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Molecular & Cellular Biomechanics 2025, 22(1), 283.
https://doi.org/10.62617/mcb283

Article

The influence of speed endurance training in different modes of sprint on muscle injury

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CITATION

Wu W, Zeng J, Liu J. The influence of speed endurance training in different modes of sprint on muscle injury. Molecular & Cellular Biomechanics. 2025; 22(1): 283. https://doi.org/10.62617/mcb283

ARTICLE INFO

Received: 8 August 2024
Accepted: 23 September 2024
Available online: 8 January 2025

Abstract: Athletes require Speed Endurance Training (SET) to enhance their speed and acceleration in their sports performance. The traditional training process faces difficulties because athletes have variability in response, imprecision analysis of training intensity, load, fatigue, overtraining, and misdiagnosis of injuries, creating problems while enduring their speed and accelerations. Therefore, this study focuses on the influence of SET across different sprinting modalities on athlete's muscle injuries. The proper endurance training procedure maximizes the recovery periods and improves the athlete's accomplishment in sprint events. During the analysis, athletes are investigated with the help of the sprint training protocols that cover mixed, long and sprint modalities. The trained sprinters are continuously observed for up to 12 weeks, and muscle injury-related information is gathered. The collected information is analyzed using Linear Mixed Effects with an Analysis of Variance (LME-ANOVA) model to assess the incidence of muscle injuries. The statistical analysis was performed on three groups to identify the relationship between the training model and injury impacts. The analysis helps to determine the severity of injuries presented in the sprint training modalities. According to the study, the sprinter's recovery process is measured, improving the sprinter's endurance and longevity.

Keywords: sprinters endurance training; athletes; sprint modalities; linear mixed-effects with ANOVA model; athletes longevity and training protocol

1. Introduction

Speed Endurance training is anaerobic training that isn't commonly used for middle-distance athletes. Compared to full-out sprints, these workouts are quite slow. Speed endurance training pushes the cardiovascular and musculoskeletal systems to their limits, allowing athletes to run at high speeds until drained [1]. In training for a 5000-meter run, one of the most crucial physical qualities is endurance of speed so that the athlete can handle the intensity of the race [2]. One exercise that raises the amount of acid produced in muscle cells is anaerobic training. If lactic acid levels are high, pH cells will be low, catalyst reaction rates will be low, and metabolic production will be impaired [3]. Runners can overcome lactic acid buildup through speed endurance training, enhance their anti-lactic acid abilities to sustain high-speed running and perform better in 400-meter races [4]. Increased frequency and duration of high-intensity actions during matches and decreased recovery time following such activities are benefits of speed endurance training [5]. Sprinting is a high-intensity, strength-and-speed-based athletic event that requires participants to complete four fundamental technical movements: initiating, accelerating, racing on the path, and sprinting [6]. Acceleration during sprints, defined as going all out to cover the most distance in the least time, is crucial in many sports' outcomes [7].

Injuries can occur in sports in a variety of ways. Muscle strain is most commonly caused by unsuitable training or bad sprint conditions [8]. Muscle fibre hypertrophy, more contractile protein, and increased maximal contractile force are all effects of strength training [9]. Research has shown that increasing or decreasing muscle flexibility does not affect the risk of endurance running injuries. However, problems may arise when flexibility levels are too high, as they disrupt the typical running pattern [10]. The percentage of injuries caused by hamstring muscle injury (HMI) at international athletics championships ranges from 0 to 35 percent, depending on gender and the sport. Another way HMI hinders athletic practice is time away from sports and the likelihood of injury recurrence. As a result of missed workouts and repeated injuries, HMI is a huge obstacle to athletic training [11]. Regarding the physical aspects of judo, things like strength endurance, the ability to execute immobilization techniques, and muscle strength are essential with grip issues, throwing tactics, anaerobic stamina to launch multiple attacks in a row, & aerobic endurance to recover quickly from each attack and one about to the following [12]. As a result, sprinting is likely to be an essential performance and injury metric in football. Possible injury scenarios in football include the swing and stance phases of sprinting, which both involve extending the hamstring muscles (eccentric musculotendinous expansion) to decelerate knee extension [13]. One way to train for sprints is using resisted sledge training, which involves pushing or pulling a resistive force in the horizontal direction of motion. Research suggests that the acceleration phase of sprinting is where resistive sledge training shines, as opposed to the maximum velocity phase [14]. It is believed that the inflammatory response and exercise-induced muscle damage (EIMD) are both essential components of the muscle regeneration process, distinct from the inflammatory response observed in trauma-induced inflammation. [15].

Injuries sustained during speed endurance training can be better studied by comparing different protocols using analysis of variance (ANOVA) in clinical settings. The intensity of muscle injuries sustained during mixed-sprint, long-sprint, and short-sprint training modalities is the primary emphasis of this objective. The study aims to glean as much useful information as possible from the data using ANOVA and clinical findings. A thorough comprehension of the effects of various training regimes on injury severity can be achieved through this method. The final goal is to help coaches and athletes create more efficient and secure speed and endurance training programs by identifying tactics that maximize performance while minimizing injury risks. The main objective of the work is listed as follows.

- To analyze the muscle injury incidences in various sprint modalities using liner mixed effects.
- To maximize the severity analysis rate across various training protocols using ANOVA-based clinical analysis.
- To inspect the influence of endurance training on muscle recovery rate by considering the athlete’s fatigue, endurance and muscle strength.

This study summarises previous research on the effects of Speed Endurance Training (SET) on muscle damage in various sprinting techniques. It solves problems with conventional training approaches, such as inaccurate analysis of training variables and unpredictable athlete reactions. Over 12 weeks, the research tracks athletes' performance and collects data on muscle injuries as they participate in one of three sprint training protocols: mixed, long, or short. Research examines the frequency and severity of injuries in training groups using ANOVA and linear mixed effects models. The goals include improving sprint performance by minimizing injury risk, maximizing recovery, and determining appropriate training protocols. Potentially redefining speed endurance training methods in sports, this study intends to improve athletes' stamina and career longevity by analyzing sprinters' recovery mechanisms.

2. Related works

Beato et al. [16] discussed preventing football injuries using strength training (ST) in this commentary. It examines the data for three types of resistance training: conventional, eccentric, and flywheel. The research shows that these ST methods can lessen the likelihood of injuries, especially accidental wounds in female athletes, when coupled with additional elements such as plyometrics and balancing training. Enright et al. [17] focused on examining the characteristics of injuries sustained by professional football players and their workload. It sorts 264 non-contact injuries by tissue kind and degree of damage after 28 days of training data. GPS devices recorded all-terrain, high-speed, and sprint distances. The research determines acute-to-chronic workload ratios and cumulative weekly loads. The method's strength lies in the thoroughness with which it analyses workloads. There were no statistically significant changes in the workload factors according to injury severity or type. Beato et al. [18] synthesized data and direct implementation; this commentary discusses the significance of football sprinting training and high-speed running. It delves into conditioning techniques, performance tracking, actionable advice, and where things are headed. The thoroughness with which the study tackles the subject is its greatest strength. According to the findings, preparation and injury prevention can be achieved through field-based drills, medium- to large-sized games, and high-intensity running training.

In response to the prevalence of ruptured hamstrings in athletics, Wan et al. [19] examined how strength and flexibility training influence peak musculotendinous strains in sprinters. After eight weeks of training, twenty male students from college were split evenly between a strength program and a flexibility program. Filipas et al. [20] compared the effects on the endurance performance of male runners who received proper training using four 16-week training periodization models. A total of sixty individuals were split into four groups: pyramidal (PYR), polarised (POL), pyramidal-to-polarized (PYR → POL), and polarized-to-pyramidal (POL → PYR). Bonilla et al. [21] presented a 4R framework—Rehydration, Refuel, Repair, and Rest—to analyze the connection between nutrition and sports post-exercise recovery. Literature reviews from three primary databases are part of the process. The benefit is that it takes a holistic view of nutrition and healing.

Clausen [22] found the best ways for Ironman triathletes to repair their muscles while they train for endurance races. It solves the issue of diminished muscle performance caused by rigorous training. The process includes searching for and evaluating applicable research in electronic databases. It zeroes down on realistic recuperation methods for a particular strenuous sport, which is a significant plus. The results indicate that foam rolling, massage, and chilling the body can help reduce training-induced performance drops. Oboh and Ogaga [23] discussed the necessity for efficient physical rehabilitation and the sports injuries discussed in this article. Its goal is to examine physical reconditioning, the effects of sedentary lifestyles, and the fundamentals of fitness regimens designed for athletic competition. This strategy is based on a literature assessment of studies addressing early sports injury detection, rehabilitation, and mental health. Papadopoulou [24] discussed the recovery time of Athletes after injuries and surgeries by following the guidelines in this paper. It tackles the issue of keeping healthy and gaining muscular mass throughout rehabilitation. The process includes going over the fundamentals and tactics of a rehabilitative diet.

Pieters et al. [25] disregard biological healing time in existing return-to-play (RTP) standards for hamstring strain injuries (HSIs). This review intends to change that. The discordance between operational recovery and physical healing is investigated. The current research on RTP criteria, recurrence costs, and biological muscle repair is reviewed as part of the process. The benefit is that it takes a functional and biological approach. Results indicate that HSIs in grades 1 or 2 should have an RTP duration of at least four weeks.

Jordan et al. [26] used the data found by tracking athletes over time to create a model of neuromuscular recovery following ACL surgery. The issue that was addressed was the fact that athletes go through different recovery processes after surgery. Asymmetries in knee extensor strength and countermovement leap force were used to fit additive mixed effects models. Provided useful personalized recovery profiles, this method explained 43% to 91% of the variation in recovery. Some surgical procedures may not have been representative of the whole due to the study's small sample size. Rudisill et al. [27] focused on rehabilitation methods and factors that predict RTP following acute hamstring injuries. It tackled issues such as prolonged recovery and a high likelihood of recurrence. The authors used MINORS and the Cochrane Risk-of-Bias Tool to evaluate the literature.

Paoletta et al. [28] assessed the usefulness of ultrasonography (US) in detecting and treating muscular injuries in athletes, focusing on those who participate in contact sports like football and track & field. The issues addressed were the high incidence, long recovery time, and danger of re-injury, which resulted in higher management expenses. Fanchini et al. [29] focused on elite football players to determine the efficacy of methods for preventing muscular injuries through exercise. Inconsistent findings across many investigations were the issue that was addressed. A total of fifteen studies, including critical reviews, randomized controlled trials, and non-randomized controlled trials, were included in the systematic review. Various methods were used to evaluate the research for bias.

Staff et al. [30] suggested the Performance-Determining Factors and Long-Term Development of Training Characteristics in Elite/International and World-Class Endurance Athletes. Over 22 years (1990–2022), 16,772 items were examined. Only 17 peer-reviewed journal papers were deemed eligible for further research. Eleven of the seventeen studies (or 69% of the total) detailed athletes from seven different nations and seven different sports; eleven were published during the last ten years.

Among the 109 athletes in this scoping study, males made up 73% and women 27%.

Weiner et al. [31] proposed a Randomized Controlled Trial for the Effect of Long-term Exercise Training on Physical Performance and Cardiorespiratory Function in Adults With Chronic Kidney Failure (CKD). Centres in Baltimore and Boston enrolled adults 55 and above with chronic kidney disease stage G3b-4. Participants were randomly allocated to either a 12-month supervised exercise program focused on aerobic fitness and strength training or a 12-month group health education control intervention. Cardiorespiratory fitness was measured at 6 months using a graded exercise treadmill test, and submaximal gait was determined at 12 months using a six-minute walk test. Alterations in renal function, glycemia, blood pressure, body mass index, and lower extremity function were considered secondary outcomes.

Kaikkonen et al. [32] recommended the Long-term effects on weight loss and maintenance by intensive start with diet and exercise. A total of 120 persons with a body mass index (BMI) greater than 30 were randomly allocated to one of three groups: intensified behavioural modification (iBM), intensified behavioural modification plus extra exercise (0–3 months; CWT1), intensified behavioural modification plus additional exercise (6–9 months; CWT2), or a control group (CON). In addition to the baseline, measures and questionnaires were taken at the beginning, 3, 9, 24, and 36 months. A 12-month phase of increased weight reduction and a 24-month phase of weight maintenance made up the intervention.

Zampieri [33] discussed the early sports specialisation in the Sphere of Long-Term Athlete Development (LTAD). This article examines the consequences of early specialization and the duties and responsibilities of those engaged in athlete development, particularly in the context of soccer, in light of the substantial increase in participation in sports globally. It lays out the steps of LTAD, a framework for child sports coaches to use in helping athletes of all abilities realize their maximum potential and remain active in the sport over the long term. To help soccer coaches avoid the pitfalls of early sport specialization, the article lays out a plan for training sessions and activities that correspond with the stages of the LTAD.

Thrower et al. [34] deliberated on enhancing well-being, long-term development, and performance in youth sports. This study was carried out by research working group of the British Psychological Society (BPS), Division of Sport and Exercise Psychology (DSEP), and it was divided into two phases: To begin, six individuals from the working group took part in two distinct focus groups. Secondly, nine sports psychology practitioners located in the UK were interviewed in detail; these individuals have substantial expertise and background in assisting young athletes. Six overarching themes emerged from the reflexive thematic analysis: (a) well-defined goals, objectives, and boundaries; (b) theoretical frameworks that are both flexible and adaptable; (c) the importance of seeking and securing connections; (d) the value of multiple perspectives; (e) the importance of indirect interventions in maximizing impact; and (f) the role of adaptation and integration in determining the effectiveness of Psychological Skills Training (PST). Insightful and novel findings on the consulting process with youth athletes are presented in the present research. Applied sports psychologists need such insights to advocate for developmentally appropriate practice based on data.

Rothschild et al. [35] suggested the machine learning analysis for Predicting daily recovery during long-term endurance training. For 12 weeks, a total of 3572 monitoring days, 43 endurance athletes, ranging from professional to recreational, had their food consumption, exercise routines, sleep patterns, heart rate variability (HRV), and subjective health assessed. Machine learning methods were used to generate both global and customized models, with the best algorithm for each model being selected. A baseline intercept-only model was used to compare the model's performance. When comparing the group models to the baseline, the prediction error (RMSE) was reduced for AM PRS (11.8 vs. 14.1) and HRV change (0.22 vs. 0.29), respectively. Regarding AM PRS and HRV change, the RMSE range was 5.5–23.6 and 0.05–0.44, respectively, while overall, individual-level prediction accuracy was better than the baseline model.

3. Analyzing the influence of SET in various modes of sprints muscle injuries

3.1. Objective of this study

Speed endurance testing (SET) played an essential role in sprinter athletes' training, consisting of maximum intensity efforts to cover speedy recovery periods. The SET process documents the athlete's activities and training procedures to minimize muscle injury-related issues. The main objective of this work is to explore muscle injury incidences and improve the sprinter's speed and acceleration using various training protocols. The training efforts are explored with the help of multiple criteria, such as sprinters' fatigue, endurance, and muscle strength, which evaluate the mixed, long, and short sprint training. These factors help to explore the SET performance by assessing the sprinter's recovery period and longevity in their sprint events. The sprinter's details are analyzed using linear mixed effects with an ANOVA (LME-ANOVA) model to determine the incidence of muscle injuries. For analyzing the working process of LME-ANOVA, the following dataset is created manually by observing the set of sprinters.

3.2. Data collection

The comprehensive study is evaluated by creating the dataset and considering various factors such as muscle injuries, sprint training, recovery, and performance metrics. The dataset covers participant information (ID, age, gender, baseline fitness level, training group), training data(training session ID, date, sprint type, distance, intensity, duration, recovery time), injury data (injury ID, injury date, type of injury, severity, diagnostic imaging and recovery days), performance measures (sprint time, muscle strength, endurance score), recovery data (level of creatine kinase, muscle soreness, recovery time) and longitudinal data (assessment period, repeated measure). The details mentioned above are created as questionnaires, 250 athletes are examined continuously, and data is collected to explore system efficiency. Then the sample information is shown in **Tables 1–5**. Clubs, university sporting teams, and public advertising were used to attract participants. Access to professional and semi-professional players actively participating in organized training programs was made possible via collaborations with local and regional sports clubs. In addition, collaborations with university sports departments allowed intramural and varsity players to participate, guaranteeing a diverse array of athletic experiences. Attracting recreation players also included public advertising, such as social media postings, community board announcements, and sports-related websites. This inclusive recruiting process increased the study's generalizability by including participants from various sports backgrounds and skill levels.

Table 1. Participant information.

Participant ID	Age	Gender	Fitness Level	Training Group
1	26	F	Medium	Long
1	26	F	Medium	Long
2	23	M	High	Short
2	23	M	High	Short

Table 2. Training data.

Participant ID	Training Session ID	Date	Sprint Type	Distance	Intensity	Duration	Recovery Time
1	111	2023-02-10	Long	350	92%	40	110
1	111	2023-02-12	Long	430	88%	45	110
2	222	2023-02-10	Short	50	83%	25	50
2	222	2023-02-12	Short	65	76%	30	50

Table 3. Injury data.

Participant ID	Injury ID	Injury Date	Injury Type	Severity	Diagnostic Imaging	Recovery Time in Days
1	-	-	-	-	-	5.4
1	IN001	2023-02-12	Strain	Mild	Tear in left hamstring	7.1
2	-	-	-	-	-	25
2	IN002	2023-02-12	Tear	Severe	Complete tear of the quadricep	30.1

Table 4. Performance measure.

Participant ID	Sprint Time	Muscle Strength	Endurance Score
1	253 Nm	32 reps	149 U/L
1	7.1	241 Nm	29 reps
2	222 Nm	30 reps	162 U/L
2	27.6	201 Nm	21 reps

Table 5. Recovery and longitudinal data.

Participant ID	CK Levels	Muscle Soreness	Recovery Hours
1	3	10	-
1	172 U/L	5	23
2	4	4	-
2	192 U/L	7	14

3.2.1. Participant criteria

The participants were selected using various inclusion and exclusion criteria. The sprinters must be 18 to 35 years old, have no previous muscle injuries and agree to participate in a 12-week SET. The participants are excluded if they undergo surgeries, chronic conditions, or intensive training programs. A thorough screening procedure was used to identify participants, ensuring they fulfilled the predefined criteria for inclusion and exclusion. Participating athletes had to be between 18 and 35, have a history of muscular injuries that haven't healed in the last six months, and be actively involved in sprint-based sports. The first step in the screening process was for potential volunteers to fill out a medical questionnaire about their current health status, history of injuries, and training. To ensure there weren't any influencing factors, this study excluded those who had recent surgery or chronic illnesses. A homogeneous sample appropriate for evaluating the effect of sprint training on muscle damage was achieved by selecting 250 athletes based on their adherence to these criteria.

3.2.2. Protocol for training

The influence of sprinters SET on muscle injury is evaluated using different modalities. The training process is divided into three groups: short sprinters (distance 40 m to 60 m), mixed groups (combination of long and short sprints), and long sprinters (distance 200 m to 400 m). After deciding on the training modalities, the schedule is created, and the training is scheduled for 12 weeks and 4 to 5 sessions/per week as frequency, varying intensity levels and adequate rest time between sessions. A purposive sampling approach was used to ensure that only athletes who fulfilled the study's precise inclusion criteria were considered for participation. Recruiting athletes from various sources, such as public advertisements, university teams, and sports clubs, was done to reduce selection bias; however, it was not random. This method was useful for recruiting athletes from all walks of life and all levels of competition. To further reduce bias, this study ensured that the final sample was varied and representative of the target community by offering equal enrollment opportunities to all eligible participants, regardless of their performance level.

The gathered information is processed by analyzing the Linear Mixed Effects and ANOVA(LME-ANOVA) to explore the relationship between the SET modalities and injury impacts. From the analysis, the sprinter's recovery time is evaluated to maximize endurance. The sample included 250 athletes, ages 18 to 35 (mean age: 26). The participants were 60% men and 40% women. Approximately 40% of the participants were professional or semi-professional athletes, 35% competed at the university level, and 25% saw themselves as recreational athletes. The athletic levels of the participants varied. A wide variety of training intensities and athletic experiences were represented in the research due to the diverse demographic features. This allowed for a complete knowledge of how different sprint training modes affect muscle damage across distinct athlete profiles.

3.3. Sprinters data analysis

The next important step is sprinters data analysis, which applies Linear Mixed

Effects (LME) and ANOVA(LME-ANOVA). The method computes the relationship between the SET modalities, such as mixed, long and short sprinters, and injury impacts to improve the sprinter's recovery rate. The LMF-ANOVA models consider the different modalities and individual variabilities to maximizes the sprinter's endurance. The LME process can handle the sprinter's repeated measures, which means the method identifies the correlation between the various measurements from a particular subject. The effective computation of repeated measures maximizes the prediction accuracy and sprint effects. The model uses random effects that explore individual variabilities and provide generalized results. In addition, the model handles the imbalance of data issues, which is an essential factor because the data may be lost during the muscle injuries. Then, the introduced LME-ANOVA approach maximizes interpretability and helps understand the impact of training on injury outcomes. The overall process of LME-ANOVA is illustrated in **Figure 1**. A possible bias in the results might be that recreational athletes are less likely to have muscle injuries than professional or college players. Future studies might benefit from a more balanced sample strategy that includes various sports disciplines and a larger percentage of leisure players to increase representativeness. Results would be more robust and applicable if random or stratified sampling were used to guarantee a more equal representation of demographic and athletic categories.

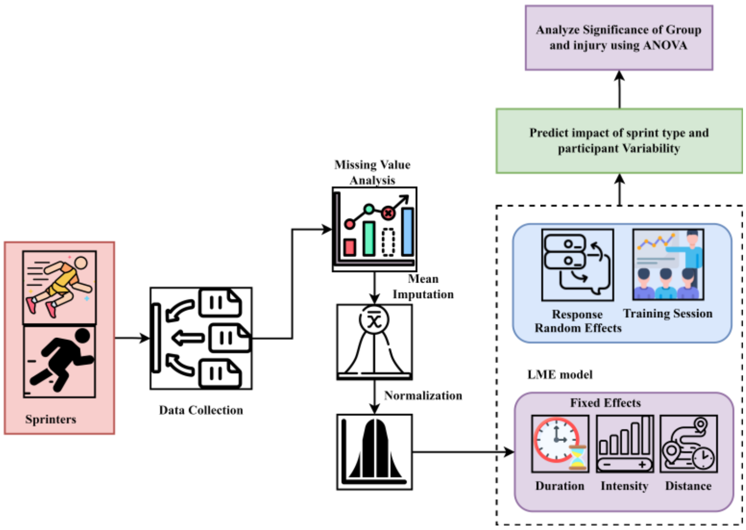

Figure 1. Working process of LME-ANOVA.

First, the linear mixed effects (LME) are applied to the participant's data to predict the impact of sprint types and participant variability. These factors are computed from the fixed and random effects. The LME works according to the linear regression model in which a fixed effect is applied to the complete population, and random effects are computed from individuals. The LME computation is defined via Equation (1).

$$y_{ij} = X_{ij}\beta + Z_{ij}\mu_j + \epsilon_{ij} \quad (1)$$

In Equation (1), y_{ij} signified as a response variable that covers sprint time and injury severity. Fixed effects, such as sprint type, are defined as X_{ij}, fixed-effects coefficients are denoted as β, random effects of individual sprinters are mentioned as

Z_{ij}, coefficients of random effect are defined as μ_j and residual error is ϵ_{ij}. The response variable y_{ij} is higher when the collected data in **Table 1** must be allowed for the data cleaning procedure. The gathered data consists of inconsistent information, creating difficulties while identifying the sprinters' impact on muscle injuries. If the dataset has a missing value, an imputation process is performed in which the missing value is replaced with the help of the mean value. The imputation process ensures the process's robustness and improves the overall system efficiency. The sprinter's particular mean value is estimated, and the missing value is replaced with the help of the computed mean value. During the analysis, the categorical values are converted into numerical values like sprint types: short = 1, long = 2 and mixed = 3. Afterwards, the min-max normalization process is performed to fine-tune the data into the same standard. Here, minimum and maximum values are utilized to normalize the subject data. Finally, the variable has been created by considering the sprinter's multiple measures. After identifying the sprinter's injury severity and sprinter time, athletes' ability was analysed using their capacity. Here, the sprint speed score is computed according to their movement speed distribution. Consider the sprinter's competition distance is S, and they are needed to complete the task T; therefore, the rate is $\rho(t)$. During the race, their speed has a relationship with wind speed F. Hence, the scaling factor is defined as $\rho(t)$ in which the movement is proportional to F. Then, the sprinter race covered distance is computed using Equation (2).

$$S = \int_{0}^{T} \rho(t) \tag{2}$$

From the above computation, the estimated $\rho(t)$ reduces the T, which helps to identify their muscle injury level. After the SET training, their speed and acceleration levels are continuously observed by giving the particular T. Then, the sprinter's energy level is estimated depending on their speed and momentum. The energy level is directly proportional to the athlete's physical strength. The computed energy is equivalent to the oxygen stored in the muscles, denoted as $Y(t)$, and for a specific period, the oxygen supplied level is denoted as δ. Hence, the energy level of sprinters is computed using Equation (3).

$$\begin{cases} \dfrac{dY}{dt} = \delta - g * \rho \\ Y(0) = Y_0 \end{cases} \tag{3}$$

In Equation (3), the initial value of energy saved in the body is represented as Y_0, sprinter's movement is g, and their speed is ρ. The LME fitted level and sprinter capacity output are applied to the analysis of variance (ANOVA). The ANOVA approach collated the injury impacts on various sprint modalities with differences. The analysis variance is computed between the mean square difference between sprint types $(\mathrm{Ms}_{\mathrm{groups}})$ and the mean square difference between residual variance obtained from LME $(\mathrm{Ms}_{\mathrm{within}})$. Then, the ANOVA is defined as $\left({}^{\mathrm{Ms}_{\mathrm{groups}}}/{}_{\mathrm{Ms}_{\mathrm{within}}}\right)$. Regularity, homogeneity of variances, and independence are three of the most important assumptions upon which Analysis of Variance (ANOVA) depends for its validation. So that p-values and confidence intervals are valid, the residuals of the difference between the anticipated and observed values should follow an approximately normal distribution. For the F-statistic to be reliable, the variances within each group must be compared to be about identical. This is called homogeneity of variances. In conclusion, all observations within each group must be completely separate from one another, with no correlation or effect between their values. It is essential to follow these assumptions to get legitimate ANOVA findings. If there are any deviations, it may be necessary to use other methodologies or change the data to fix the problems and get the correct conclusions. The analysis of variance is evaluated using hypothesis testing Hypothesis (H_n) and hypothesis (H_a), described as follows.

Hypothesis (H_n): No significant modification in injuries after various sprint modalities.

Hypothesis (H_a): Modifications were presented in injuries after applying various sprint modalities.

In Hypothesis (H_n) states that the injury impacts are similar before and after applying the SET to the sprinters on various training modalities. The Hypothesis (H_a) shows that the sprinter's muscle injury changes after giving a variety of training modalities to the sprinters. The analysis of variance is performed by computing the significance level(α); generally, it has a probability value of 0.05 or 0.01. The computed probability value (p) is compared with the α in which $p \leq \alpha$ then the Hypothesis (H_n) is rejected, which means significant incidences to support the modification in sprinters' performance. If $p > \alpha,$ then the system accepts the Hypothesis (H_n). Considering the scenario, the analysis is performed on three modalities: resistance band sprints, high-intensity interval training, and traditional sprinting. The sprinter's information for these modalities covers the injury severity and rate. Then, the null hypothesis is framed as follows,

Hypothesis (H_n): severity and injury rate are the same for the three modalities.

Hypothesis (H_a): training process creates an impact on injury rate and severity.

Then, the LME and ANOVA procedures are applied to the collected data to identify the influence of the training modalities on the muscle injury rate. The analysis of variance predicts the p-value that helps to determine the condition of accepting or rejecting the hypothesis. During the analysis, ANOVA computes the degree of freedom (DF), F-statistics, Sum of Squares (SS), P-value and Mean Square (MS) for making the final decision. The SS is the entire variation explored by the model and residuals. The number of independent values is represented as $DF,$ and the ratio between SS and DF is MS. The p-value is estimated from the probability value of the data, and the F-statistic is computed as the ${}^{\mathrm{MS}_{\mathrm{model}}}/_{\mathrm{MS}_{\mathrm{error}}}$. Several procedures are used to verify the assumptions and guarantee that the ANOVA findings are genuine. It starts with checking whether the residuals are normal using statistical tests like the Shapiro-Wilk test or visual approaches like Q-Q plots. Stabilizing variance and normalizing data by applying transformations if residuals do not follow a normal distribution is possible. After that, we check whether the variances in each group are identical by using Levene's Test, which measures the homogeneity of variances. If there are significant discrepancies, corrections like Welch's ANOVA, which is resistant to variance heterogeneity, may be used. Lastly, researchers ensure that the experimental design and data-collecting procedures keep observations independent to check for independence. If these assumptions are not satisfied, one may evaluate the data using non-parametric tests like the Kruskal-Wallis test instead of depending on ANOVA. The validity and trustworthiness of the ANOVA findings are improved by methodically checking and resolving these assumptions. The computed F-statistic was used to predict and identify the variability that happened by the type of sprints. If the calculated F-statistic value is maximum, then the sprints training model significantly changes muscle injuries. Likewise, the p-value also helps to decide the hypothesis analysis. Thus, the above analysis helps to predict the SET impacts on sprinter's muscle injuries. Then, the effectiveness of the system is evaluated using experimental analysis. Propensity score matching and regression analysis were among the statistical tools used to assess and mitigate selection bias in the research. To ensure comparability across groups and reduce possible confounding factors, propensity score matching was used to balance the characteristics of athletes across various sprint training modalities. This strategy used training and demographic data, including gender, age, and athletic level, to pair individuals. In addition, regression analysis was used to evaluate the association between training modalities and the likelihood of muscle injuries while also controlling for residual confounding variables. These statistical methods worked together to make the results more reliable and rule out selection bias as a possible explanation for the results' apparent effects, which the training treatments would have caused.

4. Experimental analysis and discussions

This section analyzes the excellence of the Linear Mixed Effects and Analysis of Variance (LME-ANOVA) model while identifying the influence of SET on a sprinter's muscle injuries. The integrated LME-ANOVA approach identifies the relationship between endurance training and the impact on muscle injuries to improve the sprinter's performance. The method uses regression analysis covering different factors to identify the sprinters' willpower and capacity to improve their performance in sports activities. The system's efficiency is evaluated using various metrics like R-square, Bayesian criterion, etc., which help assess the predictive accuracy, goodness-of-fit, and explanatory power. The R^2 measure used to predict how the model identifies the dependency between the variables, which indicates the proportion of the variance. In addition, error rates are computed to determine how effectively the model identifies the deviation between the output values. The obtained results are shown in **Table 6**. A major advantage is the capacity to handle data with various degrees of variability, such as measurements acquired from the same people under different circumstances or at different times. LME models include fixed and random effects to account for individual variations and variance among individuals. Fixed effects capture the overall impact of predictors like training modes. Recognizing the high likelihood of correlation between observations made by the same person, this two-pronged technique permits more precise estimations. Longitudinal and complicated studies benefit greatly from LME models since they can better deal with imbalanced data and missing values than conventional approaches. Using Levene's Test, this study checked for variance homogeneity to verify the ANOVA findings. With a non-significant *p*-value of 0.32, the test confirmed that the groups were homogeneous in that their variances were close to equal. Checking for normalcy, this study looked at Q-Q plots and ran the Shapiro-Wilk test; the *p*-value was 0.45. According to this *p*-value, the residuals were normally distributed, which means they met the normalcy assumption. When certain assumptions were not entirely satisfied, such as substantial variations in variance or non-normal residuals, this study used data transformations or other approaches, such as Welch's ANOVA, to ensure the findings were still valid and strong.

Table 6. Performance analysis of LME-ANOVA.

Metrics	Performance Value
R^2	0.75
Adjusted R^2	0.63
AIC	126.45
BIC	133.12
Log-likelihood	−58.73
MAE	0.235
RMSE	0.31

Table 6 clearly shows the performance analysis of the LME-ANOVA-based SET impact on muscle injuries of sprinters. The study depicted that the model ensures a high R^2 and adjusted R^2 value, which explains that the modification in the training modalities creates variations in the severity of muscle injuries. The obtained R^2 and adjusted R^2 value displays the system's robustness and improves the overall performance of the sprinters. Then, the Akaike information criterion (AIC) and Bayesian information criterion (BIC) are evaluated to explore how the LME-ANOVA model fits the analysis, which means the system covers more parameters by overcoming the data overfitting issues. The other parameter log-likelihood measure indicates that the model captures the entire sprinter's information, and the model provides reasonable suggestions to predict the changes in muscle injuries. Finally, mean absolute error (MAE) and root mean square error (RMSE) indicate that the model identifies the significant impacts of two variables with a minimum error rate. In addition, the influence of SET on muscle injuries is analyzed before and after the training process. The comparison uses different criteria, such as muscle injury incidence rate, muscle injury severity, sprint metrics and recovery metrics. These metrics are explored with varying training modalities, and the results are illustrated in **Table 7**. Since ANOVA's primary purpose is to determine whether there are statistically significant variations in averages across several groups, it is a suitable tool for comparing group differences in this setting. By comparing the mean injury rates across these three groups, ANOVA can examine the influence of different sprint training types on muscle injury incidence in this research. Using analysis of variance (ANOVA), we can see whether the variations in muscle injury rates are

statistically significant. This method improves for situations with more than two groups or conditions, allowing for an exhaustive examination of group effects and interactions. In addition, post-hoc tests may be used in conjunction with ANOVA to determine which groups vary from one another, providing even more insight into the impact of various training strategies. Assumptions for ANOVA were not completely satisfied; thus, this study made many data changes to ensure the findings were legitimate. When residuals were non-normal, this study transformed the data using methods like log or square root to bring the variation back down to a more manageable level and get closer to normalcy. In addition, this study used strong statistical procedures like Welch's ANOVA, which is better suited to deal with uneven variances if Levene's Test failed to satisfy homogeneity of variances. All while preserving the validity and trustworthiness of our statistical studies, this study resolved any assumption violations by using these modifications and other approaches.

Table 7. Analysis of incident rate and injury severity.

Metric	Training	
	Before	After
Muscle injury incident rate		
Short	13%	6%
Long	16%	7%
Mixed	13%	5%
Muscle Injury Severity		
Mild	56%	49%
Moderate	35%	23%
Severe	25%	15%

Table 7 illustrates the analysis of incident rate and injury severity exploration using the LME-ANOVA model. The study clearly shows that the endurance training process impacts the various incidents. The analysis reduces the muscle injury incidence rate from 13% to 6% on short sprints, 16% to 7% on long sprints, and 13% to 5% on mixed sprints. The low incident rate shows that the speed endurance training process modifies the injuries for athletes in short and mixed sprints. In addition, the model positively impacts long sprints and improves athletes' performance. Then, the analysis is further explored using muscle injury severity level, which is considered to be three categories: mild, moderate, and severe. The model reduces injuries from 56% to 49% for mild injuries, 35% to 23% for moderate injuries, and 25% to 15% for severe injuries. The reduced impacts on injury severity positively affect the athlete's longevity and performance. Further, the effects of SET on muscle injuries are analyzed using sprint performance and recovery metrics; the obtained value is shown in **Table 7**. This study's unique research objectives and data structure lend themselves well to the analysis of variance (ANOVA) and linear mixed effects (LME) models. According to the LME model, the data is structured hierarchically, with measurements within persons and individuals inside various training modes. Variability in injury susceptibility across individuals is one random

element that this model considers, along with fixed ones like various sprint training types. For complex explanations of the effects of training modalities on muscle injury that take individual variances into account, this is essential for dealing with repeated measurements and within-subject correlations. This strategy is supplemented by analysis of variance (ANOVA), which compares the average rates of muscle injuries across the various sprint training modalities to consider the issue of whether training techniques affect injury incidence differently. To compare the efficacy of various training programs, using the model's capacity to examine intergroup variation is necessary. Altogether, these techniques provide a thorough framework for data analysis, considering the data structure's hierarchical nature and the dependent variable's distribution (the frequency of muscle injuries).

Table 8 depicts the efficiency analysis of muscle injuries vs speed endurance training using sprint performance and recovery metrics. The analysis shows that the sprint time has changed from 25 s to 23 s, which shows that athletes' training and speed have increased. The model explores the athletes' training according to their body energy level, movement, and speed. These criteria changed their sprint time in various ways. Then, the sprinter's muscle strength is increased from 224 Nm to 235 Nm. The positive changes in muscle strength show the efficiency and effectiveness of the SET training program regimen. Finally, the training process changes their endurance score from 26 reps to 29 reps, ensuring their capacity and endurance. The model's effectiveness is further evaluated using the recovery metrics such as recovery time and muscle soreness. The mean recovery time is minimized from 16 to 9 days, which means sprinters face improvements in their health due to consistent training and can handle the training stress. Their recovery time increased, and their muscle soreness value decreased from 5 to 2 on a scale of 1 to 10. The minimum muscle soreness indicates that the sprinters can adapt to any situation and satisfy the training demands. Linear Mixed Effects (LME) models may be more appropriate for data containing individual random effects than Generalized Linear Models (GLMs) since GLMs cannot explicitly account for the hierarchical structure and correlation within the data. By providing a distributional assumption, GLMs effectively describe multiple types of dependent variables (e.g., normal, binomial, Poisson). However, GLMs are not designed to handle nested data structures or random effects. On the other hand, LME models consider inter- and intra-subject correlations and individual variances using random effects. This allows them to handle data with varying degrees of variability. Since LME models can correctly estimate the variance due to individual variations and consider the correlation between repeated observations, this becomes even more crucial when the same people are measured many times. In hierarchical data settings, GLMs without random effects might cause erroneous inferences and underestimate the variability caused by individual differences, which could lead to biased estimates and lower model fit. So, when assessing complicated data structures with individual random effects, LME models are more flexible and resilient.

Table 8. Analysis of sprint performance and recovery metris.

Metric	**Training**	
	Before	**After**
Sprint Performance		
Time of Sprint	25.0 s	23.0 s
Muscle Strength	224 Nm	235 Nm
Endurance Score	26 reps	29 reps
Recovery Metrics		
Time for recovery	16 days	9 days
Muscle Soreness (scale 1–10)	5	2

Table 9. Analysis of imaging results, creatine kinase and recovery hours.

Metric	**Training**	
	Before	After
Creatine Kinase		
Level of CK	185 U/L	145 U/L
Imaging Results of Tears		
Mild	45%	36%
Moderate	35%	25%
Severe	30%	20%
Recovery		
Recovery Hrs	14hr	9hr

Table 9 shows the impact of endurance training on muscle injuries explored using Creatine Kinase (CK), imaging tears and recovery hours results. The mean value of CL indicates a 145 U/L value after training, which is lower than before training (185 U/L). The decreased CK level shows that sprinters have less muscle damage, and the model recommends that athletes adapt to the training stress and enhance muscle resilience. Then, the imaging results of tears are investigated in which athletes have less tearing value after training. The decreased imaging results show that athletes eliminate their injuries and maintain their resilience, which also impacts their performance if they maintain consistency in training. At last, the sprinter's recovery time is reduced from 14hr to 9hr, indicating that they have fast recovery after post-training. The rapid recovery time is inversely proportional to the fatigue and muscle soreness. Thus, the experimental analysis provides a strong understanding of the impact of speed endurance training on the sprinter's muscle injuries and recovery process. The training process attains the minimum level of CK, recovery time, incidence rate, muscle injury severity rate and high sprint performance. These results directly show that athletes experience improvement in their speed and acceleration, which directly impact their sports performance. Thus, the entire analysis indicates that the training program has a positive impact on athletic performance, fast recovery, and the minimization of injury risk. Overuse and repeated stress injuries, including tendinitis or stress fractures, are more likely to occur in athletes who engage in hard training for long periods. Additionally, long-

term muscle imbalances or joint problems might result from high-intensity sprinting, impacting health and athletic performance. Incorporating sufficient rest times, cross-training, and frequent physical evaluations reduces the likelihood of long-term injuries; it is important to consider these risks when assessing the efficacy of training methods. It is helpful to understand these long-term effects to enhance training regimens for both short-term performance and long-term athlete well-being.

Firstly, it is difficult to identify the precise impacts of various speed workout modes on muscle injury incidence since machine learning models frequently require complex algorithms and multiple parameters that may be difficult to comprehend. In contrast to more conventional statistical approaches, such as LME models, which provide transparent estimates of random and fixed effects, machine learning models are sometimes more like "black boxes," making it difficult to understand how they arrived at their conclusions. The second reason is that we need to know how these factors interact to understand how to compare different training modes and how often muscle injuries occur. The study's aims are well-aligned with the clear method of assessing variance and detecting significant effects provided by LME models and ANOVA. The interpretability required to evaluate the effect of training interventions and communicate results to practitioners and stakeholders may not be provided by machine learning approaches due to their increased complexity and emphasis on prediction accuracy. Studies where clear and interpretable results are necessary for drawing practical conclusions are often better served using conventional statistical techniques. The study's sample is age-, gender-, and ability-level representative compared to the overall athlete population. For most sprint-based sports, peak performance occurs between 18 and 35; hence, this age range is relevant to active athletes. As with participation patterns in competitive sports, the gender distribution is 60% male and 40% female; however, some larger studies may have a little greater male representation. A balanced mix of professional and semi-professional athletes (40%), collegiate athletes (35%), and recreational athletes (25%), with the caveat that recreational athletes may be underrepresented when compared to larger populations that typically include more non-professional participants. Future research would benefit from including a higher percentage of recreational athletes to represent the athletic community more accurately, while this sample adequately represents athletes involved in sprint-based sports.

5. Conclusion

This paper examines the influence of speed endurance training programs on sprinter's muscle injuries. The analysis selects the participants using inclusion and exclusion criteria; around 250 sprinters are chosen for this process. The collected information is analyzed using the imputation method to eliminate the missing values and overfitting issues. Then, the normalization process is applied to fine-tune the data into a standard format, simplifying the computation. Then, linear mixed effects (LME) are computed using the regression model. The LME approach analyzes every parameter in the dataset, and variabilities are computed to predict the severity of muscle injuries. Then, the ANOVA method was applied to the LME fit model to predict the significant impact of SET on muscle injuries. The analysis computes the *p*-value and *F*-statistic value to make an effective decision. The system's efficiency is evaluated using metrics such as muscle injury incidence rate, muscle injury severity, sprint metrics and recovery metrics in which the model ensures the minimum recovery hrs (9hr) compared to before training. In addition, the process covers the athlete's energy, speed and movement to improve their longevity and efficiency during the performance. However, the system works effectively; it works only with limited samples, and the study concentrates on only 12 weeks; it requires a long-term look-up process to minimize their injury. Non-linear dynamics or complex interactions between variables may be unnoticed by the LME model since it presumes a linear connection between predictors and outcomes. Because of this, LME models risk oversimplifying the connections and missing relevant non-linear patterns or interactions. More extensive and diverse samples must be collected to monitor athletes' activities using machine learning techniques. Then, multiple sessions and training processes should be integrated to improve the sprinter's longevity.

Author contributions: Conceptualization, WW and JZ; methodology, WW; software, WW and JZ; validation, JL; formal analysis, WW, JZ and JL; investigation, JL; resources, WW; data curation, WW and JZ; writing—original draft preparation, WW and JZ; writing—review and editing, WW and JL; visualization, JL; supervision, JL; project administration, JL. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials: The data and materials of this study are available from the corresponding author.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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