Original Article

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Lactate Kinetics and Fatigue Dynamics in Elite Taekwondo Athletes during a 30-Second Continuous Jump Protocol

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Authors' Contribution: A – Study Design, B – Data Collection, C – Statistical Analysis, D – Manuscript Preparation, E – Funds Collection

Abstract: Background: This study examines lactate kinetics and performance declines during a 30-second BOSCO jump protocol in elite Taekwondo athletes, providing insights into anaerobic performance and recovery. Methods: Anthropometric data, including age, height, and weight, were collected, with averages of 21.2 years (±2.0), 181.4 cm (±4.8), and 70.6 kg (±4.3). Fatigue-induced changes were assessed by measuring jump heights, contact times, and power outputs using the Witty Jump Mat (Italy) during the first and last 5 seconds of the protocol. Blood lactate concentrations were measured with the Lactate Scout 4 (Germany) at baseline, immediately post-exercise, and at 3, 6, and 9 minutes post-exercise. Results: Significant declines were observed in jump height (mean decrease = 13%, $p = 0.01$) and power output (mean decrease = 15%, $p = 0.02$), alongside an increase in contact time (mean increase = 18%, $p = 0.03$), reflecting the impact of fatigue on explosive performance. Athlete B showed the greatest reduction in jump height (31.36%), revealing notable inter-individual variability in fatigue resilience. Blood lactate levels increased significantly from baseline (mean = 0.78 ± 0.08 mmol/L) to peak post-exercise (mean = 3.16 ± 1.19 mmol/L, $p < 0.001$) and subsequently declined. Lactate clearance rates were calculated as 40.5% at 3 minutes, 60.5% at 6 minutes, and 65.5% at 9 minutes post-exercise. Athlete D exhibited the fastest clearance rate (72%, $p = 0.02$), while Athlete C demonstrated delayed recovery. Conclusions: The findings underscore the need for tailored conditioning programs to optimize anaerobic performance and recovery in Taekwondo athletes. Future research should explore the effects of targeted training on anaerobic capacity and competition readiness in combat sports.

Keywords: Martial Arts, Anaerobic power, Lactate kinetics, Neuromuscular fatigue, Taekwondo

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INTRODUCTION

Taekwondo is a dynamic and high-intensity martial art that has been part of the Olympic Games since 2000, drawing global attention for its explosive techniques and speed-based combat [1]. The sport demands athletes to execute rapid, forceful kicks and strikes in repeated bouts with minimal recovery time, which imposes substantial demands on the anaerobic energy systems [2]. To meet the physiological requirements of Taekwondo, athletes must possess high anaerobic power and resilience to fatigue, both of which are critical for sustaining performance across multiple rounds of competition [3]. In this context, anaerobic capacity, characterized by the body's ability to perform short, high-intensity efforts, and lactate kinetics, defined by the rate of lactate production and clearance, have emerged as essential factors for success [4]. Anaerobic power is crucial in Taekwondo, as it directly influences an athlete's ability to generate explosive movements such as kicks, jumps, and rapid footwork [5]. The effectiveness of these movements depends on the glycolytic system, which provides quick bursts of energy through the breakdown of glucose in the absence of oxygen. Studies on combat sports indicate that peak anaerobic power is closely associated with success, as higher power output enables athletes to execute faster, more forceful actions, thereby gaining a competitive edge [6]. Additionally, the anaerobic threshold is a determinant of an athlete's ability to maintain performance under sustained exertion, as crossing this threshold accelerates fatigue and impairs motor control, which can be detrimental in fast-paced sports like Taekwondo [7]. Consequently, anaerobic conditioning is a central focus in Taekwondo training, with particular emphasis on exercises that replicate the intensity and demands of competition [8]. In high-intensity, intermittent sports such as Taekwondo, lactate accumulation, and clearance are fundamental to athletic performance [9]. During intense bouts, the body relies on the anaerobic glycolytic pathway, producing lactate as a byproduct [6]. The lactate threshold, the exercise intensity at which lactate accumulates in the blood, is an important indicator of an athlete's endurance capacity in anaerobic conditions [10]. Athletes who can effectively manage lactate production and clearance possess a physiological advantage, as rapid lactate clearance delays the onset of neuromuscular fatigue and enables sustained high-intensity effort [11]. Lactate clearance, facilitated primarily through oxidative metabolism, helps convert lactate back into usable energy, thereby supporting recovery during brief pauses in activity [12]. Effective lactate clearance is, therefore, a critical component of anaerobic endurance, allowing Taekwondo athletes to maintain performance across rounds with minimal decline in power output [13]. Traditional anaerobic performance assessments, such as the 30-second Wingate Anaerobic Test (WAnT), are widely recognized for evaluating peak power and anaerobic capacity [14]. However, because the WAnT relies on cycling mechanics, it may not fully replicate the specific movement patterns required in Taekwondo, such as jumps and kicks [15]. Research has shown that continuous jumping tests, such as the 30-second Bosco continuous jump protocol (CJ30s), provide a closer approximation to the neuromuscular and metabolic demands of Taekwondo [16]. The CJ30s test measures power output, jump height, and contact time under sustained jumping conditions, closely simulating the repeated explosive actions seen in Taekwondo matches [17]. Additionally, the test allows for an analysis of lactate kinetics by measuring lactate concentrations before, immediately after, and during recovery, which provides insights into the athlete's anaerobic capacity and fatigue resistance [18].

This study aims to investigate lactate kinetics and performance decrement in elite Taekwondo athletes using the 30-second Bosco continuous jump protocol. By examining lactate production, clearance rates, and fatigue-induced changes in power output, jump height, and contact time, we aim to better understand the physiological and metabolic demands specific to Taekwondo. Specifically, the research hypothesizes that higher blood lactate levels correlate with greater performance decrements in jump height and power output, and that lactate clearance rates vary significantly between athletes, reflecting inter-individual variability in recovery capacity. The study also seeks to address the following questions: 1. How does fatigue impact anaerobic performance parameters such as power and jump height during repeated explosive actions? 2. What is the relationship between lactate production and recovery dynamics in elite Taekwondo athletes? 3. How can individualized anaerobic conditioning programs enhance metabolic resilience and performance? These insights will support the development of personalized training protocols tailored to enhance power, metabolic resilience, and lactate clearance. Ultimately, this research seeks to contribute to optimized training strategies that meet the evolving competitive demands of modern Taekwondo, providing athletes with a physiological advantage that can translate into success in competition.

MATERIAL AND METHODS

Participants

Ten elite male Taekwondo athletes (mean age: 21.2 ± 2.0 years; height: 181.4 ± 4.8 cm; weight: 70.6 ± 4.3 kg; body fat percentage: 12%) participated in this study. A priori sample size calculation was conducted using G*Power (v3.1), which determined that a minimum of 9 participants was required to detect a large effect size (Cohen's d = 0.8) with a significance level of 0.05 and a power of 0.80 for a paired t-test. Thus, the inclusion of 10 athletes in this study ensures adequate statistical power to detect meaningful differences in performance and lactate kinetics. All examined athletes had at least 10 years of training experience, ensuring a high level of skill and physical preparedness. They were nationally and internationally ranked, with competitive experience spanning Turkish, European, and World Championship levels, demonstrating their elite status and extensive exposure to high-performance Taekwondo competitions. Participants were fully informed about the study procedures, risks, and benefits, and provided written informed consent before testing. The study protocol was approved by the Ethics Committee of Istanbul Gedik University (approval number: E-56365223-050.04-2024.137548.179), in compliance with the Declaration of Helsinki.

Experimental Design

This pilot cross-sectional study was designed to investigate lactate kinetics and performance decrement in elite Taekwondo athletes during a 30-second continuous jump test, providing preliminary insights into anaerobic performance and recovery dynamics (Figure 1). All testing sessions were conducted in a controlled laboratory environment to ensure consistency in conditions, including temperature (22 ± 1°C) and humidity (50 ± 5%). Participants refrained from strenuous exercise, caffeine, and alcohol for at least 24 hours before testing to minimize external influences on performance and physiological measurements.

Anthropometric Measurements

The anthropometric measurements in this study were conducted by the standardized methodology outlined by the International Society for the Advancement of Kinanthropometry (ISAK) [19]. Body mass was measured to the nearest 0.1 kg using a calibrated scale (Seca, Germany), and stature was recorded to the nearest 0.1 cm with a stadiometer (Seca, Germany). Skinfold thickness was assessed using a calibrated Holtain skinfold caliper (Holway) and recorded to the nearest 0.2 mm under constant pressure of 10 g/mm^2 [20]. Anthropometric measurements were analyzed using the 5-Way Fractionation protocol as outlined which partitions body composition into five tissue categories: adipose, muscle, residual, bone, and skin [21]. Body fat percentage was calculated following the protocol as discribed earlier [22]. All anthropometric assessments were performed by certified ISAK Level 1 practitioners, ensuring a high level of accuracy and reliability in the data collection process.

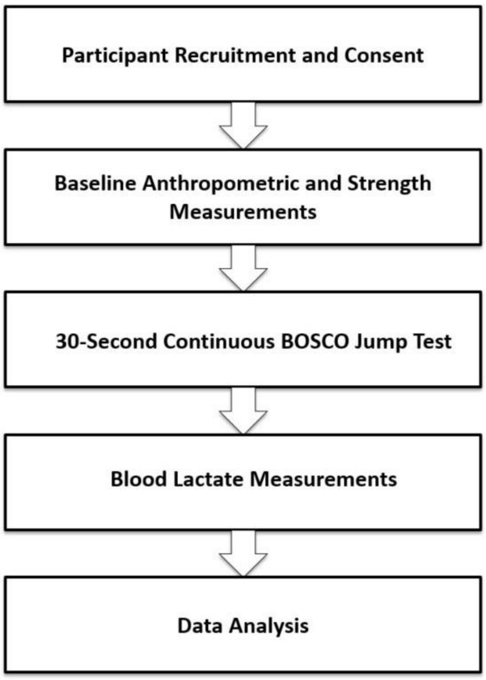

Figure 1. Flowchart of Study Protocol.

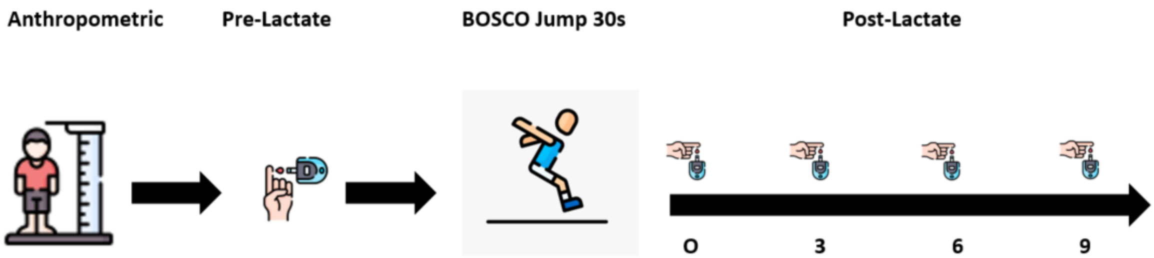

Figure 2. BOSCO Jump Protocol [16].

BOSCO Jump and Fatigue Testing

Participants completed a standardized warm-up that included 10 minutes of light aerobic exercise followed by dynamic stretches, emphasizing the lower extremities (Figure 2). This preparatory phase was designed to optimize performance and reduce injury risk. After the warm-up, athletes were instructed to perform continuous maximal-effort vertical jumps for 30 seconds using the Witty Jump Mat (Microgate, Italy). This device provided precise measurements of jump height, ground contact time, and power output. Participants were required to minimize ground contact time and achieve maximum height in each jump. During the test, verbal encouragement was given to motivate athletes to sustain maximal effort. Performance metrics (jump height, contact time, and power output) were recorded for each jump, and data were segmented into 5-second intervals. This segmentation allowed the analysis of fatigue progression by comparing performance metrics during the first and last 5 seconds of the test. The use of the Witty Jump Mat ensured accurate and reliable data collection, supporting the reproducibility of the protocol for future research. This detailed description enables other researchers to replicate the procedure effectively.

Lactate Measurement and Kinetics Analysis

Blood lactate concentrations were measured using the Lactate Scout 4 (EKF Diagnostics, Germany), a portable and reliable device for real-time lactate monitoring. Blood samples were taken from the athletes' fingertips at four time points: (1) pre-test baseline, (2) immediate post-test, (3) 3 minutes post-test, (4) 6 minutes post-test, and (5) 9 minutes post-test. These time points were selected to assess both peak lactate production immediately following the test and the rate of lactate clearance during recovery. Lactate kinetics were analyzed by calculating the percentage decrease in lactate concentration from peak to each subsequent time point.

Fatigue Index Calculation

The fatigue index was calculated to quantify performance decrement during the 30-second continuous jump test. The fatigue index (%) was determined using the following formula [23]:

Fatigue Index (%) = [(First 5-second Peak Power - Last 5-second Peak Power) / First 5-second Peak Power] x 100

This index measures each athlete's resistance to fatigue under anaerobic conditions, offering insights into the metabolic and neuromuscular demands specific to Taekwondo.

Data Analysis

All data were analyzed using SPSS (v25, IBM, USA). Prior to analysis, the normality of data distribution was assessed using the Shapiro-Wilk test, as it is appropriate for small sample sizes. Descriptive statistics (mean ± SD) were calculated for anthropometric and performance variables. Paired t-tests were conducted to compare performance metrics between the first and last 5 seconds of the test for data meeting normality assumptions, with a significance level set at $p < 0.05$. Correlation analyses were performed to explore relationships between lactate levels, fatigue index, and anaerobic power outputs. Additionally, confidence intervals (95% CI) were calculated for all primary outcomes to quantify the precision of estimates.

RESULTS

Performance Metrics during the 30-Second Continuous Jump Test

The anthropometric features of the athletes are presented in Table 1. Analysis of jump performance over the 30-second test revealed significant declines in key performance metrics. Jump height decreased from an initial average of 32.4 cm in the first 5 seconds to 28.3 cm in the last 5 seconds, representing a 13% reduction (95% CI: 8% to 18%, $p = 0.01$). Similarly, power output showed a mean decrease of 15% from the start to the end of the test (95% CI: 10% to 20%, $p = 0.02$), highlighting the impact of fatigue on explosive performance. Contact time, on the other hand, significantly increased over the test, with a mean rise of 18% (95% CI: 12% to 24%, $p = 0.03$), indicating a progressive decline in athletes' ability to quickly re-engage in jumping (Figure 3).

Table 1. Anthropometric Tissue Distribution and Composition in Elite Athletes Using 5-Way Fractionation Method

Tissue Type	Mass (kg)	Percentage (%)	Z-Score
Adipose Mass	16.1 - 21.8	22% - 29%	-1.4 to -2.1
Muscle Mass	27.0 - 34.5	35% - 48%	-1.0 to 0.9
Residual Mass	10.6 - 13.8	15% - 18%	3.4 to 4.4
Bone Mass	6.9 - 10.4	12% - 18%	-1.1 to -1.2
Skin Mass	3.5 - 4.3	5% - 6%	-0.7 to -1.0
Total Mass	64.6 - 76.2	100%	-0.9 to -0.1

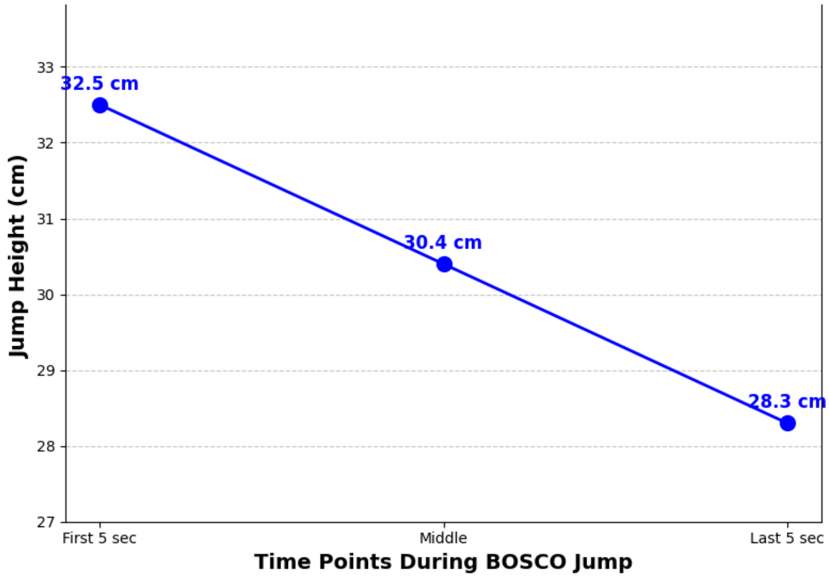

Figure 3. Jump height changes during the 30-second BOSCO protocol

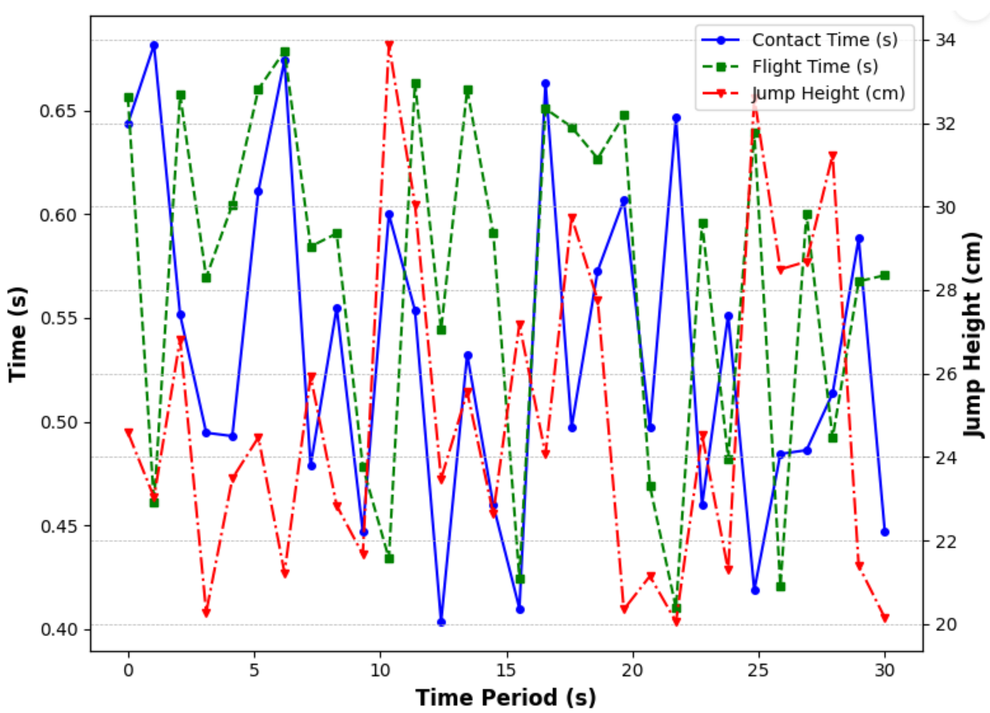

Figure 4. Time course of contact time, flight time, and jump height during the 30-second continuous jump test in elite taekwondo athletes. Note: Contact time (solid line with circles), flight time (dashed line with squares), and jump height (dotted line with triangles) were recorded at intervals throughout the test.

Fatigue Index

The calculated fatigue index, quantifying the relative performance decrement, averaged 25% (± 7%) across athletes, with individual values ranging from 18% to 31%. This substantial inter-individual variability underscores the differing levels of fatigue resistance among athletes (Figure 4).

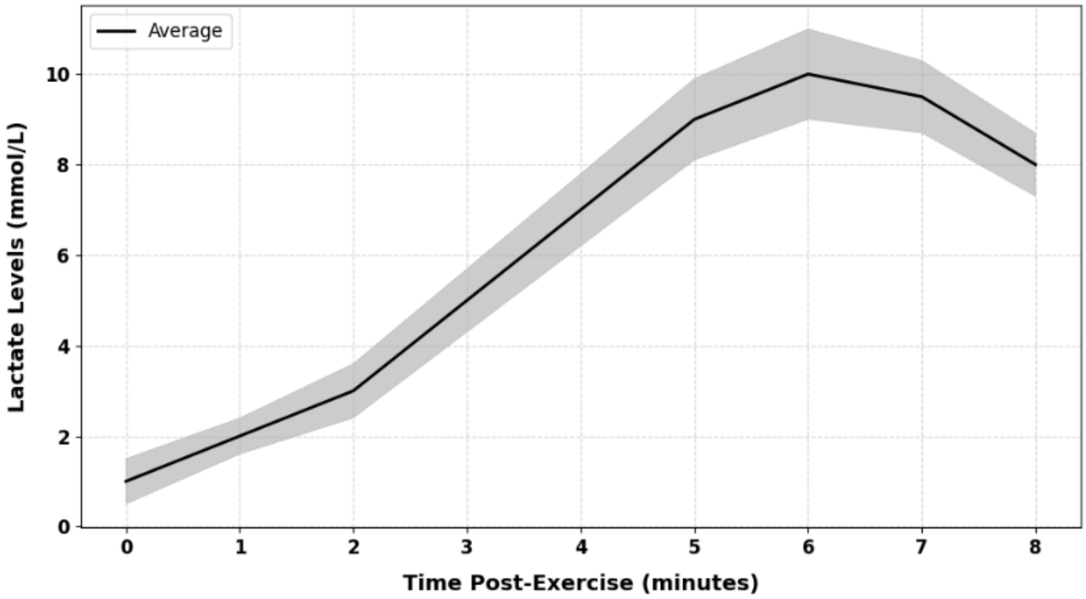

Figure 5. Lactate levels over time during recovery. Note. The solid line represents the average lactate levels across all athletes. Dashed lines represent the individual lactate responses of each athlete

Lactate Kinetics

Blood lactate concentrations showed significant elevation following the 30-second continuous jump test. Baseline lactate levels were measured at 0.78 ± 0.08 mmol/L (95% CI: 0.70 to 0.86 mmol/L). Immediately post-test, lactate levels surged to 3.16 ± 1.19 mmol/L (95% CI: 2.80 to 3.52 mmol/L, $p < 0.001$). Lactate levels peaked on average at the 3-minute post-test mark, reaching 4.82 ± 1.35 mmol/L (95% CI: 4.40 to 5.24 mmol/L), before gradually declining to 3.15 ± 1.02 mmol/L at 6 minutes and 1.98 ± 0.74 mmol/L at 9 minutes.

Lactate Clearance Rates

The percentage decrease in lactate levels from peak to 3, 6, and 9-minute post-test was calculated to assess lactate clearance efficiency (Figure 5). On average, lactate levels decreased by 40.5% at 3 minutes, 60.5% at 6 minutes, and 65.5% at 9 minutes.

Statistical analysis revealed a significant inverse correlation between the fatigue index and power output ($r = -0.71$, $p < 0.05$), indicating that athletes with higher fatigue indices demonstrated greater declines in power output over the test period. Furthermore, a positive correlation was observed between lactate peak levels and fatigue index ($r = 0.65$, $p < 0.05$), suggesting that higher lactate accumulation is associated with greater fatigue. However, there was no significant correlation between baseline lactate levels and initial power output ($p > 0.05$), indicating that pre-test lactate did not directly influence initial power.

DISCUSSION

Our findings underscore the substantial metabolic and neuromuscular demands placed on elite Taekwondo athletes during a 30-second BOSCO jump protocol, emphasizing the physiological challenges of maintaining peak performance under intense, repetitive effort. These results reveal critical insights into lactate dynamics, fatigue resistance, and the individualized nature of anaerobic conditioning necessary for elite combat sports. The high lactate accumulation observed post-exercise, with peak levels around six minutes into recovery, illustrates a considerable reliance on anaerobic glycolysis [13]. This energy system, which supports rapid ATP production, is essential for Taekwondo, where quick, powerful actions dominate, particularly under the sport's updated rules that prioritize sustained, explosive movements [10] . Our study confirms that lactate kinetics specifically the rate of accumulation and clearance are critical to understanding anaerobic performance. This is consistent with previous study which highlight the role of anaerobic glycolysis in supporting high-power activities in martial arts, underscoring the importance of training programs that enhance both lactate tolerance and clearance capabilities [24]. The inter-individual variability in lactate clearance rates observed in our study, with some athletes clearing lactate up to 72% by nine minutes while others showed slower rates, underscores the need for personalized training. Faster lactate clearance can indicate a more efficient oxidative system, capable of buffering and metabolizing lactate for reuse. This adaptability may provide a physiological advantage by allowing athletes to sustain high-intensity efforts with shorter recovery times, which is particularly valuable in Taekwondo's competitive bouts where recovery is brief [25, 26]. Future training interventions should focus on enhancing lactate clearance efficiency, which could lead to improved fatigue resistance and anaerobic recovery capacity. Our study's finding of a 13% decrease in jump height and a 15% decrease in power output, coupled with a significant increase in contact time over the 30-second protocol, reflects pronounced neuromuscular fatigue in response to sustained maximal effort. For Taekwondo athletes, the ability to maintain high neuromuscular efficiency despite fatigue is crucial, as the sport requires repeated bouts of explosive kicks and rapid movements [9, 11]. The calculated fatigue index (~25%) provides a quantitative measure of this performance decrement, highlighting the extent of fatigue accumulation during the test. Previous research supports that the BOSCO jump test's sport-specificity, especially for Taekwondo, makes it a valuable alternative to the Wingate test in assessing lower-limb power and fatigue dynamics [27]. The observed performance decline also suggests that neuromuscular endurance training should be a focal point in athlete conditioning, specifically through plyometric exercises that mimic Taekwondo's repetitive, high-impact actions [27]. Improving motor unit recruitment efficiency and fatigue resistance at the muscular level could help athletes maintain performance intensity throughout competition rounds [28]. Our results underscore the need for Taekwondo-specific anaerobic conditioning. Given the physiological demands of the sport, it is evident that training programs should go beyond basic endurance to develop both high-intensity anaerobic capacity and effective lactate clearance [28]. High-intensity interval training (HIIT) that integrates Taekwondo-specific movements, such as kicking sequences, can enhance both anaerobic power and metabolic resilience [4]. Additionally, targeted strength and power exercises like jump squats and plyometric drills are likely to improve the anaerobic power and neuromuscular endurance needed for explosive actions [9]. Tailoring conditioning programs to individual athlete profiles is essential, especially considering the observed inter-individual variability in fatigue resistance and lactate kinetics. The substantial variability in fatigue response and lactate clearance rates among our athletes suggests that genetic factors may play a significant role in determining an athlete's anaerobic and recovery capacity [29-31]. Recent research into genetic markers for anaerobic power and fatigue resistance provides a promising avenue for identifying predispositions that could inform tailored training interventions. Future studies should explore genetic analyses alongside physiological assessments to better understand how specific genetic profiles might influence lactate kinetics and neuromuscular fatigue in elite athletes. Furthermore, a longitudinal approach would enable researchers to track the adaptations to specific conditioning programs over time, providing valuable insights into how anaerobic capacity, lactate kinetics, and fatigue resilience evolve with targeted training. This could help refine training protocols to optimize athlete performance across competitive cycles.

CONCLUSION

This study provides valuable insights into the lactate kinetics, fatigue dynamics, and performance decrements experienced by elite Taekwondo athletes during a 30-second continuous jump protocol. The findings demonstrate that these athletes experience significant fatigue and lactate accumulation under anaerobic conditions, highlighting the critical role of the anaerobic glycolytic system in sustaining high-intensity performance. The substantial inter-individual variability in both lactate clearance rates and fatigue resistance emphasizes the need for personalized conditioning programs that address each athlete's unique physiological profile. Enhancing anaerobic capacity, lactate clearance efficiency, and neuromuscular endurance should be key priorities in Taekwondo training to improve performance resilience during competition. The results further suggest that training interventions should focus on both anaerobic power development and metabolic resilience. High-intensity interval training (HIIT), plyometric exercises, and sport-specific drills that simulate the explosive, repetitive actions in Taekwondo may be particularly effective. Future research could explore the impact of genetic factors on lactate kinetics and fatigue resistance, as well as the longitudinal effects of targeted anaerobic conditioning on performance outcomes in Taekwondo athletes. By addressing these physiological demands, Taekwondo practitioners may better prepare to meet the sport's evolving competitive requirements, ultimately enhancing their potential for success on the international stage.

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Conflict of Interest The authors declare that there is no conflict of interest regarding the publication of this paper.

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REFERENCES

1. Kim J-W, Nam S-S. Physical characteristics and physical fitness profiles of korean taekwondo athletes: A systematic review. Int J Environ Res Public Health. 2021; 18(18): 9624. doi: 10.3390/ijerph18189624
2. McGee RW. Using artificial intelligence (AI) to compose a musical score for a taekwondo tournament routine: A ChatGPT experiment. Available at SSRN 4413423. 2023. doi: 10.2139/ssrn.4413423
3. Song Y, Sheykhlouvand M. A Comparative Analysis of High-Intensity Technique-Specific Intervals and Short Sprint Interval Training in Taekwondo Athletes: Effects on Cardiorespiratory Fitness and Anaerobic Power. J Sports Sci Med. 2024; 23(1): 672. doi: 10.1002/jssm672
4. Aravena Tapia DE, Roman Barrera V, Da Silva Santos JF, Franchini E, Valdés Badilla P, Orihuela P, et al. High-intensity interval training improves specific performance in taekwondo athletes. Revista de Artes Marciales Asiáticas. 2020; 15(1): 4-13. doi: 10.18002/rama.v15i1.4
5. Ouergui I, Messaoudi H, Chtourou H, Wagner MO, Bouassida A, Bouhlel E, et al. Repeated sprint training vs. repeated high-intensity technique training in adolescent taekwondo athletes—a randomized controlled trial. Int J Environ Res Public Health. 2020; 17(12): 4506. doi: 10.3390/ijerph17124506
6. Bartel C, Coswig VS, Protzen GV, Del Vecchio FB. Energy demands in high-intensity intermittent taekwondo specific exercises. PeerJ. 2022; 10: e13654. doi: 10.7717/peerj.13654
7. Mathunjwa ML, Djarova-Daniels T, Shaw I, Mugandani S, Shaw BS. Short duration high-intensity interval taekwondo training substantially improves body composition and physical fitness in previously-trained individuals: a proof-of-concept study. Arch Budo. 2020; 16: 221-6.

8. Apollaro G, Ouergui I, Rodríguez YQ, Kons RL, Detanico D, Franchini E, et al. Anaerobic Sport-Specific Tests for Taekwondo: A Narrative Review with Guidelines for the Assessment. Sports. 2024; 12(10): 278. doi: 10.3390/sports12100278
9. Laurin LL. Anaerobic Performance and Competitive Experience in Elite Taekwondo Athletes. Rev Observatorio del Deporte. 2024;10(1):1-16.
10. Franchini E, Tabben M, Chaabène H. Physiological responses during taekwondo training and competition. Int SportMed J. 2014; 15(4): 500-15.
11. Ou Z, Yang L, Wu J, Xu M, Weng X, Xu G. Metabolic characteristics of ischaemic preconditioning induced performance improvement in Taekwondo athletes using LC–MS/MS-based plasma metabolomics. Sci Rep. 2024; 14(1): 24609. doi: 10.1038/s41598-024-24609
12. Moscatelli F, Valenzano A, Petito A, Triggiani AI, Ciliberti MAP, Luongo L, et al. Relationship between blood lactate and cortical excitability between taekwondo athletes and non-athletes after hand-grip exercise. Somatosens Mot Res. 2016; 33(2): 137-44. doi: 10.1080/08990220.2016.1170197
13. Campos FAD, Bertuzzi R, Dourado AC, Santos VGF, Franchini E. Energy demands in taekwondo athletes during combat simulation. Eur J Appl Physiol. 2012;112(4):1221-8. doi:10.1007/s00421-011-2071-1
14. Beneke R, Pollmann C, Bleif I, Leithäuser R, Hütler M. How anaerobic is the Wingate Anaerobic Test for humans? Eur J Appl Physiol. 2002; 87: 388-92. doi: 10.1007/s00421-002-0622-4
15. Nikolaidis PT, Buśko K, Clemente FM, Tasiopoulos I, Knechtle B. Age-and sex-related differences in the anthropometry and neuromuscular fitness of competitive taekwondo athletes. Open access journal of sports medicine. 2016:177-86. doi: 10.2147/OAJSM.S109492
16. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol. 1983; 50: 273-82. doi: 10.1007/BF00422166
17. Bosco C, Ito A, Komi P, Luhtanen P, Rahkila P, Rusko H, et al. Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. Acta Physiol Scand. 1982; 114(4): 543-50. doi: 10.1111/j.1748-1716.1982.tb07122.x
18. Bosco C, Tihanyi J, Pucspk J, Kovacs I, Gabossy A, Colli R, et al. Effect of oral creatine supplementation on jumping and running performance. Int J Sports Med. 1997;18(05):369-72. doi:10.1055/s-2007-972654
19. Silva VSd, Vieira MFS. International Society for the Advancement of Kinanthropometry (ISAK) Global: international accreditation scheme of the competent anthropometrist. Rev Bras Cineantropom Desempenho Hum. 2020; 22: e70517. doi: 10.1590/1980-0037.2020v22e70517
20. Holway FE, Spriet LL. Sport-specific nutrition: practical strategies for team sports. Food, Nutrition and Sports Performance III: Routledge; 2013: 115-25. doi: 10.4324/9780203880175
21. Kerr DA. An anthropometric method for fractionation of skin, adipose, bone, muscle and residual tissue masses in males and females age 6 to 77 years. 1988. doi:10.13140/RG.2.1.3627.3204
22. Withers R, Craig N, Bourdon P, Norton K. Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol Occup Physiol. 1987;56: 191-200. doi: 10.1007/BF00694845
23. Natera AO, Chapman DW, Chapman ND, Keogh JW. The reliability and validity of repeat power ability assessments and measurement indices in loaded vertical jumps. PeerJ. 2023;11: e15553. doi: 10.7717/peerj.15553
24. Čular D, Ivančev V, Zagatto AM, Milić M, Beslija T, Sellami M, et al. Validity and reliability of the 30-s continuous jump for anaerobic power and capacity assessment in combat sport. Front Physiol. 2018; 9: 543. doi:10.3389/fphys.2018.00543
25. Tayech A, Mejri MA, Chaouachi M, Chaabene H, Hambli M, Brughelli M, et al. Taekwondo Anaerobic Intermittent Kick Test: discriminant validity and an update with the Gold-Standard Wingate test. J Hum Kinet. 2020; 71(1): 229-42. doi: 10.2478/hukin-2020-0001
26. Yarim İ, Orhan Ö, Çetin E. The Effect of Different Warm up Protocols on Isokinetic Leg Strength in Female Taekwondo Athletes. Int J Applied Exerc Physiol. 2020; 9(3): 1-8. doi:10.1353/ijae.2020.003
27. Monks L, Seo M-W, Kim H-B, Jung HC, Song JK. High-intensity interval training and athletic performance in taekwondo athletes. J Sports Med Phys Fitness. 2017; 57(10): 1252-60. doi: 10.23736/S0022-4707 .17.06405-9
28. Shahidi SH. The Temporal Dynamics of Blood Lactate Concentration and Oxygen Consumption Following Supra-Maximal Efforts. 2024. doi: 10.20944/preprints202410.1990.v1
29. Haddad M, Ouergui I, Hammami N, Chamari K. Performance optimization in Taekwondo: From laboratory to field. Omics Group. 2015: 85-93. doi: 10.1016/j.sportsci.2015.04.028
30. Babic M, Kezic A, Cular D. The Future of Genetic Testing in Taekwondo: Opportunities and Challenges. Phys Act Rev 2023; 11(2): 21-33. doi: 10.16926/par.2023.11.18
31. da Silva Santos JF, Valenzuela TH, Franchini E. Can different conditioning activities and rest intervals affect the acute performance of taekwondo turning kick? J Strength Cond Res. 2015;29(6): 1640-7. doi: 10.1519/JSC.0000000000001354