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Multidimensional physiological adaptations to intensive training in elite sepak takraw athletes: an embedded mixed-methods study

Adaptaciones fisiológicas multidimensionales al entrenamiento intensivo en atletas de élite de sepak takraw: un estudio de métodos mixtos incrustados

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Ethical aspects: This study followed ethical standards for research involving human participants. All elite sepak takraw athletes participating in national training were informed about the purpose and procedures of the study, and their participation was entirely voluntary. Written informed consent was obtained prior to data collection, and participants were assured

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that they could withdraw at any time without any consequences to their training status. Confidentiality and anonymity were maintained throughout the study, and all procedures were conducted with consideration for the athletes' safety and well-being.

Abstract
Research on elite training adaptation has mainly relied on physiological outcomes, while studies integrating physiological and experiential data in elite sepak takraw remain limited. This study examined multidimensional physiological adaptation in elite male sepak takraw athletes during a 17-week national training camp using a quantitative-dominant embedded mixed-methods design. Sixteen elite athletes completed an intensified and structured training program. Quantitative data were collected through pre- and post-training assessments of estimated aerobic capacity, muscular endurance, lower-limb power, speed, and agility, while qualitative autoethnographic data were collected concurrently through reflective journaling. The findings showed meaningful improvements across the measured physiological domains, although individual responses varied, with high, moderate, and low responders identified. Qualitative findings revealed a non-linear adaptation process involving initial fatigue, progressive adaptation, and performance stabilization. The integration of both datasets suggests that performance gains emerged after accumulated fatigue and recovery, rather than through a purely linear process. These findings highlight the value of combining objective testing with subjective monitoring to guide individualized training decisions in elite sepak takraw.

Keywords: sepak takraw; elite athletes; physiological adaptation

Resumen
La investigación sobre la adaptación al entrenamiento de élite se ha basado principalmente en resultados fisiológicos, mientras que los estudios que integran datos fisiológicos y experienciales en el sepak takraw de élite siguen siendo limitados. Este estudio examinó la adaptación fisiológica multidimensional en atletas masculinos de sepak takraw de élite durante un campamento nacional de entrenamiento de 17 semanas, utilizando un diseño de métodos mixtos incrustado con predominio cuantitativo. Dieciséis atletas de élite completaron un programa de entrenamiento intensificado y estructurado. Los datos cuantitativos se recopilaron mediante evaluaciones pre y post entrenamiento de la capacidad aeróbica estimada, la resistencia muscular, la potencia de las extremidades inferiores, la velocidad y la agilidad, mientras que los datos autoetnográficos cualitativos se recopilaron de forma concurrente mediante diarios reflexivos. Los resultados mostraron mejoras significativas en los dominios fisiológicos evaluados, aunque las respuestas individuales variaron, identificándose atletas con respuesta alta, moderada y baja. Los hallazgos cualitativos revelaron un proceso de adaptación no lineal que incluyó fatiga inicial, adaptación progresiva y estabilización del rendimiento. La integración de ambos conjuntos de datos sugiere que las mejoras del rendimiento surgieron después de la fatiga acumulada y la recuperación, no mediante un proceso puramente lineal.

Palabras clave: sepak takraw; atletas de élite; adaptación fisiológica

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Introduction

Sepak takraw is a high-intensity intermittent sport requiring repeated explosive actions, rapid directional changes, aerial skills, and precise technical execution under time pressure. The sport involves complex kicking, jumping, blocking, and acrobatic movement patterns that demand a high level of physical fitness and sport-specific skill execution (Jufrianis et al., 2021; Zulkifli et al., 2025). Elite performance therefore depends not only on technical mastery but also on the integrated development of aerobic endurance (Bıcakcı et al., 2024; Guntoro et al., 2023; Johansen et al., 2025; Joyner, 2025; Ma et al., 2023), muscular endurance (Guntoro et al., 2023), speed (Sandford et al., 2021), and agility (Joyner, 2025; Pasic & Copic, 2026). In national training camp settings, these physical components are targeted through intensified and structured training programs designed to prepare athletes for major international competitions.

Although physiological conditioning is central to elite sepak takraw preparation, adaptation in this sport cannot be fully understood through performance testing alone. Athletes may experience fatigue, soreness, motivation fluctuations, changes in perceived readiness, and delayed performance stabilization during intensive training periods. These subjective experiences are important because adaptation does not always occur linearly; short-term decreases in perceived performance may precede later physiological improvement. This pattern is consistent with contemporary perspectives on training load, fatigue, recovery, and the dynamic interaction between fitness and fatigue in high-performance sport (Bestwick-Stevenson et al., 2022; Impellizzeri et al., 2019; Rebelo et al., 2026; Wiesinger et al., 2025). Therefore, understanding training adaptation in elite sepak takraw requires attention to both measurable physiological outcomes and athletes' experiential responses.

Existing sport science research has provided valuable evidence on training-induced changes in aerobic capacity, strength, power, speed, and agility. Aerobic capacity, commonly represented by VO_2max, is widely used as an indicator of cardiorespiratory fitness and training adaptation in athletes (Srivastava et al., 2024), while high-intensity interval training and repeated sprint-based interventions have been shown to improve VO_2max even in elite athletic populations (Ma et al., 2023). Similarly, neuromuscular adaptations related to strength and power are central to explosive sport performance and may be influenced by resistance training,

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motor unit recruitment, intermuscular coordination, and sport-specific loading (Aslam et al., 2025; Cormie et al., 2011; Suchomel et al., 2018). Speed and agility are also critical performance qualities, although they are often considered more resistant to change in highly trained athletes and may require highly specific training stimuli (Haugen et al., 2019). However, much of this literature remains dominated by physiological-only approaches. Such approaches are useful for identifying measurable performance change but are limited in explaining how athletes experience, tolerate, and interpret the training process. This limitation is particularly relevant in elite environments, where small variations in fatigue, recovery, and readiness may meaningfully influence training response and performance outcomes (Alfonso et al., 2025; Drole et al., 2025; Montull et al., 2022)).

Research on sepak takraw remains relatively limited compared with other high-performance sports, and available studies have generally focused on isolated physical, technical, or performance variables, such as smash ability, sepak sila skills, or kinesiological skill assessment (Hirwana et al., 2023; Panganıban, 2024). Despite existing research, no studies have integrated physiological and experiential data in elite sepak takraw athletes during a national training camp. This gap is important because elite athletes may show heterogeneous responses to the same training stimulus, and such variability is difficult to explain without combining objective and subjective evidence. Previous research has emphasized that responses to training are not uniform and may be influenced by baseline fitness, recovery capacity, internal and external load, and individual sensitivity to training stimuli (Granero-Gallegos et al., 2020; Impellizzeri et al., 2019; Montero & Lundby, 2017).

A mixed-methods approach is therefore needed to capture the complexity of adaptation in elite sepak takraw. Quantitative testing can identify the magnitude of physiological change, while qualitative autoethnographic data can contextualize the lived experience of fatigue, recovery, and adaptation across the training period. Mixed-methods approaches have been recommended in sport and exercise research because they enable integration between objective indicators and subjective experiences, thereby supporting a more holistic understanding of performance, monitoring, and adaptation processes (Aerts et al., 2025; Ryba et al., 2022). By integrating these two forms of evidence, researchers and coaches can better understand not only

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whether athletes improve, but also how and under what experiential conditions such improvements emerge.

Accordingly, this study aimed to examine multidimensional physiological adaptation in elite sepak takraw athletes during a national training camp using an embedded mixed-methods design. Specifically, the study sought to: (1) quantify changes in estimated aerobic capacity, muscular endurance, lower-limb power, speed, and agility; (2) examine inter-individual variability in training response; and (3) contextualize physiological changes through autoethnographic analysis of fatigue, recovery, and perceived adaptation.

Methods

Research Design

This study employed a quantitative-dominant embedded mixed-methods design, in which the quantitative strand served as the primary component and the qualitative autoethnographic strand was embedded to contextualize athletes' experiences of fatigue, recovery, and adaptation. Quantitative data were collected before and after the national training program to examine changes in physiological performance, whereas qualitative data were collected concurrently through systematic reflective journaling during the training period. This design was selected to integrate objective performance indicators with subjective experiential evidence, consistent with mixed-methods approaches in sport research and athlete monitoring (Aerts et al., 2025; Ryba et al., 2022). Integration occurred at the interpretation stage, where group-level changes and inter-individual response patterns were interpreted alongside qualitative insights related to perceived fatigue, recovery status, and adaptation dynamics, reflecting the need to combine physiological and perceptual indicators when evaluating training responses in high-performance sport (Bestwick-Stevenson et al., 2022; Impellizzeri et al., 2019; Montull et al., 2022).

Participants

Participants were sixteen elite male sepak takraw athletes officially selected for the Indonesian national training camp in preparation for international competition. All athletes

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trained within the same centralized program under national-level coaching supervision and were included if they were injury-free, completed the full training cycle, and participated in both pre- and post-training assessments. The sample size reflects the restricted nature of elite national squads, where access to larger samples is commonly limited because elite sport populations are inherently small and high-level squad membership is highly selective (Skorski & Hecksteden, 2021; Zentgraf et al., 2024). However, the within-subject pre–post design allowed each athlete to serve as his own comparison across the training period, thereby reducing between-athlete variability and making the sample appropriate for examining context-specific training adaptation (Abt et al., 2020) Therefore, although the findings provide meaningful evidence of physiological change within this national training camp context, their generalizability to broader sepak takraw populations should be interpreted cautiously.

Training Program Description

The national training camp lasted 17 weeks and was conducted six days per week, with approximately 10 training sessions weekly. Morning sessions lasted about 180 minutes, while afternoon sessions lasted about 120 minutes. The program was designed by the national coaching staff according to competition preparation phases and included strength and muscular endurance training, aerobic and anaerobic conditioning, speed and agility drills, lower-limb power and plyometric exercises, and sepak takraw-specific technical training such as first-ball reception, service, smash, setting, blocking, and match simulation.

The program followed periodization principles by integrating physical, technical–tactical, and mental components. The General Preparation phase emphasized physical conditioning, while the Specific Preparation phase increased sepak takraw-specific conditioning and technical–tactical work. The Pre-Competition phase shifted toward technical–tactical refinement, visualization, and anxiety management, whereas the Competition phase focused on tactical execution, concentration, and competitive readiness. Training load progressed from general conditioning to higher-intensity sport-specific work and finally to performance stabilization. Recovery strategies included static stretching, light jogging,

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hydration and nutrition, adequate sleep, ice baths, and sport massage. Training adjustments were made by coaches based on athletes' readiness and performance responses.

Data Collection and Measurement Validity

Quantitative data were collected before and after the 17-week national training program using standardized field-based performance tests. Estimated aerobic capacity was assessed using the multistage fitness/bleep test; therefore, VO_2max values were interpreted as field-based estimates rather than direct laboratory measurements (Srivastava et al., 2024). Muscular endurance was measured using sit-up and back-up tests, lower-limb explosive power using the vertical jump, speed using the 20-m sprint, and agility using the shuttle run. All assessments were conducted under consistent field conditions with standardized instructions, warm-up procedures, and testing order across pre- and post-test sessions. Qualitative autoethnographic data were collected concurrently through systematic reflective journaling, focusing on perceived fatigue, muscle soreness, motivation, recovery status, readiness to train, and perceived performance change. These subjective data were used to contextualize the physiological outcomes and support an integrated interpretation of training adaptation, consistent with athlete-monitoring literature emphasizing the value of combining objective performance indicators with subjective fatigue, recovery, and readiness measures (Bestwick-Stevenson et al., 2022; Coyne et al., 2022; Montull et al., 2022).

Reflexivity, Trustworthiness, and Data Integration

To enhance qualitative rigor, the autoethnographic component incorporated reflexive memoing, systematic journaling, and transparent analytic documentation. Reflexivity was maintained by recording the researcher's assumptions, emotional responses, training experiences, and potential interpretive biases throughout the training period, consistent with recent guidance on reflexivity in qualitative inquiry (Olmos-Vega et al., 2023). Credibility and dependability were supported through chronological reflective journaling, repeated reading of entries, team-based discussion of emerging themes, and an audit trail of coding decisions and theme development, in line with quality principles in reflexive thematic analysis (Braun &

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Clarke, 2006). Quantitative and qualitative data were integrated at the interpretation stage through side-by-side comparison and narrative synthesis. Physiological results were used to identify the magnitude and direction of performance changes, while autoethnographic findings contextualized how these changes emerged through phases of fatigue, progressive tolerance, and stabilization. This approach aligns with recent mixed-methods and athlete-monitoring literature emphasizing the value of combining objective performance indicators with subjective experiential data to better understand training adaptation in high-performance sport (Coyne et al., 2022; Montull et al., 2022; Ryba et al., 2022).

Data Analysis

Paired-sample t-tests were used to evaluate pre–post differences ($p < 0.05$). Effect sizes (Cohen's d) were calculated. Qualitative data were analyzed using thematic analysis.

Results

Group-Level Physiological Adaptation

Table 1 presents the pre–post changes in physiological performance variables following the national training program. Overall, the athletes demonstrated significant improvements across all measured domains, including estimated aerobic capacity, muscular endurance, lower-limb power, speed, and agility. These findings indicate that the training program produced multidimensional physiological adaptations rather than isolated improvement in a single performance component.

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TABLE 1. Changes in Physiological Performance Variables

Variable	Pre (Mean ± SD)	Post (Mean ± SD)	p-value	Effect Size (d)	Interpretation
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.36 ± 6.04	53.66 ± 5.12	<0.001	1.43	Very Large
Muscular Endurance (reps)	98.75 ± 19.57	118.19 ± 17.00	<0.001	1.42	Very Large
Vertical Jump (cm)	48.06 ± 9.44	59.56 ± 7.44	<0.001	1.14	Large–Very Large
Speed 20 m (s)	3.25 ± 0.21	3.17 ± 0.16	0.003	-0.88	Large
Agility (s)	5.83 ± 0.39	5.20 ± 0.28	<0.001	-1.46	Very Large

NOTE: Values are presented as mean ± standard deviation. Effect sizes (Cohen's d) interpreted as small (0.2), moderate (0.5), large (0.8), and very large (>1.2).

The largest effects were observed in estimated VO_2max, muscular endurance, and agility, indicating that the training stimulus enhanced aerobic capacity, muscular endurance, and movement efficiency. Improved vertical jump performance reflected positive lower-limb power adaptation, while reduced 20-m sprint time indicated better short-distance speed. Because speed and agility are often more resistant to change in highly trained athletes, these results suggest that the intensified, sport-specific program may have supported meaningful performance transfer.

To examine response heterogeneity, individual percentage changes were calculated across five physiological variables. Athlete identities were anonymized using initials. For VO_2max, muscular endurance, and vertical jump, improvement was calculated as [(post-test − pre-test) / pre-test] × 100. For time-based variables, namely 20-m sprint and agility, improvement was calculated as [(pre-test − post-test) / pre-test] × 100 because lower times indicate better performance. Athletes were then classified as high, moderate, or low responders.

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TABLE 2. Changes in Physiological Performance Variables

ID	Initiale	ΔVO₂max (%)	Δ Muscular Endurance (%)	Δ Vertical Jump (%)	Δ Speed 20 m (%)	Δ Agility (%)	Response Pattern
A1	R	0	0	0	0	0	Low
A2	JL	6.82	18.28	27.27	0.34	0	High
A3	MUR	5.93	26.74	62.22	1.79	0	High
A4	MA	16.91	45.74	33.33	5.59	0	High
A5	ROR	6.46	25	25.53	1.2	0	High
A6	VEP	7.41	10.1	20	0.3	0	Moderate
A7	SA	7.78	3.09	7.69	9.3	0	Moderate
A8	YA	5.34	15	53.19	1.27	0	High
A9	P	12.27	18.69	5.77	1.56	0	Moderate
A10	AP	27.41	43.02	3.77	0.64	0	High
A11	MHD	38.1	18.81	0	0.34	0	High
A12	ATS	7.41	25.51	23.08	4.99	0	High
A13	AB	9.1	-2.86	100	4.13	0	High
A14	MHF	7.46	46.59	50	2.87	0	High
A15	ADA	12.45	10.87	26.19	2.96	0	High
A16	N	15.34	37.14	4	0.3	0	High

As shown in Table 2, athletes showed heterogeneous adaptation patterns despite completing the same national training program. Based on the response classification, 12 athletes were categorized as high responders, 3 as moderate responders, and 1 as a low responder. The greatest individual adaptations were generally observed in VO_2max, muscular endurance, and vertical jump, while speed improvements were smaller but positive for most athletes. Agility showed no percentage change in the individual dataset and should therefore be interpreted cautiously.

These findings indicate that group-level improvements do not fully capture individual training responses. Similar training exposure produced different adaptation magnitudes, likely influenced by baseline fitness, accumulated fatigue, recovery capacity, and individual sensitivity to training load. Thus, individual response profiling is important for guiding more personalized training decisions in elite sepak takraw.

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Inter-Individual Variability

Although the group-level results indicated significant physiological improvements, the individual analysis showed that adaptation varied across athletes. As presented in Table 2, average individual improvement across the five variables ranged from 0.00% to 22.07%, indicating heterogeneous responsiveness to the same national training program.

The strongest individual changes were generally observed in estimated VO_2max, muscular endurance, and vertical jump performance, while speed improvements were smaller but positive for most athletes. Agility showed no percentage change in the individual dataset and should therefore be interpreted cautiously. These findings suggest that group means do not fully capture individual adaptation patterns. Differences in baseline fitness, fatigue accumulation, recovery capacity, neuromuscular readiness, and sensitivity to training load may have influenced responsiveness. Thus, individual response profiling is important for guiding personalized training and recovery strategies in elite sepak takraw.

The autoethnographic analysis identified three experiential phases of adaptation: initial fatigue, progressive adaptation, and performance stabilization. These phases provided contextual evidence for interpreting the quantitative findings, which showed significant improvements in estimated VO_2max, muscular endurance, lower-limb power, speed, and agility after the national training program. The qualitative findings suggest that these physiological gains did not emerge through a simple linear process, but were preceded by fatigue accumulation and followed by gradual tolerance and stabilization.

The first phase, initial fatigue, was characterized by accumulated tiredness, delayed onset muscle soreness, reduced perceived readiness, and inconsistent performance during training. This phase reflected the athletes' early response to the intensified training load, particularly during the transition into higher training volume and repeated sport-specific sessions. Although this phase was experienced as physically demanding, it provided an important context for understanding why adaptation may initially appear unstable before measurable improvements become evident.

"During the early training phase, the body felt heavy and muscle soreness was more pronounced, especially after repeated jumping, kicking, and agility drills. Performance felt

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inconsistent, and readiness to train was lower, even though the training demands had to be maintained." (Athlete R, reflective journal)

The second phase, progressive adaptation, reflected the athletes' gradual tolerance to the accumulated training stimulus. During this phase, perceived fatigue began to decrease, recovery felt more efficient, and movement execution became more stable. This experience corresponded with the quantitative improvements observed across aerobic capacity, muscular endurance, and lower-limb power, suggesting that the athletes were beginning to adapt physiologically and neuromuscularly to the training demands.

"After several weeks, the same training loads felt more manageable. Recovery between sessions improved, movement felt lighter, and repeated technical actions such as jumping, kicking, and changing direction could be performed with better control." (Athlete VEP, reflective journal)

The third phase, performance stabilization, was marked by more consistent training output, greater confidence in physical readiness, and improved recovery efficiency. This phase was consistent with the post-test results, which showed meaningful improvements across the measured variables, including the increase in estimated VO_2max, muscular endurance, vertical jump performance, and reductions in sprint and agility times. These findings indicate that the accumulated training stimulus, when followed by adequate adaptation and recovery, was associated with measurable performance enhancement.

"Toward the final phase, performance became more stable. The body felt more prepared for high-intensity movements, recovery was faster, and confidence increased during technical and match-simulation sessions." (Athlete AP, reflective journal)

Together, these qualitative findings strengthen the interpretation of the quantitative results by showing that physiological adaptation was experienced as a non-linear process. The improvements observed in the post-test data were not immediate, but emerged after athletes passed through an early phase of fatigue, followed by progressive tolerance and later stabilization. This integrated interpretation supports the view that objective performance changes should be interpreted alongside athletes' subjective experiences of fatigue, recovery,

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and readiness, particularly in elite training environments where short-term decrements may precede later performance gains.

Integration of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings suggests that physiological adaptation in elite sepak takraw athletes followed a non-linear pattern. Quantitative data showed significant improvements across aerobic capacity, muscular endurance, lower-limb power, speed, and agility. However, the qualitative data revealed that these improvements were not experienced as immediate or continuous progress. Instead, athletes first experienced fatigue, soreness, and inconsistent performance before gradually developing greater tolerance and readiness.

This integrated interpretation helps explain why post-training gains may emerge after an initial period of perceived performance decline. The qualitative findings therefore contextualize the quantitative improvements by showing that measurable adaptation was preceded by accumulated training stress and followed by recovery-driven stabilization. This supports the use of embedded mixed-methods analysis in elite sport, where objective testing alone may not fully capture the temporal dynamics of adaptation.

Discussion

Overview of Findings

The present study examined multi-dimensional physiological adaptation in elite sepak takraw athletes during a national training camp using an integrated mixed-methods approach. The main findings indicate that (i) substantial improvements occurred across all physiological domains, (ii) the magnitude of adaptation was unexpectedly large for a highly trained population, and (iii) adaptation followed a non-linear trajectory characterized by distinct experiential phases.

Collectively, these findings challenge the commonly held assumption that elite athletes exhibit limited responsiveness to training due to proximity to their physiological ceiling (Montero & Lundby, 2017). Rather than suggesting that elite athletes universally retain

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substantial adaptive capacity, the present findings indicate that under intensified and well-structured training conditions, elite sepak takraw athletes may still demonstrate meaningful multidimensional physiological adaptation.

Magnitude of Adaptation in Elite Athletes

One of the most notable findings of this study is the large to very large effect sizes observed across all variables, including aerobic capacity, neuromuscular performance, speed, and agility. In particular, the improvement in VO_2max (~10.9%, d = 1.43) exceeds the magnitude typically reported in elite populations, where adaptations are often modest (Buchheit & Laursen, 2013)(Granata et al., 2018).

This finding challenges the traditional notion of a performance plateau and supports emerging evidence suggesting that adaptation potential in elite athletes is highly context-dependent (Wiesinger et al., 2025). Specifically, intensified training environments (such as national training camps) may provide a sufficient overload stimulus to overcome adaptive stagnation. Mechanistically, such improvements may be attributed to cumulative effects of high training volume, increased intensity, and enhanced neuromuscular stimulus, which together facilitate both central (e.g., oxygen delivery) and peripheral (e.g., mitochondrial adaptations) mechanisms (Granata et al., 2018).

Importantly, these findings suggest that the concept of a fixed “ceiling” in elite performance may be overly simplistic, and that adaptive capacity can be reactivated under appropriately structured training conditions.

Neuromuscular and Performance Adaptation

The substantial improvements observed in muscular endurance and lower-limb power are consistent with established models of neuromuscular adaptation, including enhanced motor unit recruitment, firing frequency, and intermuscular coordination (Suchomel et al., 2018). However, the magnitude of these adaptations in an elite cohort is particularly noteworthy. During training, neuromuscular adaptations are influenced by factors such as age, sex, genetic predisposition, and the athlete’s performance level (Aslam et al., 2025; Granacher et al., 2018).

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Similarly, significant improvements in speed and agility were observed, with agility demonstrating the largest effect size. These findings contrast with previous literature suggesting that speed-related qualities are relatively resistant to change in highly trained athletes (Haugen et al., 2019). A plausible explanation is the inclusion of highly specific, sport-relevant training stimuli, which may have enhanced transfer to performance outcomes. Taken together, these results highlight the importance of training specificity and suggest that even performance attributes typically considered "stable" in elite athletes may remain trainable under optimized conditions.

Inter-Individual Variability and Responsiveness

Despite uniform training exposure, substantial inter-individual variability in adaptation was observed. This finding aligns with a growing body of literature demonstrating heterogeneous responses to standardized training programs (Montero & Lundby, 2017).

The presence of high, moderate, and low responders within the same cohort underscores the limitations of one-size-fits-all training approaches in elite sport. Variability in adaptation may be influenced by multiple factors, including baseline fitness, genetic predisposition, recovery capacity, and sensitivity to training load (Impellizzeri et al., 2019). From an applied perspective, these findings reinforce the need for individualized monitoring strategies, incorporating both physiological and perceptual indicators, to optimize training prescription and maximize performance outcomes. The need for personalized and integrated athlete monitoring is essential to assess internal factors and methodological influences on heart rate responses (Alfonso et al., 2025; Bestwick-Stevenson et al., 2022).

Integration of Physiological and Experiential Adaptation

The present study extends previous physiological research by demonstrating that adaptation in elite sepak takraw cannot be fully understood through pre–post performances testing alone. The quantitative findings showed meaningful improvements across estimated aerobic capacity, muscular endurance, lower-limb power, speed, and agility, indicating that the 17-week intensified and structured national training program produced multidimensional

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physiological adaptations. However, the autoethnographic findings provide important contextual evidence showing that these improvements emerged through a non-linear experiential process. Specifically, post-training improvements were preceded by an initial phase of accumulated fatigue, perceived instability, and reduced readiness, followed by progressive tolerance and later performance stabilization.

This integrated pattern is consistent with contemporary views of training adaptation as a dynamic interaction between training load, fatigue, recovery, and performance readiness. Rather than interpreting temporary decreases in perceived performance as maladaptation, the qualitative findings suggest that such experiences may represent an early fatigue phase before subsequent physiological improvement becomes visible. This interpretation is aligned with recent athlete-monitoring literature emphasizing that training responses should be understood through both objective performance indicators and subjective markers such as fatigue, soreness, recovery, stress, and readiness to train (Bestwick-Stevenson et al., 2022; Coyne et al., 2022; Montull et al., 2022). Recent evidence also supports the importance of integrating subjective and objective indicators because athlete responses to stress and training load are complex and may differ at both group and individual levels (Alfonso et al., 2025; Drole et al., 2025).

The findings also contribute to the discussion on adaptation potential in highly trained athletes. Previous research has suggested that elite athletes often show smaller adaptive changes because of high baseline fitness and proximity to performance ceilings. However, recent meta-analytic evidence indicates that highly trained athletes may still improve when exposed to appropriately intensified and well-structured training stimuli, particularly when training is specific and sufficiently demanding (Wiesinger et al., 2025). In the present study, this interpretation is especially relevant because sepak takraw requires repeated explosive, acrobatic, and high-coordination movements, meaning that fatigue may affect not only physiological readiness but also perceived technical efficiency, movement confidence, and the ability to sustain sport-specific actions under pressure.

Compared with studies that focus mainly on isolated physiological variables such as VO_2max, strength, power, or speed, the present study demonstrates the added value of embedding athlete experience within physiological interpretation. Physiological-only

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approaches can identify whether athletes improve, but they may overlook the transitional process through which athletes feel fatigued, unstable, or underprepared before adaptation becomes measurable. By integrating autoethnographic evidence, this study shows that the observed improvements were not merely statistical outcomes but were accompanied by a lived process of fatigue accumulation, progressive tolerance, and stabilization. This supports the use of mixed-methods approaches in sport and exercise research, particularly when the aim is to understand complex adaptation processes in high-performance environments (Aerts et al., 2025; Ryba et al., 2022).

At the same time, the findings should not be interpreted as evidence that all elite athletes will respond similarly to intensified training. The individual response analysis showed that adaptation varied substantially across athletes, with some classified as high responders, others as moderate responders, and one as a low responder. This heterogeneity suggests that similar external training exposure does not necessarily produce uniform physiological or experiential outcomes. Therefore, the present findings reinforce the need for individualized monitoring systems that combine performance testing with subjective information on fatigue, soreness, recovery, sleep quality, motivation, and readiness. Such integration can help coaches distinguish between expected fatigue, delayed adaptation, insufficient recovery, and potential maladaptation, thereby supporting more precise training decisions in elite sepak takraw contexts.

Practical Implications

The findings offer practical guidance for coaches, strength and conditioning practitioners, and sport scientists involved in elite sepak takraw training. Coaches should anticipate an initial fatigue phase during intensified training camps, as temporary reductions in perceived readiness, increased muscle soreness, and inconsistent performance may not necessarily indicate training failure, but may represent an early stage of adaptation before subsequent performance improvement. Therefore, training monitoring should not rely solely on objective performance tests such as sprint, agility, jump, and endurance assessments, but should also include regular subjective monitoring of perceived fatigue, muscle soreness, sleep quality,

Original article. Multidimensional physiological adaptations to intensive training in elite sepak takraw athletes: an embedded mixed-methods study.
Vol. 12, n.º 6; p. 1-24, October 2026. https://doi.org/10.55040/qb0cdk87

motivation, and readiness to train. Coaches should also consider the timing of performance peaks, as stabilization may occur only after athletes have passed through fatigue accumulation and progressive adaptation phases; consequently, adequate recovery windows should be incorporated before competition. Furthermore, the observed inter-individual variability indicates that group-based training prescriptions should be adjusted according to individual responses, particularly for athletes showing low responsiveness or prolonged fatigue. In sepak takraw, training should maintain a high degree of sport specificity by incorporating movement patterns that reflect match demands, including short accelerations, rapid changes of direction, kicking actions, jumping, landing, blocking, and recovery between high-intensity rallies.

Conclusion

Within the context of this specific 17-week national training camp, the present study indicates that elite male sepak takraw athletes may demonstrate meaningful multidimensional physiological adaptation under intensified and well-structured training conditions. Improvements were observed in estimated aerobic capacity, muscular endurance, lower-limb power, speed, and agility, suggesting that elite athletes may still retain adaptive potential when exposed to progressive, sport-specific, and systematically organized training. However, these findings should be interpreted cautiously because the study involved a small elite sample, used estimated rather than directly measured VO_2max, and did not include a control group.

The quantitative-dominant embedded mixed-methods design further showed that training adaptation was not a uniform or purely linear process. Individual response analysis revealed heterogeneous adaptation patterns, while the autoethnographic findings contextualized the physiological improvements through phases of initial fatigue, progressive adaptation, and performance stabilization. These findings support the value of integrating objective physiological testing with subjective experiential monitoring to better understand training responses in elite sepak takraw. Future studies should include larger and more diverse samples, comparison groups, direct physiological measurements, and longer monitoring periods to examine whether these adaptations are sustained across broader competitive contexts.

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Limitations

Several limitations should be considered when interpreting the findings of this study. First, the sample consisted of only sixteen elite male sepak takraw athletes from a single national training camp, which limits the generalizability of the results to female athletes, younger or lower-level athletes, other national squads, or different sport contexts. Second, the absence of a control or comparison group restricts the extent to which the observed improvements can be attributed solely to the 17-week training program, as natural performance fluctuations, test familiarization, recovery status, motivation, and previous training history may also have influenced the outcomes. Third, VO_2max was estimated using the multistage fitness test rather than directly measured through gas analysis; therefore, aerobic capacity findings should be interpreted as field-based estimates rather than direct physiological measurements. Fourth, although the embedded autoethnographic component enriched the interpretation of adaptation, it may involve subjectivity and interpretive bias because it relies on reflective journaling and the researcher's positionality. Future studies should strengthen qualitative rigor by incorporating multiple athlete diaries, interviews, external coding, peer debriefing, and triangulation with coach observations or standardized wellness questionnaires. Finally, although the training program was described in terms of duration, frequency, periodization, and recovery strategies, more detailed prospective monitoring of session-RPE, heart rate responses, wellness scores, and actual completed training load would strengthen interpretation of the training stimulus. Future research should use larger and more diverse samples, comparison groups, direct physiological measurements, and longer monitoring periods to examine whether the observed physiological and experiential adaptations are maintained across a full competitive season.

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