



Biomechanical and physiological perspectives on high jump training: a systematic review

Perspectivas biomecánicas y fisiológicas en el entrenamiento del salto de altura: una revisión sistemática

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Abstract

Introduction: Sports biomechanics has been widely applied to support athlete performance and minimize the risk of injury. In track and field, the high jump involves complex movement coordination and carries a high risk of injury.

Objective: This study aims to systematically review research publications on the high jump in track and field and provide appropriate recommendations for optimizing high jump athlete performance.

Methodology: This study adapted the PRISMA guidelines in conducting the data collection process. In addition, this study also included keyword analysis and literature review to provide more comprehensive data.

Results: A total of 971 studies were identified from the five databases (SCOPUS, ERIC, IEEE Xplore, PubMed, and Springer). Then, 276 articles were used for keyword analysis and 15 articles for literature review. Based on the results of the keyword analysis, evidence was obtained that research in high jump has successfully involved several aspects, one of which is sports rehabilitation. Meanwhile, the results of the literature review presented that research has developed from conventional (theory-based explanation) to more modern (involving digital technology).

Discussion: The results presented indicate that high jump research still needs to be expanded. Of the 15 articles identified, only 10 articles were suitable and could be fully reviewed. In the end, the researchers only found 10 articles discussing high jump in track and field.

Conclusions: In addition to providing quite interesting results, research on the high jump still needs to be developed so that it can become a strong reference in the future. Thus, the development of the high jump sport can be maximized, both academically and non-academically.

Keywords

Athletics performance; sport training; center of mass; risk of injury; performance optimization.

Resumen

Introducción: La biomecánica deportiva se ha aplicado ampliamente para mejorar el rendimiento de los atletas y minimizar el riesgo de lesiones. En el atletismo, el salto de altura implica una compleja coordinación de movimientos y conlleva un alto riesgo de lesiones.

Objetivo: El objetivo de este estudio es revisar sistemáticamente las publicaciones de investigación sobre el salto de altura en el atletismo y ofrecer recomendaciones adecuadas para optimizar el rendimiento de los atletas en esta disciplina.

Metodología: Este estudio adaptó las directrices PRISMA para llevar a cabo el proceso de recopilación de datos. Además, este estudio también incluyó un análisis de palabras clave y una revisión de la literatura para proporcionar datos más completos.

Resultados: Se identificaron un total de 971 estudios en las cinco bases de datos (SCOPUS, ERIC, IEEE Xplore, PubMed y Springer). A continuación, se utilizaron 276 artículos para el análisis de palabras clave y 15 artículos para la revisión de la literatura. A partir de los resultados del análisis de palabras clave, se obtuvo evidencia de que la investigación en salto de altura ha involucrado con éxito varios aspectos, uno de los cuales es la rehabilitación deportiva. Por otra parte, los resultados de la revisión bibliográfica mostraron que la investigación ha evolucionado desde lo convencional (explicación basada en la teoría) a lo más moderno (con tecnología digital).

Discusión: Los resultados presentados indican que la investigación en salto de altura aún debe ampliarse. De los 15 artículos identificados, solo 10 eran adecuados y pudieron revisarse en su totalidad. Al final, los investigadores solo encontraron 10 artículos que trataban sobre el salto de altura en atletismo.

Conclusiones: Además de proporcionar resultados bastante interesantes, la investigación sobre el salto de altura aún debe desarrollarse para que pueda convertirse en una referencia sólida en el futuro. De este modo, se podrá maximizar el desarrollo del deporte del salto de altura, tanto a nivel académico como no académico.

Palabras clave

Rendimiento deportivo; entrenamiento deportivo; centro de masa; riesgo de lesiones; optimización del rendimiento.



Introduction

Sports biomechanics is crucial in the domain of sports coaching (Tai et al., 2023). The significance of sports biomechanics lies in its ability to deliver accurate and thoroughly analyzed assessments (Lee & Park, 2022). Sports biomechanics inherently incorporates physiological elements during movement analysis evaluations (Tai et al., 2023). This seeks to furnish pertinent information for coaches and athletes concerning productive and efficient movements (Dhahbi, 2025). The incorporation of sports biomechanics into coaching renders training approaches reliant not solely on verbal assessment (Mason et al., 2020), it also contributes through data presentation (Rebelo et al., 2023). Diverse sports have effectively and sustainably integrated sports biomechanics, for example in athletics. Athletics encompasses various sports that include sports biomechanics in every event, including the high jump (Al Ardha et al., 2025).

The high jump is a complex athletic event that demands the integration of speed, strength, coordination, and precise technical execution. As a vertical jump discipline within track and field, it challenges athletes to clear a horizontal bar at maximum height without dislodging it, relying heavily on both biomechanical efficiency and physiological conditioning (Nishiumi et al., 2023). Over the years, performance in high jump has seen considerable advancements, much of which can be attributed to improvements in training methodology, technique analysis, and a better understanding of human movement science (Wang et al., 2025) (Jiménez-Reyes et al., 2017)(Jiménez-Reyes et al., 2019).

Biomechanically, the high jump is governed by principles of kinetics and kinematics (Atta et al., 2024). Key phases approach, take-off, flight, and landing must be finely tuned to optimize force generation, angular momentum, and body positioning (Wenchao et al., 2025). Studies have investigated optimal take-off angles, approach velocities, and the use of the Fosbury Flop technique, identifying critical factors that contribute to successful performance (Dapena, 1980a). In parallel, physiological components such as lower-limb explosive power, neuromuscular activation, and muscle fiber composition have been shown to influence the jumper's ability to convert horizontal speed into vertical lift (Coh & Supej, 2007). Research conducted by (Li et al., 2024), shows a strong correlation between lower-limb explosive power and jumping ability. In addition, research by (Alkjaer et al., 2013) proves the role of neuromuscular activation in jumping ability. Muscle fiber composition also plays a role in jumping ability, as shown in research by (Methenitis et al., 2020).

Despite the growing body of research in both biomechanics and physiology, the integration of these two domains in high jump training remains underexplored in a systematic manner (Barrio et al., 2023). Coaches and athletes often rely on anecdotal experience or isolated findings, lacking a cohesive evidence-based foundation to guide training regimens (Timmerman et al., 2024). A comprehensive synthesis of biomechanical and physiological research is thus essential to bridge this gap, inform best practices, and enhance training outcomes.

This systematic review aims to analyze the development of high jump research in track and field that has been published since its inception to the present. In addition, this study also aims to provide information and recommendation on the optimization of high jump athletes' performance. Through a coherent and comprehensive analysis, it will provide new insights for researchers and even high jump practitioners. Thus, this sport will experience more significant development, both academically through research and non-academically through achievements.

Method

Design

This study uses a systematic review design that applies the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. This study also uses automatic tools such as VosViewer, Publish or Perish, and Mendeley as media for collecting research data and analyzing research data more effectively and efficiently.



PICOs Framework

The researcher employed an instrument known as the PICO framework during the data collection phase. The PICO framework is a tool frequently employed in systematic reviews to facilitate the collection of research data. Based on the PICO framework, the Population is defined as athletes in athletics, specifically high jump. The researcher did not provide any restrictions regarding the level or group of athletes involved. In this case, athletes ranging from young children to adults, from amateurs to professionals, would be included in the inclusion criteria. The Intervention is physical training that integrates aspects of sports biomechanics. The Comparison is not defined by the researcher because it is optional. Finally, the Outcomes are the optimization of high jump performance, which includes the results of evaluations and analyses of jumping ability. In addition, medical aspects such as anatomy and injuries are also related to optimization in high jump performance (variable Outcomes). As for the Study Design, the researcher focused on experimental, cross-sectional, comparative, correlational, and case study designs. This is because these designs are often used in studies related to the optimization of athlete performance, not only in high jump.

Procedure

The research procedure established in this systematic review study began with the identification of research data based on the PICO framework that had been formulated. The researcher used five databases as sources of research data, namely SCOPUS, PubMed, ERIC, Springer, and IEEE Xplore. Based on the formulation of the PICO framework, the researcher determined the keywords as material in the research data identification process. The keywords used were “high jump” AND athletics OR “track and field” AND biomechanics. The data identification process was conducted on May 26, 2025, using these keywords and based on the five previously mentioned databases.

The results of the identification process will undergo screening using the Publish or Perish software. This is done because the software allows data identified from different databases to be grouped together. This makes the screening process easier based on the established inclusion and exclusion criteria. In this study, the inclusion criteria established are research documents published in the form of articles only. The researcher also ensures that the research topics of the identified articles are consistent or relevant to the objectives of this systematic review study. The exclusion criteria are research documents not published in the form of articles.

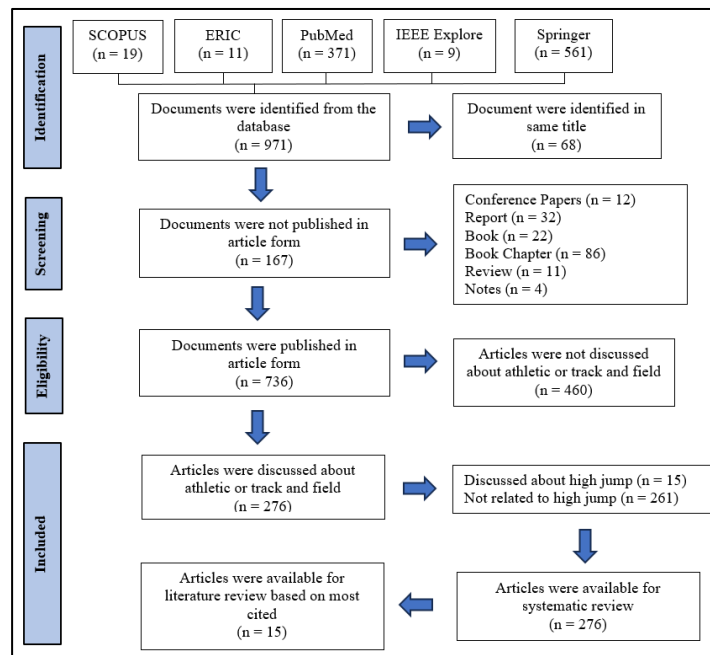
The results of the screening process will be used as the basis for conducting keyword analysis using VosViewer software. The analysis in VosViewer software was conducted based on title and abstract data that had been exported into RIS files. Researchers then used the fractional counting method, with a minimum number of keyword occurrences set at 1. In addition, researchers established associations for the type of normalization. This was done to provide visualization based on the strength (correlation) between the keywords analyzed. The results of the keyword analysis will be explained based on the year range that appears in the “Overlay” tab. Through this, researchers will be able to present data containing information on the development of research topics from year to year. Through this analysis, researchers will be able to present more comprehensive research development data. A literature review was also conducted to present previous research topics that have often been referenced by several researchers recently. The literature review was conducted based on articles with the most citations.

Results

The data collection process in this study obtained the results presented in Figure 1. Based on the screening results using the PRISMA method, 971 documents were identified through five databases. Then, a screening process was carried out, and 276 articles were found to be relevant or related to track and field. The researcher conducted a review based on the abstracts and only obtained 15 articles relevant to high jump in track and field. However, of these 15 articles, the researcher was only able to conduct a comprehensive review of 10 articles. This was because three articles did not have a full version or only had an abstract, one article was retracted, and one article was a book chapter. On the other hand, the five studies did need to be excluded because the researchers’ required studies in the form of articles that could be thoroughly reviewed for the Literature Review section. Therefore, in the Literature Review

section, the researchers only included 10 articles that were relevant or in line with the research objectives for comprehensive review.

Figure 1. Research data screening process



Research Publication and Development in High Jump Training

The results of the identification and screening process using the PRISMA flowchart in Figure 1 show that of the total number of documents identified, only 15 studies discussed high jump. In this section, the study uses screening results that discuss track and field (Figure 2 and Table 1). This was done by the researcher with the aim of providing an understanding of the development of publications from year to year. Then, this discussion will be linked to other subsections so that the interpreted results can be interrelated. Thus, the data presentation by the researcher will be more coherent.

The results presented in Figure 2 and Table 1 show significant research developments from year to year. These developments began in 1968 and continued dynamically until 2003. During those years, researchers successfully published 58 articles. Research developments began to show significant progress from 2004 to 2025. The data shown in the graph in Figure 2 presents massive and fluctuating developments, with a total of 218 articles published. This remarkable development was also marked by good contributions in the 2007-2009 period. During this period, the research published 16 articles with 139 citations. This number of citations is an indication of the exceptional quality of the research results in those years. However, considering current developments, digitalization has become a key point in research innovation. In the past, research has successfully contributed through conventional and comprehensive discussions. Previous research has successfully become a reference for the latest research to integrate digital technology with the relevance of theory or discussion in previous research. The escalation of research publications that occurred after 2009 is a sign that researchers during that period and up to now have been trying to contribute through digitalization in the world of sports, especially in the high jump in track and field.

Figure 2. Research development in high jump training

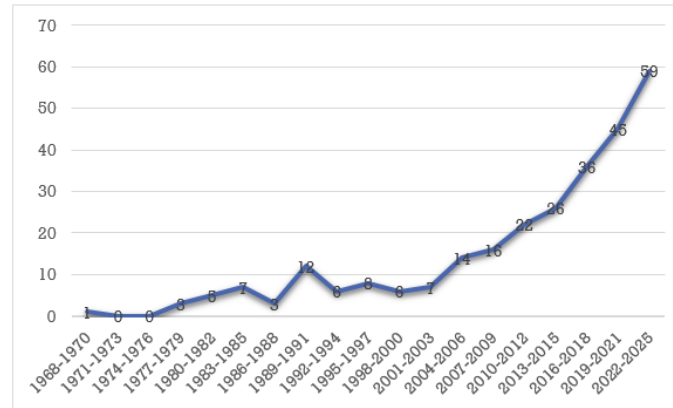


Table 1. Research publication in high jump training

Year of Publication	Paper	Cites	Average	Percentage (%)
1968-1970	1	0	0.5	0.36
1971-1973	0	0	0	0.00
1974-1976	0	0	0	0.00
1977-1979	3	0	1.5	1.09
1980-1982	5	0	2.5	1.81
1983-1985	7	48	27.5	2.54
1986-1988	3	0	1.5	1.09
1989-1991	12	0	6	4.35
1992-1994	6	3	4.5	2.17
1995-1997	8	0	4	2.90
1998-2000	6	0	3	2.17
2001-2003	7	0	3.5	2.54
2004-2006	14	46	30	5.07
2007-2009	16	139	77.5	5.80
2010-2012	22	3	12.5	7.97
2013-2015	26	10	18	9.42
2016-2018	36	0	18	13.04
2019-2021	45	9	27	16.30
2022-2025	59	16	37.5	21.38
Total	276	274	275	100

Research Keywords Analysis in High Jump Training

Keyword analysis was conducted based on the screening results in the “Included” stage, or articles that discussed track and field only. This was done by the researcher because during the screening process from start to finish, the researcher only found 15 articles that discussed high jump. Then, the researchers encountered another obstacle, namely that 5 of the 15 articles could not be reviewed. Therefore, based on the screening results at the “Included” stage, it would be more appropriate to conduct a keyword analysis because the supporting data consisted of 276 articles.

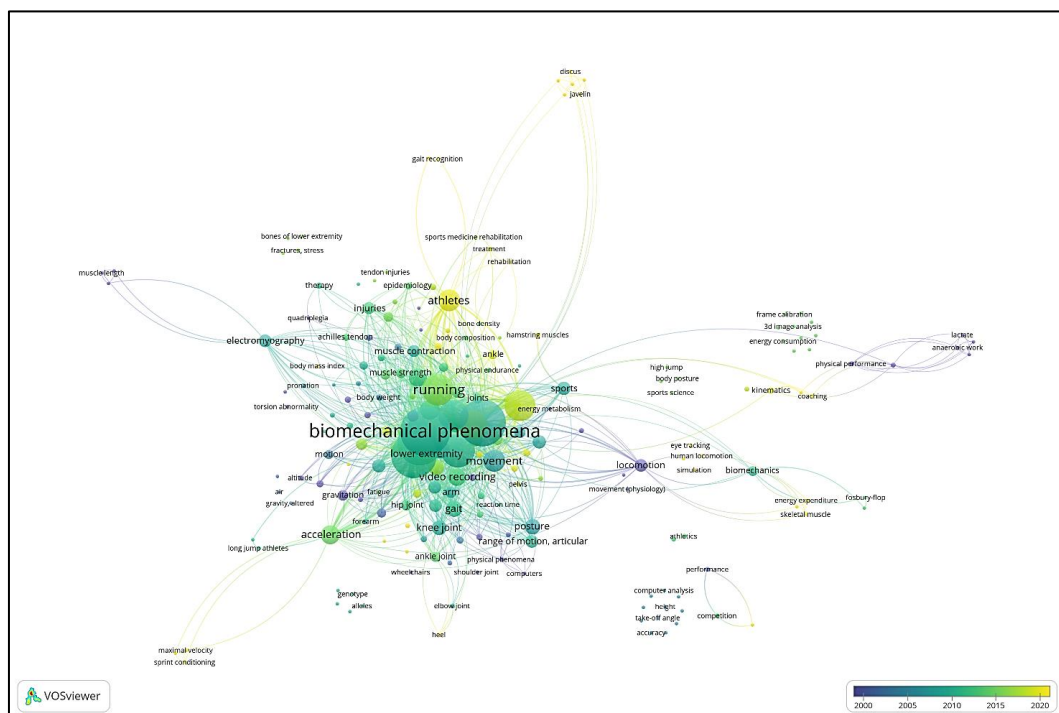
Based on the keyword analysis results presented in Figure 3, research has developed since the 2000s and continues to develop today. From 2000 to 2009, research development focused on a person's motor skills. This was marked by the emergence of the keywords “locomotion” and “movement (physiology)”. These two keywords indicate that the research focused on the movement patterns resulting from an individual's activities. In addition, the keywords “gravitation,” “range of motion,” and “posture” indicate how these movement skills are influenced by several external and internal factors. Then, the keyword “physical performance” became a result of the previous keywords.

In 2010-2019, research began to undergo digitalization by involving video-based sports biomechanical analysis. This statement is reinforced by keywords such as “biomechanical phenomena” and “video recording.” Research during this period focused more on lower body skills and physical condition. This is indicated by keywords such as “lower extremity,” “muscle strength,” “ankle joint,” “acceleration,” and

“physical endurance.” The emergence of these keywords shows that research began to measure an athlete's performance through a sports biomechanics approach. Performance measurement, which was previously conventional, has evolved through digitalization.

The period from 2020 to 2025 is a time when research development expanded into other aspects. Previously, research on high jump training had successfully involved sports biomechanics and digitalization for performance optimization. From 2020 to the present, research has begun to spread into the medical field. The emergence of the keyword “sport rehabilitation” is evidence of this expansion. Rehabilitation and sports biomechanics are two interrelated aspects. Sports biomechanics provides appropriate evaluation data for athletes and coaches, both as a means of health evaluation (rehabilitation) and performance enhancement. Therefore, keywords such as “athletes” and “coaching” also appear in this keyword analysis.

Figure 3. Keywords analysis in high jump training



Literature Review in High Jump Training Publication

A literature review was conducted with the aim of providing a more comprehensive discussion of high jump research in track and field. In the PRISMA flowchart, this subchapter should have 15 relevant articles discussing high jump. However, only 10 of the 15 articles were suitable for literature review. The researchers did not use specific assessment instruments in determining the articles to be reviewed in this subchapter (all relevant articles will be reviewed). This is because, from the total number of research data identified, only 10 articles were eligible for literature review, in accordance with the predetermined research topic and objectives.

The relevant articles identified in Table 2 have characteristics that can be reviewed through the research objectives, research sample, research design, and research results. Based on the range of publication years, these articles were published from 2005 to 2025 (present). The most publications were in 2022, with research topics related to running technique as a prelude to high jump, jump optimization through shoulder-hip interaction, and the risk of injury to high jump athletes. These three topics are interrelated, as they provide insight into how an athlete needs to pay attention to proper running technique, how they can maximize their jump, and even the injuries that may occur in high jump athletes. The three studies integrate aspects of sports biomechanics and sports rehabilitation to optimize the performance of high jump athletes.

The majority of the research samples used were elite high jump athletes, as evidenced by the six studies that used such samples. Among these six studies, one examined elite athletes with disabilities, specifically those with transtibial amputations. This phenomenon indicates that research in high jump also considers athletes with disabilities, not just non-disabled athletes.

Previous studies have attempted to prove the correct running technique in high jump in order to improve jump results with minimal risk of injury. Then, the jumping style was also studied with the aim of providing insight to athletes and coaches regarding the optimization of jump results. What physical components influence and how the angular velocity of the joints contributes to the jumping process.

In general, the results of this literature review show that studies more often use a small sample size (1-4 samples, the majority of which are male). This is also relevant to the average research design used, which is cross-sectional. The results of these studies also focus more on kinematic results (8 articles) than other types of results (1 article on injury and 1 article on kinetics).

This literature review provides fairly comprehensive qualitative data. Research developments can be observed through annual publications and how previous researchers determined the appropriate research topics. The research topics studied have undergone significant development, in the sense that what initially only provided discussion without the involvement of digital technology has now become more modern. The variety of samples has also been successfully demonstrated through 10 published articles. Starting from non-athletes, amateur athletes, young athletes, adult athletes, to athletes with disabilities. The complexity presented in the articles in this literature review can serve as a reference and benchmark for future research. Thus, research expansion can be carried out more evenly across various aspects related to sports, particularly in the field of coaching.

Table 2. Literature review

Author	Research Purposes	Participants	Study Design	Results
(Sado et al., 2022)	To illustrate that the curved RSLJ (C-RSLJ) is more appropriate than the straight RSLJ (S-RSLJ) for generating center of mass (CoM) height.	13 Male High Jumpers (mean \pm SD of age, 22.8 \pm 2.4 yr; height, 1.78 \pm 0.07 m; mass, 66.5 \pm 5.4 kg; personal best, 2.13 \pm 0.17 m (ranges, 2.02–2.31 m))	Comparative Study	A curved approach results in a higher center of mass during takeoff without elevating joint kinetic exertions compared to a straight approach. The curved approach alters the initial takeoff conditions and facilitates the conversion of horizontal kinetic energy.
(Becker & Wu, 2015)	To evaluate the efficacy of an integrated biomechanics and motor control protocol in enhancing athletic performance in the high jump.	4 Elite High Jumpers (age ranges 22-24 yr; height ranges 1.67-1.82 m; personal best ranges 1.74-1.92 m)	Experimental Study	A targeted external focus of attention cue aimed at enhancing running posture resulted in participants being markedly more upright during the approach, achieving much higher horizontal velocities at plant, and producing considerably greater vertical velocities during takeoff.
(Tan & Yeardon, 2005)	To ascertain the attributes of the approach curve and to examine its role in the production of somersault rotation.	2 Elite High Jumpers (A and B). A measured 1.96 m in height, weighed 79 kg, and achieved a personal best competition performance of 2.32 m; B measured 1.86 m in height, weighed 73 kg, and attained a personal best competition performance of 2.37 m.	Cross Sectional Study	It was observed that in each instance, the radius of the approach curve and the inward lean angle both diminished as the approach concluded. The resulting outward lean angular velocity was demonstrated to constitute a significant component of the necessary somersault angular velocity for a leap. The primary advantage of a curved approach was its ability to generate somersault velocity as the curve closed near the conclusion of the approach.
(Nolan & Patriitti, 2008)	To analyze the high jump method employed by individual elite transtibial amputee (TT) athletes.	Two elite transtibial amputee (TT) athletes.	Case Study	Both transtibial amputee athletes demonstrated a reduced horizontal approach velocity, diminished positive vertical take-off velocity, a more erect posture at touch-down, and an increased hip range of motion during the take-off phase relative to



				established non-amputee high jump techniques. These disparities may be linked to the limitations of initiating movement from the prosthetic limb during the preceding step, necessitating the adoption of an altered posture at touchdown in contrast to non-amputees.
(De la Fuente et al., 2022)	To ascertain the rupture pattern of an Achilles tendon (AT) in an elite high-jumper athlete who sustained an AT rupture during the straight-line running phase while preparing for a high-jump attempt.	An outstanding male high jumper, aged 33 years, weighing 78 kg, and measuring 1.96 m in height.	Case Study	The rupture transpired at 44% of the unilateral stance. The injured leg exhibited increased ankle dorsal flexion and knee-ankle ratio, alongside decreased knee flexion relative to the contralateral leg. An unusual pattern of rupture transpired during the transition from the mid to terminal posture phases of running. The diminished knee flexion and heightened ankle dorsiflexion during the stance indicate a disruption in knee-ankle coordination. This may have facilitated significant extension of the Achilles tendon, resulting in rupture.
(Laffaye, 2011)	To (a) identify the most predictive anthropometric variables, (b) evaluate the predictability of a novel leaping motor assessment, and (c) forecast Fosbury-flop performance by multiregression analysis.	49 girls (age 13.6 ± 0.48 years; height = 1.61 ± 0.07 m) and 68 boys (age 13.6 ± 0.47 years; height = 1.64 ± 0.10 m).	Correlational Study	The FFP performance can be forecasted using the equation: $FFP = -0.618 \text{ HEIGHT} + 0.898 \text{ HMAX} + 0.669 \text{ ABILITY} - 0.08$. This equation is analogous for both genders, indicating that 13-year-old girls and boys employ same techniques to achieve high jumps, suggesting that methods to enhance coordination or lower limb strength during training may be uniform for junior boys and girls in high jump.
(Khan et al., 2013)	To ascertain if the joint velocity during the approach run influences jump height (performance).	Twelve male high jumpers utilizing the Fosbury-flop technique had a mean age of 23.5 years (± 2.28 years), a height of 179.90 cm (± 4.43 cm), and a body mass of 66.78 kg (± 4.78 kg).	Cross Sectional Study	A strong link exists between the velocities of the ankle, hip, shoulder, and elbow joints and jump height (performance), but an insignificant relationship is observed between knee joint velocity and jump height (performance). The results indicate that the velocity of various joints during the approach run influences the jump height of high jumpers.
(Nicholson et al., 2024)	To examine the biomechanical disparities between successful and unsuccessful jumps in competition.	Seven elite male high jumpers were evaluated (body mass: 76.8 ± 7.2 kg; height: 1.94 ± 0.04 m; personal best: 2.32 ± 0.03 m).	Cross Sectional Study	During successful jumps, participants elevated their center of mass significantly ($p < 0.01$) from take-off. The touchdown in SU jumps exhibited an increased anteroposterior velocity ($p < 0.05$), reduced backward lean ($p < 0.05$), and alterations in joint angles for both the stance and trail limbs ($p < 0.05$). Athletes reduced the final contact duration during SU leaps ($p < 0.01$) following an extended flight time in the last step of the run-up ($p < 0.05$). The findings indicate that coaches must be cognizant of the necessary alterations in posture and trailing limbs to enhance input to athletes throughout training and competition.
(Fujimori & Sado, 2025)	To evaluate the qualities of the muscle-tendon unit (MTU) in male high jumpers and untrained males to examine MTU adaptation and to	Twenty-four young men participated in the study, comprising 14 untrained males (controls, mean	Experimental Study	In high jumpers, the personal best record in high jump had a strong correlation with maximum voluntary contraction

	<p>elucidate the optimal MTU characteristics for high jumping.</p> <p>age \pm standard deviation: 23.6 \pm 2.1 years) and 10 amateur male high jump athletes (high jumpers, mean age: 20.1 \pm 1.6 years).</p>	<p>(MVC) torque ($r = 0.73$), however it showed no significant correlation with tendon stiffness ($r = -0.07$). The enhancement of muscle force exertion through training is crucial for enhancing high jump performance, however tendon stiffening is not essential for performance.</p>
<p>(Nicholson et al., 2022)</p> <p>To (a) characterize the hip-shoulder separation of elite high jump athletes during competition, (b) ascertain whether disparities exist between male and female athletes, and (c) investigate the correlation between hip-shoulder separation and the biomechanical parameters that define high jump technique.</p>	<p>Twenty-nine elite high jumpers (17 males, 12 females) were video captured at a frame rate of 120–200 Hz at the finals of the 2017 and 2018 World Athletics Championships.</p>	<p>Cross Sectional Study</p> <p>The findings underscore the distinct take-off characteristics of elite athletes and their dependence on hip-shoulder interactions for generating long-axis rotation. Coaches must consider the mechanical and physical implications of hip-shoulder separation while formulating technical models, conditioning programs, and coaching tactics.</p>

The results presented in the subsections “Research Publication and Development,” “Research Keyword Analysis,” and “Literature Review” present data that are interrelated. The results of the literature review, 50% of which were published in 2022-2025, are relevant to Figure 2 and Table 1, which show massive publications in the 2022-2025 period. The availability of articles discussing high jump (15 articles) is relevant to the results of the keyword analysis, which shows a weak correlation for the keyword “high jump.” Furthermore, when linking the results of the keyword analysis with the results of the literature review, there is a relevance shown by both subsections. This relevance is through research topics in the literature review (sport biomechanics, kinematic analysis, injury) in accordance with the results of keyword analysis (biomechanical phenomena, video recording, sport rehabilitation). Through the interrelationship presented in this Result section, the results presented will provide a coherent and comprehensive understanding.

Discussion

High jump in track and field is an event that involves several physical components (Turner et al., 2025). Explosive power, flexibility, and speed are a necessary combination in performing high jump movements. In addition, movement coordination is also an important aspect in determining the results of a jump. To support the optimization of jump results for high jump athletes, targeted training is required. On the other hand, research developments in high jump can also be used as a benchmark to measure whether the sport has undergone significant development or not (Boccia et al., 2017). Therefore, this study aims to analyze research developments in high jump and the aspects that influence jump results.

Based on the results, research has undergone significant development since 1968 (Figure 2 and Table 1). These results still need to be developed further, because of the total 276 articles identified discussing track and field (Figure 1), only 15 articles researched the topic of high jump. The results of the keyword analysis present research data that is still conventional in form and has evolved to become more modern due to digitalization. On the other hand, research has progressed in the 2020s by beginning to involve medical sports, such as rehabilitation.

The data presentation shown through keyword analysis is reinforced by the literature review subsection, which provides a discussion of how research on high jump was initiated. This subsection has been proven through research results relevant to the keyword analysis subsection. The results of the literature review explain that research in high jump culminates in discussing the stages of performing high jump movements, which are ultimately correlated with injuries in sports. These results indicate the involvement of digital technology in the high jump training process, with the aim of optimizing jump results.

Biomechanical Determinant of Performance



High jump results are influenced by several factors that coaches and athletes need to pay attention to. The initial stage of the high jump is crucial (Atta et al., 2025). Before jumping, athletes need to pay attention to their running technique in order to jump correctly and achieve maximum results. The success of the jump depends on the ability to convert the initial horizontal running speed into vertical speed when jumping (Atta et al., 2025). This process involves proper foot placement, with the jumping foot placed almost vertically (ahead) under the center of mass (CoM) (Alexander, 1990). This placement causes the ground reaction force (GRF) to transition from a horizontal to a vertical position with a very short contact time when jumping (Sado et al., 2018). During the initiation phase, especially when the athlete is running, the curved approach is the most recommended running technique for high jumping (Sado et al., 2022). The running curve not only aims to achieve a good jumping position, but also biomechanically creates a centripetal force that pushes the athlete's CoM inward. The tilt resulting from the curve approach is key to reducing horizontal braking momentum and shortening the body's turning radius. Without this tilt, horizontal momentum will generate a large braking force, reducing takeoff efficiency. Additionally, athletes need to pay attention to their foot position during takeoff to achieve an appropriate jump and maximize vertical speed. Thus, by focusing more on the initial phase, running technique, and foot placement, an athlete will successfully clear the bar and achieve optimal jump results.

The starting position in high jump contributes to the effectiveness of the takeoff. On the other hand, the style of jumping also influences an athlete's success in clearing the bar. One style that is considered phenomenal and most effective is the Fosbury flop (Tan & Yeadon, 2005). The Fosbury flop is the most efficient style because it plays a role in converting energy during takeoff and when the body clears the bar. The Fosbury flop allows athletes to clear the bar and keep their center of mass (CoM) below the bar at its peak (Song, 2013). This is achieved through hyperextension of the back (lumbar hyperextension). Athletes do not need to lift their entire body mass as high as the bar, enabling them to achieve greater jump heights compared to conventional styles. The athlete's body rotation in the air is the result of hip-shoulder separation during the takeoff phase. The interaction between hip and shoulder rotation creates the angular momentum needed to rotate the body over the bar (Dapena, 1980b; Laffaye, 2012). The strength and timing of this interaction, driven by the core muscles, are the main determinants of an athlete's success in clearing the bar.

Injury Risk and Related Factors

The adaptation of techniques in performing a sports movement is considered a fundamental part (Lindsay et al., 2023). This is because it will affect the effectiveness of the movement, enabling maximum results with a low risk of injury. In this case, sports biomechanics integrated with digital technology can play a significant role in optimizing performance and minimizing injuries (Souaifi et al., 2025). The use of wearable devices in monitoring athlete performance provides relevant data to coaches and athletes for evaluation. This is certainly correlated with track and field sports, especially high jump. The optimization of performance and minimization of injury risk described in the previous chapters can be achieved through the implementation of sports biomechanics.

This is evidenced by research by Becker & Wu, (2015), which explains how 3D technology-based motion analysis has a positive impact on the performance of high jump athletes. Based on this research, in this era of digitalization, digital technology-based sports biomechanics plays an important role in facilitating athletes to develop and become more professional. The maximum implementation of sports biomechanics has been proven to have a very positive impact on improving athletic performance, not only for the high jump. Sports biomechanics can be an appropriate tool or intermediary in providing early identification of an athlete's potential or risk of injury (Penichet-Tomas, 2024). Thus, athletes will feel safe and comfortable when training and competing, so that their performance will be maximized.

The effectiveness and efficiency demonstrated by the Fosbury Flop technique cannot be separated from the risk of injury that an athlete may experience. High jump is an asymmetrical movement, because take-off is always performed on one foot. This results in repetitive unilateral stress on the take-off joints (ankle, knee, hip). This load sometimes puts excessive pressure on the joints, which can lead to potential chronic injuries such as Achilles tendonitis, patellofemoral pain syndrome, or stress fractures (Wylde et al., 2022).



Findings related to Achilles tendon injuries indicate other conditions that can cause injuries in high jump sports (De la Fuente et al., 2022). In addition to excessive unilateral load on the joints, excessive tendon stretching can trigger rupture. Lack of knee flexion during the running phase until takeoff can cause the tendon to stretch excessively (Quarmby et al., 2023). When the tendon does not have sufficient flexibility and strength to stimulate foot movement, the risk of tearing or even tendon rupture increases.

Foot coordination in performing a series of movements and stability in maintaining these movements will minimize injuries to the lower limbs (Wang et al., 2025). However, this does not mean that the upper limbs are not susceptible to injury. The bending or rotation performed by a high jumper causes hyperextension of the spine. Weak core muscle stability will affect the spine, which bears excessive weight. This excessive weight can lead to spinal injuries, such as pinched nerves. In addition, there is also a risk of injury to the back of the neck (Paley & Gillespie, 1986). An improper landing position can put excessive pressure on the cervical spine. In this case, the cervical spine is at the same risk of injury as unilateral stress, because it is used repetitively for the landing process in high jump.

Implications for Training

Based on the Literature Review section, it is recommended that high jump training strategies shift from a conventional approach to a more modern one by integrating the principles of sports biomechanics. First, in the initial phase, specifically when running, coaches and athletes are recommended to implement a curved approach. Findings by Sado et al. (2022) prove that a curved approach is more effective than a straight approach because it can produce a higher Center of Mass (CoM) during takeoff without putting excessive strain on the joints. Based on the principles of sports biomechanics, the curved approach facilitates the conversion of horizontal speed into vertical speed, which is crucial in performing rotations when passing the bar, as explained in research by Tan and Yeadon (2005). Coaches are advised to use instructions that focus on external evaluation, such as directing athletes to focus on the track or bar, which has been proven to improve running posture to be more upright and increase vertical speed during takeoff.

Second, in terms of physical conditioning, coaches need to adjust their strength training programs. Currently, the general assumption is to focus on solving tendon stiffness issues through plyometric exercises alone. A recent study by Fujimori and Sado (2025) found that high jump performance has a more significant correlation with Maximum Voluntary Contraction (MVC) than tendon stiffness.

As a result, physical training programs should prioritize increasing muscle force exertion through resistance training to improve MVC capacity. This is important to ensure that muscles can generate maximum explosive power during the short takeoff phase. Third, the recommended technique for the takeoff and flight phases is hip-shoulder separation.

Research by Nicholson et al. (2022) highlights that the rotational interaction between the hips and shoulders is a key determinant in generating long-axis rotation, which allows athletes to rotate their backs efficiently over the bar. Coaches can design technical drills that focus on optimizing this movement so that athletes can move efficiently while in the air.

Finally, in terms of injury prevention, knee and ankle coordination should be the main focus to protect the Achilles tendon. Research conducted by De la Fuente et al. (2022) identified that tendon ruptures often occur due to a lack of coordination between knee flexion and ankle dorsiflexion during the running phase. Therefore, proprioceptive exercises (sensing the body's abilities) and footwork coordination are recommended as part of a training routine to ensure that the tendon does not experience excessive stretching. Through the integration of these four aspects (curved approach, physiological, rotation, joint coordination), the training program can be optimized to achieve peak performance while significantly minimizing the risk of injury.

Research Gaps

Although this study presents meaningful insights, there are several limitations that need to be considered. First, there is a limitation in the number of articles that specifically discuss high jump in track and field compared to articles on athletics in general. Second, some of the studies discussed used small sample sizes, with 4 out of 10 articles involving only 1 to 4 samples. Third, there is a predominance of male samples (elite athletes), so data on female and young athletes is still limited. Finally, the research designs



used were mostly cross-sectional and observational, without any control variables. These research designs also limited longitudinal monitoring, so the long-term adaptation of certain techniques cannot be fully ascertained (generalization).

Given the lack of specific literature on high jump, future research is recommended to apply a stronger, more inclusive design and consider long-term effects. In addition, research should expand the sample range by considering the proportion of female and young athletes to support the generalization of training techniques. On the other hand, the integration of 3D kinematic analysis, electromyography (EMG), and AI technology is highly recommended to provide understanding through a more comprehensive evaluation process. Thus, training model development can be carried out more precisely based on real-time data.

Conclusions

This study has successfully presented data that can serve as a reference for further research to develop significantly. This study proves that there is still minimal research data related to scientific article publications on high jump competitions in track and field sports. Nevertheless, this study has succeeded in contributing to track and field sports, especially related to high jump. This statement is reinforced by the results of previous studies presented in the literature review section.

In this section, the research has proven the adaptation and evolution from conventional theory-based research to more current or modern digital technology-based research. The expansion that has occurred in the medical field, such as sports injuries, is an indication that research in high jump does not always discuss the optimization of athlete performance, but also the safety of athletes in training and competition.

The development of research in high jump has made the sport more suitable for various groups (in terms of training), ranging from young people, adults, or even athletes with disabilities. The research results shown through a literature review provide a strong basis for this statement. However, this development does not mean that the exercises or approaches that have been implemented are sufficient and appropriate. More extensive and significant research still needs to be done, considering that the results of identification related to high jump research topics are still very minimal. An increase in the number of studies on high jump is highly recommended in order to provide a broader understanding or insight into the sport, both for athletes, coaches, and other sports practitioners. Thus, research (theory) developments can be updated, appropriate training models can be developed more precisely, integration with all aspects of sport science can be carried out, and ultimately have a significant impact on both the academic (research) and non-academic (athlete performance) sides.

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