separately.

Increased flexibility was found in the rearfoot of studied feet (which was associated with increased pronation), yet the forefoot was found to be relatively stiff. This was due to higher prevalence of stiff and rigid 1st metatarsals as well as limited windlass mechanism in studied population. Additionally, inefficiency in supination response (midfoot) (*Table 34*), which in the majority of studied runners was found to be "*hard*" (limited) was found in injured population. This might further result in an increase in concentric work of plantar flexors, hence putting a greater demand of the posterior chain in the lower leg – calf, Achilles and plantar fascia (Stoggl and Wunsch, 2016) and predisposing to sustaining injuries in that area.

It is important to highlight that static pronation, established by the FPI-6 test, might not necessarily present itself to the same degree during a running cycle, when the body is exposed to variety of additional external forces during a single leg support in midstance phase (ground reaction and vertical forces). In relation to dynamic testing, females were also found to have more dynamic eversion in their feet than men during midstance in both feet (*Table 43*), with a deviation of 3.17 degrees (R) and 1.68 degrees (L) compared to 3.26 degrees (R) and –2.04 degrees (L) in males. This observation combined with the outcome of the static assessment would suggest that a static foot pronation might, to a degree, predict increased foot pronation angles in dynamic motion. Hence, if a static pronation reflects the likelihood of dynamic pronation, protocols and assessments could be developed to predict and hence prevent injuries which might be caused by excessive dynamic pronation. According to Dugan, *et al. (*2005), increased range of pronation constitutes one of the most problematic issues observed in running analysis. Even though pronation is necessary to allow the initial forces to be absorbed and evenly distributed through the body, excessive pronation results in increased ground reaction forces in the medial aspect of the lower-limb kinetic chain, mainly the medial tibia (Dugan *et al,* 2005). Increased work of the intrinsic muscles was found to be necessary to control overpronation. This often leads to tendonitis as well as greater internal rotation of the tibia and femur, which in turn might predispose to patellofemoral maltracking. Supination, even though generally less common, was previously established to affect forces acting through the lateral part of the limb (Dugan, *et al*, 2005). Furthermore, excessive foot pronation has also been associated with the occurrence of plantar fasciitis (Kozinc and Sarabon, 2017), which constitutes one of the most popular foot injuries. To date, no effective interventions for treatment have been established, hence a thorough and detailed investigation into the foot pronation and its effect on foot and knee injuries is crucial. Excessive foot pronation has also been found to affect the expected knee motion pathway during single leg, fully weightbearing position (Dugan *et al*, 2005). More studies on a larger population should be carried out to determine the relationship and validity of static and dynamic testing in motion mechanics with an aim of identifying ranges of movement which can predispose to specific lower -leg injuries. This study provided evidence for an increased knee valgus on the injured body site of the runners, however, no statistical significance was observed ($p>0.05$) between injury and knee movement pattern, both for static and dynamic data. It was concluded that this was due a small sample size in this study as well as the fact that almost all runners had a previous injury. Hence, more studies must be designed on a much bigger sample size.

The windlass mechanism was used to determine the nature of the foot. Through this test, the efficiency of great toe flexion and the effect on the plantar flexor movement was established. According to the data, in all injured population, 68.4% and 89.5% of individuals had no active windlass and a delayed windlass in their feet combined (right and left, respectively). Only 10.5% and 5.3% had a normal windlass mechanism (right and left, respectively). Data also indicated that a greater number of females than males had no windlass mechanism present (R 53.9%; L 30.8%). Males had more delayed windlass mechanism than females in their feet (R 30.8%; L 69.2%). Interestingly, in all injured runners, symmetry was found between the feet. This means, that runners were more likely to have a delayed or no windlass mechanism in both feet rather than show discrepancies in their response types. According to previous studies, limited windlass mechanism compromises the foot mobility and arch response in contact with the ground (Dugan *et al*, 2005). According to Sinclair *et al (*2014) windlass mechanism ability affects the efficiency of movement in propulsive phase of a gait cycle (push-off), which might lead to injuries in the posterior chain, mainly to plantar flexors (Kozinc and Sarabon, 2017). In the current study, the windlass mechanism was used to determine the flexibility of the forefoot and make assumptions about the likelihood of an efficient push off ability in runners. The data reported here did not, however, allow to establish the direct mechanism behind the effect of a limited windlass motion on injury pathway and specific trends. It was reported, however, that majority of injured population had a limited windlass mechanism, hence it was argued, that through its known effect on delayed response on the plantar flexors and response in the arch, it could increase the likelihood of injury occurrence to the foot, Achilles and calf (Sinclair *et al*, 2014). This was explained by the role of posterior muscles and plantar flexors in the late stance phase of a running gait (Kozinc and Sarabon, 2017). Thus, it was hypothesized that a limited range of motion in the first metatarsal which accompanies a limited windlass mechanism, might increase the prevalence of specific types of injuries to the posterior chain (plantar fasciitis, Achilles tendonitis and tendinopathy and calf strains), as more force demand will be necessary for an efficient push off of the ground resulting in developing compensatory motion pathways up the kinetic chain with no first metatarsal function (Dugan *et al,* 2005). Even though the data were found not to be statistically significant (p>0.05), it can be argued that this may be due to the small population sample. The majority of the population, as well as injured runners, exhibited compromised windlass mechanism and accompanying limited flexion in the big toe. Hence, more research should be undertaken to study the limitations in windlass mechanisms and its association with increased injury risk in runners, especially to lower extremities. Delayed windlass mechanism could be associated with variety of conditions to the toe itself, such as *turf toe, hallux rigidus* and *osteoarthritis* itself (Kennedy *et al,* 2006). It could also be hypothesised, that such limitation might develop due to overuse as well as overload placed onto the toe due to inefficiency of the push off. Interestingly, comparison across genders revealed that there were opposite trends in male and female runners, which confirms the primary hypothesis of this study, regarding differences in trends and injury development pathways in runners according to gender. Females were more likely to have no active windlass response (*Table 32*) whilst males had a greater prevalence of delayed responses, which means that the windlass is somewhat present, but requires vast amount of energy and effort to be activated. It could be argued, that this is due to increased pronation which might potentially affect the CoP (center of pressure) movement across the foot in contact with the ground (Sinclair *et al,* 2014). A pronated foot will track over the ground through the medial side which in turn, will increase the stress and pressure the first metatarsal will be exposed to. Additionally, due to the female anatomy, pelvis structure and hip width, which is typically wider than in males, it could be argued that they tend to be more toed out (Ferber *et al,* 2003), which in running, will predispose to transition of weight more through the inside part of the forefoot. Unfortunately, in this study, no specification of the foot injuries was provided. Thus, it was not possible to establish whether foot injuries reported were related to the toe and what was their presentation.

The final test which was performed in this study to establish the foot mobility in runners was a supination-resistance test (*Table 32*). It was found that an increased number of middle-distance runners overall as well as injured runners specifically were found to have a hard response to a supination resistance test, which was previously related to midfoot flexibility and thus foot mobility. Data indicated that the majority of individuals exhibited a hard response to supination test (R53.8%; L 42.3%), and 30.8% (R) and 42,3% (L) had normal response. Easy response in supination was the least common characteristics in the studied population with a prevalence of 15.4% on each side (*Table 32*). Interestingly, gender did not affect the trends significantly (p>0.05) (*Table 34*). In the majority of female runners, the supination test was found to be hard to perform and a greater force was needed to be applied to achieve a movement response in the arch. This was observed in right feet (69.2%), as well as left feet (46.2%). Only 15.4% of females had an easy supination in the right foot, whilst in the left foot, 30.7% were reported. Males were found to be more likely to have either normal (46.2%) or hard (53.9%) supination in the right foot (*Table 34*). In left feet, a normal supination was reported as (69.2%). It was proposed, that such tendency might have been associated to the overall FPI due to increased amount of pronated feet in females (*Table 26*). It was suggested, that a statically pronated foot will exhibit a lower arch index (as one of the parameters measured in a FPI test is the height of the longitudinal arch) and require more force to generate motion response. However, to our knowledge, no other study used this method as a clinical tool for foot mobility assessment, hence it was not possible to compare the outcomes of this study with literature and assess the reliability and validity of this hypothesis as well as findings.

The conclusion on foot mobility assessment was that the results of a supination resistance test should be combined with windlass mechanism data as well as the FFI-6 findings to create a specific 'foot mobility profile' of a runner. In this study, chosen static tests were undertaken to assess the mobility in different parts of the foot. The information obtained suggested that forefoot (which was assessed by windlass mechanism test), midfoot (supination test) and rearfoot (FFI-6 test) should be evaluated separately with regards to foot motion as discrepancies exist in the overall foot type (pronated, supinated, neutral) and mobility of the great toe and arch response (windlass and supination test). It was found that even though the majority of the feet in this study were identified as pronated (*Table 24*), which is normally associated with increased foot movement and deviation from a neutral position, it did not relate to the movement of the rest of the foot (midfoot and forefoot) (*Table 32* and *Table 28*). The current study proposes that a foot that pronates (in braking phase) can still exhibit a stiff big toe and thus a limited windlass mechanism, which will decrease and compromise motion of the foot in propulsive phase and will require increased amount of work in the intrinsic muscles as well as plantar flexors to compensate for this phenomenon. An easy supination was typically observed in a very mobile foot with an easy windlass mechanism, whilst harder supination response was noted in feet with a limited windlass and stiff big toe. Unfortunately, no studies to date were undertaken to determine the effect of the combination of those tests on foot mobility assessment or injury occurrence in runners. Data here suggests that an investigation into foot types, varieties in its mobility and associated joint range of motion would help to provide a better understanding of specific foot related injuries and their underlying mechanisms. This would also allow to establish if differences in foot flexibility might have an effect on injury prevalence higher in the kinetic chain.

Although the movement and type of the foot remains a factor of a great importance for running, a holistic approach should be embraced in management and prevention of running – related injuries.

Knee

According to data of this study, differences in knee injuries in male and female middle-distance runners investigated were found to be statistically significant ($p<0.005$). What was observed was that males (40%) were more likely to suffer from knee-related issues than females, who reported no current injuries to that body site.

A single-leg squat test was used in the static assessment to determine the deviation of the knee in motion pathway from a neutral position in relation to hip and foot position (measured when individuals is upright, standing. A more negative value of movement indicated a knee varus, with a pathway that described the motion of the knee towards the outside (of the foot and hip position). A more positive value referred to a knee valgus, which characterised a ‘knocked’ knee position. According to the results (*Table 38*), trends in knee motion varied in relation to body side of injured individuals. In the whole middle-distance population, a left knee valgus and a neutral position of the right knee was observed. It was also established, that in most middle-distance runners, asymmetry was observed, with each knee following a different pattern statically. In relation to gender, it was found that 46.2% of females had a neutral right knee position, followed by a valgus motion (38.5%). On the left, however, 76.9% of women had a knee valgus, and 15.4% a neutral position. In males, trends were similar. On the right side, 61.5% of males had a neutral knee position and only 23.1% had a knee valgus. On the left side, 61.5% of individuals had a knee valgus, followed by 30.1% with a neutral knee position. Analysing dynamic data, a greater deviation in right knee was observed in females than males, with a mean of 8.63cm and 7.27cm, respectively (*Table 41*).

In the injured population, knee trends were compared between gender as well as in relation to the whole population. Interestingly, the left knee valgus assessed through SLS test was more prominent in injured males (70%) and females (77.7%) than in the whole population (*Table 38* and *Table 36*). On the right side, 70% of males had a neutral knee position, compared to 55.5% of females. Furthermore, even though for the whole population asymmetry was found in the knee motion pattern, a greater symmetry in injured population was established. This suggested that the majority of individuals with a right knee valgus also exhibited a left knee valgus. Hence, it would be proposed that overall, more females had a bilateral (present on both sides of the body) knee valgus, which is in agreement with previous findings (Ferber *et al,* 2003; Mitani, 2017). Previous studies (Ferber *et al,* 2003; Fredericks *et al,* 2015), however, report increased prevalence of knee injuries in female runners, which was not confirmed in this study as no female runners reported a knee related injury. It could be argued, that this was due to increased amount of primary injuries in the hip in females. Females in this study were generally active and only one was a novice runner. The majority constituted experienced runners (*Table* 20), who often participated in long distance running events (*Table 22*). On the contrary, 40% of males reported the knee as a primary region of trauma. Hence, it was concluded that injury occurrence was not directly affected by the discrepancies in knee motion mechanics in females (*Table 38*). However, 33.3% of females, complained of hip-related injuries and foot (33.3%) and ankle problems (33.3%). As such, it was hypothesised that a knee valgus, even though more prominent in females, is not directly linked to the presence of knee injuries in the female runner population. Fredericks *et al* (2015) suggested that an increased knee valgus might have occurred due to an increased tightness up the kinetic chain (hip) or might be more associated with adapting a compensatory mechanism due to weakness in the hip area as well as increased foot movement. Mitani, *et al* (2017) and Ferber *et al* (2010) who both previously studied knee joint motion in runners according to gender, also provided evidence for a significantly higher angle of internal rotation of the knee joint in females compared to males. This was only partially confirmed. Indeed, more knee valgus was observed, but the differences were not statistically significant ($p>0.05$). This was previously explained by a greater Q-angle in females than males, as well as decreased gluteal muscular strength, which potentially compromised the ability to maintain a strong, relatively straight position of the lower limb in a single leg activity (Saratagio *et al,* 2014). Knee injury was more prominent in males and these results were contradictory to previous studies, where more knee injuries were commonly found in female population than males (Dugan *et al* 2005; Ferber *et al,* 2003).

It is worth highlighting that females had reported a history of multiple lower leg injuries, which means that even though at the time of data collection the knee was not their primary area of pain, they might have at some point suffered from knee-related pains. This, in turn, could be associated with the type and severity of their current issues and might explain the increased prevalence of both hip and foot injuries. It could be argued that current foot and foot injuries could have developed as a result of increased knee motion and adapted running style.

Hip

Data on hip injuries indicated that there was a significant difference between the prevalence of injuries in that region in male and female middle-distance runners ($p<0.05$). What was found was that none of the male runners, and 33.3% of females suffered from hip-related traumas. Dynamic testing (hip drop value) was the only method used to establish the motion in the upper leg area. The most important aspect for this part of analysis was the effect of a dynamic movement pattern on single leg activity due to changes incurred by impact, braking and gravity forces which were acting upon the supporting leg in midstance (fully weightbearing position). According to Geraci *et al* (2005) in many runners, the pelvis drops to the side of the swinging leg, resulting in a weight shift towards the supporting leg and trunk flexion to that side, then gradually returning to a neutral position as propulsive phase commences. It was established that an average hip drop of all injured individuals from a neutral position was 7.84 degrees and 8.14 degrees in right and left hip drop respectively (*Table 42*). Interestingly, no relationship was established between hip drop and injury occurrence. In injured males, the value of the hip drop was established as 8.07 degrees and 8.15 degrees in the right and left hip respectively (*Table 43*). In females, a decreased value of left hip drop was noted (7.58 degree) with a 8.09 degree drop in right hip. This was not confirmed by other studies that investigated hip motion – other findings point out an increased imbalance and greater amount of bilateral hip drop in females than males. It could be argued that due to a high prevalence of injury history in studied populations runners weaknesses to the upper limb which might have occurred through developing compensatory mechanisms in runners. Additionally, runners recruited in this study had an increased running experience. This might have influenced data and it was also concluded that the sample size for this study was very small hence might have affected the overall outcomes of the analysis. Ferber *et al* (2003), explained increased hip imbalance in females due to a larger hip width to femoral length ratio which leads to greater hip adduction and have also been shown to exhibit greater active hip internal rotation than men. According to Fredericson and Misra (2007) excessive hip drop in a single leg stance reflected an imbalance in hip muscle and was associated with the weakening of the abductor muscles. These were found to be a factor that predisposes to overuse injuries in the lower limb. Additionally, according to Robinson and Nee (2007), hip strength asymmetry, not just overall muscle weakness, is also a factor in knee injuries. It was not possible to identify weaknesses and tightness of individuals in the hip region and the effect on injury occurrence in the lower leg. Thus, no information was obtained on the role of hip instability and weakness and injury development pathway. However, data allowed observation of an increased instability and hip drop deviation mainly on one side of the body (right) in both male and female runners, especially. Since that side was opposite to the side where most of the injuries in this study occurred (left) it was proposed that that the drop was caused by the weakness of the supportive leg during midstance and had an effect on the efficiency of the foot and knee movement on the injured side

Conclusion

Data in this study provided evidence for gender-specific trends in middle-distance runners. Furthermore, it was established that male and females exhibit different characteristics in relation to their foot type, as assessed through a Foot Posture Index, Windlass mechanism test as well as supination resistance test. Further research should focus on studying the relationship between foot types and the effect on foot range of motion. Furthermore, an investigation into foot mechanics and the underlying injury mechanism pathways should be evaluated. It was also proposed that more focus should be put into developing effective clinical tests to determine foot function and increase the validity and reliability of collected data.

Chapter IV: DISCUSSION FOR STUDY 1 AND 2

The main objective of this research was to investigate the relationships between personal and training-related characteristics and running-related injuries in recreational runners, with a specific focus on the effect of distance and gender on injury occurrence and trends. Due to the simplicity and affordability, running attracts a high number of amateur runners who are willing to participate in running events without previous experience (Fonseca *et al*, 2015). It could be argued, that due to popularity of amateur running events, the type and characteristics of runners participating in distance running events have changed from what it was 20 years ago. Nowadays, a significant number of runners who currently run half and full marathons are getting places through charities rather than clubs (which was common in the past), so their running and fitness abilities do not influence the likelihood and rates of their event participation. Simultaneously, the number of novice and recreational runners participating, compared to the amount of experienced and professional athletes is increasing (Tonoli *et al, 2010*). As a consequence, a shift in the distribution of the running population can be observed, as well as an overall increase in the population taking part.

Injury prevalence

To date, even though a vast amount of research investigated mechanisms and causation of sport injuries, information on RRI aetiology is limited (Malisoux *et al*, 2014). It was, however, established that a variety of personal characteristics, as well as training-related factors might affect injury rates (Malisoux *et al*, 2014). Furthermore, RRI were found to be multi-factorial and hence it was concluded that single factors are not enough causes for injury development. Runners have different running routines, years in training and adaptability period. They also run for different reasons and at different intensities. Hence, it is challenging to control all of these associated running conditions and make adequate recommendations aiming to reduce injury rates. In Study 1 and Study 2 of this paper, extremely high injury rates were reported in runners. While investigating the existing literature (Fredericson *et al*, 2007; Van Gent *et al*, 2007), it was found that the prevalence of injuries in runners was lower and associated risk factors were explored in a number of different ways. Some authors, such as Gomez-Molina, *et al* (2017), Fredericks *et al* (2015) and Malisoux, *et al,* (2014) focused on determining running-related training aspects, such as distance, intensity and frequency of training, as well as footwear type worn by runners. Whereas, others (Fonseca *et al*, 2015; Räisänen *et al*, 2018) and were more interested in studying internal variables and rates of injury occurrence such as gender, age, BMI and previous injury history (personal characteristics). Mitani (2017) and Gomez-Molina *et al,* (2017) investigated running motion with an aim of identifying common biomechanical features which might have been associated with injuries through abnormalities in motion. However, none of the previous studies that the author is aware of to date, focused on combining internal and external factors and assessing their effect on running biomechanics to investigate if and which injury is likely to occur. As such, the current research was designed to investigate the effect of anthropometric variables, training-related characteristics as well as functional parameters related to running gait biomechanics exhibited by studied individuals. Furthermore, an analysis of underlying anatomical and functional differences between genders in relation to foot, knee and hip movement and establish their association with injury occurrence was undertaken.

This thesis consisted of two separate studies, one which was designed to determine injury trends and prevalence according to distance that the individuals were covering on a weekly basis (Chapter II). The second study examined middle-distance runners specifically to determine injury trends and investigate the influence of gender on injury occurrence rates (Chapter III).

In Study 1, which is presented in Chapter 2 of this thesis, the focus was put on determining injury prevalence and trends in short, middle- and long-distance runners with an aim of identifying populations at highest injury risk. In addition, the analysis was also designed to determine the most important risk-factors associated with the injury for each of those distance groups. Thus, Study 1 investigated the prevalence of injuries in runners in relation to their weekly distance, as the initial hypothesis was that an increase in weekly running distance might lead to different trends in the prevalence of running-related traumas. For the purpose of this research, it was suggested that specific body sites might be at greater injury risk due to increased running exposure and overuse caused by high forces and stress load with prolonged running. The results of this study reported that between 81%-86% of individuals who run recreationally, regardless of their gender and training distance, sustained a running-related injury. This is significantly higher than in any other research undertaken to date (that is known of) on large populations (n=1000+). This could be due to non-uniform definition of RRI and recreational runners, the cohort examined as well as variety in methodology. The main benefit for this study of having such a large population is that a genuine cross section of the running population could have been evaluated. It must be highlighted, however, that the data for the following study was collected in a Sport Lab. It could be argued, that due to that fact injury rates of the studied population could have been higher, as those individuals would be more likely to seek assessment/recommendations to treat or manage injuries. The injury trends might also have been affected, as Profeet Sports Lab offers footwear recommendation and insole manufacture service. Due to that fact, rates of foot injuries might be been increased. It was concluded, however, that even if runners are more likely to come to the Lab if injured this is important too as they are prioritising this advice, which makes it more important for such clinics to be evidence based. It could also be argued that due to the technique of analysis in this study, which was retrospective, runners had no preconceived ideas about reporting injury. Furthermore, the method of data collection also gives important information about the trend in injured runners of continuing to run despite injury/multiple injury with potential for further risk as a result.

Due to a large sample size, it was possible to categorise and investigate runners based on their weekly distance as well as mileage and frequency of a single running session. Hence, all runners were divided into short, middle- and long-distance populations and analysis was undertaken to establish intrinsic and extrinsic factors that had a positive relationship with injury occurrence and existing patterns. What was found, however, was that distance did not predispose to specific traumas, as demonstrated by the variation of injuries reported by runners in different populations. A statistical significance ($p<0.05$) was, however, established in the effect of gender of participants and the likelihood of injury occurrence in short and middle-distance runners. Data revealed, that female gender is positively linked to injury. Furthermore, it was found, that there was a significant difference in hip injuries between males and females in this study. Interestingly, the most common injuries in all runners, regardless of gender, were knee injuries. The biggest difference in injury occurrence was found in the middle-distance population (15%), which hence constituted the main focus of Study 2.

As mentioned previously, even though runners were found to be very prone to sustaining injuries by a variety of studies, contradictory data exist on trends in injury patterns for males and females (Middelkoop *et al,* 2008; Malisoux *et al,* 2015; Mitani, 2017). This could be affected by sample sizes as well as the fact that males and females are often investigated separately. Furthermore, the number of female participants is often smaller than males (Mitani, 2017) This was also the case in this study. Regardless, the main finding of Study 1 indicated that there was greater predisposition to injuries in females than males, which agreed with the previous study of van der Worp *et al,* (2015) but contradictory to evidence provided by Malisoux *et al,* (2015), who found males to be at higher injury risk. This study established that running distance does not affect injury rates of trends in runners. However, it was found that all distance groups investigated – regardless of whether they were short, middle- or long-distance recreational runners, females were more likely to get injured, with injury prevalence as high as 91%-95%, which is significantly higher than reported in previous studies. This is higher than in any other research to date. Importantly, while comparing different populations of runners in Study 1, the biggest difference in injury rates between genders was observed in the middle-distance population– where males had the least injuries when compared to all other distance groups (76%). The prevalence in females, on the other hand, for that group was 91%. Due to difference in male and female population size (n=130 and n= 76 respectively), it was argued that a smaller number of females might have affected the percentages of injury rates reported for that population and affect the representation of data and differences between the male gender. It was, however, possible to conclude that female gender is one of the most important risk factors that contributes to the increased likelihood of developing an injury in runners, regardless of weekly distance and running level (abilities). Available data on the effect of distance and gender on injury rates are conflicting, as both were previously found to be protective of injury as well as positively linked to injury risk. In this study, it was concluded that protective trend of distance in relation to injury could be due to a faster muscular adaptation of males to increased physiological and biomechanical demands of higher weekly mileage. It was also hypothesised that males were more likely to adhere to training and running exposure and be involved in more cross training, especially strength training. On the other hand, it could be argued that females were more likely to seek professional help and recommendation from a sport clinic only when injured, which would increase the rates of injuries reported in this study.

Hence, second Study was designed with an aim of determining the gender-specific factor which might predispose females to RRI. The data in this investigation revealed that females were more likely to have more pronated feet than males and exhibited a greater angle of knee valgus on one side (left). Both excessive pronation, as well as knee valgus has previously been associated with RRI in female runners (Dugan *et al,* 2005; Mitani 2017).

In Study 1, knee injuries were found to be most common in all injured runners which is in agreement with previous studies on recreational runners. Differences, however, were established in injury trends between genders. In both short and middle-distance runners, females were found to be at an increased risk of hip injuries than males. This was found to be statistically significant ($p<0.05$). Males were found to suffer more from shank traumas. Due to a higher prevalence of hip injuries in women compared to lower limb issues in men, it was hypothesised that the injury occurrence and pathway in the knee might differ between male and female runners. This trend was confirmed by Study 2 and was found to be statistically significant ($p<0.05$). 40% of males and none of the females suffered from knee injuries at the time of data collection. Additionally, 33.3% of females reported hip injuries, whilst none of the male runners had traumas to that region. Difference was also observed in foot characteristics of middle-distance runners. Overall, females were found to have more pronated feet than males ($p>0.05$), a significant difference was also established in relation to supination resistance response between genders ($p<0.05$). Thus, it was argued, that knee and hip injuries could be associated with certain abnormalities in differences in foot flexibility, lower limb function as well as overall strength. In this study, females also exhibited more knee valgus, which was thought to appear as a result of lack of appropriate hip stabilization that could be specific for female gender. Hence, further research is needed to determine the effect of foot flexibility and its effect on lower extremity biomechanics as even though the data in this study identified a pattern, failed to prove statistical significance. More investigation should be undertaken in evaluating the effect of windlass mechanism and supination resistance test, which even though was not found to be gender specific, indicated that rearfoot, midfoot and forefoot flexibility of a foot might differ. In this study, the majority of injured runners had a limited range of motion in the 1st metatarsal and exhibited a delayed and rigid windlass mechanism. Furthermore, supination resistance response was also found to be "*hard*" which indicates that the foot motion through the midfoot was compromised and required more muscular demand and greater eccentric work by the plantar flexors, which in turn might affect the efficiency of the push off.

Injury-risk in middle-distance runners associated to gender

A variety of internal and external factors were evaluated in relation to injury occurrence (Saragiotto *et al*, 2014; Kozinc and Sarabon, 2017). For second study in this paper, the main hypothesis was that due to structural and anatomical differences between genders, males and females would exhibit different degrees of flexibility, especially with regards to foot and ankle (Ferber *et al*, 2003). This was proposed to further influence overall gait biomechanics, which combined with amount of strength and musculature might further affect rate of injuries in runners (Dugan *et al*, 2005; Mitani, 2017). The findings of Study 1 identified that across the whole middle-distance population investigated, there were almost no differences in respect to training routine, as well as age or event they were training for or the total weekly distance (30-40km/week) between individuals. Interestingly, the majority of injured runners had a greater running experience as well as extensive history of injuries. It was proposed that this might have contributed to new injuries due to increased running exposure and hence overuse. It was previously established, that running-related overuse injuries tend to be less severe, and it might be possible that some runners continued to run with an underlying injury, which in turn increased the likelihood of a new injury development (Vitez *et al,* 2017). Interestingly, significant differences in overall injury prevalence between males and females were identified only for the knee and hip traumas ($p<0.05$) in the second study, which is in line with the results of Study 1. Overall, knee injuries, shank and foot injuries were the most prominent in males, whilst in females, hip, foot and ankle injuries were most evident. It was proposed that this was due to anatomical and functional differences between men and women in relation to foot mobility, knee and hip alignment as well as overall flexibility which was previously mentioned by researchers but not yet investigated thoroughly in its link to injury (Räisänen *et al,* 2018). Foot characteristics (increased static foot pronation), as well as static knee motion (increased static valgus, as identified by a SLS test) were found to differ in males and females yet were not statistically significant ($p>0.05$). With regards to foot characteristics, type of movement exhibited by the foot, as well as windlass mechanism response, no relationship was established with injury occurrence and was found not to differ significantly between genders ($p>0.05$). The data of supination resistance test, however, allow to establish that the type of response reported in middle-distance runners was gender specific ($p<0.05$). Due to that fact it was concluded that this needs further investigation and it was proposed that improved protocols and assessment aimed to provide better understanding of foot segments mechanics and its flexibility should be developed, as it seems that different parts of the foot (forefoot, midfoot and rearfoot) exhibit different ranges of passive and active range of motion. This, in turn could have an impact on injury predisposition in runners.

Limitations & Strengths

This study, like most injury studies, has certain limitations. For one, there was a smaller number of females, than males who were recruited for Study 1. It could be argued, that due to that fact the results of gender – specific analysis might have been affected and allow large standard deviation on the outcome variables. Another limitation of this study is that the participants, who were recruited for Study 2 were found to present similar characteristics in terms of BMI, age, previous injury history as well as level of running. It was established that all runners apart from one had an injury history and none were novice runners. Furthermore, running a self-selected running speed which varied in individuals could have affected the gait biomechanics and thus some of the parameters measured in this study. However, it was the aim of this study to represent runners who reflect general population (in relation to speed, weekly mileage, age and other training-related factors).

Another limitation could be the environment that the individuals were running in – the data collection was performed in a closed laboratory space and the individuals run on the treadmill, rather than road (which was their main terrain). This might have affected the kinematics of their gait, especially if a person was not used to running on a treadmill. Furthermore, the data collection and video analysis only lasted for 5 minutes. Middle distance runners were found to run for a significantly longer period of time so it could be argued that due to fatigue, their biomechanics would change at the end of a longer run as some of the parameters would be compromised. That could not have been reflected fully in the dynamic analysis in this study.

In case of Study 1, the limitation was the lack of data of this kind of information. Hence, it is unknown whether any of these factors might have affected injury prevalence and trends that were observed in this study. Another important limitation is that Study 1 constituted a retrospective cohort study, where the data collection was obtained through information paper-based forms which were not designed specifically for this research but was used previously in the clinic as a registration tool. Hence, the set of information available for analysis was limited. No information was available on training intensity as well as a specific injury location or even the side of injury in runners. Furthermore, no association between biomechanics or any personal characteristic and injury occurrence was possible due to lack of data.

In study 2, a variety of personal and training-related factors were investigated, however, no information was obtained in data collection on the strike type pattern of investigated individuals. It could be argued that due to that and overall differences in biomechanics and injury patterns might not been fully accounted for. Finally, the data collection in both studies were retrospective (with 6 months recall period) and based on a customer registration form (Study 1) and a questionnaire (Study 2) – thus, recall bias could have influenced the prevalence and trend of injuries in both studies.

Regardless of the limitations, this research provides evidence that further investigation is needed to replicate and test these findings in a much bigger population, especially with prospective, randomised control studies. Regardless, it could be stated that results obtained in both of the studies undertaken as a part of this research provide clues of how to modify and control factors which have a strong relationship with the occurrence of injuries.

Apart from the limitations, there were several strengths in this research. Primarily, the size of the cohort of Study 1 can be considered a strength, as data from 1000 individuals were collected and analysed. Furthermore, in Study 2, a thorough video assessment and analysis was undertaken to collect data necessary for biomechanical analysis in individuals. An important strength of this research was that there was no bias towards a certain injury whilst assessing risk factors in both studies, as no emphasis was placed on particular injury site or risk factors.

Future Direction

The results presented in this research suggest that both injury occurrence and injury patterns are gender specific. Furthermore, certain factors related to female gender might directly predispose to injury development. Hence, an individual approach should be taken whilst analysing injury risk in both genders. This is especially important due to an increasing participation in amateur running events and taking up running by individuals as a way of staying active and healthy as well as ensuring mental health wellbeing. Future research should consider developing large cohort studies to investigate intrinsic factors related to gender as well as in-depth analysis of injury development pathway and biomechanics.

Impact / Application

Running-related injury occurrence has been suggested to result in high socio-economic costs (Tonoli *et al,* 2010), especially if it requires prolonged medical treatment and giving up running for a certain period of time by an individual. Furthermore, an increased number of injuries in novice and less experienced runners might affect their adherence towards a training program as well as discourage them from maintaining an active and healthy lifestyle. Hence, it is crucial for researchers and health professionals to understand the mechanism of RRI and associated risk factors in order to make safe and effective recommendations as well as develop appropriate treatment plans (different for male and female runners) for specific injuries. Focus should be put on prevention rather than treatment - an identification of risk factors for overuse issues would be a great start to manage modifiable variables. Furthermore, only then an implementation of specific training programs aiming to reduce the prevalence of running injuries might be possible.

Conclusions

In order to keep runners healthy and active, it is crucial to understand the complexity of running biomechanics and the underlying pathway of associated injuries. The present research consisted of two separate studies and investigated the effect of distance and gender on injury prevalence and trends in runners. Based on results in this study, it was concluded that distance did not predispose runners to injuries and did not affect the likelihood of sustaining traumas to a specific anatomical site. It was found, however, that female gender was a risk factor for running-related injuries, both in short and middle-distance populations of runners. Furthermore, female gender was related to a higher risk of hip injury than male in this study. Differences in foot type were also established, indicating that females tend to have more pronated feet than males. Hence, future research into prevention of RRI should focus of investigating the effect of gender on foot flexibility and its further effect on lower extremity function (especially in relation to foot and knee relationship), as well as hip injury biomechanics. Furthermore, more investigation is necessary in relation to knee valgus and foot and ankle injuries in runners. New assessments and protocols for foot mobility in relation to forefoot, midfoot and rearfoot separately should be developed to determine the association between windlass mechanism characteristics, supination resistance response type and injury development in runners.

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APPENDIX I. The Registration form completed by individuals who came to Profeet for a consultation with a running technician in 2010-2011.

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ASSESSMENT REGISTRATION FORM

Your Name:			
Date of Appointment:		**Date of Birth:**	
Address:			
		Post Code:	
Email Address:	Please provide your email address so that we can remind you of your follow up check up and keep you up to date with the latest Profeet news. You can of course unsubscribe at any time.		
Mobile Phone No:		**Alternative No:**	

How did you hear about Profeet?
Please tick most appropriate

- Word of Mouth ☐
- Returning Customer ☐
- Gym Day ☐
- Passing by ☐
- Personal Trainer ☐ please specify
- Internet Weblink ☐ please specify
- Advertisement ☐ please specify
- Reader offer/promo ☐ please specify
- Profeet flyer ☐
- Mag/News article ☐
- Google: search ☐ please specify
- Google: sponsored link ☐ please specify
- Marathon ☐ please specify
- Human Race/ Run Kingston ☐
- Other ☐ please specify ....

Why are you coming to Profeet?
Please tick most appropriate

- Comfort ☐
- Pain relief ☐
- Performance ☐
- Other (please specify): ....

Are you training for an event?

Yes ☐ No ☐ **If yes:**

What event? ....

When is it? ....

What is your goal? ....

Staff use only: **Tech number:**

Insole: XS S M L XL XXL XXXL

Returning customer: Yes No

Other: ____________________

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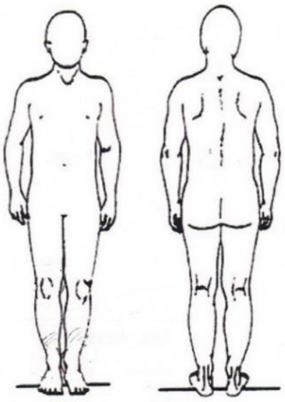
CLIENT ACTIVITY INFORMATION

Job Description:	
Activities: *Please circle*	Running Cycling Walking Triathlon Team Sports Gym Skiing Snowboarding Other ....
Sessions per week: *Please circle*	1 2 3 4 5 6 7 7 +
Time per session: (mins) *Please circle*	10 – 15 15 – 45 45 – 60 60 – 120 120 +
Distance per week: *Please circle*	Miles / Km 5 – 10 10 – 15 15 – 20 20 – 25 25 – 30 30 – 35 35 – 40 40 +
Aims & Objectives: *Please circle*	General Walking Running 10K Half Marathon Marathon Other ....
Current aches & pains:	
Any diagnosis given?	
By whom?	
Any Past Medical History? *(operations, fractures, sprains)*	
Mark on the diagram any areas of current pain or previous injury using these symbols: **x** current ache or pain # previous injury * numbness. ↓ spread of pain	 Notes:

In order for our qualified technicians to analyse and assess your physiological background, we need to perform an analysis. Your appointment will last up to an hour, and for this we charge £40.

APPENDIX II. *The summary of personal (age, number of injuries) and training-related characteristics (events, Running Frequency, session duration and weekly distance) for each distance group investigated in this study in relation to gender.*

	Short Female		Short Male		Mid Female		Mid Male		Long Female		Long Male	
	227		309		76		130		36		37	
%		**85.9**		**77.83**		**91.6**		**76.0**		**90**		**82.2**
INJURY												
KNEE	95	41.9	130	42.1	30	40	63.0	48.5	18	50	13	35.1
BACK	31	13.7	37	11.9	6	8	9.0	6.9	3	8.3	7	18.9
SHANK	36	15.9	64	20.7	13	17.3	27.0	20.8	6	16.7	6	16.2
FOOT	69	30.4	95	30.7	25	33.3	36.0	27.7	6	16.7	11	29.7
HIP	25	11.0	12	3.9	9	12	7.0	5.4	6	16.7	3	8.1
ANKLE	25	11.0	48	15.5	12	16	20.0	15.4	10	27.8	4	10.8
THIGH	15	6.6	18	5.8	8	10.7	10.0	7.7	3	8.3	4	10.8
AGE												
18-24	12	5.3	18	5.8	3	4	5	3.9	1	2.7	0	0
25-34	103	45.3	117	37.9	37	49.3	65	50.0	19	52.8	17	45.9
35-44	73	32.2	108	34.9	24	32	52	40.0	11	30.6	12	32.4
45-54	30	13.2	57	18.4	10	13.3	7	5.4	5	13.9	8	21.6
55+	9	3.9	9	2.9	2	2.7	1	0.8	0	0	0	0
EVENTS												
TRIATHLON	5	2.2	16	5.1	2	2.7	9	6.9	1	2.8	1	2.7
MARATHON	33	14.5	37	11.9	27	36	43	33.1	23	63.9	20	54.1
HALF-MARATHON	39	17.2	48	15.5	20	26.7	23	17.7	5	13.9	0	0
10 KM	33	14.5	38	12.3	4	5.3	8	6.2	0	0	0	0
GENERAL FITNESS	108	47.6	163	52.8	17	22.7	38	29.2	7	19.4	4	10.8
IRONMAN	1	0.4	1	0.3	0	0	4	3.1	0	0	4	10.8
LESS THAN 5KM	3	1.3	1	0.3	0	0	1	0.8	0	0	0	0
SUPER MARATHON	0	0	0	0	0	0	0	0	0	0	1	2.7
ULTRAMARATHON	2	0.9	0	0	3	4	1	0.8	0	0	7	18.9
TRACK	0	0	0	0	1	1.3	0	0	0	0	0	0
OTHER	3	1.3	5	1.6	1	1.3	3	2.3	0	0	0	0
SESSIONS												
1	4	1.0	5	1.6	0	0	5	3.8	0	0	0	0
2	20	5.2	42	13.6	2	2.7	5	3.8	1	2.8	0	0
3	73	18.9	100	32.4	5	6.7	21	16.2	2	5.6	7	18.9
4	69	17.8	79	25.6	23	30.7	40	30.8	13	36.1	7	18.9
5	29	7.5	47	15.2	20	26.7	30	23.1	18	50	9	24.3
6	12	3.1	18	5.8	11	14.7	7	5.4	1	2.7	5	13.5
7	16	4.1	11	3.6	13	17.3	17	13.1	1	2.7	6	16.2
7+	4	1.0	7	2.3	2	2.7	5	3.8	0	0	3	8.1
DIST/WEEK												
5-10	55	24.2	63	20.4	0	0	0	0	0	0	0	0
10-15	75	33.0	100	32.4	0	0	5	3.8	0	0	0	0
15-20	57	25.1	63	20.4	0	0	0	0	0	0	0	0
20-25	30	13.2	49	15.9	2	2.7	2	1.5	0	0	0	0
25-30	3	1.3	14	4.5	20	26.7	13	10	0	0	1	2.7
35-40	1	0.4	4	1.3	24	32	14	10.8	0	0	0	0
40+	0	0	1	0.3	20	26.7	66	50.8	36	100	36	97.3
TIME/SESS												
10-15	2	0.9	0	0	0	0	0	0	0	0	0	0
15-45	63	27.8	87	28.2	9	11.9	15	11.5	2	5.56	0	0
45-60	139	61.2	171	55.3	42	56	59	45.4	13	36.1	12	32.4
60-120	19	8.4	48	15.5	20	26.7	45	34.6	18	50	19	51.4
120+	4	1.8	3	0.9	5	6.7	11	8.5	3	8.3	6	16.2
NO OF INJURIES												
ONE	157	69.2	212	68.6	49	64.5	90	69.2	21	58.3	26	70.3
MORE THAN 1	70	30.8	97	31.4	27	36	40	30.8	15	41.7	11	29.7

APPENDIX III. *Informed consent form provided to individuals who volunteered for Study 2.*

Kingston University London

Informed Consent Form:

An investigation of running-related injury patterns and associated foot mechanics in long and short distance runners.

Ethics Code: 1617/029

Statement by participant

I .... give my consent to the research procedures that are outlined above, the aim, procedures and possible consequences of which have been outlined to me

- I confirm that I have read and understood the information sheet/letter of invitation for this study. I have been informed of the purpose, risks, and benefits of taking part.

Study title: An investigation of running-related injury patterns and associated foot mechanics in long and short distance runners.

- I understand what my involvement will entail and any questions have been answered to my satisfaction.
- I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice.
- I understand that all information obtained will be confidential.
- I agree that research data gathered for the study may be published provided that I cannot be identified as a participant.
- Contact information has been provided should I (a) wish to seek further information from the investigator at any time for purposes of clarification (b) wish to make a complaint.

Participant Signature: .... Date: ....

Participant Name: …………………………………...

Participant ID: ………………………………………

Statement by investigator

- I have explained this project and the implications of participation in it to this participant without bias and I believe that the consent is informed and that he/she understands the implications of participation.

Researcher Signature: .... Date:………………………………

Researcher Name: ....

APPENDIX IV. *Running-related questionnaire provided to individuals who participated in Study 2*

Kingston University London

RUNNING – RELATED QUESTIONNAIRE (STUDY 2)

Gender: ☐ male ☐female
Age:__________ **Height (cm):** ________ **Weight(kg):**________
Shoe size (UK):_________

PART 1.

1. **How long have you been running for?**

☐ less than a year
☐1-2 years
☐ 3-5 years
☐ 6-8 years
☐ 9 + years

2. **How many times per week do you run?**

☐ 3
☐ 4
☐ 5
☐ 6
☐ 7
☐ 7+

3. **What type of distance (km) do you normally cover per week (total)?**

☐ 30-40 km
☐ 40-50 km
☐ 50-60 km
☐ 60-70 km
☐ 70+ km

4. **What is the minimum distance that you cover during a single run (km)?**

☐ 8-10 km
☐ 11-13 km
☐ 14-16 km
☐ 17-19 km
☐ 20-22 km
☐ 23-25 km
☐ 26+ km

5. **<u>What is the maximum distance that you run in a single running session (km)?</u>**

☐ 10-15 km
☐ 16-18 km
☐ 19-22 km
☐ 22-25 km
☐ 25-28 km
☐ 28-31 km
☐ 32+ km

6. **<u>What is your average training speed km/h (min/km)?</u>**

☐ 8.00 km/h (7:30)
☐ 9.00 km/h (6:40)
☐ 10.00 km/h (6:00)
☐ 11.00 km/h (5:27)
☐ 12.00 km/h (5:00)
☐ 13.00 km/h (4:37)
☐ 14.00 km/h (4:17)

☐ Other:______________________________

7. **<u>What is the fastest pace that you tend to run at?</u>**

☐ 12.00 km/h (5:00)
☐ 13.00 km/h (4:37)
☐ 14.00 km/h (4:17)
☐ 15.00 km/h (4:00)
☐ Other:_______________________________

8. **<u>What is the slowest pace that you run at?</u>**

☐ 8.00 km/h (7:30)
☐ 9.00 km/h (6:40)
☐ 10.00 km/h (6:00)
☐ 11.00 km/h (5:27)
☐ Other:_______________________________

9. **<u>Please specify your most recent Average Race Pace (m/km):</u>**

☐ 8.00 km/h (7:30)
☐ 9.00 km/h (6:40)
☐ 10.00 km/h (6:00)
☐ 11.00 km/h (5:27)
☐ 12.00 km/h (5:00)

☐ 13.00 km/h (4:37)
☐ 14.00 km/h (4:17)
☐ 15.00 km/h (4:00)

10. <u>What is your current PB (if applicable)?</u>

Specify: ____________________________

11. <u>What type of running surface do you normally run on (tick all that apply) ?</u>

☐ Road
☐ Treadmill
☐ Trails
☐ Towpath
☐ Mixed
☐ Other (please specify):______________________________

12. <u>Specify your running routine with regards to the number of short and long runs per week:</u>

<u>Short Runs:</u>

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5+

<u>Long runs:</u>

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5+

13. <u>Are you currently training for anything?</u>

☐ Yes (*please specify*) ________________________________
☐ No

14. <u>What type of events do you participate in most frequently?</u>

☐ Half marathons
☐ Marathons

☐ Triathlons
☐ Half Ironmans
☐ Ironmans
☐ Other:________________________________

15. **Do you do any cross training?**

☐ Yes
☐ No

16. ***Is “yes” , please provide the type of activity you are mainly involved in:**

☐ Swimming
☐ Cycling
☐ Weight training
☐ Cross Fit
☐ Other:____

17. **How many times per week do you cross train?**

☐ 1-2
☐ 3-4
☐ 5-6
☐ 7-8

18. **Do you currently incorporate any strengthening and conditioning as a part of your training routine?**

☐ Yes
☐ No

19. **Have you ever had a running coach or went through gait retraining?**

☐ Yes
☐ No

20. **Have you EVER suffered from a running-related injury?**

☐ Yes
☐ No

21. ***If so, please provide the anatomical region of that injury:**

☐ Foot
☐ Ankle
☐ Knee
☐ Shank
☐ Tight
☐ Lower back
☐ Hip

☐ Left
☐ Right

22. What type of tissue did the injury involve?

☐ soft tissue (muscle)
☐ bone
☐ joint
☐ unknown

23. Are you CURRENTLY suffering from a running- related injury or suffered from one (or more) in the PAST 6 MONTHS?

☐ Yes
☐ No

24. *If so, please specify the site of your injury (tick all that apply):

☐ Foot
☐ Ankle
☐ Knee
☐ Shank
☐ Tigh
☐ Lower back
☐ Hip

25. What type of running shoe are you currently running in?

☐ Neutral
☐ Guidance
☐ Support

Brand: __________________________

Model: __________________________

26. Do you wear insoles/specialist orthotics whilst running?

☐ Yes
☐ No

27. How do you normally buy your shoes?

☐ Based on comfort (off the shelf)
☐ Based on internet reviews
☐ Through a specialist running store (prescribed)

☐ Other:________________________________

PART 2. ***Please fill out per single injury (if suffering from more than one injury)*** ***Leave BLANK if non-injured.***

INJURY SPECIFIC QUESTIONS:

1. Where is the current pain located? (specify region)

☐ Foot
☐ Ankle
☐ Knee
☐ Shank
☐ Tight
☐ Lower back
☐ Hip

☐ Left
☐ Right

Specify further the anatomical location - eg. arch, heel, front, inside:

____

2. Which type of tissue does the injury involve?

☐ soft tissue
☐ bone
☐ joint
☐ unknown
☐ Other:___________________________________

3. Describe type of pain that you are experiencing:

☐ Cramping
☐ Numbness
☐ Burning
☐ Sharp
☐ Throbing
☐ Shooting.
☐ Other (specify):_______________________________

4. Describe the nature of injury that you currently suffer from:

☐ Acute

☐ Chronic

5. Is the pain intermittent?

☐ Yes
☐ No

6. When does the pain occur (tick all that apply)?

☐ Mainly in the morning
☐ It's constant
☐ During the run
☐ After a run
☐ At the end of the day

7. Do you experience more pain as you build up the mileage?

☐ Yes
☐ No

8. Did the injury require treatment?

☐ Yes
☐ No

9. *If "yes", what type of treatment was provided?

Please specify (eg. Physio, sport massage):______________________________

10. Any medical diagnosis obtained?

☐ Yes
☐ No

11. If "yes", specify what diagnosis was given and by whom:

____

APPENDIX V. Foot Posture Datasheet

Foot Posture Index Datasheet

Patient name	***ID number***

	FACTOR	PLANE	SCORE 1 Date__________ Comment________		SCORE 2 Date__________ Comment________		SCORE 3 Date__________ Comment________	
			Left -2 to +2	**Right** -2 to +2	**Left** -2 to +2	**Right** -2 to +2	**Left** -2 to +2	**Right** -2 to +2
Rearfoot	Talar head palpation	*Transverse*						
	Curves above and below the lateral malleolus	*Frontal/ transverse*						
	Inversion/eversion of the calcaneus	*Frontal*						
Forefoot	Prominence in the region of the TNJ	*Transverse*						
	Congruence of the medial longitudinal arch	*Sagittal*						
	Abd/adduction forefoot on rearfoot	*Transverse*						
	TOTAL							

Reference values
Normal = 0 to +5
Pronated = +6 to +9, Highly pronated 10+
Supinated = -1 to –4, Highly supinated –5 to -12

APPENDIX VI. *Data of average hip drop, knee and foot angle deviation values for all investigated runners.*

Gender	*Average right knee deviation angle (from neutral)*	*Knee motion pattern*	*Average left knee knee ankle (from neutral)*	*knee motion pattern**
F	23	*valgus*	15	*valgus*
F	5	*neutral*	10	*valgus*
M	-6	*varus*	9	*neutral*
F	-11	*varus*	-4	*varus*
M	5	*varus*	15	*valgus*
F	14	*neutral*	13	*valgus*
M	16	*valgus*	5	*valgus*
M	17	*valgus*	20	*valgus*
F	2	*neutral*	19	*valgus*
M	10	*valgus*	10	*valgus*
F	6	*neutral*	13	*valgus*
M	7	*neutral*	17	*valgus*
M	5	*neutral*	8	*neutral*
F	10	*valgus*	21	*valgus*
F	-1	*neutral*	5	*neutral*
M	9	*neutral*	9	*valgus*
M	5	*neutral*	15	*valgus*
M	3	*neutral*	18	*valgus*
F	6	*neutral*	13	*valgus*
M	5	*neutral*	18	*valgus*
F	15	*valgus*	22	*valgus*
M	7	*neutral*	8	*neutral*
F	9	*neutral*	11	*valgus*
M	17	*valgus*	16	*valgus*
F	18	*valgus*	24	*valgus*
F	7	*neutral*	4	*neutral*
M	-4	*varus*	-3	*varus*