TAEKWONDO KICKS AT THE CENTER OF BIOMECHANICAL RESEARCH: SYSTEMATIC REVIEW

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Abstract:

Taekwondo is an Olympic martial art that emphasizes complex kicking techniques requiring meticulous biomechanical execution. Understanding the mechanical determinants of these kicks is essential for performance enhancement and injury prevention. This systematic review aims at combining the available literature on the kinematic and kinetic features of taekwondo kicks to understand the biomechanics of the technique and training implications. A comprehensive search was done in the PubMed, Scopus, and Web of Science databases following PRISMA 2020 guidelines. The studies included used experimental methods, were published in scientific peer-reviewed journals and focused on the biomechanics of taekwondo kicks from the post-1996 period. A total of 294 articles were identified, and 86 studies met the inclusion criteria. The analysis revealed four main themes: dollyo chagi (n=49), ap chagi (n=9), yeop chagi (n=4), multiple kicks (n=12) and other kicks (n=12). The most consistent determinants of performance were hip joint torque and ground reaction forces (kinetics), and distal segment velocity (kinematics). Dollyo chagi had the highest rotational dynamics, necessitating power and speed, while yeop chagi showed how mass can be efficiently utilized to produce force. Ap chagi used a proximal-to-distal energy transfer mechanism to achieve the most efficient energy transfer. This review confirms the importance of biomechanics in the execution of taekwondo kicking techniques. It determines energy transfer, joint coordination, and muscle activation as crucial factors that describe the performance. Coaches should focus on hip mobility drills and proximal-to-distal sequencing exercises to enhance power output while minimizing joint loading to reduce injury risks.

Keywords: *taekwondo, kicks, biomechanics, kinetics, kinematics*

Introduction

Taekwondo is a martial art with a great history and evolution of sport. The term taekwondo literally means ‘the way of the hand and foot,’ and it is most famously known for its kicking techniques (Yel, Çakır, Kurcan, & Coşkuntürk, 2023). The growth of taekwondo has been influenced by various cultural and social factors. After the Korean wars, taekwondo began to gain popularity as a sport all over the world, which led to its widespread practice in different countries. This vogue also led to the development of both technical and performance aspects of taekwondo (Ölmez, 2023). The international status of taekwondo was also boosted by the inclusion into the Olympic Games’ programme for the first time in 1988 in Seoul (Moenig, Cho, & Song, 2012; Pena-Sanchez, Mieles-Ramirez, Patino-Palma, 2022). Within the framework of competitions, taekwondo is divided into two discipline areas: kyorugi (sparring) and poomsae (recognized and freestyle categories), which employ different kicking strategies. It has been found that 48.8% of the kicks used were ap chagi (front kick), 30.2% were yeop chagi (side kick), and 7.5% were pyojok chagi (Kang, 2005).

Since biomechanics is the study of the motion of objects, it is the most critical aspect of sports because, based on its findings, athletes can improve their movement, increase their performance, and reduce the likelihood of getting injured. Ignoring this kind of analysis might lead to applying poor movement strategies during an activity. Helmi, Hidayah, Pramono, Hartono, and Iskandar (2024) explained how biomechanical assessments could help in correcting muscle imbalance, which correction would decrease the load on the ligaments and joints, and, therefore, improve the current training methods. In the field of sports biomechanics, kinematic and kinetic assessments are valuable techniques for analyzing the movement and forces involved in athletic performance. In this way, coaches can better design their training regimens and develop competitive strategies based on an understanding of the angles, velocities, and accelerations of various body segments during athletic tasks.

Physical capabilities of taekwondo practitioners are crucial in determining their performance and success in competitions. Several studies have identified that taekwondo requires a certain level of muscular strength, endurance, agility, flexibility, and aerobic capacity to enable athletes to perform complex movements inherent in taekwondo (Khayyat, Sağır, Hataş, Smolarczyk, & Akalan, 2020). For instance, J. Kim and Nam (2021) claimed that a proper conditioning regimen is indispensable for the development of physical fitness of taekwondo athletes, which is critical for success in competitive situations. This systematic conditioning includes specialized training protocols that meet the specific physiological demands of taekwondo, which enables the athletes to display their abilities at their best during competitions. Just as the effects of physiological performance indicators on taekwondo execution are important, biomechanical factors are also crucial in enabling the accurate and effective application of these physiological parameters, including kinetic and kinematic aspects and technical proficiency (Estevan, Freedman Silvernail, Jandacka, &Falco, 2016). Taekwondo is characterized by various kicking techniques that require strength and power and accurate biomechanical execution for high effectiveness with the least injury risk. A particular biomechanical consideration in taekwondo regards the generation of force during kicking actions. Power in the legs is necessary for executing techniques like sidekicks and jump kicks efficiently, according to Maheswari (2023). This capability is not only a matter of muscular strength; it also requires the integrated control of several segments of the body to produce force during the kick.

The biomechanics of taekwondo kicking techniques can be categorized systematically based on their kinematic characteristics into swing, push, and combination kicks. Each category calls for a distinct biomechanical methodology with respect to joint angles and muscular activation. For instance, swing kicks such as dolyo chagi (round house kick), dwirugi (reverse round house kick), naeryeo chagi (axe kick), bandal chagi (45-degree kick), ap chagi (front kick) involve rapid hip rotation and coordinated hip and knee movements to reach maximum height and velocity (Gavagan & Sayers, 2017). These kicks are only effective when the athlete is able to maintain balance and control throughout the movement, which is often assessed through biomechanical analysis of joint kinetics and muscle activation profiles (Jandacka, Estevan, Janura, & Falco, 2013). The biomechanics of dollyo chagi (round house kick) can be explained by the principles of angular momentum and force production. In executing the kick, the athlete must perform a great hip rotation. This rotation is needed to generate the angular momentum that is required for kicking the leg forward. Sousa, Gamonales, Louro, Sobreiro, and Godoy (2023) found that using the hip effectively enhances the power, speed, and accuracy of the kick. The whole kinetic chain of the hip, knee and ankle joints must be coordinated during this motion for the optimal kicking mechanics. For instance, the stability of the pivoted leg during kicks is important for balance and technique performance. Chang, Lin, Chu, and Chow (2021) claim that the kinematics of the pivot leg is an important factor in the execution of swing kicks, and that knee and hip joint angles have a significant effect on the overall efficiency of the kick.

The yeop chagi, or side kick, is a fundamental taekwondo technique executed in the frontal plane and characterized by high impact force. This kick involves a complex interplay of muscle activation, joint movement, and body mechanics that can be explained by different biomechanical theories (Yılmaz, 2021; Yılmaz & Ateş, 2024). The technique of yeop chagi is described as a thrusting action where the practitioner assumes a preparation position with the striking leg behind the supporting leg to the side. At the same time, the movement from the supporting leg is realized through the rotation of the lower extremity joints through the three planes. The movement is initiated in the sagittal plane from a stepping posture, followed by the leg abduction and hip flexion on the striking side in the horizontal plane while the supporting leg rotates. These two movements are integrated; the knee attains full flexion, and the pivoted foot makes a 180-degree rotation. This stage is characterized by acceleration forces through the knee, while the trunk undergoes lateral flexion The execution of the kick, which is the last stage of the movement, is also characterized by the proper and distinct posture of the knee and hip extension, with the foot in a dorsiflexed position, and the strike has to be performed with the heel (Gorski & Orysiak, 2019; Yılmaz, 2021; Yılmaz & Ateş, 2024). Considering the biomechanical diversity across various kicking techniques, a systematic evaluation of literature is required to understand how these movements have been examined in previous research. A systematic review is a rigorous and structured approach to synthesizing research evidence on a specific topic or question. It involves a comprehensive search for relevant studies, followed by a critical appraisal of their quality and findings. The aim is to provide a reliable summary of the available evidence, which can inform decision-making in various fields, particularly in healthcare and policymaking. Systematic reviews are distinguished from traditional literature reviews by their methodological rigour, transparency, and reproducibility, which are essential for minimizing bias and enhancing the reliability of conclusions drawn from the evidence (Page, et al., 2016; Pieper, et al., 2022).

The aim of this systematic review is to explain taekwondo kicks based on biomechanics and to produce new or combined training methods for the development of these techniques in the light of the information in literature. At the same time, although it is an Olympic sport and a branch practiced in almost all countries of the world, it aims to shed light on future studies by defining the gaps in the scientific literature on athlete performance by emphasizing the scarcity of scientific publications on taekwondo.

Method

Our systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page, et al., 2021) (Figure 1). The protocol was registered in OSF—Open Science Framework (https://doi.org/10.17605/OSF.IO/EAGUF) to ensure methodological rigour and transparency. (McKiernan, et al., 2016)

Data management and initial screening

The initial database search yielded 294 articles: 125 from Web of Science, 94 from Scopus, and 75 from PubMed. These records were imported into Zotero reference management software (Kratochvíl, 2017; Meade, Diciurcio, Radack, Michael, & Woods, 2023; Shapovalova, Shapovalov, & Shapovalov, 2024) for screening and deduplication. A total of 123 duplicate records were removed, leaving 171 articles for title and abstract screening.

Inclusion and exclusion criteria

To ensure relevance and quality, the following inclusion and exclusion criteria were applied:

Inclusion criteria: (a) Articles written in English. *(b)* Published in peer-reviewed journals. *(c)* Experimental, cohort, or case studies. *(d)* Studies focusing on taekwondo kicks. *(e)* Studies reporting biomechanical outcomes.

Exclusion criteria: (a) Systematic reviews, meta-analysis, and commentary studies. *(b)* Studies that did not report biomechanical outcomes. *(c)* Studies focused on sports other than taekwondo. *(d)* Studies examining techniques other than kicks. *(e)* Articles published prior to 1996 because during that period there was no digital technology that was relevant to this study.

Screening and eligibility assessment

During the title and abstract screening of 171 records, two articles were excluded for not being in English. This resulted in 169 articles eligible for full-text retrieval. Of these, four articles were

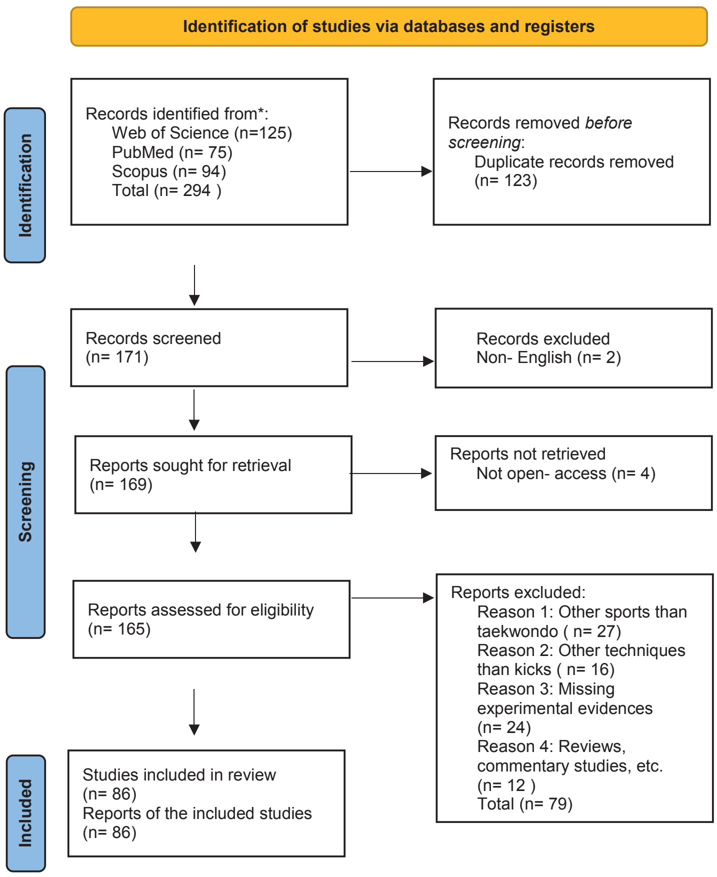

Figure 1. PRISMA flow diagram.

excluded because the full texts were inaccessible. The remaining 165 articles underwent detailed eligibility assessment.

Upon full-text review, 79 articles were excluded for the following reasons:

- 12 were systematic reviews, meta-analyses, or commentary studies.
- 24 were not experimental studies.
- 16 did not examine taekwondo kicks.
- 27 focused on other sports instead of taekwondo.

After this strict conjugation process, 86 articles were determined to meet the inclusion criteria and were thus included in the analysis.

Quality assessment of the included studies

Two authors (EAY and OA) have independently applied the Downs and Black's (1998) checklist to assess the quality of the studies included in the review (Table 1). This tool is used to rate both randomized and non-randomized studies on aspects like reporting, external validity, internal validity (including bias and confounding factors), and statistical power and has the maximum possible score of 27. The Quality Index had high internal consistency (KR-20: 0.89), as did the subscales, with the exception of external validity (KR-20: 0.54). Good test-retest (r 0.88) and inter-rater (r 0.75) reliability of the Quality Index were also observed.

Results and discussion

The systematic analysis of the 86 included studies identified distinct biomechanical patterns across different kicking techniques. The findings are categorized into five main themes: multiple kicks (n=12), ap chagi (n=9), yeop chagi (n=4), dollyo chagi (n=49), and other kicks (n=12). Each theme synthesizes the available evidence on kinetic and kinematic variables, along with muscle activation patterns where available.

Table 1. Summary of the selected studies

Author	Year	Type of the kicks	Type of the study	Sample size	Outcomes
Sorensen et al.	1996	Ap chagi	Experimental study	n= 17	Kicking efficiency relies on leveraging motion-dependent dynamics rather than muscle activation alone.
Pedzich, et al.	2006	Multiple kicks	Experimental study	n= 5	Dwit chagi exhibited slightly lower maximal F than yeop chagi (6% lower for Fmax).
Falco et al.	2009	Dollyo chagi	Experimental study	n=31	Elite athletes generated significantly higher forces compared to novices, regardless of distance. Sub-elite athletes force generation was influenced by distance, suggesting less refined technique.
Machado et al.	2010	Dollyo chagi	Experimental study	n= 10	Taekwondo athletes exhibited better motor coordination due to skill-focused training.
Kim et al.	2010	Dollyo chagi	Experimental study	n= 12	Pelvis rotation and HF were key components for adjusting to target distances.
Kim et al.	2011	Multiple kicks	Experimental study	n=12 (males)	Dollyo chagi demonstrated the highest kicking V and shorter ET, attributed to simpler inter-joint coordination. Pushlike movements (e.g., dwit chagi) minimize motion complexity, favoring rapid execution but sacrificing velocity.
Wasik	2011a	Yeop chagi	Case study	n= 1	The athlete achieved maximum strike dynamics when the leg was 82% extended, indicating an optimal point for force application and efficiency.
Wasik	2011b	Yeop chagi	Case study	n= 6	Effective kicks were characterized by high foot and knee velocities, achieved during the leg-lifting phase. GRF was critical for balance and energy transfer during the kick.
Estevan et al.	2011	Dollyo chagi	Experimental study	n= 27	Sub-elites relied on weight to generate force, compensating for weaker technical execution. Elites performance was more technique-dependent, leveraging kinetic chain efficiency. Elites performed kicks faster than sub- elites across all distances.
Estevan et al.	2012	Dollyo chagi	Experimental study	n=36	Normalized IF and ET were recorded across weight categories.
Falco et al.	2013	Dollyo chagi	Experimental study	n= 49	Target distance affected the kick performance; as distance increases, IF decreased and RT increased.
Estevan & Falco	2013	Dollyo chagi	Experimental study	n= 33	Short and normal distances were optimal for novices due to reduced RT and ET. Elites athletes adapted effectively to changes in target height and distance, maintaining consistent RT, ET, and IF.
Jandacka et al.	2013	Dollyo chagi	Experimental study	n= 10	Higher demands on the hip joint at 90° make it mechanically challenging but do not necessarily improve performance.

Author	Year	Type of the kicks	Type of the study	Sample size	Outcomes
Woo et al.	2013	Naeryeo chagi	Experimental study	n=15	The novel protector enhances performance while maintaining protection, unlike traditional designs.
Thibordee & Prasartwuth	2014	Dollyo chagi	Experimental study	n= 16	RF activation could predominantly contribute to the powerful dollyo chagi. Moreover, high BF co-activation and optimal angle of ankle PF of about 35° could help achieve the high IF.
Estevan et al.	2014	Dollyo chagi	Experimental study	n= 43	RKSES is a reliable tool to predict and enhance performance in the roundhouse kick. Self-efficacy training should emphasize technical aspects for males and tactical elements for females.
Huang & Cheng	2014	Dollyo chagi	Experimental study	n= 13	Maximizing hip flexion and rapid knee extension are critical for achieving peak ankle velocity.
Martins et al.	2014	Dollyo chagi	Experimental study	n= 13	The use of kihap enhances the impact of A kicks, likely through improved muscle coordination and psychological arousal.
Darius et al.	2014	Turning dollyo chagi	Experimental study	n= 6	Optimal joint coordination (hip ~90°, knee ~20°, ankle ~50° dorsiflexion) correlated with maximum IF. Experienced athletes demonstrated significantly higher AV and IF compared to inexperienced athletes. Dominant legs produced stronger impacts and faster movements than non-dominant legs.
Wasik & Shan	2014	Naeryeo chagi	Experimental study	n=6	Caucasian athletes could use naeryeo chagi more effectively against taller opponents (4-7% taller).
Ruiz et al.	2015	Multiple kicks	Case study	n= 1	Hip rotation correlated positively with PS and ACC in all kicks. Joint angles, such as HF and HA, occasionally exceeded normal ranges, posing potential injury risks.
Wasik et al.	2015	Ap chagi	Experimental study	n= 6	Knee motion during the “knee/foot up” phase was critical for generating momentum. Deceleration occurred after the Vpeak to stabilize the body.
Wasik & Shan	2015a	Dollyo chagi	Experimental study	n= 6	Kicking V and foot take-off dynamics are the primary determinants of turning kick effectiveness.
Barnamei & Kharazi	2015	Dollyo chagi	Experimental study	n= 6	The knee joint was a critical contributor to power generation and variability control in the dollyo chagi.
Moreira et al.	2015	Dollyo chagi	Cross- sectional study	n= 6	Dollyo chagi velocity depends on both dynamic explosive strength (CMJ) and isometric strength (leg press). GRF and RFD are crucial for effective momentum transfer in a proximodistal sequence.
Wasik & Shan	2015b	Dollyo chagi	Experimental study	n= 6	The presence of a target significantly alters the kinematic profile of the dollyo chagi, shifting the focus from speed to precision and power generation.
Jung & Park	2020	Dollyo chagi	Experimental study	n= 12	Smaller angles (e.g., 0° and 45°) allow for faster kicks while maintaining offensive efficiency. Larger back-step angles (e.g., 90°) impose greater mechanical demands, leading to reduced kicking velocity but enhanced defensive readiness
Wasik	2010	Dollyo chagi	Case study	n= 1	The dynamics of the kick depends on the speed of take-off of the foot and the speed of the rotation movement of the arms. Duration of the kick comprises the time of foot take-off, which is influenced by the speed and acceleration of the jump, and the time of rising resulting from the power of raising muscles and the technique of the movement.
Cheng et al.	2015	Dwit chagi	Experimental study	n= 10	Jumping dwit chagi required greater GRFs for take-off but did not produce stronger impacts. Dwit chagi were more effective at generating F due to stable ground contact of the support leg, which acted as a rotation axis.
Wasik & Gora	2016	Ap chagi	Case study	n= 1	Target selection significantly affects the kinematic patterns of ap chagi.
Ortenburger et al.	2016	Ap chagi	Experimental study	n= 6	Physical targets influence kick kinematics, reducing maximum velocity due to the cognitive and mechanical demands of accuracy.
Li	2016	Dollyo chagi	Experimental study	Not men-tioned	Recovery phase is crucial for defense, as it occupies more than 30% of the kick’s total duration.
Estevan et al.	2016	Dollyo chagi	Experimental study	n= 6	ISP significantly affects coordination patterns and variability in taekwondo roundhouse kicks. The 45° stance offers biomechanical advantages in stability, speed, and accuracy.

Author	Year	Type of the kicks	Type of the study	Sample size	Outcomes
Buśko et al.	2016	Dollyo chagi	Experimental study	n= 28	Reaction times varied between lead and rear limbs, with slower reaction times typically observed for rear-leg kicks. Significant intergender differences were observed in kick forces, with male athletes generating higher F overall.
Moriera et al.	2016	Bandal chagi	Experimental study	n= 20	Subelite athletes need targeted training to improve neuromuscular coordination and RT. Elite athletes rely on precise cocontraction strategies and higher segmental velocities for explosive and efficient kicks.
Preuschl et al.	2016	Naeryeo chagi	Experimental study	n= 27	Maintaining an upright torso and using hip extension with a straighter knee during the leg-lowering phase enhanced Vimpact.
Wasik & Gora	2016	Dwit chagi	Case study	n= 3	Movement coordination between knee and foot is essential for generating momentum and maintaining control. Peak Vfoot occurs at ~80% of leg length. The Vknee during chambering and extension is critical for efficient execution.
Gora et al.	2024	Multiple kicks	Experimental study	n= 12 (7 males, 5 females)	Male athletes exhibited higher effective mass and IF. Yeop chagi higher effective mass and IF due to greater linear motion. Dollyo chagi kicks are faster but rely more on rotational mechanics, reducing effective mass contribution.
Kim et al.	2017	Dollyo chagi	Experimental study	n= 12	Elite athletes demonstrated superior RT and AV. Sub-elite athletes relied more on agonist muscle activation for power generation while relied heavily on agonist-dominant activation, increasing variability.
Gavagan & Sayers	2017	Dollyo chagi	Experimental study	n= 24	Effective dollyo chagi depends on a combination of rapid pelvic axial rotation, HF, and KE V.
Zhou	2017	Naeryeo chagi	Experimental study	n= 24	Higher-level athletes demonstrated superior biomechanics, including faster execution, greater range of motion, and more efficient force application.
Huang & Cheng	2014	Multiple kicks	Experimentalstudy	n=12	High-intensity sessions significantly increased fatigue, affecting kicking speed and accuracy.
Wasik et al.	2018	Ap chagi	Experimental study	n= 14 (8 males, 6 females)	Male athletes exhibited higher overall velocities, while females faced greater challenges in accuracy-demanding scenarios.
Barnamehei et al.	2018	Dollyo chagi	Experimental study	n= 15	High VM and RF activity are essential for maximizing kick velocity and minimizing injury risks.
Moreira et al.	2018	Dollyo chagi	Experimental study	n= 14	Elite athletes displayed superior neuromuscular coordination and biomechanical efficiency, resulting in faster and more powerful dollyo chagi kicks.
Aandahl et al.	2018	Dollyo chagi	Cross-over study	n=16	EMG measurements confirmed the presence of PAP.Changes in the timing of knee extension and hip rotation contributed to a whip-like motion sequence, enhancing kicking speed
Gorski & Orysiak	2019	Multiple kicks	Experimental study	n= 12 (7 males, 5 females)	Dominant limbs generate higher F across all kick types. FFM is a significant predictor of kick F, especially for yeop chagi.
Wasik et al.	2019	Ap chagi	Experimental study	n= 14 (8 males, 6 females)	Men generate higher Vfoot during ap chagi compared to women, across varying target types.
Estevan et al.	2013	Yeop chagi	Experimental study	n= 16	IF, balance maintenance, and AV across stances were evaluated.
Miziara et al.	2019	Dollyo chagi	Experimental study	n= 9	Effective dollyo chagi depend on precise sequential muscle activation and proper joint angle transitions. Both phases are crucial for high-performance kicks.
Guan et al.	2024	Dollyo chagi	Experimental study	n=20	Core stability improvements, changes in AV of the hip and knee, and IF were analyzed.
Ervilha et al.	2020	Dollyo chagi	Experimental study	n= 23	Elite athletes achieved shorter PMT and total task time due to efficient muscle activation patterns. Higher EMG in trunk and lower limb muscles (except VL) suggests more effective energy transfer.
Guimaraes et al.	2020	Dwit chagi	Experimental study	n= 24	Variability training is effective for motor learning, enabling better control over degrees of freedom and improving kick performance.

Author	Year	Type of the kicks	Type of the study	Sample size	Outcomes
Wasik et al.	2021a	Multiple kicks	Experimental study	n=12	Dollyo chagi adapted better to dynamic targets, demonstrating superior biomechanical control and AV adjustments. Ap chagi maintained higher overall V but suffered significantly in accuracy during dynamic conditions
Nadzalan et al.	2022	Ap chagi	Experimental study	n= 18	Kicking V decreased significantly with increasing WR loads, highlighting the trade-off between resistance and speed ($p < 0.01$).
Ryu & Lee	2021	Ap chagi	Experimental study	n= 17	LFA correlated negatively with impact variables like vertical loading rate and vertical stiffness.
Sant'Ana et al.	2017	Dollyo chagi	Experimental study	n= 18	Changes in RT, performance time, and muscle activity during fatigue.
Straiotto et al.	2021	Dollyo chagi	Experimental study	n= 18	Elite athletes demonstrated higher segment V and generated 24% greater target ACC than sub-elites.
Diniz et al.	2021	Dollyo chagi	Experimental study	n= 47	While karate excels in speed, muay thai focuses on power, and TKD balances both.
Wasik et al.	2021b	Dollyo chagi	Experimental study	n= 15	Training shield allowed for the highest FV due to the ability to transfer full torque without deceleration Traditional stance restricted motion, leading to reduced V.
Liu et al.	2021	Dollyo chagi	Experimental study	n= 9	Higher attack angles (90°) demand increased pelvic motion and joint angle adjustments for effective execution. Linear velocity adjustments in the pelvis are critical to generating optimal force and accuracy.
Amado Forero et al.	2021	Dollyo chagi	Experimental study	n= 3	Experienced practitioners achieved higher AVpeak and ACC, especially in the knee and hip. EMG data showed greater muscle activation in advanced participants during key phases of the kick.
Chang et al.	2021	Dollyo chagi	Experimental study	n= 12	High kicks posed greater risk for non-contact knee injuries due to increased valgus angles and reduced knee flexion during deceleration.
Moreira et al.	2021	Bandal chagi	Cross- sectional study	n= 14	The combination of HF/HE torques and knee AV effectively discriminated between elite and sub-elite athletes (accuracy: 85.7%).
Moreno et al.	2022	Multiple kicks	Experimental study	n= 12 (Males)	Dollyo chagi were the fastest and most powerful, taking 62% less ET compared to chigo chagi. Normalized results confirmed that target height and kick type significantly influence mechanical power.
Tsui & Pain	2022	Multiple kicks	Experimental study	n= 9	Higher-performing athletes exhibited better timing of HR and KE, leading to more efficient energy transfer. Dollyo chagi demonstrated greater V and F generation due to enhanced rotational mechanics.
Ibrahim et al.	2022	Ap chagi	Cross-over study	n= 25	Moderate resistance (5%) showed the best balance between activation and biomechanics.
Jung & Park	2022	Dollyo chagi	Experimental study	n=10	Footwork and segmental contributions should be tailored to improve kicking speed and precision.
Huang et al.	2025	Dollyo chagi	Experimental study	n= 18	Higher segmental V and M in RKH contributed to superior impact magnitudes. Elite athletes' ability to optimize thigh and SV improved impact performance on EBP.
Wasik et al.	2022	Dollyo chagi	Experimental study	n= 15	The sport version's faster execution and higher velocity make it more suitable for combat and dynamic sparring.
Zhong & Xu	2022	Dollyo chagi	Experimental study	Not specified	Dollyo chagi performance relies heavily on dynamic coordination and center of gravity stability.
Jung & Park	2018	Dollyo chagi	Experimental study	n=10	45° back-step provides a balance between effective striking and defensive readiness.
Mesaric et al.	2024	Dollyo chagi	Experimental study	n= 20	Reactive strength, as measured by DJ power, is particularly influential in determining execution speed. Leg extensor power is a critical determinant of roundhouse kick speed in taekwondo.
Xiao & Cheng	2022	Dollyo chagi	Experimental study	n= 15	Proper synchronization of the kinetic chain is essential for maximizing kick V and accuracy.
Osman et al.	2022	Naeryeo chagi	Experimental study	n= 30	Motivational self-talk significantly enhances naeryeo chagi performance by improving both height and speed.

Author	Year	Type of the kicks	Type of the study	Sample size	Outcomes
Wasik et al.	2023	Multiple kicks	Experimental study	n= 1	Athletes with better control over effective mass achieved higher F outputs.
Yao	2023	Multiple kicks	Experimental study	n= 5	The rotational range and agility were inversely proportional to the athlete's weight class.
Lin et al.	2023	Yeop chagi	Experimental study	n= 20	Advanced kinematics, such as higher AV at hip and pelvis, are critical for high-target performance
Wasik et al.	2023	Dollyo chagi	Experimental study	n= 13	Effective execution relies on precise coordination of HR and KE.
Liu et al.	2023	Double dollyo chagi	Experimental study	n= 2	Enhanced symmetry in biomechanics improves performance and reduces asymmetry-related constraints.
Nadzalan et al.	2021	Naeryeo chagi	Experimental study	n= 20	Higher WR loads required greater stabilization efforts, reflected in elevated GRF.
Gora et al.	2024	Multiple kicks	Experimental study	n= 9	Men displayed higher foot acceleration, contributing to greater F generation despite similar effective mass.
Jia et al.	2024	Dollyo chagi	Experimental study	n= 15	Proper knee flexion and hip extension velocities are critical for effective scoring.
Sun et al.	2024	Dollyochagi	Experimental study	n= 10	"Hit" actions rely on efficient coordination between distal TA and proximal RF muscles. "Miss" actions demonstrate greater reliance on proximal stabilizers like the BF, leading to energy inefficiencies.
Jia et al.	2023	Double dollyo chagi	Experimental study	n= 12	HF and ankle internal rotation AV explained 69% of effective scoring variability (adjusted $R^2 = 0.69$).
Janep et al.	2024	Naeryeo chagi	Experimental study	n= 30	GRF of the supporting leg increased with WR loads but showed minor differences between 5%, 10%, and 15% ($p > 0.05$). Kicking velocity significantly decreased as WR loads increased ($p < 0.01$) opposite to kicking time.

Note. RF: rectus femoris, VL: vastus lateralis, VM: vastus medialis, BF: biceps femoris, COG: center of gravity, Fpeak: peak force, KB: kick boxing, Vtoe: toe velocity, FL: front leg, KF: knee flexion, HE: hip extension, DL: dominant leg, NL: non-dominant leg, KE: knee extension, AV: angular velocity, HR: hip rotation, IF: ımpact force, HW: heavy-weight, WW: welter-weight, FW: feather-weight, ET: execution time, HI: high ımpact, LO: low ımpact, PF: plantar flexion, KV: knee velocity, RT: reaction time, HF: hip flexion, AVhip: hip angular velocity, AVknee: knee angular velocity, TA: tibialis anterior, GM: gastrocnemius medialis, PP: preparation phase, CP: chamber phase, ERP: extension and recoil phase, RMS: root mean square, TO-MF: toe-off to maximum knee flexion, MF-IM: maximum knee flexion to impact, Gmax: gluteus maximus, ST: static target, EDT: erratic-dynamic target, RP: reaction phase, SP: swing phase, VKE: knee extension velocity, MVC%: maximal voluntary contraction, RKH: round-house kick with the highest impact magnitude, RKL: round-house kick with the lowest impact magnitude, FV: foot velocity, SV: shank velocity, M: momentum, SM: shank momentum, FM: foot momentum, EBP: electronic body protector, SSD: self-selected distance, Vmax: maximum velocity, Vlat: lateral velocity, Vv: vertical velocity, HA: hip abduction, PMT: pre-motor time, MoT: movement time, TFL: tensor fascia latae, CRP: continuous relative phase, VC: vector coupling, ISP: ınitial stance position, PPV: pelvis peak velocity, PTV: thigh peak velocity, PFV: foot peak velocity, CMJ: counter movement jump, RFD: rate of force development, RKSES: roundhouse kick self-efficacy scale, DJ: drop jump, PF: plantar flexion, COM: center of mass, PAP: post-activation potentiation, MIF: maximum ımpact force, IR: ınternal rotation, ADF: ankle dorsiflexion, RF: rectus femoris, VL: vastus lateralis, GRF: ground reaction force.

Theme 1: Multiple kicks (n=12)

Analyzing multiple taekwondo kicks shows that different techniques have different biomechanical advantages and performance characteristics. Out of the 12 (one case study, 11 experimental studies) reviewed studies, the most significant comparisons were made between the techniques of dollyo chagi, ap chagi, yeop chagi and dwit chagi (back kick).

Kinetic variables

Several studies that examined the kinetic characteristics, power outputs, and performance effects of various taekwondo kicks described the physical and mechanical properties of multiple kicking techniques. The study compared kicks such as dollyo chagi, ap chagi, yeop chagi, and dwit chagi, and explained how dollyo chagi differs from other kicks in terms of mechanical power and speed. Using dollyo chagi, Moreno-McManus et al. (2022) reported a mechanical power output of 11500.11W and this was achieved to a greater extent when the dominant leg was used. Similarly, the rotational mechanical advantages of dollyo chagi which enhance speed and efficiency of energy transfer were also pointed out (Tsui & Pain, 2012). There was a positive relationship between the performance of elite level athletes in achieving hip rotation and knee extension for enhanced performance. Higher power output was also recorded when dollyo chagi was performed with the dominant leg by different studies (Gora, Mosler, Podstawski, & Wasik, 2024b; Gorski & Orysiak, 2019; Wasik, Mosler, Gora, & Scurek, 2023a), which emphasizing the role of technique in achieving desired performance outcomes. Literature also pointed out that body mass affects the impact force, and that yeop chagi involves more linear motion of the body and, therefore, heavier effective mass. In this case, dollyo chagi is a speed favourite, but yeop chagi is another kick that can result in more impact force due to linear technique and use of the total body mass to enhance force output (Gora, et al., 2024b). Fatigue's effect on performance was investigated by Liu (2021), and the findings show that accumulated fatigue under high-intensity exercise conditions reduces impact forces by 10-12%. This means, energy management during intense training sessions is critical. Also, Pedzich et al. (2006) and Gorski and Orysiak (2019) found a positive relationship between body mass and force output.

The study also looked at gender-based differences in performance (Gora, Mosler, Ortenburger, & Wasik, 2024a). Male athletes manifested higher foot acceleration and impact force in dollyo chagi and yeop chagi than female athletes. On the other hand, the effective force generation by the female athletes was achieved by technical optimization since they had lighter body mass. This finding shows that there are different biomechanical strategies used by male and female athletes.

The results of these studies show that understanding the biomechanical properties of taekwondo kicks is vital for improving performance. The speed and power outputs of dollyo chagi are particularly noted, while yeop chagi take advantage of compelling mass advantages. The data also reveal gender differences and fatigue factors that call for technical optimization to achieve optimal performance. These comprehensive investigations provide valuable insights for designing training programmes that optimize the balance of the kicks, power, and speed to enhance individual performance and strategic technical development.

Kinematic variables

Additional information regarding inter-joint coordination, speed, and accuracy can be obtained from the kinematic properties of multiple taekwondo kicks. Because of its rotational control, dollyo chagi is superior in dynamic scenarios, whereas ap chagi, a linear kick, has its own set of biomechanical characteristics. In static conditions, Wasik, Mosler, Ortenburger, and Gora (2021a) showed that dollyo chagi had hip angular velocities of 540 ± 85°/s and higher accuracy. However, ap chagi had a higher strike velocity (12.8 ± 1.7 m/s) but was poor in precision in dynamic conditions. These findings support the essentiality of optimal balance between speed and accuracy for performance.

Agility and body weight have a significant impact on movement efficiency. The lighter athletes rotate faster, while heavier athletes take more strike distances, which means that the training should be focused to the individual's body composition (Yao, 2023). Kim, Kim, and Im (2011) also found that for rotational kicks such as dollyo chagi, there were more direct inter-joint coordination paths, which resulted in shorter execution time and higher speed. On the other hand, techniques like dwit chagi have slightly longer execution times because they involve more complex movements.

Precision and control become even more crucial in dynamic target conditions. The kicks such as dollyo chagi achieved the highest speed (8.55 m/s) and acceleration (93.14 m/s²), though at the cost of increased injury risk due to exceeding normal joint ranges (Ruiz, Fernandez, & Jimenez, 2015). These findings also underscore the importance of maintaining safe joint mechanics when trying to achieve speed and accuracy.

In summary, the use of kinetic and kinematic analysis of taekwondo kicks reveals the technical and physical requirements for the best performance. The rotational speed and control benchmark remains to be dollyo chagi, while the force generation is excellent in linear techniques like yeop chagi. Thus, training programmes should be tailored to the individual's body mass, energy management, and joint safety to improve performance with the least chance of getting injured.

Theme 2: Ap chagi (n=9)

The kinematic and biomechanical characteristics of ap chagi have been explored in nine studies, including a case analysis, one cross-over experimental study, and seven experimental studies. With these investigations, kinetic and kinematic variables that govern performance are thoroughly understood, and thus, ready to be optimized for peak performance with minimal risk of injury.

Kinetic variables

The kinetic aspects of ap chagi address the importance of energy transfer, balance, and resistance. Ap chagi, with its linear path, depends very much on proximal to distal energy transfer for generating force. Analyzing landing mechanics after jumping ap chagi, Ryu and Lee (2021) found a significant bilateral asymmetry in injured athletes. These include ankle plantar flexor strength (11.5% vs. 3.3%) and hip abductor/adductor strength (13.3% vs. 6.3%). These adverse landing mechanics include altered foot angles, increased vertical loading rates, reduced stiffness, and collectively heightened injury risk. These findings support the necessity of targeted training interventions to correct muscular imbalance and enhance landing stability.

Kinematic variables

Ap chagi kinematics depends on accurate inter-joint coordination, speed and ability to adjust to environmental demands. From Sorensen, Zacho, Simonsen, Dyhre-Poulsen, and Klausen (1996), it becomes clear that proximal to distal energy transfer, where high angular velocities of the hip effectively transfer energy to the knee and then to the ankle to optimize kicking performance, is crucial. This dynamic coordination is more effective than isolated muscle activation in determining performance outcomes.

Wearable resistance (WR) training has become a key component in the optimization of kinetic performance for ap chagi. Moderate resistance loads of 5% of body mass increased muscle activation of the *rectus femoris* and *gastrocnemius* by 15-18% with no negative impact on kick velocity or height (Ibrahim et al., 2022). However, Nadzalan et al. (2022) found that heavier resistance loads of 10-15% of body mass significantly impaired performance and reduced kick velocity and joint range of motion, particularly hip flexion and knee extension. These findings highlight the need for right resistance loads to achieve the optimal training adaptation and biomechanical efficiency. Also, Wasik, Czarny, Malolepszy, and Drozdek-Malolepsza (2015) and Wasik, Mosler, Ortenburger & Gora (2021a) analyzed performance across the chamber, execution, and impact phases and found that knee velocity was the primary determinant of foot velocity (10.4 m/s, r = 0.92, p<.05). Short execution times always improved performance, but precision tasks such as hitting small or dynamic objects reduced velocity due to increased motor control.

Biomechanical performance of ap chagi is also dependent on gender and leg dominance. Wasik et al. (2018) and Wasik, Ortenburger, and Gora (2019) found that male athletes kicked the ball at higher velocities across all types of targets than female athletes, and with greater consistency in the dynamic scenarios. Without physical constraints, kicks executed without resistance (i.e., kicks into the air) reached the highest velocities. On the other hand, strikes made against physical targets, such as shields or small objects, greatly reduced speed of the kick due to the combined cognitive and mechanical demands of accuracy. However, the female athletes had trouble maintaining speed and accuracy in precision demanding conditions like hitting table tennis balls (Ortenburger, Wasik, & Gora, 2016). This indicates different motor strategies and accuracy-speed trade-offs between the genders and suggests the need for individualized training programmes.

These findings highlight the multifaceted nature of ap chagi performance optimization. Rather, for speed and precision, use proximal-to-distal energy transfer, knee velocity, and dynamic motor control. Additionally, the kinematic outcomes of performance are influenced by gender-based differences and target conditions, and thus, individualized training approaches are necessary. Furthermore, wearable resistance training at moderate loads can be a useful method to increase muscle activation and kicking efficiency without negatively affecting performance. Future training programmes should include resistance calibration, corrective exercises for muscular imbalances, and task-specific kicking drills to enhance biomechanical efficiency and reduce the risk of injury.

Theme 3: Yeop chagi (n=4)

Yeop chagi, a sidekick technique with a linear trajectory, was analyzed in four studies, including two case analyses and two experimental studies. Two studies examined both kinetic and kinematic parameters, and the other two focused only on kinematics. These findings are critical for optimizing performance and training strategies.

Kinetic variables

Wasik (2011a, 2011b) analyzed and detailed the kinetic and kinematic dynamics of yeop chagi to identify the critical performance parameters. The foot velocity was fastest at 5.65 ± 1.22 m/s (z-axis) and this occurred at about 82% of the full leg extension. The knee velocity was 3.21 ± 1.02 m/s (z-axis) and 3.04 ± 0.79 m/s (y-axis). The execution times from movement initiation to full leg extension were 0.71 ± 0.11 seconds, with leg-lifting times of 0.39 ± 0.09 seconds. The ground reaction forces in the supporting foot were 1253 ± 248 N, which shows how they contribute to balance and energy transfer. The leg lifting phase was identified as the most important phase in terms of optimization of dynamics because the time and coordination of the movement greatly influenced the impact of force and speed.

Stance position before the execution of yeop chagi was in the focus of Estevan, Jandacka, and Falco's (2013) study. The narrow stance (feet shoulder-width apart) had the fast execution times (298 ± 35 ms) but the low impact forces (2320 ± 190 N). On the other hand, the wide stance (feet twice shoulder-width apart) produced high impact forces (2645 ± 210 N, p<.05) because of the improved balance and stability. These findings focus on the importance of adjusting stance width in relation to the performance objectives and the requirements for speed and force. These findings show that coordination between velocity and timing is an important factor that should not be underestimated. The athletes who optimized the leg-lifting dynamics and used the ground reaction forces efficiently performed better, which supports the need for specific training strategies.

Kinematic variables

Literature investigated yeop chagi kinematics at different target heights for elite level athletes and found out the necessary adjustments for high target kicks. Increasing target heights demanded greater hip flexion angles (+18%, p<.05), faster linear foot velocities (+12%, p<.01), and increased pelvis tilt and rotation in the leg lifting phase. These adjustments of the core and hip for stability and flexibility are necessary to guarantee consistent performance in complicated situations (Lin, et al., 2023).

These studies explain the complex dependence of yeop chagi performance on stance, kinematics and kinetics. Fast execution is only achieved with a narrow stance, but with reduced impact force; a wide stance, on the other hand, results in higher force and stability that can be achieved through adjusting the stance to fit the desired performance (Estevan, Jandacka, & Falco, 2013). Accurate coordination of kinematics, particularly of the knee and foot velocities, is crucial for the optimization of speed and impact force; this coordination starts from the leg lifting phase (Wasik, 2011a,b). Additionally, high target kicks need more flexibility and control and as a result, the core stability and pelvis mobility are vital for accuracy and velocity (Lin et al., 2023). Hence, training programmes should aim at improving execution time, stance, and kinematic efficiency for improved performance and precision in yeop chagi

Theme 4: Dollyo chagi (n=49)

A total of 49 studies examined the most dynamic and rotationally demanding techniques in taekwondo—dollyo chagi. Of these, two were cross-sectional, and 47 were experimental in design. Four studies addressed kinetic parameters, 26 kinematics, and 21 both aspects. The following findings, although based on different studies, collectively provide valuable information regarding the biomechanical fundamentals of dollyo chagi.

Kinetic variables

The analysis of the kinetics of dollyo chagi is important for coordination of joints, muscles, and energy management for the best results to be achieved. Hip rotation, knee flexion, and proximal-to-distal energy transfer were identified by Li (2016) and Jia et al. (2024) as the three stages of the technique and as the primary contributors to impact force and accuracy. The force of the strike was found to be as high as 591 kg (Li, 2016); however, hip angular velocity and knee flexion contributed to 72% of the score variability, according to Jia et al. (2024), meaning that these two aspects are crucial for efficient performance. Transitions of the dollyo chagi kick's phases became smoother, and stability improved at a 45° stance, according to Estevan, Friedman Silverman, Jandacka, and Falco (2016). Coordinated kinetic chains are necessary for high velocities, with synchronization between the pelvis and foot (Huang & Cheng, 2014a). Gavagan and Mayers (2017) compared taekwondo with other martial arts and found that taekwondo athletes produced higher impact forces but had longer execution times, which distinguish the discipline.

Training interventions have a significant impact on kinetic outcomes. Core stability training increased hip angular velocity (+14.2%) and knee velocity (+9.8%) and hence, increased the impact forces (Guan, Li, Li, Kim, & Kim, 2024). But Sant'ana, Franchini, da Silva, and Diefenthaeler (2017) observed a 12.5% decrease in impact force and slower reaction times after a fatiguing high intensity interval training, indicating that there is a need for endurance focused protocols to maintain performance.

Other spatial variables include target distance and attack angles, which were also very important. Falco et al. (2009) and Falco, Molina-Garcia, Alvarez, and Estevan (2013) found that increasing distance reduced impact forces and increased reaction times. However, Liu, Lin, Tang, Hamill, and Chang (2021) found that increased attack angles needed more pelvic rotation and hip flexion to get the optimum velocity and trajectory.

The level of expertise determines the efficiency of performance. Smoother neuromuscular coordination, faster reaction times and greater ground reaction forces were seen in elite athletes than in sub elite athletes (Darius, et al., 2014; Moreira, et al., 2018). Consistency and biomechanical constraints are also enhanced by symmetry, for both the dominant and non-dominant leg (Liu, et al., 2021).

There were also gender differences observed in some studies. Mesaric, Peric, and Zakrajsek (2024) discovered that male athletes had higher velocities and forces because they had better segmental coordination and power production. But the role of hip mechanics in force production was more evident in female athletes. In fact, gender affected self-efficacy and performance parameters, with male athletes being strong in the technical aspect and females being strong in the tactical aspect (Estevan, Alvarez, Falco, Molina-Garcia, & Castillo, 2014).

In conclusion, the kinetic performance of dollyo chagi is determined by the combination of joint and muscle coordination, fatigue, target location, and other variables. Therefore, core stability, symmetry, and endurance training interventions are most likely to lead to technical performance and competitive effectiveness improvements.

Kinematic variables

Segment coordination is critical in dollyo chagi technique. Jung and Park (2022) established initial contribution of the thigh (51-64%) and calf (15-28%) to the toe velocity, with the calf making a relatively greater contribution to the impact phase. Similarly, the importance of knee extension velocity, especially of the dominant leg to obtain better kicking performance (Wasik, Mosler, Gora, & Scurek, 2023a). Weight categorization has a significant effect on the kinematic variables. Also, the maximum foot velocity (~16 m/s) was attained by proper muscle activation and coordination of joints during extension phase (Barnamehei, et al., 2018). Specifically, the sport-specific variant of dollyo chagi was faster and had higher velocities than the variant used in training, which is more efficient for combat (Wasik, et al., 2022). There were complex dynamic effects on kinematic performance. Hip and ankle angular velocities were identified as significant predictors of scoring effectiveness in double dollyo chagi kicks (Jia, et al., 2023). Wasik and Shan (2015b) also found that target-oriented kicks enhance motor control but reduce speed. Martins, Cantergi, and Loss (2014) reported that using the kihap—a vocal exhalation technique—boosted the impact speed by 10% due to better muscle coordination and psychological readiness.

Estevan, Falco, Alvarez, and Molina-Garcia (2012) found that heavyweight athletes applied more force, while light athletes were fast and agile and performed better in dynamic conditions. Diniz et al. (2021) also stated that taekwondo has a balanced biomechanical profile because it is based on speed, while karate is based on power and muay thai is based on striking the parts of the body. Chang, Lin, Chu, and Chow (2021) pointed out the dangers of high kicks, including increased knee valgus angles and decreased knee flexion, which are risk factors for ACL injuries. Kim, Kwon, Yenuga, and Kwon (2010) discovered that the farther the target, the more pelvic rotation was required. Kim et al. (2017), and Jung and Park (2018) discovered that defensive footwork angles decreased velocity and increased execution time, but better control was achieved with bigger angle. Hip and ankle angular velocities also play a significant role in performing effective double dollyo chagi kicks (Jia, et al., 2023). Other factors that affect dollyo chagi performance include foot movements and other factors.

Muscle activation patterns are also crucial. Elite athletes were found to have shorter pre-motor times and higher integrated EMG activity, which indicated better neuromuscular efficiency (Ervilha, Fernandes, Souza, & Hamill, 2020). Barnamei and Kharazi (2015) also addressed the importance of knee angular velocity in order to produce power and minimize variability. Amado Forero, Mateus Suarez, Rincon, Sierra Sanchez, and Torres Pinzon (2021) found that expert practitioners had more efficient movements and better weight distribution, which resulted in better kicking dynamics.

For increasing the kinematic performance, training interventions are proposed to be effective. In one study the resistance warm-up increased the velocity of the kick and the level of muscle activation (Aandahl, Von Heimnurg, & Van den Tillaar, 2018). Xiao and Cheng (2022) used deep learning techniques to analyze performance in terms of biomechanics. In addition, the co-activation of the *biceps femoris* and *vastus lateralis* increased speed during the loading phase by stabilizing the knee joint. Other technical and mechanical aspects were also examined (Miziara, et al., 2019).

These studies show that there is an intricate relationship between segment coordination, muscle activation, and other factors in dollyo chagi performance. Techniques that enhance joint movement, control, and dynamic variables are most efficient and least likely to result in injury. These findings can be useful for coaches and athletes in developing effective strategies for improving their performance and winning competitions.

Theme 5: Others (bandal chagi, naeryeo chagi, dwit chagi) (n=12)

This theme includes 12 studies examining bandal chagi (n = 2), naeryo chagi (n = 7), and dwit chagi (n = 3). Six studies analyzed kinematic parameters exclusively, while the remaining six investigated both the kinetic and kinematic aspects. The findings offer critical insights into the biomechanical dynamics of these specialized taekwondo kicking techniques.

Kinetic variables

The analysis of kinetics of the techniques used reveals the differences in the requirements of each technique. From the study by Moreira et al. (2021), it was found that in bandal chagi, hip flexion and extension torque (240°/s) increased as the velocity of the linear movement of the foot and the expertise levels of athletes. Thus, elite athletes utilize hip strength and kinematic efficiency to achieve optimal performance. Also, Moreira, Falco, Menegaldo, Goethel, Paula, and Gonçalves (2016) compared neuromuscular performance of elite and sub-elite athletes in bandal chagi. Elite athletes had significantly higher linear and angular velocities of their knees and feet, and better joint stabilization due to higher co-activation levels of muscles like *vastus lateralis* and *rectus femoris*. Such neuromuscular advantages made the production of fast and explosive kicks possible through improved energy transfer with minimal inefficiency. In contrast, sub-elite athletes had slower reaction times, reduced GRFs, and lower neuromuscular efficiency, which indicate where they might need additional training.

Similar studies by Janep, Osman, Mohamad, Tan, Malik, and Nadzalan (2024) and Nadzalan, Janep, Jahizi, Malek, Ibrahim, and Mohamad (2021) on wearable resistance (WR) training revealed that moderate WR loads of 5-10% improved naeryo chagi performance through enhancing lower-body strength and stability with no negative impact on velocity. However, heavy WR loads (>10%)

decreased kicking velocity and increased execution time but with increased GRF, which implies that more stabilization is required. These findings were further supported by Zhou (2017), who also included attack velocities and GRF utilization as factors that distinguished elite female athletes in performing naeryo chagi. Better segmental coordination of the body allowed the kick to be executed at an earlier phase, and the overall performance was better, which is important for high-level kicking techniques.

Dwit chagi, back kick, and its jumping variant were compared, and both techniques took approximately the same amount of execution time, but back kicks had higher target acceleration with more stable GRFs, which means that power and efficiency are valued more. On the other hand, jumping dwit chagi needed more coordinated and adaptable whole body, but they offered some tactical benefits in real combat, despite having less force (Cheng, Wang, Kuo, Wang, & Huang, 2015).

These included studies demonstrate that there is an intricate relationship between strength, stability, and coordination without which the performance of taekwondo kicking cannot be optimized. Training programmes should vary resistance loads, enhance segmental coordination, and stress biomechanical accuracy to enhance power, velocity, and efficiency across techniques.

Kinematic variables

Studies on kinematic analysis provided more detailed information on the alterations in the technique and tactics for the performance. The study by Woo, Ko, Choi, Her, and O'Sullivan (2013) revealed that the novel protective design enhanced naeryo chagi performance. The protective gear caused an increase in hip flexion (+11.2°) and toe height (+5.8%) with no negative impact on speed or efficiency. This shows that advanced protective gear can improve performance while ensuring safety. Preuschl, Hassmann, and Baca (2016) examined the jumping front-leg naeryo chagi and found that impact velocity was most accurately predicted from pelvic tilt angular displacement and hip extension velocity. The optimal impact force was attained when the torso was kept upright, and the knee was straighter during the leg-lowering phase, which demonstrates the necessary biomechanical adjustments for maximum power in dynamic conditions. Studies also established that in naeryo chagi, the length of the downswing period is directly related to foot velocity. The optimal power output occurs at approximately 45° leg angles during the downswing, which implies that proper weight transfer and dynamic posture are required (Wasik & Shan, 2014).

Variability training was identified as an important method for improving dwit chagi performance. Guimarães, Ugrinowitsch, Dascal, and Okazaki (2020) found that such training led to a reduction in inter-limb variability, improved control of hip and knee angular velocity, and faster execution time. Wasik and Gora (2016b) also addressed the importance of quick knee chambering and accurate foot trajectory control to achieve peak foot velocity in dwit chagi, where experienced athletes had higher velocities and shorter execution times due to better neuromuscular control. Psychological factors also affect performance. Osman, Lee, Abd Malek, Azmi Abdullah & Nadzalan (2022) found that motivational self-talk improved kick height and velocity compared with instructional self-talk and a control condition. From a psychological perspective, reducing cognitive load and adopting an outcome-focused approach can improve performance efficiency."

These findings emphasize the significance of integrating biomechanical accuracy, psychological approaches, and advanced training techniques for maximum performance. By addressing these aspects, athletes can fine-tune their performance in bandal chagi, naeryo chagi, and dwit chagi to reach their best while maintaining consistency and safety.

From the data collected from the analysis, it is clear that the kinetics and kinematics of kicks in taekwondo are an area of sport that should be explored further. Through a comprehensive review of 86 scholarly articles, we identified several significant outcomes. The dollyo chagi kick was found to be the most popular kick with power and velocity attributed to it emerging from its rotational dynamics. Yeop chagi has been identified to have most force production through its linear trajectory and the use of mass. Ap chagi kick demonstrates proximal to distal energy transfer for optimal efficiency as a critical feature. In contrast, bandal chagi and dwit chagi kicks and their techniques are discussed in terms of their biomechanical benefits and strategic applications. Also, there were noticeable effects of gender and fatigue on the performance parameters and individualized training schedules to improve efficiency with minimum risk of injury. We would also like to emphasize that training approaches and programmes should be personalized and that their resistance intensities should be adjusted to the gender, experience level and weight class of the athletes. These findings focus on the technical and biomechanical requirements for effective taekwondo performance.

Some restrictions of the studies included in the study are also presented. Most of the studies did not incorporate a thorough analysis of kinetic and kinematic variables, which would have allowed for a more sophisticated analysis of the interactions between different biomechanical factors. Furthermore, absence of longitudinal research makes it difficult to explain how training interventions affect performance outcomes. The use of different equipment and techniques in the studies also limits the comparison of the findings.

Although there are several systematic reviews and meta-analyses on the biomechanics of taekwondo or the biomechanics of some taekwondo kicks, are that this is the first study in the literature that covers all kicks, which is its strength. Based on our analysis, we have identified potential factors that may enhance performance such as joint coordination, energy transfer, and muscle activation to aid athletes, coaches and researchers. Our findings agree with previous studies which point to the importance of biomechanical efficiency in improving athletic performance. Additionally, the review also identifies other performance factors such as the effect of psychological factors and new training tools like wearable resistance as recommendations for future research.

Our study has several recommendations for future studies. There is a need for experimental studies that integrate biomechanical, physiological and psychological variables to understand better the determinants of performance. Standardization of techniques will strengthen the future generation of research. Moreover, the use of new tools such as motion capture and machine learning may improve the validity and usefulness of biomechanical analysis. These advances will help in refining training methods and would be beneficial to the overall field of sports science as they involve understanding complex movement patterns that are characteristic of martial arts.

Limitations

This study has several limitations like other systematic reviews. First, due to the diversity of methods, variables and outcome measures used across the included studies, a meta-analysis could not be done. Second, despite our best efforts, insufficient data were obtained from subcategories (especially less explored kicks such as dwit chagi and naeryo chagi) for a more detailed analysis of their biomechanics. Lastly, since this review is based on secondary data from other researchers, there may be some methodological inconsistencies or biases. Therefore, future investigations are suggested to enhance methodology, increase participant numbers, and use meta-analysis.

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