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Longitudinal analysis of injury risk in runners: Prevention strategies and treatment approaches

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Abstract: Injuries to runners are an important issue in the world of sports, given the high number of incidents that impact performance and continuity of training. This study is motivated by the high prevalence of injuries, especially in the hamstring, knee, and ankle muscles, as well as the limited data-driven prevention approaches. The main objective of this study was to analyze injury risk factors longitudinally and evaluate the effectiveness of prevention strategies applied over one year. The study used a longitudinal panel design involving 60 runners aged 18–30 years. Data collection techniques included Oslo Sports Trauma Research Center questionnaires (OSTRC-Q), digital training logs, Visual Analogue Scale (VAS), Functional Movement Screen (FMS), and field observation for 12 months. Logistic regression analysis was used to determine the risk of injury. Results showed that weekly training load >80 km, injury history, BMI >25, and low adherence to prevention programs significantly increased the risk of injury ($p<0.05$). In conclusion, a prevention program that is consistently implemented can significantly reduce the risk of re-injury.
Keywords: *Functional movement screen, Injury prevention, Runner injury, Training load.*

1. Introduction

Sports injuries, especially in runners, are a common phenomenon and a major concern in the world of sports. Based on data from *the National Running Survey* [1, 2], approximately 60-70% of runners are injured each year, with the majority of injuries occurring in the knee, ankle, and hamstring muscles. According to Hreljac [3] and Peterson et al. [4], injury patterns vary depending on factors such as running technique, training volume, and footwear. These injuries not only impact runners' performance but can also lead to absenteeism from training or competitions, and may cause psychological effects such as anxiety and frustration. With increasing public participation in running as part of a healthy lifestyle, it is essential to understand more deeply the patterns and risk factors associated with injuries in runners.

One of the significant trends in recent years is the change in runners' training patterns influenced by the rise of long-distance competitions, such as marathons [5, 6]. Research by Kluitenberg et al. [7] shows that the intensity and duration of training contribute to an increased risk of injury, especially in amateur runners. However, injury prevention efforts are often less effective because the approach used is not evidence-based and does not consider individual variation. This raises the need to develop a more personalized and data-driven strategy.

Although many studies have addressed injuries in runners, most are cross-sectional, making them less capable of describing long-term changes in injury risk. For example, research by Gabbett [8] analyzes only the relationship between the body's biomechanics and injury risk at a single point in time,

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without considering how these factors develop over time. Longitudinal studies are necessary to provide a more comprehensive understanding of injury risk dynamics and to develop effective prevention strategies.

Further, the existing literature often focuses only on intrinsic risk factors, such as the biomechanical structure and physical condition of runners, while extrinsic factors, such as running surfaces, footwear, and exercise patterns, still receive less attention [9]. This creates a gap in our understanding of how the combination of these factors affects the overall risk of injury. This study aims to fill this gap by holistically analyzing the risk factors for injury in runners.

In addition, existing injury treatment approaches also face challenges in their implementation. For example, conventional rehabilitation methods often do not take into account the individual needs of the runner, resulting in less than optimal results. A study by van Mechelen et al. [10] and Willwacher et al. [11] shows that only 40% of runners who receive injury rehabilitation achieve full recovery within the expected time. This study will evaluate the various treatment approaches used by runners to identify the most effective methods.

This research is expected to make a new contribution to the development of science, both theoretically and practically. Theoretically, this study will enrich the literature on sports injuries with a longitudinal approach, which is still rarely done in this field. In practical terms, the results of the study can provide concrete recommendations for runners, coaches, and sports health practitioners to prevent injuries and improve the effectiveness of treatment.

By understanding trends, challenges, and gaps in previous research, the study aims to identify injury risk patterns in runners, evaluate effective prevention strategies, and develop better treatment approaches. The longitudinal analysis conducted in this study allows the observation of the dynamics of injury risk over a period of time, providing more in-depth insights than cross-sectional studies.

2. Methods

This study employs a longitudinal quantitative approach with a panel study design to analyze the risk of runner injury over time and evaluate the prevention strategies and treatment approaches applied. Participants consisted of 60 active runners aged 18–30 years, who were purposively selected based on criteria of regular involvement in training and had not suffered a serious injury in the past six months. The general characteristics of the participants are shown in Table 1.

Table 1.
General characteristics of participants.

		Mean/Frequency	**Information**
Gender	Man	n = 36 (60%)	Active subjects of 3 athletic clubs
	Woman	n = 24 (40%)	
Age (Years)		24.7 ± 4.3	Age range 18 – 30 years old
Body mass index (kg/m2)		22.1 ± 1.9 kg/m²	Normal BMI range for runners
Weekly training frequency		5 – 6 sessions/week	Competitive workout routine
Long training experience		3.8 ± 1.2 years	Minimum of 2 years of continuous training
Runner type	Middle Distance	n = 33 (55%)	Focus on 800m–1500m and 5K–10K runners
	Log Distance	n = 27 (45%)	

Key instruments include an OSTRC-Q questionnaire for injury history and occurrence, a digital exercise log to monitor the frequency, duration, and intensity of exercise, a checklist of prevention strategies, a Visual Analogue Scale (VAS) for pain, and a Functional Movement Screen (FMS) for biomechanical risk. Data was collected over 12 months through periodic reporting and monthly checks.

Data analysis was carried out descriptively and inferentially using Generalized Estimating Equations (GEE) and Cox Proportional Hazards Model, as well as thematic analysis for qualitative data.

3. Result

The study involved 60 active runners at the start, but only 54 runners (90%) completed monitoring up to the 12th month. During the study period, 103 injuries were recorded, with an average of 1.91 injuries per runner per year. The most common injuries occurred in the hamstring muscles (30.1%), followed by the knee (22.3%), and the ankle (18.4%). The following will be explained in the form of tables and figures.

Table 2.
Summary of injury and runner characteristics

Variable	Mean ± SD	Frequency (%)	Information
Total number of injuries	103 Injuries		1.91 injuries/runners/year
Highest injury locations	Hamstring	n = 18 (30.1%)	
	Knee	n = 13 (22.3%)	
	Ankle	n = 11 (11.4%)	
Weekly training load	10.4 ± 2.1 (early) → 13.7 ± 2.5 (3rd month)		Sharp increase before the peak injury phase
Score FMS	13.8 ± 2.3 → 16.1 ± 2.0		Increase in preventive-compliant runners
Effective prevention strategies	Dynamic warm-ups, strength training, and sports massage		Based on perception and re-injury data

Trend analysis showed that the incidence of injuries increased significantly in the 3rd and 9th months, which coincided with the period of exercise intensification ($p = 0.041$). The average weekly training load score increased from 10.4 ± 2.1 hours in the first month to 13.7 ± 2.5 hours in the 3rd month, then decreased gradually after the 6th month. FMS scores showed significant improvement in the group that consistently implemented preventive strategies such as dynamic warm-up and muscle and mass strengthening exercises (the average FMS score increased from 13.8 ± 2.3 to 16.1 ± 2.0; $p < 0.01$). Here is a graph of monthly injury trends in runners over a 12-month period.

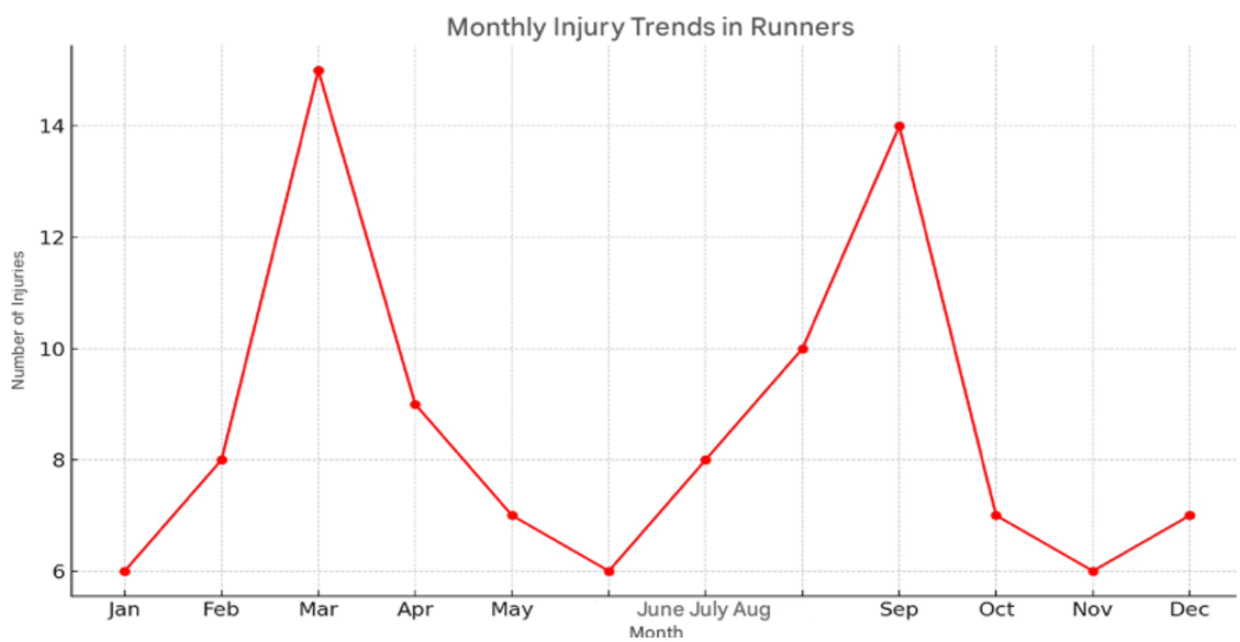

Figure 1.
This graph shows a significant increase in March and September, which can be attributed to the phases of increased training intensity and the number of injuries suffered by runners.

The following will explain the odds of re-injury based on the level of compliance with the prevention program and injury predictors.

Table 3.
Odds of Re-Injury Based on Compliance Rate with Prevention Programs.

Compliance Level	Total Subjects	Spinal Cord Injury (n)	No Injury (n)	OR	95% CI	P-Value
High	30	4	26	1.00		
Low	24	18	6	4.33	1.25 – 15.01	0.021*

Note: Information: (OR) Odds ratio; $p < 0{,}01$*, (CI 95%) Confidence interval.

Table 3 shows an odds ratio (OR) of 4.33, indicating that runners with low adherence to prevention programs are four times more likely to experience re-injury than compliant runners. The p-value of 0.021 indicates that this difference is statistically significant. The 95% confidence interval (CI 95%) ranged from 1.25 to 15.01, which supports the significance of the result.

Table 4.
Logistic Regression Analysis Results.

Variable Predictor	B	SE	OR	95% OR	P-Value
Training Load > 80 km/week	1.74	0.65	5.70	1.60 – 20.28	0.007**
Previous Injury History	1.21	0.53	3.36	1.19 – 9.46	0.022*
IMT > 25 (Overweight)	0.98	0.49	2.66	1.02 – 6.91	0.045*
Low Compliance Rate	1.46	0.57	4.31	1.40 – 13.25	0.011*

Note: Information: SE (Standard Error), OR (Odds Ratio), 95% CI OR (Confidence Interval for Odds Ratio), p < 0,01*, p < 0,01**.

Based on Table 4, the four variables above are statistically significant ($p < 0.05$) in predicting runner injury risk. The variable with the highest OR was Weekly Training Load (>80 km/week) with OR = 5.70 ($p = 0.007$), indicating that high training volumes greatly increased the risk of injury. A history of previous injuries, high BMI, and low adherence are also predictors that significantly contribute to the likelihood of injury.

4. Discussion

Key findings from the study showed that injuries occurred most frequently in the hamstring muscles (30.1%), the knee (22.3%), and the ankle (18.4%), with an average of 1.91 injuries per runner per year. A significant increase in training load at 3 months (from 10.4 ± 2.1 to 13.7 ± 2.5 hours/week; $p = 0.041$) coincided with the injury spike, supporting the overload theory of Hreljac [3] and Ceyssens et al. [9], which states that the accumulation of biomechanical stress due to overexercise increases susceptibility to injury. These results are also consistent with research by Kluitenberg et al. [7] and Nielsen et al. [12], which highlights the positive relationship between training volume and increased risk of injury in amateur runners. Prospective and cohort studies provide human evidence that preexisting biomechanical deficits and high training loads predict later overuse problems, aligning with mechanical-fatigue models. Screening measures of strength, kinematics, and training load have been associated with subsequent overuse injuries in athletes [13].

The Functional Movement Screen (FMS) score increased significantly in the group that consistently performed preventive strategies such as dynamic warm-ups, strength training, and massage (from 13.8 ± 2.3 to 16.1 ± 2.0; $p < 0.01$), demonstrating the effectiveness of this approach in reducing injury risk. It supports the findings [14, 15] indicating that an FMS score below 14 is significantly associated with a higher injury risk. Recent research by Taddei et al. [16] confirms that functional strengthening interventions improve postural stability and movement efficiency, which are crucial in preventing sports injuries. Functional strengthening interventions enhance postural control and movement efficiency, both of which are vital for injury prevention. The combination of a comprehensive injury history assessment and neuromuscular-focused rehabilitation is among the most evidence-based strategies for reducing reinjury rates and optimizing long-term athletic performance [17, 18].

Logistic regression analysis showed that a weekly training load above 80 km increased the risk of injury with OR = 5.70 (p = 0.007), which means runners with high training volumes were five times more likely to injure themselves. This reinforces the concept of "training load threshold" in theory [19], which states that there is a threshold of physiological adaptation to exercise stress. Research by Soligard et al. [20] in the context of young athletes also found that a sharp increase in exercise volume correlated with an increase in non-contact injuries. Growth and maturation effects: young athletes have growth-related sites (physes, apophyses, entheses) that are biomechanically less able to tolerate repetitive stress, explaining higher susceptibility to certain overuse lesions in adolescents.

Adherence to prevention programs shows a significant influence on the risk of re-injury. Runners with low compliance levels had a fourfold greater chance of re-injury (OR = 4.33; p = 0.021). This finding aligns with studies by McCall et al. [21] and Hein et al. [22], which conclude that the implementation of injury prevention programs consistently reduces the prevalence of injuries across various sports. Behavioral factors such as adherence play a crucial role, as theorized in the Health Belief Model [23], where perceptions of benefits and barriers influence an individual's adherence to health programs. Insufficient recovery, such as inadequate rest, prevents the restoration of tissue structure and cellular homeostasis, shifting the balance toward net degradation and increasing susceptibility to injury [24].

Previous injury history is a significant predictor (OR = 3.36; p = 0.022), supporting the principle of "history as the best predictor" that has long been affirmed in the sports medicine literature [25]. This phrase refers to a well-established concept in sports medicine and injury prevention: an athlete's past injury history is one of the strongest predictors of future injury risk. In practical terms, clinicians and sports scientists emphasize that previous musculoskeletal injuries (such as ankle sprains, hamstring strains, or ACL tears) often lead to biomechanical, neuromuscular, or structural changes that increase susceptibility to reinjury. Therefore, during preseason screening or return-to-play evaluations, injury history is treated as a key risk factor, often more predictive than strength, flexibility, or conditioning metrics. A recent study by Peterson et al. [4] also shows that the soft tissue that has been injured has decreased regenerative capacity, making it more susceptible to reinjury. Predictors of tendon pain: In a prospective cohort of recreational runners, those who developed Achilles tendon pain already had decreased knee flexor strength and abnormal lower-leg kinematics before symptom onset, and episodes were linked to high-impact fast training sessions [26]. Therefore, preventive interventions should be more intensive in individuals with a history of injury, not only during the rehabilitation phase but also in the design of long-term exercise programs.

BMI above normal (BMI > 25) also plays a role as a predictor of injury (OR = 2.66; p = 0.045), which suggests that overweight runners tend to experience greater biomechanical stress on the major joints. This is in accordance with the findings by Hulme et al. [27], which state that excess body mass increases the reaction force of the soil, potentially triggering overuse injuries. On the other hand, recent research by Soligard et al. [20] and Gabbett [8] emphasizes the importance of personalizing training loads based on body composition as an injury risk mitigation strategy. Overuse injury is best conceptualized as a mechanical-fatigue process in which cycles of loading create microdamage that accumulates when recovery is insufficient, producing progressive vulnerability to symptomatic injury [17, 26]. Training factors that change the magnitude, rate, or frequency of load (for example, sudden increases in intensity or high-impact sessions) raise cumulative mechanical stress and thereby increase the probability that tissue damage will exceed repair capacity [28, 29].

Overall, the results of this study support the hypothesis that factors such as high exercise volume, injury history, low adherence to prevention programs, and high BMI contribute significantly to increased risk of injury. These findings not only provide empirical evidence for academics to develop longitudinal-based injury prediction models but also have practical implications for coaches and medical teams in designing adaptive exercise programs and individually-oriented preventive interventions. The implementation of these results can improve runner safety while driving a more holistic and data-driven approach to injury management. Key practical inferences from these studies are that both measurable

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biomechanical deficits (strength, joint kinematics) and training-related load patterns (intensity, sudden progression, cumulative volume) jointly determine who accrues damaging stress and thus who becomes vulnerable to overuse injury.

5. Conclusion

This finding shows that injury risk in runners is closely associated with excessive training loads, prior injury history, elevated body mass index, and poor adherence to injury prevention protocols. Injuries were most frequent in the hamstring, knee, and ankle, particularly during periods of intensified training. Interventions such as dynamic warm-up routines, strength training, and body mass control were associated with reduced injury incidence.

These results support the implementation of data-informed, individualized training and rehabilitation strategies to optimize performance while mitigating injury risk. The study provides actionable insights for athletes, coaches, and sports health professionals, offering a foundation for evidence-based practice in endurance training.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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