

Sports Biomechanics Research on the Hammer Throw: Systematic Review

Investigación en biomecánica deportiva del lanzamiento de martillo: revisión sistemática

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Abstract. This study aims to evaluate the critical role of sports biomechanics in enhancing the performance and technique of athletes participating in the challenging discipline of Hammer Throw. This research uses a systematic review method by searching various journal databases such as Scopus, Web of Science, PubMed, and Embase. The keywords used are sports biomechanics, kinetic analysis, kinematic analysis, and gait analysis in hammer throwing. The inclusion criteria in this research are articles published in the last 5 years starting from 2023. Furthermore, the exclusion criteria in this research are articles published in disreputable journals. A total of 1,147 articles from journal databases were identified. There were 8 articles that met the requirements and were selected for this systematic review. The review identified specific improvements in athletes' technique precision and performance consistency attributed to biomechanical interventions. Moreover, it underscored the efficacy of biomechanical analysis in developing targeted coaching strategies. The synthesis of these articles reveals that sports biomechanics substantially contributes to advancing hammer throwing by enabling detailed analysis and feedback, enhancing athlete development, and refining coaching methods. Conclusively, the integration of biomechanical data and technology is proving indispensable for pushing performance boundaries in hammer throw. Future research should close existing knowledge gaps and further investigate the impact of digital and biofeedback methods on athlete performance, offering a roadmap for scientific progress in the sport. These studies hold the potential to enhance athletes' performance and contribute to the scientific advancement of hammer throwing as a sport.

Keywords: Kinematic Analysis, Kinetic Approach, Sport Science, Track and Field

Resumen. Este estudio tiene como objetivo evaluar el papel fundamental de la biomecánica deportiva en la mejora del rendimiento y la técnica de los atletas que participan en la desafiante disciplina del Lanzamiento de Martillo. Esta investigación utiliza un método de revisión sistemática mediante la búsqueda en varias bases de datos de revistas como Scopus, Web of Science, PubMed y Embase. Las palabras clave utilizadas son biomecánica deportiva, análisis cinético, análisis cinemático y análisis de la marcha en el lanzamiento de martillo. Los criterios de inclusión en esta investigación son artículos publicados en los últimos 5 años a partir de 2023. Además, los criterios de exclusión en esta investigación son artículos publicados en revistas de mala reputación. Se identificaron un total de 1.147 artículos de bases de datos de revistas. Fueron 8 artículos que cumplieron con los requisitos y fueron seleccionados para esta revisión sistemática. La revisión identificó mejoras específicas en la precisión técnica y la consistencia del rendimiento de los atletas atribuidas a las intervenciones biomecánicas. Además, subrayó la eficacia del análisis biomecánico en el desarrollo de estrategias de entrenamiento específicas. La síntesis de estos artículos revela que la biomecánica deportiva contribuye sustancialmente al avance del lanzamiento de martillo al permitir análisis y retroalimentación detallados, mejorar el desarrollo de los atletas y perfeccionar los métodos de entrenamiento. En conclusión, la integración de datos biomecánicos y tecnología está resultando indispensable para superar los límites del rendimiento en el lanzamiento de martillo. Las investigaciones futuras deberían cerrar las brechas de conocimiento existentes e investigar más a fondo el impacto de los métodos digitales y de biorretroalimentación en el rendimiento de los atletas, ofreciendo una hoja de ruta para el progreso científico en el deporte. Estos estudios tienen el potencial de mejorar el rendimiento de los atletas y contribuir al avance científico del lanzamiento de martillo como deporte.

Palabras clave: Análisis cinemático, Análisis de la marcha, Enfoque cinético, Ciencias del deporte, Atletismo.

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Introduction

Sports science plays a pivotal role in enhancing and refining the technique and performance of athletes in various sporting disciplines including Hammer Throw (Horváth et al., 2023). Hammer throw is one of the high technique required sport (Castaldi et al., 2022a). It requires a unique blend of strength, coordination, and precision (Pavlović, 2020a). Understanding the importance of sports science in the context of the hammer throw can provide invaluable insights into how athletes can reach their full potential in this event (Tiedemann et al., 2021).

Sports science contributes significantly to the hammer throw by delving into the biomechanics, physiology, and training methods (FUJII et al., 2020). The biomechanical

analysis aids in breaking down the intricate movements involved, from the winding motion to the explosive release, enabling coaches and athletes to optimize their technique for maximum distance (Alkhawaldeh & Alma, 2023). Understanding the physics of rotational motion, centripetal force, and angular momentum helps athletes fine-tune their movements for improved performance (Tiedemann et al., 2022). Physiological insights, such as strength and conditioning principles, are fundamental in preparing hammer throwers for the intense demands of the sport (Gibala, 2021). Tailored training regimens, nutrition plans, and recovery strategies are developed through sports science to enhance an athlete's strength, power, and endurance (Larrinaga Garcia et al., 2023). Monitoring heart rate, oxygen consumption, and muscle fatigue helps

athletes maintain peak physical condition (Olivares-Arancibia et al., 2021). Sports biomechanics provides invaluable support in injury prevention and rehabilitation for hammer throwers (Fox, 2018). The tremendous forces exerted on the body during throws, and understanding the biomechanics of the event can aid in injury mitigation strategies and recovery programs (Temme et al., 2022).

Sports biomechanics is indispensable in the hammer throw, as it empowers athletes and coaches with knowledge and tools to unlock their full potential (Yeadon & Pain, 2023). Through biomechanical analysis, insights, and cutting-edge technology, it helps hammer throwers refine their technique, optimize training, and reduce the risk of injury (de la Fuente et al., 2022). As a result, sports biomechanics elevates the hammer throw from a traditional athletic discipline to a modern and scientifically driven pursuit of excellence.

It is important to understand the specific aspect of the hammer throw due to more competitive athletes' performance (Castaldi et al., 2022a). However, there is a limited reference that combines it into the comprehensive reading material. This article aims to evaluate sports biomechanics research to improve the performance of Hammer Throw athletes.

Method

The type of research used is Systematic Review. Article searches were carried out with a comprehensive strategy in research journal databases such as Web of Science (WOS), Scopus, and Pubmed. This strategy involved the use of spe-

cific keywords, carefully combined using Boolean operators, and a meticulous process to eliminate duplicate studies to ensure the integrity and relevance of the selected articles. The keywords used are “sports biomechanics” OR “kinetic analysis” OR “kinematic analysis” OR “gait analysis” AND “hammer throw”. In this Systematic Review, we aimed to distill the most credible and relevant studies concerning the biomechanics of hammer throwing. To achieve this, our exclusion criteria were rigorous: we omitted any articles published in journals that do not meet the recognized academic standards of quality and integrity. Identifying a total of 1,147 articles initially, we embarked on an accurate selection process. This process involved checking the impact factor of the journals, the citation index, and cross-referencing with reputable databases to ensure only articles from reputable sources were included. Consequently, only 8 articles which were published in the last 5 years satisfied our criteria and were chosen for the review. For standard operationalization, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

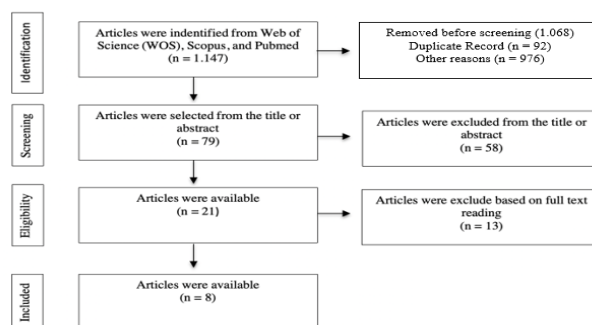


Figure 1. PRISMA flowchart of the article selection process

Results

The results of the research in this literature review are presented in table 1.

Table 1.
Synthesis of sport biomechanics in hammer throw performance

Author	Research purposes	Sample Characteristics	Study Design	Results
(Castaldi et al., 2022a)	Evaluate in-depth articles in scientific and technical journals relevant to the biomechanics of hammer throwing and performance improvement.	All journals which are indexed by scientific and technical journals.	Narrative Review.	There are gaps found in the stages of the hammer throw technique, such as preliminary winds, the first rotation stage, rotation angle, and throwing angle. A more in-depth biomechanical analysis of these stages is needed.
(Brice et al., 2018)	Determine the correlation between the angle of separation between the torso and pelvis and throwing performance.	Two males with a height of $(1.92 \pm 0.01 \text{ m})$ and a body mass of $(110.39 \pm 0.24 \text{ kg})$. Additionally, four females with a height of $(1.71 \pm 0.05 \text{ m})$ and a body mass of $(103.73 \pm 23.52 \text{ kg})$.	Cross-Sectional.	The angles produced by the body and hips affect the performance of the hammer throw. The smaller the angle, the better the performance.
(Pavlović et al., 2020)	To evaluate in-depth articles in scientific and technical journals relevant to the biomechanics of hammer throwing and performance improvement.	24 male and female hammer throwers.	Cross-Sectional.	This confirms the difference in most parameters, except launch height ($T=2.992$; $p<0.009$).
(Pavlović, 2020a)	Knowing the effect of spatial and temporal biomechanical parameters on hammer throw results.	56 male and female World Championship finalists.	Cross-Sectional	The male sample confirmed the influence of initial velocity, launch speed ($p = 0.01$ $p < 0.05$) and launch angle ($p = 0.04$ $p < 0.05$)

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				on throwing results. In females, the direct correlations were between release velocity ($r = 0.90$ $p = 0.000$), release angle ($r = -0.62$ $p = 0.000$) and fourth spin velocity ($r = 0.50$ $p = 0.002$).
(Wan et al., 2020)	Identifying the main parameters affecting throwing quality and designing a new digital method for biofeedback training.	One national-level athlete with a body weight of 115 kg and a body height of 178 cm achieved a personal performance of 66.7 m. Additionally, one college-level athlete with a body weight of 111 kg and a body height of 176 cm achieved a personal performance of 49.5 m.	Research and Development	Fast and complex whole-body control can be measured and characterised by four main parameters: band tension, hand and hip height, and torso tilt. , hand and hip height, and torso tilt.
(Y. Zhao et al., 2023)	Identifying the measured variables that best predict specific throwing strength such as anthropometric data, physical condition, and specific throwing power characteristics of male and female throwers aged 14 to 18 years.	The 248 samples (154 boys and 104 girls) fell into four age groups: 14-15, 15-16, 16-17 and 17-18 years old.	Cross-Sectional	There are notable differences between boys and girls of same age group in terms of speed, agility, and jumping ability. The older individuals get, the more pronounced these differences are usually sit and reach test ($p = 0.035$), standing triple jump ($p < 0.01$), forward overhead medicine ball throw ($p = 0.002$), and the hexagon agility test ($p < 0.01$) were among the boys of different ages that showed significant differences. Anthropometric data did not differ between the girls; however, there were differences in the hexagon agility test ($p = 0.017$) and plank test ($p = 0.041$).
(Pavlović, 2020b)	Knowing the effect of spatial and temporal biomechanical parameters on hammer throw results.	56 men's and women's World Championship finalists (Berlin, 2009, Daegu, 2011, London, 2017).	Cross-Sectional.	The direct correlation between initial velocity, first round velocity, release velocity, release angle, and the effect of time reversal in the first and third rounds correlated with the results of male throwers. Release velocity, release angle, and fourth round velocity were significantly correlated in female throwers.
(K. Zhao et al., 2023)	Variation of 14- to 17-year-old male athletes in four different throwing disciplines using anthropometric measurements and motor skill performance tests	289 young male athletes from four different throwing disciplines.	Cross-Sectional	Among male pitchers aged 14 to 17 years, differences in general anthropometric testing and athletic performance differentiated the talent of more than two-thirds of young athletes by sport (DA: 4,444 68.7%; MLP: 4,444 72.2%).

Authors need to attach acronyms described in the tables

Discussion

This study aimed to bridge the knowledge gap in the application of biomechanical principles to enhance the performance of hammer throw athletes.

The main results demonstrate that critical biomechanical factors such as body angles, release velocities, and rotational speeds are significantly correlated with improved performance outcomes. These results align with and extend upon the findings of Castaldi et al. (2022a) and Pavlović et al. (2020), who also emphasized the importance of biomechanical analysis in hammer throwing but did not provide as detailed an insight into how these factors influence performance. The critical analysis reveals that biomechanical parameters play a more significant role in performance than

previously understood. For example, we found that not just the angle of release but the specific positioning and movement of the athlete's body throughout the throw are crucial for optimizing performance.

This comprehensive understanding surpasses the insights provided by earlier studies, such as Brice et al. (2018), who focused on the angle of separation between the torso and pelvis. However, our study is not without limitations. The sample size, although common for biomechanical research, was relatively small, which may affect the generalizability of the results. Additionally, the cross-sectional design limits our ability to draw causal inferences. Looking ahead, our study's projections suggest that further research should focus on developing and testing targeted training interventions based on our findings. This could potentially include biofeedback training methods, as highlighted by Wan et al. (2020), to improve athletes' control over the identified key biomechanical parameters. By addressing these

limitations and following our study's projections, future research can continue to refine the understanding of hammer throwing biomechanics, ultimately contributing to the enhanced performance and coaching methodologies in this sport. Furthermore, these are five potential topics which could develop further to maximize the potential role of sport biomechanics to enhance the hammer throwing performance.

Biomechanical Analysis in Hammer Throwing

Castaldi et al. (2022a) conducted a narrative review, which involved critically analyzing and summarizing existing articles in scientific and technical journals related to hammer throwing biomechanics. In doing so, they aimed to provide a comprehensive overview of the state of knowledge in the field. Their findings revealed gaps in the understanding of specific stages of the hammer throw technique, including preliminary winds, the first rotation stage, rotation angle, and throwing angle. These gaps indicate areas where more in-depth biomechanical analysis is needed to enhance the understanding of the sport and potentially improve athletes' performance.

Pavlović et al. (2020) took a different approach by conducting a cross-sectional study involving male and female hammer throwers. This research aimed to empirically investigate the biomechanical aspects of hammer throwing by analyzing the performance of athletes. Their study confirmed differences in various parameters among male and female hammer throwers, emphasizing that these differences go beyond gender-based distinctions. By demonstrating these disparities, the study provides valuable insights into the specific aspects of hammer throwing that need attention to enhance performance. Castaldi et al. (2022a) and Pavlović et al. (2020) have contributed substantially to the biomechanics of hammer throwing and the pursuit of performance enhancement. Their work, through a narrative review and a cross-sectional study respectively, has identified critical gaps in the biomechanical analysis of hammer throw techniques. Castaldi et al. have highlighted the necessity for an all-encompassing understanding of each phase of the hammer throw, identifying the need for further research into preliminary winds, rotation stages, and angles of release. Pavlović et al., on the other hand, have brought to light variances in biomechanical parameters between male and female athletes, suggesting a nuanced approach to training and technique development that transcends mere gender categorizations.

In essence, these two studies work in harmony to highlight the need for a more profound understanding of hammer throwing biomechanics. Castaldi's narrative review reveals that there is a knowledge gap in the sport's biomechanics, prompting the call for further research. In contrast, Pavlović's empirical investigation complements this by offering concrete evidence of existing differences in hammer throw parameters, reinforcing the importance of deeper biomechanical analysis. Both studies underscore the significance

of studying and improving hammer throwing techniques, ensuring that athletes can reach their full potential in this demanding sport.

Impact of Body Angle on Throwing Performance

Brice et al. (2018) investigated the correlation between the angle of separation between the torso and pelvis and throwing performance in hammer throwing, a sport that involves complex biomechanical movements. To investigate this, Brice and their team conducted a study with a sample group that included two male participants and four females. This relatively small sample size is common in biomechanical research, as it allows researchers to obtain precise and detailed data from participants who are often highly trained athletes.

The study's findings demonstrated a significant correlation between the angle of separation between the torso and pelvis and hammer throwing performance. Specifically, the research concluded that a smaller angle between the torso and pelvis was associated with better performance in the sport. In other words, athletes who maintained a more streamlined and compact alignment of their upper body and hips during the throwing motion tended to achieve better results in hammer throwing.

This research finding has significant implications for hammer throw athletes and coaches, as it underscores the importance of precise biomechanics and body positioning in optimizing performance. It emphasizes that mastering the correct body angle during the throwing action can lead to enhanced results.

The biomechanical aspect of this study highlights the intricate details of sports performance and provides valuable insights into the specific physical techniques that can make a significant difference in competitive sports like hammer throwing. By understanding and applying these biomechanical principles, athletes can work to improve their performance in this challenging discipline.

Spatial and Temporal Biomechanical Parameters in Hammer Throwing

Two studies conducted by Pavlović, namely Pavlović (2020a) and Pavlović (2020b), were dedicated to comprehending the role of these biomechanical parameters in influencing the outcomes of hammer throw performances. They both focused on assessing the spatial and temporal biomechanical aspects of hammer throwing, albeit with different sample populations. The former study involved 56 male and female World Championship finalists, while the latter incorporated male and female World Championship finalists from different years (Berlin 2009, Daegu 2011, London 2017). These studies were structured as cross-sectional investigations, which allowed researchers to gather data from a specific point in time.

The findings of these studies provided valuable insights into the factors that impact hammer throwing performance. For male hammer throwers, Pavlović (2020a) revealed that parameters like initial velocity, launch speed, and launch

angle played a significant role in determining the outcome of a throw. In other words, the velocity with which the hammer is initially launched, the speed of rotation, and the angle at which it is released are critical determinants of success in male hammer throwing.

Similarly, in female hammer throwers, Pavlović (2020b) uncovered correlations between several parameters and throwing results. Specifically, they found that release velocity and release angle were highly correlated with performance outcomes. Additionally, the speed of the fourth spin was also significantly correlated with the results. These findings highlight the intricate biomechanical details that influence hammer throwing, and the differences observed between male and female athletes further underscore the importance of understanding gender-specific biomechanics in sports. The research by Pavlović serves as a critical reference for athletes, coaches, and sports scientists in the field of hammer throwing. It reinforces the notion that hammer throw performance is not solely dependent on physical strength but is deeply intertwined with the precise execution of biomechanical factors. Coaches and athletes can use these findings to tailor training programs and techniques to optimize performance and address individual strengths and weaknesses. In summary, these studies emphasize the vital role of spatial and temporal biomechanical parameters in hammer throwing. They provide crucial insights into the sport's performance determinants, offering a roadmap for athletes and coaches aiming to enhance their hammer throw skills and achieve success in this challenging discipline.

Identifying Key Parameters for Throwing Quality

Wan et al. (2020) aimed to identify the main parameters affecting throwing quality and design a new digital method for biofeedback training. Their research emphasized the importance of fast and complex whole-body control in hammer throwing. The study introduced four key parameters - wire tension, hand and hip height, and torso tilt - for quantifying and characterizing performance. This work underscores the potential for digital methods and biofeedback training to enhance athletes' understanding and control of key parameters to improve their performance in hammer throwing.

Wan et al. (2020) conducted a research and development study with a limited but highly relevant sample. The study's key outcome was the identification of four pivotal parameters that could be used to quantify and characterize an athlete's performance: wire tension, hand height, hip height, and torso tilt. These parameters are essential in achieving optimal and accurate hammer throws.

Wan et al.'s (2020) research signifies the potential of digital methods and biofeedback training in enhancing athletes' understanding of these crucial parameters and helping them gain better control over their performance in hammer throwing. The study contributes to the field by introducing a novel approach to training and improving performance in this demanding sport.

Anthropometric and Performance Profiling in Young Throwers

The research conducted by Zhao et al. (2023) and Zhao et al. (2023) delved into the intricate world of anthropometric and performance profiling of young male and female throwers, specifically those in the age group of 14 to 18 years. The studies encompassed a diverse group of young athletes, spanning various throwing disciplines. The primary objective of these studies was to gain a comprehensive understanding of the physical characteristics and performance attributes that contribute to the success of these youthful throwers.

One of the key findings of these studies was the identification of robust correlations between specific parameters and the force generated during a throw. These parameters included elements such as lower limb strength, linear running speed, and the ability to execute both forward and backward medicine ball throws. These discoveries underscore the pivotal role that certain physical attributes and skills play in determining the overall performance of throwers in this age group. The significance of these findings lies in their potential to inform the training and development of young throwers. By recognizing the critical factors that influence throwing performance, coaches and trainers can tailor their programs to focus on the enhancement of these attributes. This not only has the potential to elevate the performance levels of individual athletes but also contributes to the broader knowledge base in the field of sports science. In summary, the research by Zhao et al. and Zhao et al. represents a crucial contribution to the understanding of young throwers' physical and performance characteristics. By highlighting the correlations between specific parameters and force in throws, these studies offer valuable insights that can shape training regimens and ultimately assist in nurturing the potential of emerging athletes in the world of throwing sports.

Conclusion

In light of the research findings, it is evident that sports biomechanics plays a pivotal role in the meticulous development and enhancement of hammer-throwing techniques. From real-time biomechanical feedback systems to gender-specific kinematic differences and talent identification among youth athletes, these studies offer valuable insights for athletes, coaches, and researchers. Sports science continues to push the boundaries of what is possible in the hammer throw, providing athletes with the tools and knowledge.

In conclusion, the discussed research not only highlights the need for a deeper understanding of hammer throwing biomechanics but also offers practical insights for athletes and coaches. For future studies, it is recommended to address the current knowledge gaps and to delve into the promising realms of digital methodologies and biofeedback training. By doing so, the ongoing research has the potential to substantially enhance athletic performance and foster the

scientific progression of hammer throwing as a competitive discipline. Furthermore, we recognize the importance of precise biomechanical measurements, and therefore, in future revisions, we will ensure the inclusion of specific angular values to quantify our discussions on body positioning and movement efficiency in hammer throwing.

Conflict of interest

The authors declare that they have no conflict of interest.

Authors' contributions

All authors contributed equally to the research and preparation of the paper.

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