The impact of biomechanical analysis on sports performance of taekwondo athletes: a scoping review

El impacto del análisis biomecánico en el rendimiento deportivo de los atletas de taekwondo: una revisión exploratoria

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Abstract

Background: biomechanical analysis plays a fundamental role in enhancing athletic performance and preventing injuries, as it encompasses both qualitative and quantitative methods to evaluate techniques and tactics in taekwondo.
Objective: this article aims to investigate recent technological advancements applied to taekwondo from a biomechanical perspective, focusing on kinematic and kinetic aspects based on studies published in the last five years.
Methodology: A comprehensive review was conducted, analyzing biomechanical assessments that contribute to improving athletic performance through optimized techniques and tactics.
Results: The findings highlight that variables such as arm swing speed and knee joint angle are crucial for effective jumping techniques. Moreover, the precise evaluation of strike force is essential for monitoring performance. Performance differences were also noted based on experience, weight category, and gender. Elite athletes demonstrate greater impact forces and faster execution times, while medalists show superior reaction times, hip mobility, and favorable anthropometric traits.
Conclusions: The integration of biomechanical technologies in training enhances technical efficacy, supports injury prevention, and enables individualized strategies. These insights provide a robust foundation for future research and practical applications in taekwondo performance optimization.

Keywords

Athletes; kinematic; kinetic; martial art; performance.

Resumen

Introducción: el análisis biomecánico desempeña un papel fundamental en la mejora del rendimiento deportivo y la prevención de lesiones, ya que engloba métodos cualitativos y cuantitativos para evaluar técnicas y tácticas en taekwondo.
Objetivo: indagar los avances tecnológicos recientes aplicados al taekwondo desde una perspectiva biomecánica, centrándose en los aspectos cinemáticos y cinéticos, basándose en estudios publicados en los últimos cinco años.
Metodología: Se realizó una revisión exhaustiva que analizó las evaluaciones biomecánicas que contribuyen a mejorar el rendimiento deportivo mediante técnicas y tácticas optimizadas. Resultados: las variables como la velocidad de balanceo del brazo y el ángulo de la articulación de la rodilla son cruciales para técnicas de salto efectivas. Además, la evaluación precisa de la fuerza de impacto es esencial para la monitorización del rendimiento. También, se observaron diferencias de rendimiento en función de la experiencia, la categoría de peso y el género. Los atletas de élite demuestran mayores fuerzas de impacto y tiempos de ejecución más rápidos. Los medallistas muestran tiempos de reacción superiores, movilidad de cadera y características antropométricas favorables.
Conclusiones: La integración de tecnologías biomecánicas en el entrenamiento mejora la eficacia técnica, favorece la prevención de lesiones y permite estrategias individualizadas. Estos conocimientos proporcionan base sólida para futuras investigaciones y aplicaciones en la optimización del rendimiento en taekwondo.

Palabras clave

Atletas; cinemático; cinético; arte marcial; rendimiento.

Introduction

Biomechanical analysis plays a fundamental role in enhancing athletic performance and preventing injuries, as it encompasses both qualitative and quantitative methods to evaluate techniques and tactics (Teferi & Endalew, 2020). In sports science research, particularly in biomechanics, a wide range of technologies are utilized, including optical devices, electromyography, and inertial tracking systems, to analyze athletes' movements in detail (Edriss et al., 2024). These tools support the development of more effective training processes, underpinned by advanced technologies such as motion capture, computational fluid dynamics, and body dynamometry, all of which are essential for the application of biomechanics in sports (Bandeiras, 2019). Moreover, the use of biomechanical analysis tools has proven valuable not only in high-performance settings, but also in improving student assessments during school-based physical activities (Abdelkader et al., 2021).

In the context of martial arts, recent studies have examined a variety of biomechanical aspects, particularly focusing on kinematics and kinetics. For instance, research on pencak silat, a traditional Southeast Asian martial art known for its fluid motions and choreographed techniques, has contributed to a broader understanding of movement dynamics (Karo-Karo et al., 2023). Similarly, taijiquan (i.e., tai chi), an ancient Chinese discipline that integrates combat elements with meditative movement, has been studied for its emphasis on body control, breathing, and internal energy flow (Chu, 2022). Across different martial arts, scholars have explored variables such as timing, speed, joint angles, and force production (Hariri & Sadeghi, 2018; Sant'Ana et al., 2023). The increasing use of mobile technologies and wearable sensors has further enriched the biomechanical analysis of combat sports such as taekwondo, offering real-time data collection and analysis to support training and performance assessment (Ortega et al., 2022; Sant'Ana et al., 2023). Although the field of martial arts biomechanics is still relatively young, with systematic research beginning in the 1990s, interest has grown significantly—particularly in countries such as the United States, Brazil, and Poland (Góra & Pluto-Prądzyńska, 2023). This body of research has contributed to optimizing performance, reducing injury risk, and improving training methodologies in combat sports.

Within this field, biomechanical studies in taekwondo have provided valuable insights into the effectiveness of different kicking techniques. Postural stance, for example, has been shown to affect execution time, with positions at 0° and 45° being more efficient than the 90° stance (Estevan et al., 2011). Techniques such as the axe kick, roundhouse kick, and front-leg kick have been examined through 3D motion capture and force plate analyses (Hsieh & Huang, 2012; Tsai et al., 2005; Yao, 2023), with findings highlighting the importance of joint angles, angular velocity, and ground reaction forces in determining the speed and power of each kick (Estevan et al., 2011; Tsai et al., 2005).

Kinematic and kinetic analyses have further revealed critical performance factors. For example, the roundhouse kick depends on thigh muscle activation and coordinated knee flexion-extension for effective execution (Tan & Wang, 2000), while the side kick benefits from optimal leg extension and knee velocity to maximize foot speed and reduce execution time (Wąsik, 2011). Hip extension during the downward phase of the naeryo-chagi kick also significantly influences its velocity (Kloiber et al., 2007). Similarly, the bandal chagi is executed more effectively when there are large changes in knee joint angles and maximum hip flexion as the kicking and supporting legs cross (Choi & Kim, 2009).

Some studies have found that elite taekwondo athletes exhibit faster execution times, greater linear and angular velocities, and higher ground reaction forces compared to their sub-elite counterparts (Moreira et al., 2015). Interestingly, no significant differences in limb kinematics have been observed between dominant and non-dominant legs among high-level competitors, suggesting a high degree of bilateral proficiency (Falcó et al., 2009). Overall, the successful execution of taekwondo kicks is characterized by a coordinated sequence of movements initiated from the hip, progressing through the thigh, and culminating at the foot (Tan & Wang, 2000).

Given this background, the present study proposes a scoping review of biomechanical literature to objectively identify the kinematic and kinetic variables most frequently analyzed in studies of taekwondo performance. This approach aims to map current methodological practices, highlight the most and least explored research areas, and promote the generation of new knowledge to support evidence-based training and performance optimization in combat sports.

Method

This study was conducted considering the scientific literature on biomechanics in Taekwondo, highlighting kinematic, kinetic, and dynamic factors. The PRISMA statement was used as a guide for the proper execution of the scoping review. In addition, this study followed the review criteria proposed by Arksey and O'Malley (2005), who established a methodology structured in five stages, with the aim of providing a methodological framework for conducting scoping studies as a way to review the literature. which is presented below.

Identifying the Research Question

The issue addressed is the limited number of studies that comprehensively analyze biomechanical variables and their potential to enhance the technical training process in taekwondo athletes, particularly with regard to the analysis of technical gestures. Additionally, the study aims to identify which variables show similarities across existing research.

Identifying Relevant Studies and study Selection

The primary purpose of this research is to conduct a comprehensive and systematic search for published studies relevant to the research question. This includes articles from indexed scientific journals with impact factors, published in English within the last six years (2018–2024), that incorporate kinematic, kinetic, or dynamic processes in their methodology.

The procedure for identifying pertinent articles was carried out in June 2024 by three researchers, using academic databases such as Google Scholar, PubMed, Web of Science (WOS), and Scopus. The search strategy utilized Boolean operators with the query: biomechanics AND taekwondo athletes AND technical gestures, to select relevant manuscripts.

The process identified several studies, which were subsequently analyzed using the Mendeley software for an initial screening to eliminate duplicate manuscripts or those not meeting the inclusion criteria. The selected articles were further evaluated to determine their inclusion in the final study selection.

The exclusion criteria for the studies were: previous studies which were established more than or equal to six years ago (≤ 2017), language other than English, articles that did not include kinematics, kinetics, and dynamics studies, and review articles that did not objectively specify the evaluation teams.

Charting the Data

The reviewers conducted a systematic analysis of the manuscripts to identify variables, focusing on similarities in methodologies, equipment, and results. They categorized the studies based on three key characteristics: (1) study population characteristics, (2) methodological approaches, and (3) results and conclusions. During this phase, data were extracted and entered into charting forms using Excel, enabling systematic organization and streamlined analysis of the findings. This process facilitated comparisons across interventions, aiding in the identification of patterns, research gaps, and emerging themes in the field of sports performance biomechanics in taekwondo. Ultimately, this approach enhances the understanding of the field studied and supports researchers and stakeholders in making informed decisions based on the manuscripts selected for further analysis.

Collating, Summarizing and Reporting the Results

Data was extracted using charting techniques and organized into standardized forms in Excel, categorized by variables such as the efficacy of striking techniques and performance metrics associated with biomechanical movements. The analysis was conducted through tables that facilitated the identification of data patterns. A narrative summary combined the findings, structuring the information for subsequent interpretation within the context of sports performance biomechanics in taekwondo. This approach ensures systematic organization and rigorous analysis, providing coaches and taekwondo athletes with a scientific foundation for optimizing training.

This study adopts the scoping review framework proposed by Arksey and O'Malley (2005) due to its systematic and rigorous approach to identify and analyzing literature. This methodology ensures clarity in formulating the research question, precision in selecting relevant studies, and effective data organization, yielding a coherent synthesis. By facilitating the identification of knowledge gaps and informing future research in sports performance biomechanics in taekwondo, this approach provides a robust foundation for making advances in this field.

Results

The data were analyzed following the established criteria and tabulated to identify the most consistent variables, which made it possible to determine the number of studies that met the requirements. The selection of these studies was performed by the three researchers. Initially based on the titles and then by reading the abstracts, the relevance of each study was evaluated according to the objectives, determining that 19 studies fulfilled the established criteria. Figure 1 illustrates the process of acquiring the information, as well as the screening procedure used to identify relevant studies, by using the PRISMA report flowchart as a reference (Page et al., 2021).

The PRISMA diagram outlines the selection process for the studies included in the review. A total of 2,697 records were identified across four databases. After removing duplicates, language-incompatible records, and irrelevant studies, 2,534 records remained for screening. Of these, 130 were evaluated according to their title and abstract, and 34 full-text articles were reviewed. Ultimately, 19 studies met the eligibility criteria and were included in the final analysis.

Figure 1. PRISMA Flowchart for Manuscript Selection

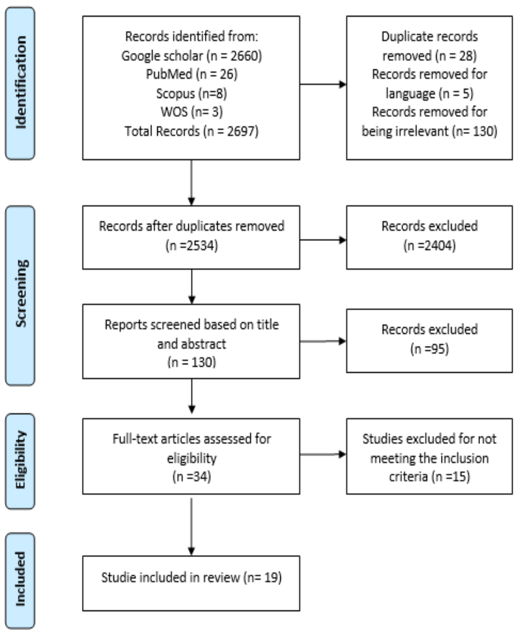

Table 1 presents the general characteristics of the population of all studies with a sample range of participants, the lowest value being 6 and the highest 34 where the participation according to sex was: Men (47%), did not specify the population (32%), both sexes (16%), and Women (5%). In terms of experience level: Elite (37%), black belt (16%), unspecified (16%), national athletes (16%), university (10%), and master's (5%).

Table 1. General Characteristics of the Population Found in the Manuscripts

Author (year)	n	Age (years)	Experience (years)	Weight (kg)	Height (cm)	Sex	Level
Jung and Park (2018)	10	21.7 ± 0.5	NR	60.6 ± 3.7	173.1 ± 4.3	Male	Elite
Son et al. (2018)	11	19.6 ± 0.8	NR	68.4 ± 8.3	178.8 ± 6.6	Both genders	College level
Górski & Orysiak (2019)	6	20 ± 3.2	NR	75.3 ± 10.9	185 ± 8.5	No mentioned	Elite Olympic
Moreira et al. (2019)	34	35	24	72	177	No mentioned	Black belt

Miziara et al. (2019)	8	17 to 19	NR	69.5 ± 12.5	NR	Male	Black belt
Ervilha et al. (2020)	16	23 ± 4	12 ± 4	62 ± 9	171 ± 5	Both genders	Elite vs novice
Liu et al. (2021)	19	19.9 ± 0.9	NR	67.8 ± 9.6	177.5±6.0	Male	Elite
Moreira et al. (2021)	7	23.6 ± 2.1	7.92	69 ± 9.5	168 ± 5	Both genders	Elite
Nadzalan et al. (2021)	24	22.1 ± 1.3	NR	69.8 ± 4.5	173 ± 8.0	No mentioned	Black belt
Wąsik et al. (2021)	15	22.5 ± 6.2	NR	71.9 ± 11.5	175.7 ± 8.4	Male	Elite black belt
Huang et al. (2022)	18	19.8 ± 1	NR	68.2 ± 9.7	178.1 ± 5.6	No mentioned	Elite
Ibrahim et al. (2022)	25	22.5 ± 1.3	NR	75.9 ± 13.6	172 ± 14	Male	Elite
Jung and Park (2022)	10	21.7 ± 0.5	8.91 ± 1.1	60.6 ± 3.7	173.1 ± 4.3	No mentioned	No mentioned
Wasik et al. (2022)	15	21.9 ± 6.8	NR	71.1 ± 11	175.7 ± 8.4	Male	Master
Jia et al. (2023)	12	18 ± 2.2	NR	70 ± 14.8	182.1 ± 8.6	Male	College level
Liu et al. (2023)	12	19.6 ± 2	3.8 ± 2.0	70 ± 9.8	180 ± 7.3	Male	National
Sun et al. (2023)	10	NR	NR	NR	NR	Female	National
Yao (2023)	30	NR	NR	58, 68, 80	NR	No mentioned	No mentioned
Góra et al. (2024)	14	28.5 ± 6.5	NR	77.5 ± 6.1	180 ± 1.4	Male	National

Table 2 shows that according to the methodology, the most used devices were: Vicon motion capture system (60%), force platforms (37%), electromyography (21%), and other equipment (16%). The Roundhouse kick technique was the most studied (74% of the articles). Observational studies predominated 84% of articles), and the predominant biomechanical analyses were: kinematic 84%, kinetic 26%, and EMG 21%.

Table 2. Methodological overview of the studies

Author (year)	Used devices	Techniques	Type of study	Analysis type
Son et al. (2018)	Oxford Metrics Vicon MX-T10 infrared cameras and AMTI OR6-7 force plate	Unspecified	Case-control study	COP, variables in the time domain
Jung and Park (2018)	MX-13 Vicon™ motion capture system, calibration frame with 36 control points, and a reflective marker on target	Roundhouse kicks	Observational	Kinematics
Moreira et al. (2019)	Eighteen reflective markers, Smart Capture kinematic system (BTS®) with 7 cameras, and two force plates	Roundhouse kicks	Observational	Kinematics
Miziara et al. (2019)	OptiTrack 3D motion capture system and Shimmer 2R wireless system for EMG	Roundhouse kicks	Observational, cross-sectional or repeated-measures study	Kinematics variables, and EMG
Górski and Orysiak (2019)	Dynamometric punching bag with built-in accelerometers and BTS6v0 software	Roundhouse kick and side kick	Observational	Dynamics
Ervilha et al. (2020)	Surface EMG from Noraxon and an electrogoniometer from EMG-System	Roundhouse kicks	Cross-sectional observational study	Fractionated reaction time and EMG
Nadzalan et al. (2021)	Vicon T10s motion analysis system with six infrared cameras and reflective markers	Axe kick	Within-subjects, repeated measures design	ROM, kinematics
Wąsik et al. (2021)	Ten NIR Vicon MX-T40 infrared cameras	Roundhouse kicks	Observational and correlational	Kinematics
Huang et al. (2022)	Eight Eagle digital infrared high-speed cameras and a Daedo electronic body protector	Roundhouse kicks	Observational	Kinematics and kinetics
Wasik et al. (2022)	10 NIR Vicon MX-T40 infrared cameras	Roundhouse kicks	Descriptive observational and comparative	Kinematics
Jung and Park (2022)	Vicon motion capture system with 7 high-speed cameras (250 Hz)	Roundhouse kicks	Observational	Kinematics
Ibrahim et al. (2022)	Multiple high-speed Vicon T10s cameras, an electromyography (EMG) system with EMG workstation software, and a force platform	Front kick	Randomized, controlled, within-subjects study with a repeated-measures design	Kinematics and kinetics
Yao (2023)	Three-dimensional kinematic motion capture system	Unspecified	Observational	Kinematics
Liu et al. (2023)	Vicon system for 3D motion capture, Kistler force platform, and Daedo EBP	Roundhouse kicks	Cross-sectional observational study	Kinematics and dynamics
Sun et al. (2023)	EMG Noraxon Ultium 32 wireless surface electromyography system, Vicon Nexus 1.85 motion capture system, and 12 HD 16-megapixel cameras	Roundhouse kicks	Within-subjects, observational	EMG, kinematics
Jia et al. (2023)	Vicon optical motion capture system, Kistler 3D force plates, and DAEDO Protector and Scoring System	Roundhouse kicks	Cross-sectional observational study	Kinematics and dynamics
Góra et al. (2024)	Force plate (AMTI, model MC12-2K, 2000 series) and wireless IMU sensor (Ultium by Noraxon)	Side kick, turning kick, and which kick	Observational, within-subjects, non-controlled experimental study	Kinetics and dynamics

Table 3 shows that the most common results revealed significant differences in several variables related to performance and kicking technique in taekwondo. The studies reviewed highlighted notable differences in factors such as speed, muscle activation, impact strength, and technical performance, comparing various conditions, techniques, or groups of athletes. Significant differences accounted for 52.63% of the results, while 15.79% showed no significant differences, and 10.53% corresponded to specific results. Regarding the statistical tests, 42.11% of the studies used an ANOVA, 26.32% applied t-tests, and 26.32% used repeated-measures ANOVAs. Other analyses included the Wilcoxon test (15.79%), Pearson's correlation (15.79%), and the Mann-Whitney test (10.53%), while 5.26% of cases did not specify the analyses.

Table 3. General data on results and conclusions

Author (year)	Variables	Important results	Statistical	Conclusions
Jung and Park (2018)	Angles of backward step	Larger angles increased foot velocity; smaller angles enabled quicker counterattacks but left athletes more vulnerable	Repeated measures ANOVA with Bonferroni post-hoc test	The optimal angle for effective defense and attack was 60°, approximately two-thirds of 90° in the x- and y-axes
Son et al. (2018)	Velocity and RMS in AP and ML directions	Postural stability was lower in the uninjured leg of the CAI group when standing on one leg with eyes closed	2-way repeated measures ANOVA; independent and paired t-tests	Individuals with CAI require proprioceptive, neuromuscular, and strength training to reduce the risk of recurrent ankle sprains
Górski and Orysiak (2019)	Impact force of dominant and non-dominant leg kicks	Significant differences between dominant and non-dominant legs in impact force and correlation with anthropometric indicators	Repeated measures ANOVA, Scheffé post-hoc, t-tests, Pearson's r	The optimal posture for maximal impact force was with the dominant leg further from the target
Miziara et al. (2019)	Muscle activity: hamstrings, vastus lateralis, biceps femoris	Hip and knee extension are required during the stance phase to initiate kicking; both phases are crucial	Wilcoxon and Spearman tests	Training programs must consider both stance and flight phases
Moreira et al. (2019)	Muscle force production	ROM, angular velocities, and force production indicate that slow movement is a distinct technique	Not mentioned	Slow movement may complement but not replace traditional training
Ervilha et al. (2020)	Premotor time, response time, and movement time	Elite athletes had shorter premotor time and total task time, but longer response time compared to novices	t-tests and Cohen's d effect size	Elite athletes initiate movement more quickly after an auditory cue, with shorter total task and movement time
Liu et al. (2021)	Pelvic, hip, and knee kinetics during kicks	Velocities and angles increased with greater attack angles	Repeated measures ANOVA and effect sizes	Proximal rotational and linear kinematics should be adjusted to deal with varied attack angles
Moreira et al. (2021)	Isokinetic torque, kick duration, velocity, and impact	Variables with higher effect sizes were used in LDA to predict competitive level	ANOVA, Mann-Whitney, Pearson/Spearman, LDA, effect sizes	Hip strength is the main muscular factor influencing kicking performance
Nadzalan et al. (2021)	Dominant/non-dominant leg during axe kicks with loads	3% body mass load had no significant kinematic effect; 5% and 8% loads affected performance	Repeated measures ANOVA	3% loads can be useful in training; heavier loads may negatively impact technique
Wąsik et al. (2021)	Target form and movement velocity	Shield target led to highest overall velocity; air target produced highest velocity in proximal segments; ball target yielded highest foot velocity	ANOVA and MANOVA	Hard targets are useful for motor preparation, soft targets for technical training
Huang et al. (2022)	Leg segments before and after impact	Elite athletes achieved greater impact by increasing linear velocity of the kicking leg segment	Paired t-tests (with effect sizes), Pearson correlation	Momentum after contact and velocity of the proximal segment before impact are key factors for scoring
Ibrahim et al. (2022)	Kinetics and muscle activation with wearable resistance (WR)	No significant differences were found with various WR loads	Repeated measures ANOVA	Long-term effects of WR on performance should be investigated
Jung and Park (2022)	Segment contribution to foot velocity	Significant differences between thigh, trunk, and whole-body depending on displacement phase	Repeated measures ANOVA with Bonferroni post-hoc test	During MKF phase: thigh contributed 51–64.4%, trunk 16.7–29.9%, whole body 5.1–13.4%
Wasik et al. (2022)	Execution time and peak velocity of the kicking leg	Significant differences between limbs; leg length did not affect kicking speed	ANOVA and Pearson correlation	Leg length does not influence the velocity of the roundhouse kick
Jia et al. (2023)	Double roundhouse kick biomechanics vs. scoring success	Angular and linear velocities positively correlated with successful scoring	Pearson correlation, stepwise multiple regression	Ankle angular velocity of the dominant leg and linear velocity of the non-dominant foot significantly influenced scoring
Liu et al. (2023)	Lower limb biomechanical characteristics	No significant differences in time or CG between legs; significant differences in knee moment and vertical velocity	Wilcoxon signed-rank test	DRK requires high symmetry; important variables showed significant asymmetries
Sun et al. (2023)	Muscle activation in successful vs. failed kicks	No EMG differences in preparation and execution phases; time differences observed between hits and misses	Paired t-tests and post hoc analysis	In failed attempts: thigh muscles generated force; in successful ones: lower leg muscles acted on the thigh
Yao (2023)	Biomechanics and scoring across weight categories	Differences in angles, velocity, torque, action time, and displacement between weight categories	Independent t-tests, ANOVA	Weight differences influenced horizontal kick velocity
Góra et al. (2024)	Force, foot acceleration, and effective mass in kicks	Turning kick: 2,661.53 N, 150.56 m/s², 20.12% mass; Side kick: 4,596.15 N, 74.34 m/s², 73.09% mass	Mann-Whitney U test	Training should focus on increasing effective mass and foot acceleration to improve force output

Discussion

This review aims to compile the most recent technological advances applied to taekwondo from a biomechanical perspective, with a particular focus on kinematic and kinetic aspects, based on studies published in the last six years. We believe that this work will provide researchers with a solid basis to initiate new studies and facilitate decision-making in future research, by addressing key themes throughout the manuscript.

The biomechanics of taekwondo has been the focus of recent research, which has advanced the understanding of how biomechanical variables influence athletes' performance, technique, and safety in this martial art. Studies such as Jung and Park (2018) conducted an in-depth analysis of how defensive techniques affect the execution of roundhouse kicks, identifying key variables such as the duration of strike phases and trunk angle. Their findings highlight the significance of the backward step angle, suggesting that an optimal angle of approximately two-thirds of 90° enhances both attack effectiveness and defensive capability, offering potential applications in training programs to optimize efficiency in real combat scenarios.

Similarly, Górski and Orysiak (2019) investigated the impact force of kicks, distinguishing between those performed with dominant and non-dominant limbs. Their research indicates that factors such as body mass and composition significantly affect strike effectiveness, suggesting that coaches should tailor training programs to account for these differences to enhance each athlete's specific strengths. Additionally, their study proposes that targeted balance and neuromuscular training could aid in injury prevention, calling for further research into personalized techniques for rehabilitating recurrent ankle sprains in taekwondo athletes.

Another valuable contribution comes from Ervilha et al. (2020), who explored differences in reaction time and muscle activation patterns between elite and novice athletes. By breaking down reaction time into specific components, they demonstrated that improving these times is crucial for optimizing technical performance. This underscores the need for training programs tailored to these factors to develop more effective and safer skills, particularly for athletes at varying levels of experience.

Further experiments, such as those by Moreira et al. (2019), have shown that kick execution speed significantly impacts muscle force production. This finding suggests that training should incorporate diverse methods, including real and dynamic combat scenarios, to maximize technique effectiveness under high-pressure competitive conditions. Incorporating analyses of different training approaches, such as speed and endurance training, could enhance not only technique execution but also postural stability, a critical factor in a sport requiring high mobility and agility.

From a different perspective, Jia et al. (2023) emphasized the link between lower limb biomechanical indicators and effective scoring in the double roundhouse kick (DRK) technique. They identified twelve variables that were significantly correlated with competition scores, highlighting the need for a detailed biomechanical approach to improve these techniques. However, many studies, including this one, faced limitations such as small sample sizes, a focus on single techniques, and a lack of real combat context, which restricts the generalizability of findings to broader populations and settings.

The table of participant characteristics (Table 1) reveals a diversity in age (17–35 years), level of experience (novice to elite), and weight categories, which strengthens the contextualization of the biomechanical findings. However, inconsistencies in reporting experience, sex, or injury history, combined with small sample sizes (6–15 participants), limit comparability and generalizability. Future studies should prioritize larger, more heterogeneous samples and longitudinal injury data to enhance safety outcomes.

The table on devices and methodology (Table 2) highlights the use of advanced technologies such as motion capture, force platforms, and electromyography, ensuring precise kinematic and dynamic measurements. Yet, the reliance on observational designs and the absence of real combat simulations reduces ecological validity, suggesting a need for experimental studies that integrate comprehensive analyses in dynamic settings with standardized protocols.

Finally, the table on variables and results (Table 3) demonstrates a rigorous approach, with robust statistical tests identifying critical factors such as velocities, forces, and muscle activation. However, the focus on a limited range of techniques (primarily roundhouse kicks), small samples, and insufficient injury data, weaken applicability. Future research should explore a wider variety of techniques, incorporate simulated combat analyses, and develop integrated biomechanical models to improve performance and injury prevention in taekwondo.

Looking ahead, it is essential for future studies to broaden sample diversity, encompassing athletes of varying skill levels, sexes, and taekwondo styles, to achieve a more comprehensive understanding of biomechanical differences. Investigating the impact of targeted training programs on reaction time and muscle activation across different athletes with different levels of experience, as well as examining the influence of environmental variables in competitions, will be critical. Combining advanced biomechanical analyses with psychological and neuromuscular measurements could provide a more holistic perspective on taekwondo performance.

Conclusions

The biomechanics of taekwondo has established itself as a critical field for optimizing athletes' performance and technique, as evidenced by recent studies that analyzed variables such as angles, velocities, impact forces, and muscle activation patterns. Research underscores the importance of optimal angles (e.g., 60° in the backward step), the influence of limb dominance and body composition on kick effectiveness, and the need to enhance reaction times and postural stability to refine technical execution. However, limitations such as small sample sizes, observational designs, and the absence of real combat contexts limit the generalizability of the findings. Future research should prioritize larger and more diverse samples, integrate kinematic and dynamic analyses in simulated combat scenarios, and explore a wider range of techniques and personalized training programs. Combining advanced technologies with interdisciplinary approaches, including psychological and neuromuscular measurements, will be essential for developing training strategies that maximize technical and competitive performance in taekwondo.

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