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Posterior thigh muscles flexibility profiling: a comparative study of trail and road runners

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ABSTRACT

Purpose of the study: To identify and analyse differences in posterior thigh muscles flexibility profiles between recreational runners on trail and road surfaces.

Methods: This study employed an observational cross-sectional design. The sampling technique used was purposive sampling, in which respondents were selected based on predefined inclusion and exclusion criteria. Posterior thigh muscles flexibility was assessed using an inclinometer through the Passive Straight Leg Raise (PSLR) test. Data were analysed using an independent *t*-test based on normality of distribution and homogeneity of variances.

Results: The *p*-value was 0.321 for the right posterior thigh muscles and 0.927 for the left, indicating no statistically significant differences in flexibility between groups.

Conclusions: The type of running surface did not demonstrate a measurable effect on posterior thigh muscle flexibility in the study population. The findings of this study underscore the importance of implementing targeted training programs aimed at both preventing injury and strengthening the posterior thigh muscles.

Keywords: trail surface, road surface, runner, posterior thigh muscles injury, exercise

Conflict of interests: the authors declare no conflicts of interest.

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Оценка гибкости мышц задней группы бедра: сравнительное исследование бегунов по пересеченной местности и шоссе

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РЕЗЮМЕ

Цель исследования: выявить и проанализировать различия в профилях гибкости мышц задней группы бедра у бегунов-любителей, бегающих по пересеченной местности и шоссе.

Методы: в этом наблюдательном поперечном исследовании участвовали 78 бегунов-любителей, отобранных с помощью целенаправленной выборки. Гибкость мышц задней группы бедра оценивалась с помощью инклинометра с помощью пассивного подъема прямой ноги. Данные анализировались с помощью независимого *t*-критерия после проверки на нормальность и однородность.

Результаты: обнаружено отсутствие статистически значимых различий в гибкости между правыми и левыми мышцами задней группы бедра (p = 0,321 и p = 0,927 соответственно).

Выводы: в ходе исследования не было выявлено значимого влияния типа поверхности для бега на гибкость мышц задней группы бедра у участников исследования. Отмечена важность внедрения тренировочной программы для укрепления и профилактики травматизма мышц задней группы бедра.

Ключевые слова: поверхность тропы, поверхность дороги, бегун, травма подколенного сухожилия, упражнение

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1. Introduction

Running is an activity that has grown rapidly globally and in Indonesia over the past decade. Running activity increased by 39 % in 2023 compared to 2022, with 53 % of runners being amateurs [1]. Community growth is also evident, with the global running community projected to increase by 59 % in 2024 [2, 3]. The same trend is also occurring in Indonesia, with more than 80000 active runners recorded in 2024 [4, 5]. However, despite this growth, the average daily step count of Indonesians remains at 5375, well below the recommended 11000 to 12000 steps per day as recommended by National Institutes of Health (2020) [6–8]. Road running is the most popular due to its accessibility and safety, while trail running is growing rapidly thanks to the significant motivation of emotional well-being and closeness to nature [9–11].

Running, however, is a high-risk activity for musculoskeletal injuries due to repetitive mechanical loading and training errors. The most common injuries include patellofemoral pain, iliotibial band syndrome, shin splints, plantar fasciitis, posterior thigh muscles strains, and Achilles tendinopathy. Posterior thigh muscles injuries are not most prevalent injury. However, this type of injury received significant attention, accounting for 5 to 15 percent of long-distance running injuries [12–14], with incidence rates of 0.2 to 0.7 per 1000 training hours. This injury is more prevalent among high-mileage runners (more than 60 kilometers per week), athletes engaged in interval or trail running, and runners over the age of 35 [15].

Both trail and road runners are susceptible to posterior thigh muscles injuries. In road running, repetitive motion and acceleration contribute to strain risk, while in trail running, the risk is elevated during downhill movement, on slippery terrain, or in sudden directional changes, which involve high eccentric posterior thigh muscles loading [16–18]. Key factors in posterior thigh muscles injuries include muscle strength, the posterior thigh muscles-to-quadriceps (H/Q) ratio, previous injury history, and particularly posterior thigh muscles flexibility [19, 20].

Furthermore, some studies show that flexibility can reduce posterior thigh muscles injuries during running activities. Additionally, a review by Afonso et al. (2021) [21] states that posterior thigh muscles flexibility is still not a significant risk factor for injury. However, biomechanical studies show that muscles with poorer flexibility have lower force absorption capacity, thereby increasing the incidence of injury, especially during stretching.

Research comparing posterior thigh muscles flexibility in trail and road running remains limited. Existing studies have mostly addressed movement mechanics, load distribution, muscle activation, neuromuscular responses, and injury risk. However, the distinct biomechanical demands of each surface, including ground impact, posterior thigh muscles activity, and gait patterns, may influence posterior thigh muscles strain differently. This makes it a relevant area for further investigation [22–24].

Analysing posterior thigh muscles flexibility in trail and road runners is essential for guiding physiotherapists in developing targeted injury prevention and rehabilitation strategies. The findings may also support decisions during the return-to-sport phase by identifying suitable terrains based on post-injury functional outcomes and recurrence risk. Moreover, these insights can inform coaches in designing training periodisation that combines both surfaces [25–28].

The aim of the study was to identify and analyse the differences in posterior thigh muscles flexibility profiles between trail and road runners. The hypothesis of this study is that different running surfaces, namely road surfaces and cross-country terrain, may result in differences in mechanical load and in the regulation of the musculoskeletal and neuromuscular systems. However, there is no significant difference in the elasticity (flexibility) of the posterior thigh muscles between runners who train regularly on one type of surface and those who train regularly on another surface.

2. Literature Review

2.1. Road Running

Road running involves running on asphalt or concrete and is classified as a high-impact aerobic exercise that engages large muscle groups to enhance cardiovascular fitness. Bearbero reported that endurance and strength training improve running economy, VO_2 max, and gait efficiency [29, 30]. Furthermore, research by Singh in 2022 found that outdoor running is more effective than treadmill running for improving fitness and muscle mass [31].

The flat contour of road surfaces makes running more stable and predictable, with shorter stride length and ground contact time. Muscle activation is primarily driven by large muscle groups such as the gluteus, posterior thigh muscles, and quadriceps, requiring relatively simple coordination [32, 33].

2.2. Trail Running

Trail running is an activity that involves running in natural environments, typically not on roads, but rather on trails characterised by forests, mountains, hills, or mixed terrain. This activity emphasises the body's adaptation to uneven and unstable routes and surfaces with elevation differences, obstacles, and challenges [34]

Similar to road running, trail running also offers significant health benefits. Trail running trains the cardiovascular system's ability to optimise aerobic capacity and endurance through uneven terrain and track inclines. Furthermore, this activity can also enhance mental well-being, as scientific studies show that exposure to nature can reduce cortisol levels (stress hormones), anxiety, and depression symptoms. During the activity, the mind tends to focus and concentrate, reducing negative thoughts and positively affecting mood. Due to its uneven terrain and inclines, trail running increases metabolic energy expenditure or energy use compared to regular running on flat surfaces or using a treadmill, making it an excellent programme for individuals pursuing an ideal body weight [35–38].

The terrain in trail running consists of irregular surfaces like rocks, soil, and roots, which demand greater balance and dynamic stability. This results in shorter, more variable strides and longer ground contact time for stabilisation. The activity engages stabiliser muscles such as the tibialis posterior, peroneus, and core muscles, requiring more complex movement coordination and environmental responsiveness [39, 40, 41].

2.3. Biomechanical load of road running and trail running

Trail and road running have different surface characteristics, which result in different demands and physical exertion. Therefore, it is crucial for the body to adapt to running on these surfaces (Table 1).

3. Methodology

3.1. Study design

This study used a cross-sectional approach to analyse posterior thigh muscles flexibility differences between trail and road runners. Data collection was conducted at a single time point with a sample of runners from the road runner and trail runner groups, who were members of running communities in the Special Region of Yogyakarta, Indonesia. This study was approved by the Health Research Ethics Committee (KEPK) of the Faculty of Health Sciences, UMS, with ethical approval number 4723/B.2/KEPK-FKUMS/I/2023.

3.2. Subjects

This study included 78 runners who underwent posterior thigh muscles flexibility assessments. The sample size was determined using G*Power for an independent-samples *t*-test, with a significance level of 0.05, power of 80 %, and an expected effect size of 0.5, yielding 78 participants were selected using purposive sampling in accordance with predefined inclusion and exclusion criteria. Participants were grouped into trail and road runners based on their community registration data. Recruitment took place in September–October 2023, with data collection conducted from mid-November 2023 to mid-January 2024. Inclusion criteria for this study were:

1. All participants who ran more than 32.19 km per week over the past six months.
2. All participants who have run explicitly on hard surfaces (asphalt or concrete) and trail runners (hills) over the past 3 months.
3. Participants who were runners or joggers aged between 18 and 35 years at the time of recruitment.

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Table 1

Biomechanical load of trail and road running [38]

Таблица 1

Биомеханическая нагрузка при беге по пересеченной местности и шоссе [38]

Variable	Road Running	Trail Running
Stride	Long and consistent strides due to flat surfaces	Short and quick strides, characterised by increased cadence and adjustments to varying terrain conditions
Contact Time	Generally shorter due to flat terrain, making running more efficient	Tends to be longer as runners are more cautious when stepping and landing
Impact Forces	Relatively high due to faster speeds and more complex surfaces	Relatively low due to slower speeds and more careful landing techniques
Joint Movements	Stable and predictable movements with minimal variation	More dominant characteristics include knee flexion and ankle dorsiflexion to adapt to the terrain
Running Economy	More effective and efficient due to consistent paths and minimal obstacles	Running economy tends to be lower than treadmill or road running due to the variability of the terrain
Biomechanical Variability	Relatively stable surfaces result in lower variability. However, longer stride patterns increase the risk of overuse injuries if not balanced with proper training	Constantly changing surfaces lead to high biomechanical variability. This increases the adaptive load and demands on neuromuscular performance

4. Chronic and acute musculoskeletal conditions experienced by participants in the past 6 months were exclusion criteria for this study.

3.3. Outcomes

The primary outcome was posterior thigh muscles flexibility, measured via passive straight leg raise (PSLR) test using and inclinometer, with good instrument reliability (ICC 0.81–0.88). A PSLR score > 800 indicated normal flexibility. Key exposure variables included previous injury history and weekly running distance over the past 3–6 months, assessed through self-reported questionnaires and fitness tracker data. To reduce bias, researchers used random sampling, validated instruments, and standardised measurement procedures.

3.4. Procedure for measuring posterior thigh muscles flexibility with an inclinometer

a. Patient position:
   1. Patient position: supine lying on a mat or examination table.
   2. Both legs should be straight, with the knees and hips in full extension.
   3. Both arms should be relaxed at the sides of the body.

b. Inclinometer preparation

The research team can ensure that the inclinometer is calibrated and the instrument is at 0 degrees when positioned on the tibia or femur.

c. Movement manoeuvre
   1. The assessor passively lifts one leg (right or left) while ensuring knee extension and mobility occur at the hip joint.
   2. The assessor ensures the contralateral limb remains straight to prevent lifting or compensation, which can be manually held in place with a belt or by another assessor.
   3. Ensure the inclinometer is aligned with the longitudinal line.
   4. Pelvic stability was maintained throughout the procedure, and all measurements were conducted by the same assessor to ensure standardised testing conditions.

d. Results
   1. The assessor records the angle the inclinometer displays (in degrees). Repeat the procedure once more to ensure reliability.
   2. Repeat the procedure for the contralateral limb (if necessary) [42, 43]. Data on posterior thigh muscles flexibility were collected by the research team using the Passive Straight Leg Raise test with an inclinometer, as described above. Other primary exposure data were collected via an online questionnaire completed by the runners. All participants, divided into two groups, had equal opportunities to undergo measurements for both outcome data and characteristics or exposure.

3.5. Data analysis

Data in this study were analysed using SPSS version 26. Posterior thigh muscles flexibility was set as a continuous variable, and data distribution was assessed prior to inferential analysis. Variables with normal distribution were analysed using an independent samples *t*-test with a two-tailed significance level of $p < 0.05$, while the Mann–Whitney *U* test was applied when normality assumptions were not met. In addition to *p*-values, effect sizes were calculated using Cohen's d to determine the magnitude of differences between groups, with values interpreted as small (≈ 0.2), moderate (≈ 0.5), or large (≥ 0.8). Negligible effect sizes indicate limited practical or clinical differences despite statistical findings. Demographic characteristics, including runner type and history of iliotibial band syndrome, were analysed descriptively using frequencies and percentages to support the interpretation and discussion of the results.

4. Results

In October 2023, 177 runners from Yogyakarta-based communities were identified. Eighty-three met the inclusion criteria: aged 18–35 and running an average of 32.19 km per week over the past six months, with consistent engagement in road or trail running. Ninety-four were excluded due to age (*n* = 68), recent lower limb injuries (*n* = 12), or refusal to participate (*n* = 14). During follow-up, five participants were excluded due to incomplete data, yielding a final sample of 78 runners included in the analysis.

Descriptive analysis showed the mean age was 27.67 ± 4.76 for road runners and 23.36 ± 4.72 for trail runners (range: 18–34 years). Mean right posterior thigh muscles flexibility was 95.89 ± 14.04 in road runners and 92.69 ± 13.66 in trail

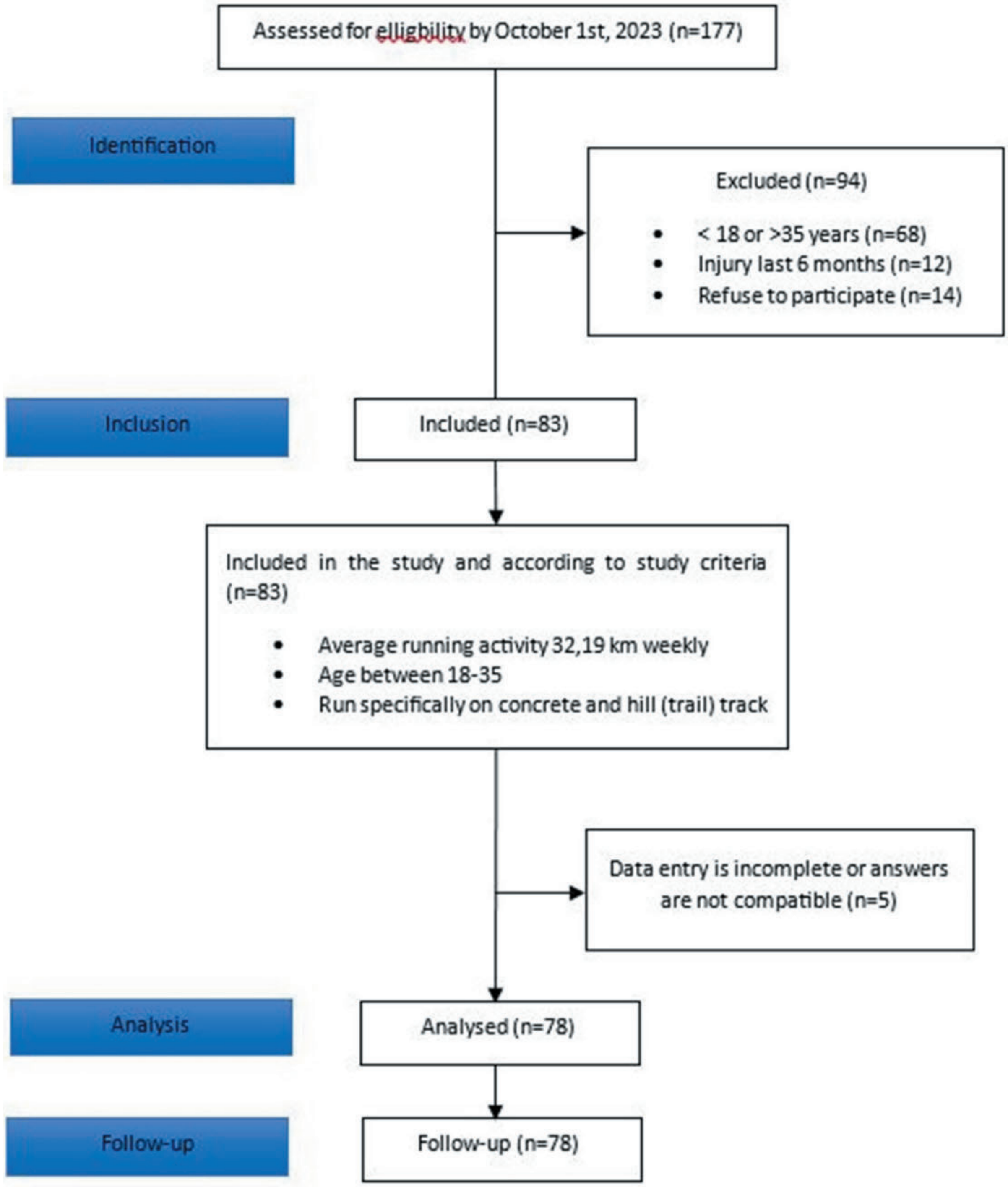

Fig. 1. Flow Chart Diagram for Research Sampling
Рис. 1. Блок-схема выборки исследования

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Table 2

Descriptive Characteristics of Trail and Road Runners

Таблица 2

Описательные характеристики бегунов по пересеченной местности и шоссе

Variable	Group A (Hard Surface Runners)						Group B (Trail Runners)					
	N	%	Mean ± SD	Min	Max	Sig*	*N*	%	Mean ± SD	Min	Max	Sig*
Demographics												
Age	39	100	27.67 ± 4.76	18	34		39	100	23.36 ± 4.72	18	34	
Weekly Running Distance (km/week)	39	100	37.05 ± 3.28	33	45		39	100	36.49 ± 3.14	33	43	
Posterior thigh muscles Flexibility												
Right Posterior thigh muscles Flexibility (^{0})	39	100	95.89 ± 14.04	65	130	0.64	39	100	92.69 ± 13.66	70	130	0.64
Left Posterior thigh muscles Flexibility (^{0})	39	100	93.97 ± 14.33	70	120		39	100	93.85 ± 14.35	65	120	
Injury History (> 6 months)												
Posterior thigh muscles Strain (+)												
Right	9	23.1	NA	NA	NA		15	38.5	NA	NA	NA	
Left	13	33,3	NA	NA	NA		13	33.3	NA	NA	NA	
Iliotibial band syndrome (+)												
Right	17	43.6	NA	NA	NA		13	33.3	NA	NA	NA	
Left	22	56.4	NA	NA	NA		26	66.7	NA	NA	NA	

Note: * Homogeneity Test between Group A and B. ** The injury occurred more than six months ago and is no longer present.
Mean ± SD = Average ± Standard Deviation; Min / Max = Minimum and Maximum values; Sig* = Statistical significance value $p > 0{,}05$; NA = Not Available (data not provided)

Примечание: * Проверка однородности между группами A и B. ** Травма произошла более шести месяцев назад и в настоящее время отсутствует.
Mean ± SD = Среднее ± стандартное отклонение; Min / Max = минимальное и максимальное значения; Sig* = статистическая значимость при $p > 0.05$; NA = нет данных (данные не получены)

Table 3

Comparison of Posterior thigh muscles Flexibility Between Trail and Road Runners

Таблица 3

Сравнение гибкости мышц задней группы бедра у бегунов по пересеченной местности и по шоссе

Variable	Trail Runners ($n = 39$)	Road Runners ($n = 39$)	*p*-value	Effect Size (Cohen's d)
Right Posterior thigh muscles Flexibility	92.69 ± 13.66	95.89 ± 14.04	0.310	0.230
Left Posterior thigh muscles Flexibility	93.85 ± 14.35	93.97 ± 14.33	0.920	0.008

runners. Left posterior thigh muscles flexibility was similar between groups (road: 93.97 ± 14.33; trail: 93.85 ± 14.35), all within the normal range. Less than 40 % of participants in both groups had a prior posterior thigh muscles injury (> 6 months ago). Notably, iliotibial band syndrome (+) on the left side was reported by over 50 % of participants in both groups.

Analysis showed no significant differences in posterior thigh muscles flexibility between trail and road runners for either side (right: $p = 0.310$; left: $p = 0.920$). The mean right and left posterior thigh muscles flexibility in trail runners were 92.69 ± 13.66 and 93.85 ± 14.35, while in road runners were 95.89 ± 14.04 and 93.97 ± 14.33. An independent *t*-test was used for the right side (normal distribution), and the Mann-Whitney test for the left (non-normal distribution). Effect sizes (Cohen's $d = 0.230$ and 0.008) suggest negligible differences between groups.

5. Discussion

Most running injuries occur in the lower extremities, with posterior thigh muscles injuries accounting for 5–15 % of all running injuries. Although relatively low compared to other injuries, this condition can reduce running performance. Long-distance runners on any track face the same risk of increased posterior thigh muscles strain injuries, primarily due to the characteristics of long-distance running, which involves prolonged and repetitive activity, leading to muscle overload, particularly in the posterior thigh muscles, resulting in increased stiffness. This study found no difference in flexibility profiles between runners on hard surfaces (concrete or asphalt) and trail runners. The workload characteristics of the running surface can explain this.

The posterior thigh muscles workload between trail and road runners appears relatively comparable due to shared fundamental characteristics such as load type, duration, intensity, muscle activation patterns, terrain influences, and injury risk; however, biomechanical analyses reveal distinct differences. Trail runners experience greater eccentric contraction loads, particularly when navigating downhill terrain, while road runners are exposed to consistent and repetitive workloads, including higher loading during sprints and constant speeds, in contrast to the slower pace, prolonged contraction durations, and increased stabilisation demands in trail running [24, 44].

Regarding posterior thigh muscles flexibility, the repetitive and rhythmic nature of road running may lead to muscle stiffness and shortening over time without adequate mobility exercises, whereas trail running encourages more varied posterior thigh muscles activation due to terrain gradients, elevation changes, and stride adaptations. Nonetheless, the high eccentric contraction demands in trail running can also increase the risk of tightness if recovery is inadequate [24, 44, 45].

Running on hard surfaces such as asphalt and concrete causes greater impact forces than other surfaces, which leads to greater demands on muscles and joints, including the posterior thigh muscles. The ability to absorb impact, especially on the knee joints on these surfaces, can increase posterior thigh muscles stiffness when done repeatedly and for long periods of time [46].

Conversely, trail running surfaces with uphill and downhill inclines demand varied posterior thigh muscles activity, involving concentric contractions during ascent and eccentric contractions during descent, the latter contributing to increased muscle strain. This variation results in a comparable risk of repetitive microtrauma and reduced posterior thigh muscles flexibility over time, similar to that observed in hard-surface runners. These biomechanical differences underscore the importance of incorporating flexibility training for the lower extremities in running programmes to mitigate injury risk [47, 48].

According to Sanchez's 2023 study, among three types of running surfaces, concrete, synthetic track, and grass, the highest average and peak acceleration occurred on concrete, leading to greater biomechanical load on the lower limbs. Peak acceleration on concrete was approximately 36 percent higher than on synthetic track and grass. Runners on the concrete tend to exhibit fewer steps with longer strides, which often results in overstriding or excessive heel strike, increasing running acceleration and contributing to posterior thigh muscles overload [49, 50].

However, posterior thigh muscles injuries are not solely attributed to the running surface, as other contributing factors include footwear, running technique, foot strike, and landing patterns. Repeated ground contact during landing may cause cumulative overload, potentially resulting in chronic posterior thigh muscles injuries.

Factors determining posterior thigh muscles flexibility quality include muscle imbalance between the posterior thigh muscles, glutes, quadriceps, and muscle strength. Research has found that runners with weak gluteus muscles tend to have posterior thigh muscles flexibility issues. Additionally, running form also affects posterior thigh muscles function. For example, poor running technique, such as overstriding or suboptimal pelvic performance, can increase posterior thigh muscles performance, as pelvic performance is related to overall lower limb efficiency. Running form is associated with foot strike pattern, cadence, body posture, and arm swing. Another factor is stretching habits. For instance, regular stretching can improve or maintain posterior thigh muscles function and flexibility. Dynamic stretching is recommended before running activities as it enhances posterior thigh muscles efficiency [51–53].

The study revealed a negative correlation between low posterior thigh muscles flexibility and peak strain during running, indicating that reduced flexibility leads to increased muscle strain and a higher risk of injury. Conversely, good flexibility enhances anterior pelvic tilt during both stance and swing phases, promoting optimal coordination between the gluteus and posterior thigh muscles to generate forward propulsion for improved running performance [54–56].

Additionally, a study by Skroce found no significant differences in static balance outcomes (BESS), VO_2 Max prediction, or adaptations in functional characteristics such as speed and stride length. Trail running demands greater postural control and muscle activity due to its unstable terrain, while road running offers a stable, rhythmic activity that effectively stimulates cardiovascular responses, making it a safer option for beginners. Its predictable nature is particularly suitable for individuals initiating a running programme [16, 57].

The running surface influences how runners adjust their stride to maintain balance, with leg muscle stiffness varying depending on surface type. On hard surfaces like asphalt or concrete, leg stiffness tends to decrease, while on elastic surfaces such as grass or soil, stiffness increases. Both low and high levels of limb stiffness pose risks of injury to bones, ligaments, and muscles, including the posterior thigh muscles. Low stiffness can impair elastic movement control, reducing the muscles' and tendons' ability to absorb and regulate forces efficiently. Conversely, high stiffness often correlates with reduced muscle flexibility, which hinders movement efficiency and leads to unnatural running techniques, ultimately limiting the body's ability to adapt to changes in force and heel strike impact [58–61].

Reduced leg stiffness during running on harder or more complex surfaces, such as concrete, is associated with increased muscle activity to absorb impact and maintain stability, including greater activation of the posterior thigh muscles. In contrast, when leg stiffness increases during the late swing (eccentric) phase, the activity of the posterior thigh

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muscles, particularly the semimembranosus, tends to be elevated [62, 63].

During running, the knee performs repetitive extension, especially at the end of the swing phase, when the posterior thigh muscles is maximally lengthened and contracts eccentrically to assist hip flexion and lower leg rotation. Running on sloped surfaces increases knee joint load and the risk of posterior thigh muscles injury. According to Park et al., a 19 % increase in knee extension moment over time contributes to injury by accumulating joint stress and fatigue [62]. Eccentric posterior thigh muscles activity intensifies during downhill or trail running, increasing workload and inflammation risk. This demands more negative work from the hip and knee. As downhill gradients grow, ankle force declines, shifting greater load to the knee. Trail runners should focus on knee flexion ROM training to boost negative work and stability on slopes.

Research indicates that running on moderately sloped surfaces, with inclination or declination angles of approximately 4 degrees or a grade of ± 6.98 %, does not significantly impact lower limb joint performance or ground reaction force (GRF), making such terrain safe for use in training or post-injury rehabilitation programmes [64].

However, posterior thigh muscles flexibility is not the sole factor contributing to posterior thigh muscles injuries. Studies have shown that while flexibility is indeed a risk factor, other elements such as gender, muscle imbalances, core stability, environmental conditions, fatigue, genetics, and a history of previous posterior thigh muscles injuries also play significant roles. Posterior thigh muscles injuries typically result from a combination of intrinsic and extrinsic factors; therefore, a comprehensive understanding of these variables is essential to develop effective and well-targeted prevention and intervention strategies [65].

Based on the results of this study, there are clinical practice implications regarding the role of physiotherapy for the characteristics of these two surfaces due to different biomechanical challenges. For runners who are used to hard surfaces (asphalt or concrete), physiotherapy can optimise running biomechanics analysis to identify inefficient movements and strategic training programmes for muscle strengthening to achieve balanced muscle function, especially in the gluteus, posterior thigh muscles, quadriceps, and calf muscles. This is an effort in the preventive programme for runners.

Preventive programmes serve not only to reduce injury risk but also to improve running performance. These programmes should be structured according to specific goals and focus on three essential components: strength, agility, and flexibility, all of which influence the risk of posterior thigh muscles injury and support the correction of running form to ensure runner safety [66].

Additionally, physiotherapists should consider individual risk factors such as knee extension deficits, posterior thigh muscles-to-quadriceps strength ratio, and eccentric posterior thigh muscles strength. Evidence suggests that eccentric training programmes can reduce posterior thigh muscles injury risk by 56 to 70 percent, improving H/Q ratio balance, reducing asymmetry, and enhancing flexibility [67]. Thus, physiotherapy interventions should focus on individual risk profiles and prevention rather than symptoms and post-injury therapy.

The clinical practice implications for trail runners include training strategies that enhance physical capacity, particularly proprioception, balance, core strength, and efficient running form adapted to trail environments. These strategies are especially relevant for preventive programs to reduce the risk of posterior thigh muscles and other running-related injuries. In physiotherapy, the findings support the development of intervention and rehabilitation programs during the sport-specific, functional, and return-to-sport phases, as well as reinjury prevention. Additionally, the baseline data from this study can inform educational initiatives regarding the selection of running shoes that align with individual foot anatomy and running style [68, 69].

This study has several limitations. The sample size was relatively small, and several potential confounding factors were not considered, including training programs, footwear, stretching routines, running speed and form, prior injury history, muscle strength, anatomical variations, and gender. These variables may influence posterior thigh muscles flexibility both directly and indirectly. Although flexibility is important, it is only one component in a complex system related to injury risk. Focusing solely on flexibility, without considering elements such as muscle strength and neuromuscular coordination, is unlikely to significantly reduce posterior thigh muscles injury incidence. This study considers data on differences in exercise intensity or the type of shoes worn by respondents. The cross-sectional study design cannot show a causal relationship, only a correlation between variables. Future research should examine these factors in greater depth.

6. Conclusion

This study found that the type of running surface did not demonstrate a measurable effect on posterior thigh muscle flexibility in the study population. The findings of this study underscore the importance of implementing targeted training programs aimed at both preventing injury and strengthening the posterior thigh muscles.

Authors' contribution

Farid Rahman — conceptualization, methodology, investigation, data collection and interpretation, writing — original draft, writing — editing, visualization, and project administration, formal analysis.

Muhammad Shamil Muwaffaq — conceptualization, methodology, investigation, writing — original draft, writing — editing, visualization, project administration, formal analysis.

Rizqy Febriansyah — conceptualization, methodology, investigation, writing — original draft, writing — editing, visualization, project administration, formal analysis.

Muhammad Raihan Ishad — conceptualization, methodology, writing — original draft, writing — editing, visualization, project administration, formal analysis.

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