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Review article

Analyzing Sports Biomechanics of Hurdling Training: A Systematic Review

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Abstract

Background. Hurdling is a dynamic and technically demanding sport within athletics. It requires a unique combination of speed, agility, coordination, and strength to support good technique and achievement. The ability to excel in this sport depends on the athlete's mastery of these components, making it an interesting subject for sports science research.

Objectives. This study aimed to evaluate existing research on sports biomechanics as it relates to improving hurdling performance.

Materials and methods. The study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology of the relevant literature. A total of 15 articles published between 1990 and 2023 were identified as relevant to the focus of the study and selected for in-depth analysis.

Results. The findings showed that sports biomechanics research in hurdling training has mainly concentrated on the following key areas: kinematics analysis, the application of technology, and the potential injury studies. Although significant progress has been made in understanding the biomechanics of hurdling training, this study suggests the need for further and more comprehensive research. The research mentioned should delve deeper into the biomechanical factors influencing performance in order to develop optimal training methods and injury prevention strategies.

Conclusions. This review underscores the importance of continued research in this area, as it has the potential to enhance training approaches and improve athletic performance in hurdling.

Keywords: hurdling training, kinematic analysis, technology applications, sports injuries, kinetic analysis.

Introduction

Sports science has undergone a significant development from mere physical activity to a more structured physical activity (Shestakov & Fomichenko, 2021). Sports science began to become part of a legitimate academic field with numerous scientific studies in sport and physical training (Yan & Girard, 2023). Advances in technology and research methodologies resulted in the expansion of the scope of sports science (Schweinbenz, 2016). Sports science is a scientific field that includes aspects such as sports physiology (Lundgren et al., 2015), sports biomechanics (Forte et al., 2021), sports psychology (Zhang et al., 2021), sports nutrition (Amawi et al., 2022), sports rehabilitation (Moylan & Horne, 2013), and sports technology and analysis (Godfrey et al., 2023). The use of wearables, GPS and other software, is aimed at monitoring and improving the performance of athletes (Yu et al., 2022). In addition, sports science also includes the study of the social and cultural aspects of sport, as well as issues such as inclusion, gender and ethics, indicating an increasingly holistic approach to understanding and optimizing athletic performance (Strudwick, 2023).

The advancement of sports science has significantly contributed to understanding the complexities of athletic performance across various disciplines (Edouard et al., 2021). One example that can be observed is in the hurdle race number. Hurdles requires high coordination, balance, and timing to integrate sprinting with the technical demands of passing obstacles (Yendrizal et al., 2023). Hurdles represent a unique blend of techniques requiring athletes to master those combinations and achieve optimal performance (López Del Amo et al., 2018). Optimizing this performance is done through structured and organized training (Terrell & Ficquette, 2023). Evaluation and conditioning of athletes must be carried out, therefore the athlete performance can be monitored regularly (Nie, 2022).

The implementation of sports science, one of which is in sports biomechanics, becomes a means or media for evaluation and training conditioning for coaches and athletes (Navarro et al., 2021). The integration of biomechanical analysis into hurdling is pivotal for dissecting the multifaceted elements that contribute to an athlete's success (Adashevskiy et al., 2014). It also provides insight into technique optimisation, injury prevention and performance enhancement (Gaudino et al., 2021).

Biomechanics as a sub-discipline of sports science, plays a crucial role in elevating the understanding and execution of hurdling (Gong et al., 2023). Through the detailed examination of kinetic and kinematic analysis, biomechanics aids in identifying critical factors influencing hurdling efficiency and effectiveness (Hanley et al., 2021; Nagahara et al., 2021). This allows for the precise tweaking of technique, informed by evidence-based practices that can lead to significant improvements in speed, height, nor overall performance (Iskra & Coh, 2011). Biomechanical analysis should consider on aspects such as obstacle clearance technique, step pattern optimisation, and the body angle formed from the jump (Čoh et al., 2020).

This systematic review study aims to evaluate and analyze the development of sports biomechanics research in hurdling training. The competitive nature of hurdling and its technical complexity require innovative methods to enhance athlete performance. This systematic review also aims to explore the current landscape of biomechanics research in hurdling, identifying key findings, gaps in the literature, and potential areas for future investigation. By synthesizing the existing body of knowledge, this review seeks to provide athletes, coaches, and sports scientists with actionable insights that can be applied to training and competition, ultimately pushing the boundaries of what is achievable in the discipline of hurdling.

Materials and Methods

Materials for Analysis

Data collection was conducted on 22nd July 2024, through the SCOPUS website using the keywords "sports" AND "biomechanics" AND "hurdles". Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was applied in this study (Figure 1). During the identification process, there were 43 articles in the period 1990-2023, but not every year of publication related to the keywords used.

Organization of the Study

This was followed by a screening process and found 8 articles that were not related to sports and 20 articles that were not related to sports biomechanics. Based on the screening process, 15 eligible articles were obtained, but the researcher only selected 10 articles. The selection was based on the most citations and the most relevant articles according to the keywords and objectives of this study.

Methods of Analysis

This research is a qualitative method with a systematic review design. The database in this study comes from the SCOPUS database. The selection of the SCOPUS database as a systematic review study material is because SCOPUS is an internationally accredited and credible platform. referred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was applied in this study (Figure 1).

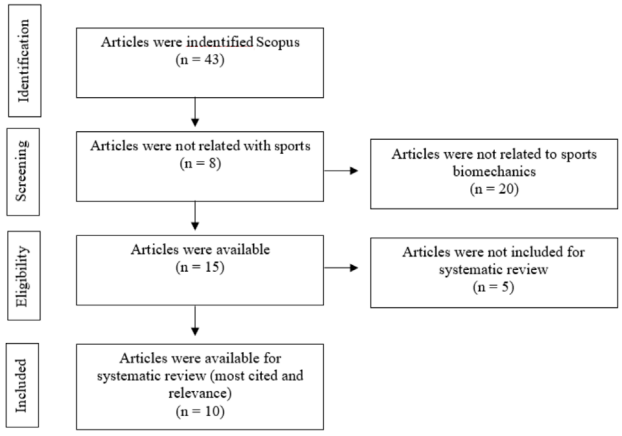

Fig. 1. PRISMA flowchart of the article selection process

Results

Publications of Sports Biomechanics in Hurdles

Research conducted in the field of sports biomechanics, especially in hurdling, has not experienced significant development. This is shown through the presentation of graphs or data based on the analysis of search results according to the keywords used through the SCOPUS database (Figure 2). Based on the results of data collection, research from 1990-2011 was stagnant, there was no significant increase in those

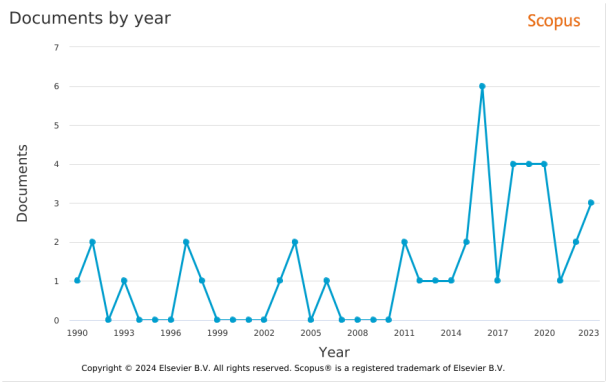

Fig. 2. Publications of sports biomechanics in hurdles

years. The increase began to occur in 2012-2023, with the peak of publication results in 2016 totalling 6 publications. However, the following year experienced a decline, and began to show a stagnant graph.

There is a disclaimer in the research results presented in this graph. The results presented are not all publications that are relevant to the keywords used. The results presented are divided into several fields that are not relevant to the keywords, such as 'gymnastic', 'animals OR dogs', 'economy', and others. Adjustments were not made by the researcher due to the lack of research conducted in the field of sports biomechanics in hurdling. If adjustments are made, the graph will not be formed effectively due to the small number of publications.

Countries Contributed on the Sports Biomechanics in Hurdles

The results in this study are similar to those presented in Figure 2. These results were not adjusted to capture the trend of research development across countries. Although the results are complex, they can be used as a visualisation in observing the developments that occur. So that it can be an evaluation in further research.

Based on the results presented (Figure 3), the United Kingdom (UK) is the country with the most contributions in sports biomechanics in hurdling. This is evidenced by the number of publications as many as 18 articles, more than 2 times that of the United States (US). The US ranked second with the number of publications is 8 articles. European countries occupy the top position and are followed by Australia at number 3. Asian countries are no less existent by ranking 4th and 6th, namely China and Japan. The results presented show that publications in sports biomechanics in hurdling are dominated by countries in Europe.

Systematic Review on the Sporst Biomechanics in Hurdles Training

The articles selected for review were the result of a screening process using the PRISMA method. The selection of articles with the most citations and the most relevant was carried out by the researcher by giving special notations to the articles that had been reviewed. The results of the review obtained 10 best articles that fit the criteria and objectives of this study (Table 1).

Discussion

The application of sports science brings changes and the development in hurdling. Sports science has connections with various fields and results in hurdling training. Especially sports biomechanics which possibly assist the athletes to optimize their performance and minimize the risk of injury (Bartlett & Bussey, 2013). The identification results in the SCOPUS database, presented the research trends about sports biomechanics in hurdles increases dynamically. European countries such as the United Kingdom and the United States are at the top of publications, with 18 and 8 studies respectively. Furthermore, the results of the systematic review are divided into 5 discussion topics. These topics are based on the conclusions of the 10 articles systematically reviewed in this study. The discussion on the systematic review is presented as follows.

Velocity and Angular Momentum as Important Role in Hurdles Training

Velocity and angular momentum are related in the hurdling technique. In Velocity provides momentum to the runner when taking off (Ozaki & Ueda, 2022). Based on

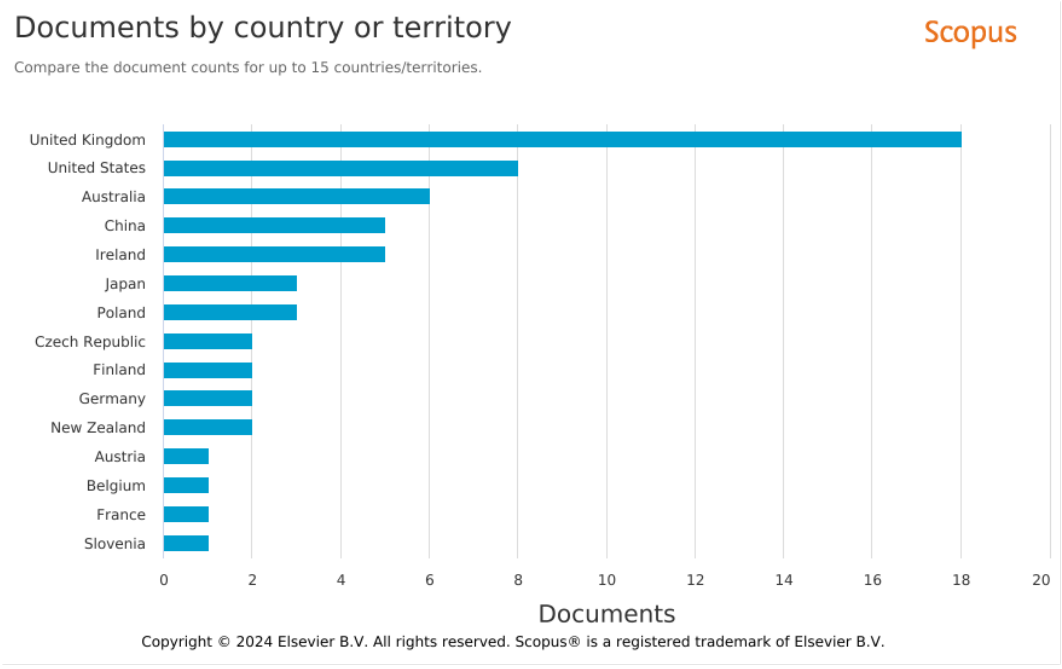

Fig. 3. Countries contributed on the sports biomechanics in hurdles

Table 1. Research results on the sport biomechanics in hurdling training

Author	Research purposes	Sample Characteristics	Study Design	Results
McDonald & Dapena, 1991	To obtain three-dimensional (3D) linear kinematic data on the techniques employed by Olympic-level male and female hurdlers during competition.	Thirty-two hurdlers – 23 men and 9 women – were captured on video using three-dimensional techniques at the 1988 US Olympic Trials.	Cross-Sectional Study	A rise in vertical velocity and a fall in forward horizontal velocity when the hurdle step is being taken off. After the hurdle, the forward velocity was mostly restored during the second support period. The center of mass's (CM) downward descent was not stopped until the second support phase after the hurdle was cleared. For the male participants, the center of mass (c.m.) parabola's peak was situated almost exactly above the hurdle, but for the female participants, it was situated 0.30 m forward of the hurdle. The findings showed that, in comparison to the men, the women used a parabola with a larger margin above the hurdle.
A. Salo & Grimshaw, 1998	To investigate the kinematic variability and sources of variation in sprint hurdle video motion analysis.	Four women and three men competing at the national level in the 100-meter hurdles for Britain offered their time to take part in the research. The women's mass was 62 kg (mean + SD), their height was 1.76 m (mean + SD), and their age was 20.1 years (mean + SD). For the men, the corresponding figures were 1.83 + 0.05 m, 80 + 8 kg, and 26.9 + 1.7 years. The men's and women's personal best times for the sprint hurdles were 14.11–15.38 seconds for the 110-meter hurdles and 13.65–14.15 seconds for the 100-meter hurdles, respectively.	Cross-Sectional Study	When used in conjunction with the analytical system and operated by a single person, the results generated are sufficiently precise and consistent for the majority of variables used in the kinematic analysis of tasks like hurdle clearance. According to the operator and the combination of analytical processes, displacement variables showed the highest degree of repeatability.
Krzeszowski et al., 2016	To create an algorithm for the estimate of parameters for hurdle clearance that are established by analyzing image sequences.	Five hurdlers in various training phases participated in the analysis. Two Polish youth champions and four Polish runners-up were among the candidates whose names were on file.	Cross-Sectional Study	The assessment of tracking quality was conducted using both qualitative visual assessments and ground truth data. By manually matching a 3D model to the hurdlers in the picture, ground truth data were produced.
A. I. T. Salo & Scarborough, 2006	To investigate how an athlete's own performance changes in a sprint hurdles run in terms of technique.	Four athletes—two men and two women—representing national or international standards voluntarily took part in the study and provided their informed consent. The female athletes, identified as Athletes A and B, were 1.68 ± 0.04 m tall, 25.5 ± 2.1 years old (mean ± SD), and weighed 58.5 ± 6.3 kg.	Cross-Sectional Study	On each run, athletes showed a decrease in their running speed over the hurdle at the ninth hurdle compared to the third hurdle. In addition, every participant showed signs of exhaustion during the ninth hurdle clearing. It is noteworthy that the athletes' observed technical modifications were not consistent. Even in situations where weariness may be affecting performance, athletes can learn how to cross the hurdle at a higher horizontal velocity with this method.

Table 1 (continued)

Author	Research purposes	Sample Characteristics	Study Design	Results
Hasenkamp et al., 2017	To analyze the distribution of total body angular momentum between the head, arms, and legs during the women's and men's 110-meter hurdle races. This was carried out in order to evaluate the validity of the theories put out in the literature and, if needed, to provide new explanations.	Thirteen hurdlers—nine female and twenty-three male—were videotaped using three-dimensional techniques during the 1988 US Olympic Trials.	Cross-Sectional Study	The hurdle clearance is contingent upon angular momentum in the negative X direction, which we have designated as "forward rotation." This corroborates the hypotheses previously put forth by other authors. It was found that the majority of the angular momentum is present in the right leg during the initial stages of the airborne phase.
Čoh et al., 2020	To analyze the biomechanical characteristics of the fifth hurdle clearing technique used by two world record holders, Dayron Robles of Cuba (who established a time of 12.87 seconds in 2008) and Colin Jackson of Great Britain (who set a time of 12.91 seconds in 1994), in the 110-meter hurdle event.	Two elite hurdlers from around the world took part in this experiment: Dayron Robles from Cuba (body mass 79 kg, height 191 cm) and Colin Jackson from Great Britain (body mass 75 kg). Both athletes were world record holders in the 110-meter hurdles, their area of expertise.	Comparative Study	The height differential of 10 cm between Dayron Robles and Colin Jackson results in a lower flight parabola for the Cuban athlete during hurdle clearance. In comparison to Jackson's achievement, Robles' technique of hurdle clearance is more effective. It is possible to argue that the strategies each athlete used to clear the hurdle have already reached the peak of their effectiveness.
Otsuka & Isaka, 2019	To compare different competitive-level 400-meter hurdlers within and between groups in order to assess their running pace and step characteristics.	14 male 400-meter hurdlers competing at the national level and 13 male world-class hurdlers (best records: 49.28 ± 0.41 s and 47.71 ± 0.44 s, respectively). Between 2010 and 2014, three of the athletes were ranked in the top 20, with one person accomplishing this accomplishment twice. These two instances—the first in the World rankings and the second in the Japan rankings—occurred in different rankings.	Observational Study	The national-level hurdlers' times were far longer than those of the elite hurdlers, as evidenced by a comparison of their times from the first and second parts of the competition. SL and SF did not significantly differ between national-level hurdlers and world-class hurdlers during the later phase. Comparing competitors in the same group showed that none of them shown a distinct preference for running faster during the beginning part of the race, as indicated by their shorter finishing times.
Falbriard et al., 2020	To determine whether inertial and magnetic sensors put on shoes may be used to identify the leading leg in 400-meter hurdles and detect hurdle clearance. Furthermore, the study sought to offer an examination of the spatiotemporal aspects of the hurdlers inside the intervals delineated by their positions.	Ten male athletes (aged 22 ± 4 years, measuring 183 ± 2 cm, weighing 69 ± 6 kg, and clocking 57 ± 3 seconds) and six female athletes (aged 23 ± 3 years, measuring 165 ± 4 cm, weighing 55 ± 2 kg, and clocking 64 ± 3 seconds) volunteered to compete in a single 400-meter hurdles event, each of which was outfitted with an IMU. Six female participants (165 ± 4 cm in height, 55 ± 2 kg in weight, 64 ± 3 s in time) volunteered to compete in a 400 m hurdles event that was outfitted with IMUs.	Cross-Sectional Study	The leading leg could be identified with 100% accuracy and hurdle clearance could be detected with 100% accuracy using the flight phase length method. Additionally, we achieved 100% accuracy in hurdle clearance detection and 99.7% accuracy in identifying the leading leg in a unipedal setup by merging the swing phase duration with the foot orientation.

Table 1 (continued)

Author	Research purposes	Sample Characteristics	Study Design	Results
Q. Li, 2014	To analyse the hurdle knee joint, ankle joint, and elbow and shoulder injuries from a medical perspective, combining this with an understanding of human structure. It makes suggestions on how to prevent and treat each type of injury, with the aim of standardising technical motions, reducing hurdler injury, and contributing to the development of hurdle techniques in our country.	A questionnaire survey was conducted on 400 hurdlers, with 250 male and 150 female participants.	Survey Study	In the research process, a questionnaire was initially distributed to 400 athletes, with the aim of identifying the most common body parts affected by sports-related injuries. The results indicated that ankle, knee, shoulder and elbow joints were the most frequently injured areas, with respective incidences of 31 %, 17 %, 16 % and 16 %.
Schmidt et al., 2020	The original paper is discussed in this commentary, with an emphasis on the ecological validity and the suitability of MIMU systems in field-based contexts, such elite athlete training or competition.	A recent paper entitled "Hurdle Clearance Detection and Spatiotemporal Analysis in 400 Meters Hurdles Races Using Shoe-Mounted Magnetic and Inertial Sensors" was published.	Review Study	We suggest that both the change of the data processing techniques and the basic assumptions underlying the error estimation are inappropriate for use in such an applied environment. As such, these metrics do not fairly represent the real performance of athletes at a modest skill level.

(McDonald & Dapena, 1991), velocity will increase when the athlete's position passes the hurdle, and will decrease when the athlete passes the hurdle. Optimal velocity will create effective angular momentum. Angular momentum created with width and height, will minimise the risk of athlete failure in jumping over the hurdle (Hasenkamp et al., 2017). In addition, through good angular momentum will have an impact on the smooth landing process as well. Thus, the risk of leg injury from hurdles athletes can be minimised.

Variables for Kinematic Analysis of Hurdling Training

Two-dimensional analysis or kinematics analysis supports the techniques in sport training and competition (Peebles et al., 2021). Kinematics analysis in hurdles reviews several aspects that affect the outcome of hurdle running. Running speed, jump height, foot angle, and jump angle are some of the kinematics analysis variables observed (Otsuka & Isaka, 2019; A. Salo & Grimshaw, 1998; A. I. T. Salo & Scarborough, 2006). The height and angle of the jump are important variables that determine the athlete's success in passing the hurdle. The kinematic analysis has the potential to provide the ideal recommendation for each athlete to improve their performance.

Hurdles Clearance Technique of the Professionals

Technical mastery is key to the success of a sport (Hassan & Morgan, 2015). Professional athletes do not show significant differences in their technique. According to the study of Čoh et al. (2020), the height difference is often highlighted when looking at the techniques of professional athletes. This difference is due to the difference in velocity of each athlete. The height distance between the body and the hurdle indicates the effectiveness of the professional athlete's technique. Furthermore, the effective results were influenced by the structured training method.

The Application of Technology in Hurdling Training

Technology has developed rapidly in the 21st century (da Silva et al., 2023). These developments have made significant changes in sports (G. Li & Huang, 2020). The role of technology in sports is presented through the application of a various kind of technology development and innovations to support sports activities. Wearable devices are one example of technological developments in sports (Wang, 2017). Falbriard et al. (2020), also tried to develop wearable devices to measure the jumping height and the body angle. It aims to measure the effectiveness of the movements made by athletes. The results of these measurements were used as evaluation material for athletes and coaches to determine the appropriate training program. The development of wearable devices that utilize magnetic components and sensor system were also carried out in hurdling training (Falbriard et al., 2020). However, there are some other potential improvements to enhance the utilization of the technology (Schmidt et al., 2020).

Sports Biomechanics Prevents Sports Injury in Hurdling Training

The kinematics analysis performed in sports biomechanics has another role, which is to assess the potential for injury related to the movements demonstrated by athletes (Saleh et al., 2021). The motion analysis result will be examined by a team of sports injury experts to prevent potential injuries (Hao, 2017). Motion observation could be conduct-

ed by analysing the joint position or range of motion (ROM) of an athlete's body (Ahmad et al., 2017). An effective ROM decreases the injury risk of the athlete, and vice versa (Park et al., 2020). Li (2014), explained that the support of the feet during take-off and landing will be considered to minimize injuries to the knees and ankles during hurdling training and competition. In conclusion, sports biomechanics has the potential for injury screening and evaluation for every sport, especially hurdling athletes.

Conclusions

Sports biomechanics research in hurdling shows a dynamic development trend. The result of the systematic review shows that sports biomechanics research on hurdling training is more focused on analyzing two-dimensional kinematics. The analysis was focused on hurdling athlete's range of motion (ROM), speed, and height. In addition, the application of technological advances could potentially be developed further. Recent studies show more reviews related to injuries in hurdles sports. This statement is evidenced by the screening results using the PRISMA method and only obtained 15 relevant articles. Furthermore, sports biomechanics research in hurdling training could be inquired about broader and more varied factors correlating hurdles.

Based on these research data, the researcher suggests that in future research, more in-depth research can be carried out related to sports biomechanics in hurdling training. Analysis of kinetics such as leg muscle power, agility, or flexibility of athletes can be studied in future research. In addition, research using special technology, artificial intelligence, and big data for hurdling training and talent scouting can also be done. Thus, the development of research in hurdles can be more widespread and experience a significant increase.

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Conflict of interest

The authors has declared that there is no conflict of interest.

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Аналіз спортивної біомеханіки тренувань з бар'єрного бігу: Систематичний огляд

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Реферат. Стаття: 9 с., 1 табл., 3 рис., 44 джерел.

Історія питання. Бар'єрний біг є динамічним і технічно складним видом легкої атлетики. Для забезпечення оптимальної технічної підготовки та досягнення високих результатів необхідна унікальна комбінація швидкості, спритності, координації та сили. Здатність досягти успіху в цьому виді спорту залежить від володіння спортсменом зазначеними компонентами, що призводить до зростання інтересу до цього виду спорту з боку дослідницької спільноти в спортивній науці.

Мета дослідження. Мета цього дослідження полягала в оцінці існуючих наукових праць у галузі спортивної біомеханіки щодо поліпшення показників результативності у бар'єрному бігу.

Матеріали та методи. Дослідження проведено із використанням методології «Переважні елементи звітування для систематичних оглядів та мета-аналізів» (PRISMA) задля аналізу релевантної літератури. Загалом 15 наукових статей, опублікованих між 1990 і 2023 роками, були визначені як такі, що відповідають тематиці дослідження, і відібрані для проведення поглибленого аналізу.

Результати. Отримані результати показали, що дослідження спортивної біомеханіки тренувань з бар'єрного бігу переважно зосереджені на таких ключових сферах: аналіз кінематики, застосування технологій та вивчення потенційних ризиків травматизму. Незважаючи на значний прогрес, досягнутий у розумінні біомеханіки тренування бар'єрного бігу, в даній науковій праці вказується на необхідність проведення подальших і більш комплексних досліджень. В рамках зазначених досліджень необхідно поглибити вивчення біомеханічних факторів, що впливають на результативність спортсменів з метою розробки оптимальних методів тренувань і стратегій щодо запобігання травматизму.

Висновки. Проведений аналіз підкреслює важливість продовження досліджень у цій галузі, оскільки потенційно сприяє вдосконаленню тренувальних підходів та покращенню показників спортивної результативності у бар'єрному бігу.

Ключові слова: тренування з бар'єрного бігу, кінематичний аналіз, застосування технологій, спортивні травми, кінетичний аналіз.

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