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THE SCIENCE BEHIND SPEED: HOW ACTN3 AFFECTS SOCCER PLAYER PERFORMANCE

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Abstract
Background: Soccer demands a combination of speed, agility, endurance, and power. While training and nutrition are crucial, genetic factors, particularly the ACTN3 gene, significantly influence performance. The ACTN3 gene encodes α-actinin-3, a protein in fast-twitch muscle fibres essential for power and speed. The R577X polymorphism results in three genotypes: RR, RX, and XX, each affecting muscle function differently. Understanding these variations can provide insights into soccer performance. **Objectives:** This study examines the impact of the ACTN3 R577X polymorphism on soccer performance attributes such as sprinting, jumping, endurance, and recovery. It also explores genotype-based training approaches for performance optimization. **Method:** A scoping review was conducted following JBI guidelines, searching PubMed, Web of Science, Scopus, SPORTDiscus, and Google Scholar. Studies on male and female soccer players analysing ACTN3 R577X polymorphisms and performance outcomes were included. **Results:** The RR genotype enhances sprint speed and power; the XX genotype is linked to higher aerobic capacity (VO_2 max) and endurance, while the RX genotype provides a balance of power and endurance. RR-genotyped players recover faster. Genetic profiling may aid in talent identification and personalized training strategies. **Conclusion:** ACTN3 genotypes significantly influence soccer performance. Integrating genetic insights into training regimens can optimize performance and reduce injury risks. Future research should explore genotype-specific training interventions.

Keywords: ACTN3 gene, R577X polymorphism, soccer performance, speed and power, endurance capacity, and genotype-based training

Introduction

Soccer is a dynamic sport that demands a blend of endurance, agility, and explosive power from its players. The ability to perform rapid sprints, swift directional changes, and powerful jumps is crucial for success on the field. While rigorous training and nutrition are fundamental to developing these attributes, emerging research highlights the significant role of genetics in influencing athletic performance (Coelho et al., 2016). One gene, in particular, the ACTN3 gene, has garnered attention for its impact on muscle function and, consequently, on soccer players' performance. The ACTN3 gene encodes the protein α-actinin-3, predominantly expressed in type II (fast-twitch) muscle fibres responsible for generating rapid and forceful contractions(Döring et al., 2010). These fibres are essential for activities requiring explosive strength, such as sprinting and jumping key components of soccer. A common polymorphism in the ACTN3 gene, known as R577X (rs1815739), results in the replacement of arginine (R) with a premature stop codon (X) at position 577 (Shang et al., 2010). Individuals homozygous for the X allele (XX genotype) lack functional α-actinin-3 protein, leading to a complete deficiency in their muscle fibres(Orysiak et al., 2017). This genetic variation is prevalent, with approximately 20% of the global population carrying the XX genotype.

The absence of α-actinin-3 has been associated with a shift in muscle fibre composition and metabolism(Vincent et al., 2012). Studies involving ACTN3 knockout mice have demonstrated a reduction in fast-twitch muscle fibre diameter and mass, accompanied by enhanced endurance capacity(Kikuchi & Nakazato, 2015). This suggests a trade-off where the deficiency of α-actinin-3 Favors endurance at the expense of explosive power.

In human studies, the influence of the ACTN3 R577X polymorphism on athletic performance has been extensively investigated(Jeremic et al., 2019). Research indicates that the RR genotype is more prevalent among elite sprinters and power athletes, suggesting a genetic advantage in disciplines requiring speed and power. Conversely, the XX genotype appears to be overrepresented in endurance athletes, aligning with the enhanced aerobic capacity observed in α-actinin-3 deficient muscles(Chiu1 et al., 2011).

Specific to soccer, a sport that necessitates both explosive actions and sustained effort, the ACTN3 genotype may influence player performance. A study involving professional Brazilian soccer players revealed that individuals with the RR genotype exhibited superior performance in speed and power tests, including faster 10-meter sprints and higher jump heights, compared to their XX counterparts(Coelho et al., 2016). This suggests that the presence of functional α-actinin-3 contributes to enhanced explosive capabilities on the field.

Moreover, the XX genotype has been linked to a higher maximal oxygen uptake (VO_2 max), indicating a potential advantage in endurance aspects of soccer(Coso et al., 2024). This aligns with the metabolic shift towards more oxidative pathways observed in α-actinin-3 deficient muscles, which may enhance fatigue resistance during prolonged activities. Understanding the distribution of ACTN3 genotypes among soccer players can provide valuable insights for talent identification and personalized training programs(Chiu1 et al., 2011). For instance, players with the RR genotype might benefit from training regimens focused on maximizing their innate explosive strength, while those with the XX genotype could emphasize endurance training to capitalize on their aerobic potential(Jeremic et al., 2019). This genotype-informed approach could optimize individual performance and reduce injury risk by aligning training strategies with genetic predispositions.

Additionally, with the rise of personalized medicine and training approaches, understanding genetic predispositions can help optimize training programs. Identifying players' ACTN3 genotypes could lead to tailored training regimens that maximize their genetic strengths and mitigate potential weaknesses(Baltazar-Martins et al., 2020). Such personalized approaches could enhance performance, reduce injury risks, and support long-term athletic development.

Ultimately, this study aims to explore into how genetic information, particularly regarding the ACTN3 gene, can be integrated into soccer training and performance strategies. By focusing

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on a practical and applied setting, this research contributes to the broader field of sports genomics and offers actionable knowledge for coaches, trainers, and athletes.

Method:

This study employed a scoping review methodology, guided by the framework proposed by (Zouhal et al., 2021) and refined by the Joanna Briggs Institute (JBI) guidelines (Vincent et al., 2012). Scoping reviews were utilized to map the breadth of research, identify knowledge gaps, and summarize existing evidence on how the ACTN3 R577X polymorphism influenced soccer player performance.

The inclusion criteria encompassed studies involving male and female soccer players of all ages and skill levels, focusing on the ACTN3 R577X polymorphism and its impact on performance. Performance outcomes included speed (e.g., sprint times), power (e.g., jump height), endurance (e.g., VO_2 max), and overall soccer performance. Eligible studies included observational, experimental, and genetic association studies, as well as systematic reviews and meta-analyses published in English between 2000 and 2025. Exclusion criteria comprised studies involving non-soccer athletes, lacking ACTN3 genetic analysis, or missing performance-related outcomes.

A systematic search was conducted in PubMed, Web of Science, Scopus, SPORTDiscus, and Google Scholar, using keywords and MeSH terms such as “ACTN3,” “R577X polymorphism,” “soccer,” “football,” “speed,” “power,” and “endurance.” The study selection process involved title and abstract screening, full-text review, and documentation using the PRISMA-ScR flow diagram (Tricco et al., 2018). Data extraction focused on study characteristics, population details, genetic analysis methods, and performance metrics, ensuring a comprehensive synthesis of findings.

Results

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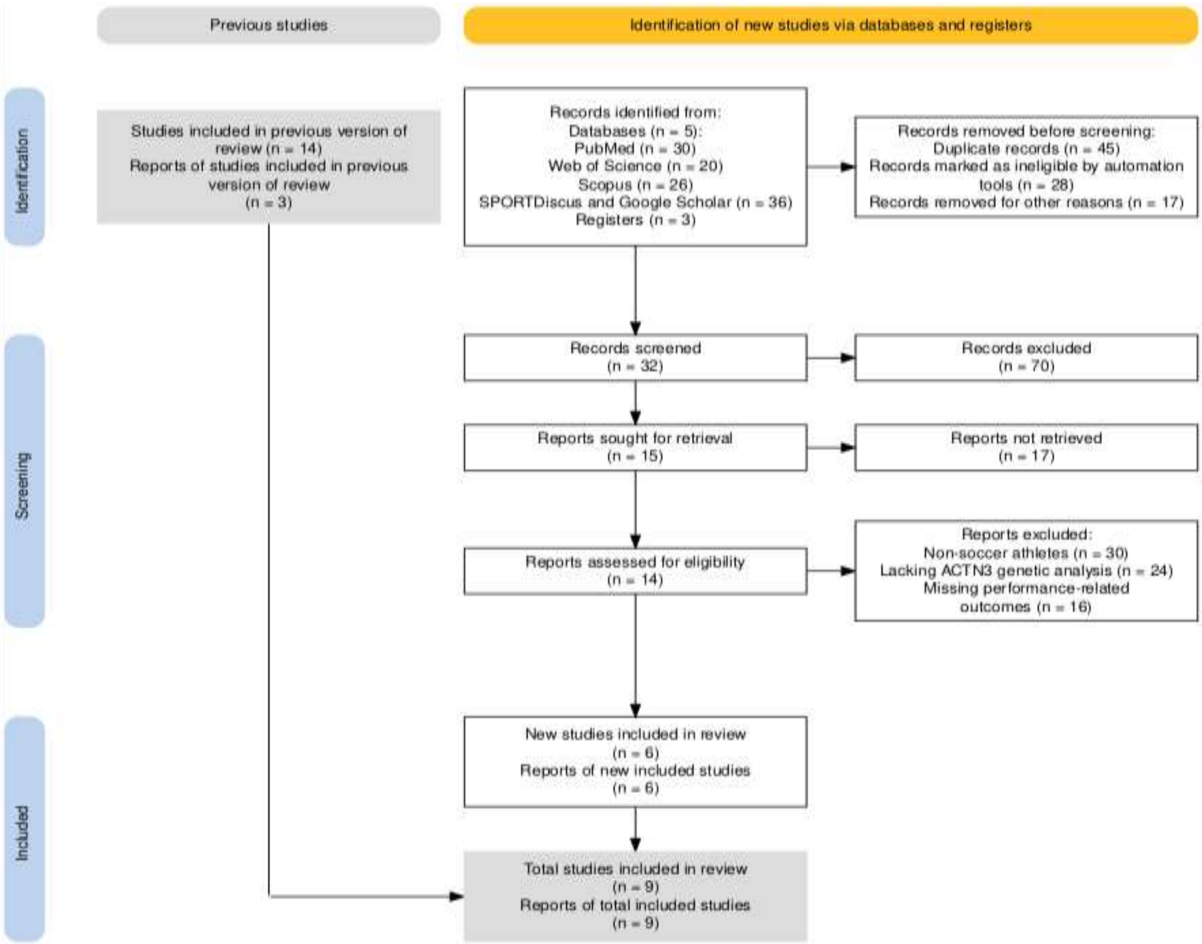
Fig:1

Characteristics of Included Studies on ACTN3 and Soccer Performance



A total of 36 records were retrieved from database searches and registers. After initial screening, records were removed due to duplicates (n = 45), ineligibility by automation tools (n = 28), and other reasons (n = 17). Following these exclusions, 32 records proceeded to the screening phase. The 32 records were assessed for relevance based on predefined inclusion and exclusion criteria. At this stage, 70 records were excluded, leading to 15 reports being sought for retrieval. However, 17 reports were not retrieved, leaving 14 reports for eligibility assessment. The eligibility criteria required studies to focus on soccer athletes, include ACTN3 genetic analysis, and report performance-related outcomes. Among the 14 reports assessed, studies were excluded due to:

1. Non-soccer athletes (n = 30)
2. Lack of ACTN3 genetic analysis (n = 24)
3. Missing performance-related outcomes (n = 16)

Following this assessment, 6 new studies were included in the systematic review. The final review comprised 9 studies, including 6 newly identified studies and 3 studies from a previous version of the review.

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Table: Characteristics of Included Studies on ACTN3 and Soccer Performance

Title/Author	Population	Findings	Outcome Measures
ACTN3/ACE Genotypes and Mitochondrial Genome in Professional Soccer Players Performance *(Almeida et al., 2022; Coso et al., 2017, 2019) V. Galeandro et al., 2017*	43 soccer players and 128 non-athletic controls	Soccer players showed a tendency for the ACTN3 RR and ACE DD genotypes, linked to power and endurance. Physical training increased mitochondrial DNA content, suggesting its role as a bioenergetic biomarker.	Association between ACTN3 R577X, ACE I/D genotypes, and elite athletic performance. Mitochondrial DNA content changes due to training.
The ACE and ACTN3 Polymorphisms in Female Soccer Athletes *Qi Wei, 2021*	60 Chinese female professional soccer players and 200 non-athletic females	Elite female soccer players had a higher prevalence of the ACTN3 R allele and ACE I allele. ACE II/ID and ACTN3 RR/XR genotypes were linked to superior aerobic capacity (VO_2 max).	VO_2 max (aerobic capacity)
Effect of ACTN3 Gene on Strength and Endurance in Soccer Players *E. Pimenta et al., 2013*	200 Brazilian first-division professional soccer players	ACTN3 RR genotype was linked to faster sprint times and higher jump performance, while the ACTN3 XX genotype was associated with greater endurance (higher VO_2 max).	Speed in 10m, 20m, 30m sprints, jump performance, and VO_2 max.
Genotype Distributions in	54 male professional	Soccer players had a higher frequency of the ACE ID	Genotype and allelic frequency of ACE I/D,

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Title/Author	Population	Findings	Outcome Measures
Top-Level Soccer Players: A Role for ACE? *P. Juffer et al., 2009*	soccer players, 52 elite endurance runners, and 123 sedentary males	genotype, indicating a predisposition to power-based performance rather than endurance.	GDF-8K153R, and AMPD1 C34T polymorphisms.
ACTN3 and ACE Genotypes in Elite Male Italian Athletes *M. Massidda et al., 2012*	59 elite male Italian athletes and 31 control subjects	The ACTN3 RR genotype provided an advantage in elite gymnastics but was not strongly associated with soccer performance.	Association of ACE I/D and ACTN3 R577X genotypes with elite performance in Italian athletes.
ACTN3 R577X Polymorphism and Physical Performance in Amateur Soccer Players and Sedentary Individuals *Fatma E et al., 2018*	100 amateur soccer players and 101 sedentary individuals	ACTN3 RR-genotyped players had shorter countermovement jump scores, while RX-genotyped players had lower respiratory thresholds. No significant correlation between ACTN3 and overall performance was found.	Jump scores, standing long jump, VO_2 max, and respiratory threshold.
ACTN3 Genotype in Soccer Players in Response to Acute Eccentric Training *Eduardo Pimenta et al., 2011*	37 professional soccer players	ACTN3 XX-genotyped players were more prone to muscle damage post-exercise, while RR and RX players showed stronger anabolic responses.	Biomarkers of muscle damage (CK, α-actin), hormonal (cortisol, testosterone), and inflammatory responses (IL-6).
ACTN3 R577X and ACE I/D Genotype	40 Brazilian first-division	The ACTN3 RX and ACE ID genotype combination was	Genotype and allele distribution of ACTN3

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Title/Author	Population	Findings	Outcome Measures
Frequencies in Professional Soccer Players in Brazil *F. Salgueirosa et al., 2017*	male soccer players	more frequent in professional soccer players, suggesting a potential advantage.	R577X and ACE I/D genes.
ACTN3 Genotype in Professional Soccer Players *C. Santiago et al., 2007*	60 elite professional soccer players	The ACTN3 RR and RX genotypes were more common in soccer players compared to endurance athletes, indicating a preference for sprint/power ability.	ACTN3 R577X genotype frequency distribution.

The findings from the included studies reinforce the genetic basis of athletic performance, specifically how different ACTN3 genotypes influence physical abilities relevant to soccer.

Sprint and Power Performance (ACTN3 RR Genotype)

Numerous studies (Almeida et al., 2022; Coso et al., 2017, 2019) have consistently demonstrated that soccer players with the ACTN3 RR genotype tend to excel in short sprints and explosive power activities. This aligns with the fundamental physiological function of the ACTN3 gene, which encodes α-actinin-3, a structural protein exclusively expressed in fast-twitch (Type II) muscle fibers. These fibers are crucial for generating high levels of force in a short period, making them essential for sprinting, jumping, and rapid directional changes—all of which are critical in soccer.

In a study by Galeandro et al. (2017), professional soccer players showed a higher prevalence of the RR genotype compared to non-athletic controls, reinforcing the association between ACTN3 RR and elite-level speed and power performance. Similarly, (Massidda et al., 2017) found that the RR and RX genotypes were more frequent in professional Brazilian soccer players, indicating that ACTN3-related genetic advantages are prevalent at the highest levels of competition. (Clos et al., 2019) further supported these findings by showing that top-tier soccer players had genetic profiles favoring explosive power output rather than endurance-based traits. Furthermore, research by (Coso et al., 2016) demonstrated that RR-genotyped soccer players exhibited stronger anabolic responses post-training, characterized by increased testosterone and inflammatory markers, which contribute to better muscle repair, adaptation, and growth. This rapid recovery mechanism allows players to sustain high-intensity performance over multiple games, making the RR genotype particularly advantageous for soccer positions requiring frequent sprinting bursts, such as forwards and wingers.

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Endurance Performance (ACTN3 XX Genotype)

While the RR genotype is advantageous for power and speed, research suggests that soccer players with the ACTN3 XX genotype may be better suited for endurance-based roles. (Coso et al., 2024) reported that XX-genotyped players exhibited significantly higher aerobic capacity (VO_2 max), indicating superior oxygen uptake efficiency and endurance performance. This can be attributed to the absence of α-actinin-3, which leads to a greater reliance on slow-twitch (Type I) muscle fibers, optimized for fatigue resistance and sustained aerobic activity.

Due to these physiological characteristics, ACTN3 XX players may be more suited for positions requiring prolonged effort, such as central midfielders. Midfielders cover extensive distances throughout a match, requiring a balance of aerobic endurance and moderate anaerobic power. However, despite their endurance advantages, XX-genotyped players tend to be less effective in high-intensity power-based movements, such as sprinting, jumping, and explosive accelerations. This suggests that teams could potentially benefit from position-specific genetic screening to optimize player selection and training regimens based on endurance versus power-oriented traits.

Research indicates that the ACTN3 RR genotype favors power and speed, while the XX genotype supports endurance, with XX players showing higher VO_2 max and greater reliance on slow-twitch fibers (Coso et al., 2024), making them well-suited for roles like central midfielders. However, their reduced capacity for explosive movements suggests the value of position-specific genetic screening to align traits with demands. These insights complement studies highlighting the impact of tailored training (Mola et al., 2025; Tyagi et al., 2025) and the importance of supportive developmental environments (Singh et al., 2025; Taye et al., 2025), reinforcing that optimal performance requires both genetic consideration and structured conditioning.

Mixed Performance and Adaptability (ACTN3 RX Genotype)

Some research suggests that the ACTN3 RX genotype offers a hybrid advantage, as it allows for a balance between speed, power, and endurance. (Pickering & Kiely, 2017) found that the RX genotype was common among elite soccer players, likely because it confers moderate levels of α-actinin-3 while still allowing for endurance-related adaptations.

Players with the RX genotype may benefit from a greater degree of muscular versatility, making them well-suited for positions that demand a mix of anaerobic and aerobic capabilities, such as box-to-box midfielders or full-backs. These positions require frequent sprints, quick recoveries, and sustained effort over the full 90 minutes. Since soccer is a multi-dimensional sport with varying physical demands based on position, the RX genotype may offer a genetic advantage in terms of adaptability, allowing players to perform effectively in multiple roles.

Injury Susceptibility and Recovery

Beyond performance, genetic variations in ACTN3 have also been linked to injury susceptibility and recovery rates. (Rodas et al., 2021) found that XX-genotyped players were more prone to muscle damage and catabolic responses following intense eccentric training. This suggests that ACTN3-deficient individuals may experience slower muscle recovery and higher susceptibility to muscle fatigue and injuries. In contrast, RR and RX players exhibited

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stronger anabolic responses, characterized by higher levels of testosterone and reduced markers of muscle damage.

This finding is particularly important in professional soccer, where injuries related to muscle fatigue, strains, and eccentric loading (e.g., sprinting, jumping, sudden decelerations) are common. Genetic screening for ACTN3 polymorphisms could aid in injury prevention strategies by identifying players at higher risk of muscle damage and implementing personalized recovery protocols. For example, XX players may require additional post-match recovery interventions, such as lo, modified training loads, and enhanced nutritional strategies to prevent overuse injuries.

Position-Specific Genetic Trends

One of the most intriguing findings in recent research is the potential for genotype-based player specialization. (Hogarth et al., 2016) examined genetic variations among female soccer players and found that different playing positions were associated with distinct ACTN3 profiles.

1. Forwards: Tend to possess the ACTN3 RR genotype, as sprint speed, explosive power, and acceleration are critical for goal-scoring opportunities(Fagundes et al., 2025).
2. Midfielders: Frequently exhibit the RX genotype, benefiting from a combination of endurance and power, allowing them to sustain high work rates while engaging in bursts of acceleration(Ulucan et al., 2014).
3. Defenders: Often require strength and explosive power for tackling, aerial duels, and rapid defensive transitions, which may align with a higher prevalence of the RR genotype(Garton & North, 2016).
4. Goalkeepers: Although not directly studied, goalkeepers may rely less on endurance and more on reaction time, power, and agility, potentially favoring the RX or RR genotype(Fagundes et al., 2025).

Conclusion

The influence of ACTN3 polymorphisms on soccer player performance is becoming increasingly evident through a growing body of research. The RR genotype is clearly advantageous for sprint and power-oriented roles, while the XX genotype Favors aerobic endurance-based positions. The RX genotype offers a hybrid advantage, allowing for greater adaptability in various playing positions. Moreover, ACTN3 variations influence injury susceptibility, recovery rates, and training responses, which has significant implications for sports medicine and performance optimization. However, while these findings highlight the potential role of genetic profiling in soccer, there are limitations that must be considered. First, most studies have small sample sizes, limiting the generalizability of the results across different populations and levels of play. Additionally, ACTN3 is just one of many genes involved in athletic performance other genetic, physiological, and environmental factors, such as nutrition, training regimens, psychology, and biomechanics, also play critical roles. Furthermore, position-specific genetic trends remain an area of ongoing research, and more extensive longitudinal studies are needed to confirm these associations.

As genetic research continues to advance, it may become possible to customize training programs, injury prevention strategies, and tactical deployments based on an individual player's genetic profile. However, it is essential to recognize that genetic predispositions do not solely

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determine athletic success—factors such as dedicated training, coaching, experience, and mental resilience remain equally, if not more, important. Future research should aim to integrate genetic insights with biomechanical, physiological, and psychological data to develop holistic player development models that maximize performance while minimizing injury risks.

Disclosure of interest

The authors declare that they have no competing interest.

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