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Analysis of aerobic ability for taekwondo athletes through the application of heart rate and blood pressure monitoring system

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Abstract

Background and Study Aim Taekwondo is a combat sport characterized by high-intensity intermittent actions that place substantial demands on the cardiovascular and metabolic systems of athletes. Competitive performance in taekwondo depends on the ability to sustain repeated high-intensity efforts while maintaining effective recovery between rounds, which highlights the importance of aerobic capacity alongside anaerobic performance. Despite the application of various monitoring approaches in training practice, the relative effectiveness of combining heart rate and blood pressure monitoring for evaluating aerobic adaptations in taekwondo athletes remains a matter of practical interest. This study aims to analyze the physiological responses and cardiovascular adaptations of Taekwondo athletes during an aerobic training program through the application of a wearable sensor monitoring system.

Material and Methods A quasi-experimental one-group pretest–posttest design was applied to 20 senior taekwondo athletes (age 20.35 ± 1.09 years) at Universitas Pendidikan Indonesia. The intervention consisted of a 4-week taekwondo technique-based aerobic training program. The training frequency was three sessions per week, with a duration of 45–60 minutes per session. HR was continuously monitored using a Polar H10 chest strap sensor, while BP was measured using the Omicron BW-3205 digital monitor. Data were recorded at rest, at peak load, and at the 1st and 2nd minutes post-exercise to measure heart rate recovery (HRR). Data analysis used the Shapiro–Wilk normality test, the paired samples t-test for normally distributed data, and the Wilcoxon signed-rank test as a non-parametric alternative for systolic blood pressure (SBP) data that were not normally distributed. Statistical significance was set at $p < .05$, and effect sizes were calculated using Cohen's d.

Results The study showed that during aerobic training sessions, athletes experienced an increase in recovery ability of 24.3% in the first minute (37.00 ± 6.63 bpm to 46.00 ± 6.95 bpm, $p < .001$, Cohen's d = 2.46) and 13% in the second minute (47.00 ± 7.16 bpm to 53.00 ± 5.44 bpm, $p < .001$, Cohen's d = 2.50). Furthermore, significant improvements in cardiovascular efficiency were observed. Resting systolic blood pressure (SBP) decreased by 5.6% (126.00 ± 9.17 to 119.00 ± 5.05 mmHg; $p = .000$, Cohen's d = 0.78), while post-exercise SBP showed a more pronounced decrease of 10.8% (148.00 ± 14.46 to 132.00 ± 13.32 mmHg; $p = .002$, Cohen's d = 1.18). Significant improvements in HRR and hemodynamic efficiency (SBP) demonstrate positive cardiovascular adaptation to the 4-week training program.

Conclusions This study concludes that the integration of real-time HR and BP monitoring systems is effective for evaluating and optimizing the endurance of taekwondo athletes. The findings support the use of wearable technology as an evaluation tool for coaches to design more measurable, personalized, and data-driven training programs. Such programs may help mitigate the risk of overtraining while achieving peak performance.

Keywords: aerobic ability, blood pressure, heart rate, monitoring system, taekwondo athletes.

Introduction

Taekwondo is a high-intensity combat sport in which competitive success is determined not only by technical and tactical proficiency but also by the athlete's ability to tolerate and recover from repeated physiological stress. Matches involve frequent explosive actions interspersed with short recovery periods, placing considerable demands on both cardiovascular regulation and metabolic efficiency. In this context, the balance between energy supply, cardiovascular responses, and recovery dynamics becomes a key factor influencing sustained performance across rounds. The complex interaction between aerobic capacity, heart rate behavior, and blood pressure responses reflects the multifactorial nature of endurance and recovery processes in taekwondo training and competition.

In this context, taekwondo is characterized by high-intensity, intermittent activity in which athletes are required to perform a series of explosive kicks and punches within a short period, followed by brief phases of active or passive recovery [1]. These characteristics demand complex physiological capacities, involving the simultaneous contribution

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of both aerobic and anaerobic energy systems. Modern competition rule amendments have significantly increased match intensity, requiring superior endurance and recovery capabilities compared with previous standards [2]. While anaerobic capacity often determines success in critical actions such as quick kicks, the aerobic system plays a crucial role in recovery during each burst of activity and between rounds, enabling athletes to maintain high performance throughout the match [1, 3, 4].

Monitoring athletes' physiological status is a crucial aspect of modern training programs to optimize performance and minimize the risk of injury or overtraining [5, 6]. Rapid advancements in wearable sensor technology have revolutionized the objective and continuous collection of physiological data [7]. Heart rate (HR) monitors such as the Polar H10 have demonstrated high accuracy when compared with standard reference tools, including electrocardiograms (ECG). This makes them suitable for precise HR measurement during exercise [8, 9]. Such technology enables more effective application of target HR zone concepts in field-based training settings [10]. Wearable monitoring systems continue to evolve rapidly, including developments toward contactless remote monitoring [11], underscoring the importance of leveraging current technology.

Aerobic capacity is a crucial foundation for taekwondo athletes. Optimal aerobic capacity enables athletes to delay the onset of fatigue, enhance heart rate recovery (HRR), and maintain performance throughout a match [12]. HRR, defined as the rate of heart rate decline after exercise, is a sensitive indicator of cardiorespiratory fitness and is strongly associated with aerobic capacity and recovery status [6, 13]. Systematic monitoring of HRR provides valuable information about an athlete's physiological condition during training. It can help identify overreaching or undertraining states and ensure positive adaptation to the prescribed training program [5, 14].

In addition to heart rate, blood pressure (BP) responses during and after exercise represent important physiological parameters that provide comprehensive information about cardiovascular function [15]. During dynamic exercise, systolic blood pressure (SBP) typically increases in proportion to workload, whereas diastolic blood pressure (DBP) remains stable or may slightly decrease [15, 16]. BP response patterns, including peak SBP, may reflect normal physiological adaptation or indicate a potential risk of future hypertension, even in young normotensive individuals and trained athletes [17, 18]. Conversely, an excessively low blood pressure response during exercise may also have long-term health implications [19]. Therefore, careful monitoring of blood pressure responses in taekwondo athletes can provide important indicators for both performance-related assessment and cardiovascular health risk prevention.

Analysis of research findings has shown that performance and recovery in taekwondo are closely associated with the interaction between aerobic capacity, cardiovascular regulation, and the ability to tolerate repeated high-intensity efforts. Researchers emphasize that indicators such as heart rate dynamics, heart rate recovery, and blood pressure responses provide meaningful information about both functional readiness and physiological adaptation in combat sport athletes. At the same time, the complexity of cardiovascular responses during sport-specific aerobic training highlights the importance of integrated monitoring approaches that reflect real training conditions. In this context, a systematic examination of physiological and cardiovascular responses using objective monitoring tools represents a logical step toward improving the evaluation of aerobic training effects in taekwondo athletes. This study aims to analyze the physiological responses and cardiovascular adaptations of Taekwondo athletes during an aerobic training program through the application of a wearable sensor monitoring system.

Materials and Methods

Participants

The participants in this study were 20 senior taekwondo athletes aged 19–22 years (20.35 ± 1.09 years) from Universitas Pendidikan Indonesia. The sampling technique used was total sampling, in which the entire population meeting the inclusion criteria was selected as the study sample [20].

The inclusion criteria were as follows:

- active senior-level athletes;
- a minimum of 3 years of competitive experience.

The exclusion criteria were as follows:

- a history of cardiovascular disease;
- current musculoskeletal injuries;
- use of medications affecting heart rate or blood pressure.

This study was formally approved and supervised by the Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, under the Dean's Decree Number 133/UN40.A6/PK.03.03/2025. All participants provided written informed consent prior to their involvement in the study.

Research Design

This study employed a quantitative research method with an experimental approach, emphasizing the collection of numerical data and objective measurement of research variables [21]. The approach focuses on systematic procedures for data collection, analysis, interpretation, and reporting of results [22, 23]. Experimental research is designed to identify and measure the effects of specific variables through controlled manipulation, involving independent variables, dependent variables, participants, and a defined experimental protocol [24, 25].

The study applied a quasi-experimental one-group pretest–posttest design, which is commonly used in applied and field-based research settings to examine changes within a single group over time [26, 27]. In this study, physiological measurements obtained during the initial training session were treated as pretest data, while measurements collected during the final session served as posttest data, allowing evaluation of the cumulative effects of the aerobic training program.

The intervention consisted of a 4-week taekwondo-based aerobic training program conducted every Monday, Wednesday, and Friday at 16:00. The program was designed to maintain a target exercise intensity of 60%–80% of maximum heart rate (HRmax). The 4-week duration was selected as it is sufficient to elicit and detect meaningful physiological adaptations [28]. Each training session lasted approximately 45–60 minutes and consisted of three main phases.

1. *Warm-up (10–15 minutes):* Light jogging, dynamic stretching, and basic taekwondo movements were performed to prepare the cardiovascular and neuromuscular systems.
2. *Core training (3 sets × 6 minutes):* This phase was designed to provide a high aerobic stimulus relevant to competition demands [1]. Each set involved progressively increasing intensity and was separated by 2 minutes of passive rest between sets. The structure of each set was as follows:
   a. Phase 1 (first 2 minutes): Combination of three free kicks to establish movement rhythm.
   b. Phase 2 (second 2 minutes): Combination of two free kicks and one spinning kick to increase technical complexity.
   c. Phase 3 (third 2 minutes): Combination of four forward dollyo chagi kicks and two backward kicks to achieve peak intensity.
3. Cool-down (5–10 minutes): Static stretching exercises were performed to facilitate recovery.

Data collection was conducted using validated instruments to ensure measurement accuracy and reliability. Heart rate (HR) was continuously monitored during the training sessions using a Polar H10 chest strap sensor synchronized with the Polar Beat application at a 1-second sampling rate. This device was selected because it has demonstrated high accuracy and comparability with electrocardiogram (ECG) measurements across various physical activities [29].

HR data were recorded at the following time points during each session:

- *Resting HR:* recorded after participants sat quietly for 5 minutes before the warm-up;
- *Peak HR:* defined as the highest HR value recorded at the end of each core exercise set;
- Heart rate recovery (HRR): recorded as HR values measured at the first and second minutes after the completion of each core exercise set.

Blood pressure (BP) was measured using an Omicron BW-3205 upper-arm automatic digital blood pressure monitor. During all BP measurements, participants were seated upright with the arm relaxed and supported at heart level. Measurements were obtained at the following time points:

- *Resting BP*: measured simultaneously with resting HR before the warm-up;
- *Post-exercise BP*: measured after completion of the core training to assess the hemodynamic response to the overall session load. A standardized delay of 1–2 minutes was applied due to sequential equipment use, during which participants remained seated and at rest.

Statistical Analysis

The collected data were analyzed using SPSS software (version 25). Descriptive statistics were used to summarize the data, including mean values and standard deviations for all measured variables. Data normality was assessed using the Shapiro–Wilk test, which is a prerequisite for the application of parametric statistical procedures. Hypothesis testing was conducted to determine whether significant differences existed between pretest and posttest measurements. A paired samples t-test (two-tailed) was applied to compare measurements obtained from the same group at different time points, as commonly used in similar research designs [30]. The significance level was set at $p < .05$. Results are reported with 95% confidence intervals (CI), and effect sizes were calculated using Cohen's d and interpreted as small (0.2), medium (0.5), and large (0.8) [31].

Results

The results of the normality tests for heart rate recovery (HRR), resting heart rate, and peak heart rate are presented in Tables 1 and 2. These analyses were conducted to verify the assumption of normal data distribution prior to further parametric statistical testing.

Table 1. Normality Test of Heart Rate Recovery

HRR	Test	Statistic	df	Sig.
Minute 1	Pre	.946	20	.311
	Post	.931	20	.162
Minute 2	Pre	.905	20	.052
	Post	.943	20	.267

Table 2. Normality Test of Resting Heart Rate and

Peak Heart Rate

Sub-variable	Session	Statistic	df	Sig.
HR pre warm-up	1st	.960	20	.544
	12th	.946	20	.313
Peak HR	1st	.933	20	.173
	12th	.966	20	.669

Before conducting hypothesis testing, the assumption of normal data distribution was evaluated using the Shapiro–Wilk test. As shown in Tables 1 and 2, the normality test results indicated significance values of .311 and .162 for the pretest and posttest data at minute 1, as well as .052 and .267 for the pretest and posttest data at minute 2, respectively. Because all significance values were ⩾ .05, the heart rate recovery data at both the first and second minutes were considered normally distributed, allowing further analysis using parametric methods.

In addition, the assessment of resting heart rate and peak heart rate also demonstrated normal distribution. For resting heart rate, the significance values for the first and twelfth sessions were .544 and .313, respectively. Peak heart rate showed significance values of .173 for the first session and .669 for the twelfth session. Since all values exceeded the $\alpha = .05$ threshold, the heart rate variables met the normality assumption, thereby justifying the use of the paired samples t-test for subsequent analyses.

The results of the paired samples t-test for resting heart rate, heart rate recovery, and peak heart rate are presented in Table 3.

Based on the results presented in Table 3, the paired samples t-test demonstrated statistically significant differences between pretest and posttest measurements (Sig. (2-tailed) = .000 < .05). Therefore, the null hypothesis was rejected, indicating significant changes in the analyzed heart rate variables following the intervention.

The changes in heart rate recovery across training sessions are illustrated in Figures 1 and 2.

As shown in Figure 1, heart rate recovery in the

Table 3. Paired Samples t-Test of Resting Heart Rate, Heart Rate Recovery, and Peak Heart Rate

Pair	Comparison	Mean Difference	t	df	95% Confidence Interval of the Difference	Sig. (2-tailed)	Cohen's d
					Lower	Upper	
Pair 1	Pretest HRR minute 1 – Posttest HRR minute 1	16.300	10.988	19	13.195	19.405	.000
Pair 2	Pretest HRR minute 2 – Posttest HRR minute 2	17.400	11.190	19	14.145	20.655	.000
Pair 3	Resting HR (pre warm-up), 1st session – 12th session	-4.200	-4.344	19	-6.224	-2.177	.000
Pair 4	Peak HR, 1st session – 12th session	8.650	19.529	19	7.723	9.577	.000

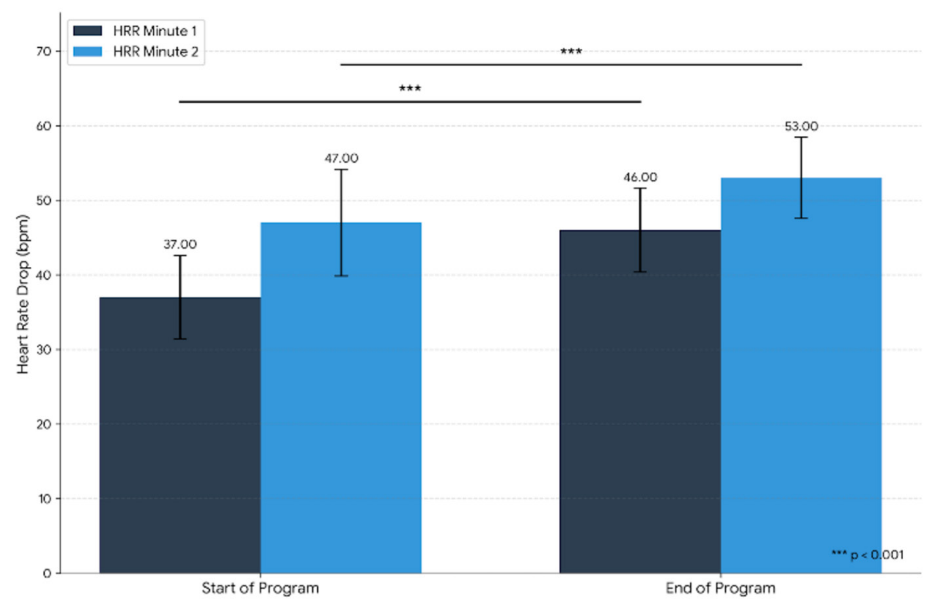

Figure 1. Heart Rate Recovery (1-Minute and 2-Minute)

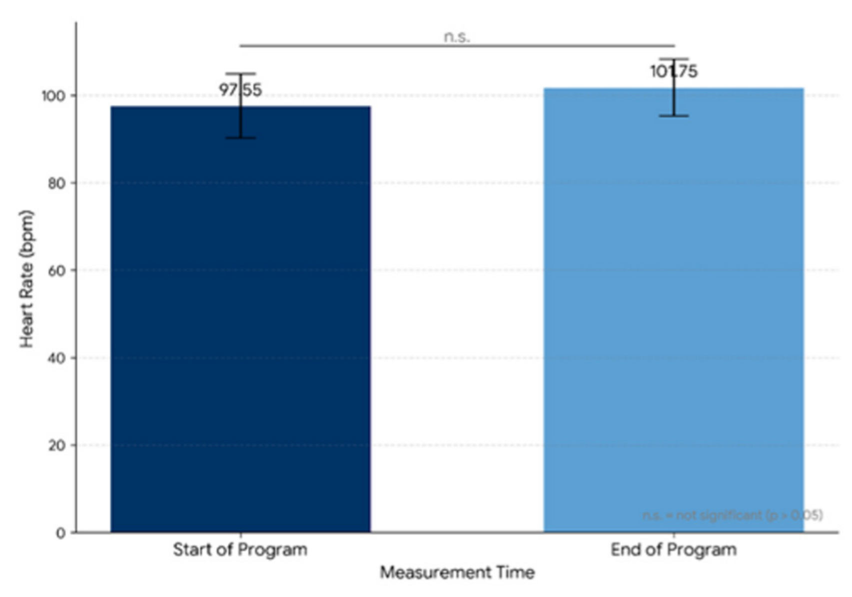

Figure 2. Average Resting Heart Rate

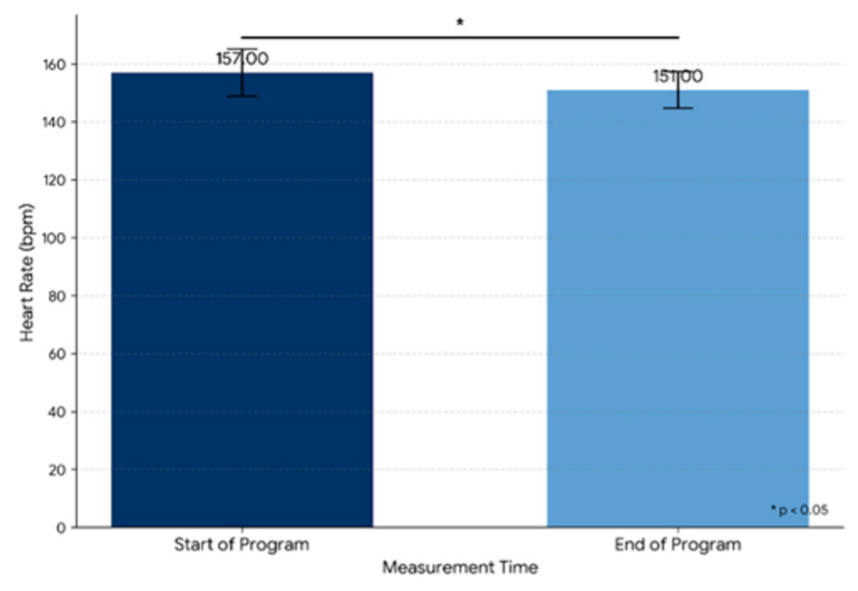

Figure 3. Average Peak Heart Rate

final session exhibited an 18% greater increase compared with the first session. This improvement reflects positive adaptation of the autonomic nervous system [1] and indicates enhanced recovery capacity during repeated high-intensity efforts.

As illustrated in Figure 2, changes in resting heart rate did not demonstrate a statistically significant difference. The mean value increased slightly from 97.55 ± 7.36 bpm to 101.75 ± 6.50 bpm. This response may be interpreted as a sign of functional overreaching, reflecting accumulated fatigue associated with effective training stimuli rather than maladaptive overtraining.

The changes in peak heart rate during standardized workload conditions are shown in Figure 3. As presented in Figure 3, the average peak heart rate achieved under the same workload decreased from 157.00 ± 8.09 bpm at the beginning of the program to 151.00 ± 6.36 bpm at the end of the intervention. A reduction in peak heart rate at an identical external load is a recognized indicator of improved cardiovascular efficiency.

The results of the Shapiro–Wilk normality test for systolic blood pressure (SBP) are presented in Table 4.

Table 4. Normality Test of Systolic Blood Pressure

Systolic	Test	Shapiro-Wilk		
		Statistic	df	Sig.
Pre-exercise	Pre	.807	20	.013
	Post	.955	20	.454
Post-exercise	Pre	.954	20	.426
	Post	.916	20	.082

As shown in Table 4, the Shapiro–Wilk test indicated that the SBP pretest pre-exercise data were not normally distributed (p = .013). Although the remaining three SBP datasets demonstrated normal distributions (p > .05), the presence of one non-normally distributed variable violated the normality assumption required for the paired samples t-test. Consequently, changes in SBP were analyzed using the Wilcoxon signed-rank test as a non-parametric alternative to ensure the validity of the statistical analysis.

The results of the non-parametric analysis of systolic blood pressure (SBP) changes across the training program are presented in Table 5.

As shown in Table 5, because resting SBP data at the beginning of the program were not normally distributed (p < .05), changes in SBP were analyzed using the Wilcoxon signed-rank test. The results indicated a statistically significant reduction in resting SBP from the beginning to the end of the program (Z = -3.974, p = .000, Cohen's d = 0.78). A similarly significant decrease was observed in post-exercise SBP (Z = -3.144, p = .002, Cohen's d = 1.18), indicating a substantial effect of the 4-week aerobic training intervention on systolic blood pressure regulation.

The graphical representation of systolic blood pressure changes across the training program is presented in Figure 4.

As illustrated in Figure 4, systolic blood pressure before exercise decreased by 7 mmHg (5.5%), from 126.00 mmHg to 119.00 mmHg (p = .000), with a large effect size (Cohen's d = 0.78). A more pronounced reduction was observed in post-exercise SBP, which decreased by 16 mmHg (10.8%), from 148.00 mmHg to 132.00 mmHg (p = .002), accompanied by a very large effect size (Cohen's d = 1.18). These findings demonstrate improved hemodynamic efficiency, indicating enhanced cardiovascular adaptation at rest and following exercise.

Table 5. Wilcoxon Signed-Rank Test Systolic Blood Pressure

Statistic	SBP Pre Exercise 12th Session – SBP Pre Exercise 1st Session	SBP Post Exercise 12th Session – SBP Post Exercise 1st Session
Z	-3.974	-3.144
Asymp. Sig. (2-tailed)	.000	.002
Cohen's d	.78	1.18
Mean Diff	7.100	15.700
95% Confidence Interval of the Difference (Lower)	2.789	9.498
95% Confidence Interval of the Difference (Upper)	11.411	21.902

Note. Significance was determined using the Wilcoxon signed-rank test due to non-normal data distribution. Other variables were analyzed using the paired samples t-test.

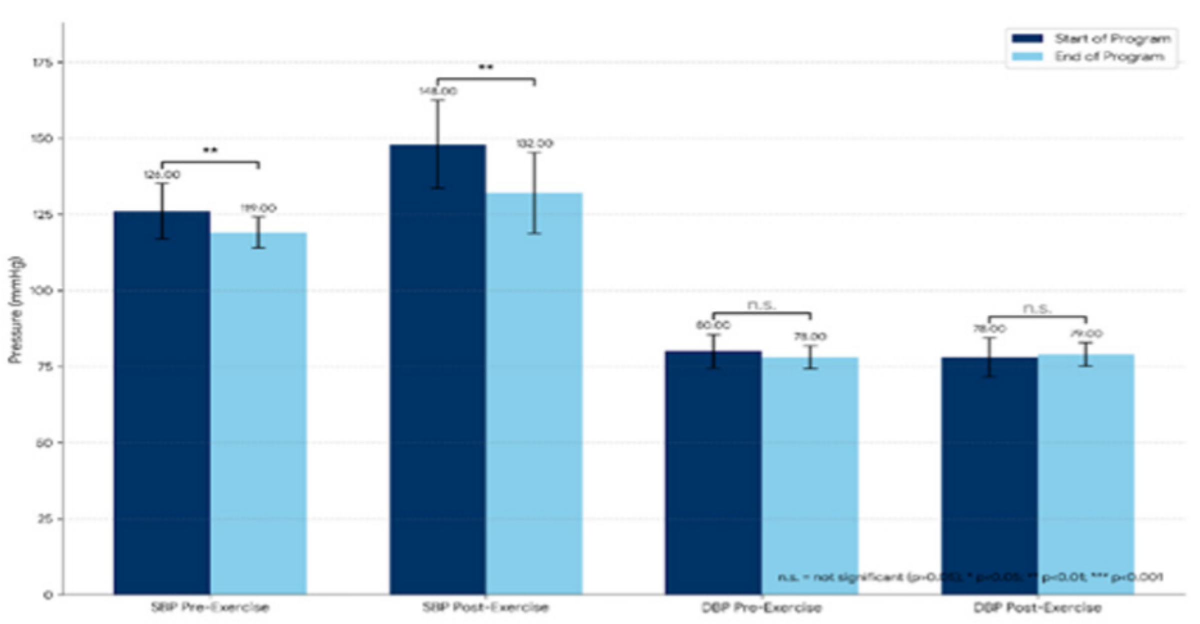

Figure 4. Systolic Blood Pressure

Discussion

This study aims to analyze the physiological responses and cardiovascular adaptations of taekwondo athletes during an aerobic training program through the application of a wearable sensor monitoring system. One of the key findings of the study was an improvement in heart rate recovery during the first two minutes of rest. After the 4-week training program, athletes demonstrated a 24.3% increase in recovery capacity, with heart rate decrease values rising from 37.00 ± 6.63 bpm to 46.00 ± 6.95 bpm in the first minute, and a 13% increase in the second minute, from 47.00 ± 7.16 bpm to 53.00 ± 5.44 bpm. The associated effect sizes (Cohen's d = 2.46 and 2.50) indicate that these changes were statistically meaningful and relevant from a practical perspective. From a physiological standpoint, heart rate recovery reflects the reactivation of the parasympathetic nervous system following the cessation of physical activity [6]. Heart rate recovery is commonly used as a non-invasive indicator of aerobic fitness, as athletes with higher aerobic capacity generally exhibit faster recovery due to more efficient restoration of physiological homeostasis after exertion [5]. The observed increase in heart rate recovery suggests that the 4-week taekwondo-based aerobic training program contributed to improvements in cardiovascular system efficiency. These findings are consistent with previous research reporting a positive association between improvements in heart rate recovery and enhanced aerobic performance in taekwondo athletes [32].

Improved cardiac autonomic regulation supports faster recovery between rounds, which is an important factor in competitive performance [2]. Athletes who recover more efficiently between rounds are better able to maintain technical execution, movement speed, and strength throughout the match, which is relevant in high-intensity taekwondo competition. While the physiological effects of aerobic training on heart rate recovery and blood pressure have been documented in combat sports, many studies rely on laboratory-based protocols or intermittent manual measurements that limit ecological validity in field conditions [1, 3]. In contrast, the present study integrates continuous, real-time physiological monitoring using wearable sensors within a taekwondo-specific aerobic training context. This approach allows the identification of adaptive states such as functional overreaching, in which improved recovery capacity may coexist with elevated resting heart rate, providing a more differentiated interpretation of training-induced physiological responses than pre-post comparisons alone.

The change in resting heart rate did not reach statistical significance and showed a slight increase from 97.55 ± 7.36 bpm to 101.75 ± 6.50 bpm. This pattern can be interpreted within the framework described in the meta-analysis by [6] and the conceptual model proposed by [5], which indicate that heart rate responses to training are not necessarily linear. During periods of intensified adaptation, resting heart rate may remain unchanged or increase modestly, reflecting a state of functional overreaching in which the organism is responding to elevated training demands. The concurrent improvement in heart rate recovery, in the absence of a reduction in resting heart rate, suggests that training-induced adaptations were primarily expressed through enhanced recovery efficiency rather than changes in basal cardiovascular status. This observation aligns with the findings of the present study and is consistent with previous evidence indicating that aerobic training stimuli preferentially influence autonomic recovery mechanisms, such as heart rate recovery, rather than resting heart rate regulation [5, 6].

The contribution of this study is associated with the systematic application of wearable technology to support individualized recovery monitoring in a field-based training environment. The use of a 1-second sampling rate via the Polar Beat system enabled detailed tracking of cardiovascular responses during and after taekwondo-specific technical drills. This approach illustrates how real-time physiological monitoring can support the transition from standardized training structures toward data-informed training management. In this context, work-to-rest ratios can be adjusted based on the athlete's observed recovery dynamics rather than relying solely on predetermined time intervals.

This study identified changes in blood pressure efficiency following the training intervention. Resting systolic blood pressure (SBP) decreased by 5.5%, from 126.00 ± 9.17 mmHg to 119.00 ± 5.05 mmHg. A reduction in resting SBP is commonly interpreted as an indicator of cardiovascular adaptation and suggests potential hemodynamic health benefits, which is consistent with the established effects of aerobic exercise [33].

A more pronounced change was observed in the post-exercise SBP response, which decreased by 10.8%, from 148.00 ± 14.46 mmHg to 132.00 ± 13.32 mmHg under the same workload conditions. A reduction in post-exercise SBP at an identical workload reflects improved hemodynamic efficiency. This indicates that after 4 weeks of training, the cardiovascular system was able to meet oxygen demands with a lower pressure response, thereby reducing cardiac workload during exercise [16]. These findings are consistent with previous evidence indicating that well-trained athletes typically demonstrate controlled and efficient blood pressure responses rather than simply lower absolute values [12, 18]. The stability of diastolic blood pressure (DBP) further suggests a normal vascular response to the applied exercise stimulus.

Overall, the results of this study indicate that monitoring heart rate (particularly heart rate recovery) and blood pressure represents a practical and objective approach for evaluating the effects of training programs in taekwondo athletes. From a practical perspective, heart rate recovery data can be used by coaches as an indicator to assess whether a training program contributes to improvements in aerobic fitness. Continuous monitoring of individual heart rate and blood pressure responses allows training intensity and volume to be adjusted in accordance with each athlete's physiological capacity [10]. In addition, monitoring physiological responses, including resting heart rate and heart rate recovery, may assist in identifying insufficient recovery, enabling timely adjustments to training before maladaptive responses such as overtraining develop [13].

Limitations of the Study

This study has several limitations that should be acknowledged. First, the use of a one-group pretest–posttest design without a control group limits the ability to attribute the observed changes exclusively to the training intervention, as also discussed in similar methodological contexts [34]. Second, aerobic capacity was assessed using field-based physiological indicators. Although the Polar H10 provides accurate heart rate measurements, variables such as heart rate recovery and blood pressure remain indirect markers of aerobic fitness and cannot replace laboratory-based assessments, including metabolic gas analysis for direct determination of maximal oxygen consumption (VO_2max).

Third, the intervention period of four weeks represents a relatively short timeframe for examining longer-term cardiovascular adaptations. Fourth, physical activity outside the structured training sessions, as well as sleep patterns and nutritional intake (e.g., caffeine or supplements), were not strictly controlled or continuously monitored. Participant compliance was addressed through verbal instructions and reminders at the end of each session, which may have allowed for the influence of confounding factors on heart rate and blood pressure responses during the intervention period.

To extend the interpretation of physiological findings, future studies may consider incorporating comparison groups assessed using conventional evaluation approaches, such as manual heart rate measurement at the carotid or radial artery. In addition, linking data obtained from wearable monitoring systems with performance-based field tests, including the Yo-Yo Intermittent Recovery Test or taekwondo-specific anaerobic performance tests, as applied in previous research [35], may allow for a more integrated examination of the relationship between physiological responses and sport-specific performance outcomes.

Future Research Directions

Based on the findings and limitations of the present study, several directions for future research can be outlined:

- the application of a randomized controlled trial (RCT) design with an active control group or a crossover design to improve internal validity and strengthen causal interpretation of training effects;
- the extension of the intervention duration beyond six weeks to allow observation of medium- and longer-term physiological adaptations;
- the examination of associations between physiological data obtained from wearable devices and field-based performance tests, such as the Yo-Yo Intermittent Recovery Test or taekwondo-specific anaerobic tests, to clarify the relationship between physiological capacity and sport-specific performance outcomes [35];
- comparative analyses between data derived from wearable sensors and laboratory-based reference measures, including maximal oxygen consumption (VO_2max) assessment or heart rate variability (HRV) monitoring, to provide a broader characterization of autonomic recovery responses;
- the implementation of more structured lifestyle monitoring approaches, such as physical activity logs or nutrition and sleep tracking tools, to reduce the influence of potential confounding factors.

Conclusions

Based on the analysis and discussion, this study concludes that a 4-week aerobic training program based on taekwondo techniques is associated with measurable cardiovascular adaptations in university-level athletes. This conclusion is supported by three interrelated findings. First, an increase in heart rate recovery (HRR) was observed, indicating changes in aerobic capacity and autonomic regulation. Second, changes in hemodynamic efficiency were identified through reductions in systolic blood pressure at rest and after exercise, suggesting an adaptation of cardiovascular responses to the applied training load. Third, resting heart rate did not demonstrate a corresponding decrease, which may reflect a state of functional overreaching during the training period rather than incomplete adaptation.

From a practical coaching perspective, the results illustrate the applicability of physiological monitoring for training evaluation. Heart rate recovery can be used as an indicator of an athlete's recovery status and readiness for subsequent training sessions. The concurrent observation of improved HRR alongside elevated resting heart rate underscores the importance of monitoring multiple physiological markers rather than relying on a single indicator. Such an approach may assist coaches in adjusting training load and recovery strategies to reduce the likelihood of maladaptive responses. Overall, the findings indicate that combined heart rate and blood pressure monitoring can serve as practical and objective tools for assessing aerobic-related adaptations in taekwondo athletes under field conditions and for supporting informed training management decisions.

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Conflict of Interest

The authors declare that there are no conflicts of interest related to this study.

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