



OPEN ACCESS

EDITED BY

Prof. dr. Adriana Lukic Ljubojevic, Ph.D.
University of Banja Luka, Bosnia and
Herzegovina.

*CORRESPONDENCE

Asha Devi T.
kbhas81@gmail.com

RECEIVED: March 03, 2026

ACCEPTED: July 26, 2026

PUBLISHED: September 27, 2026

COPYRIGHT © 2026 (Author)

- Asha Devi T.
- Uma V.
- Suresh Kumar M.
- Ivin Jebakumar K.



This work is licensed under a Creative
Commons Attribution-ShareAlike 4.0
International License.

Neuromuscular Adaptations to Fartlek versus Interval Training in Adolescent Female Volleyball Players: A Surface Electromyography-Based Randomized Controlled Study

Asha Devi T.^{1*}, Uma V.¹, Suresh Kumar M.¹, Ivin Jebakumar K.¹

¹Ganesar College of Arts and Science (Affiliated to Bharathidasan University, Tiruchirappali),
Ponnamaravathy, Pudukkottai, Tamilnadu, India.

ABSTRACT

Background & objective: Volleyball is a fast-paced game that demands speed, agility, explosive power, endurance, and coordination. Various training models have long been practiced to enhance these attributes. The present study was initiated to provide scientific validation by identifying muscular activation effectiveness and correlating physiological variables with data derived from different training methods.

Materials & Methods: A three-group true experimental research design involving 45 adolescent female volleyball players was employed. The interventional strategies compared were Fartlek and interval training over a 4-week duration. The study examined selected physiological variables, including VO₂ max, resting heart rate, and muscular endurance. Neuromuscular analysis of the Deltoid, Biceps Brachii, Triceps Brachii, Rectus abdominis, Quadriceps, and Gastrocnemius muscles was administered using cumulative average muscular activation data collected from sEMG signal amplitudes. Data were analyzed using ANCOVA to determine the effectiveness of the training methods.

Results: The findings indicate that Fartlek training results in higher muscular activation, which impacts neuromuscular coordination and consequently influences the performance skills of the volleyball players. Furthermore, employing electromyographical analysis provided a foundation for adopting muscular activation analysis in future studies.

Conclusions: Fartlek training stands ahead of interval training in terms of its impact on selected physiological variables. The study confirms that Fartlek training is more effective than interval training and clarifies the underlying reasons for this superiority.

Keywords

explosive power; VO₂max; volleyball athletes; normative standards; physical fitness; performance evaluation.

CITATION APA STYLE 7:

T, A. D., V, U., M, S. K. ., & K, I. J. . (2026). Neuromuscular Adaptations to Fartlek versus Interval Training in Adolescent Female Volleyball Players: A Surface Electromyography-Based Randomized Controlled Study. *INSPIREE: Indonesian Sport Innovation Review*, 7(03), 290-301. <https://doi.org/10.53905/inspire.v7i03.189>

INTRODUCTION

Contextual Framework

Physical training paradigms in physical education and competitive sports have evolved significantly to address the multifaceted requirements of high-performance athletes (Amiri et al., 2025; Lin et al., 2025, p. 313). Volleyball, in particular, is defined by its intermittent nature, characterized by frequent, high-intensity actions—such as explosive jumping, rapid changes of direction, and powerful spiking—interspersed with short, varied recovery periods (Hernández-Martínez et al., 2023, p. 1270519; Ramírez-Campillo et al., 2021, p. 636141). These dynamic demands necessitate a sophisticated integration of anaerobic power, aerobic endurance, and advanced neuromuscular coordination to maintain performance consistency throughout a match (Jaworski et al., 2020, p. 9; Rebelo et al., 2024, p. 2). To optimize these physical attributes, coaches and sport scientists utilize diverse training methodologies, including interval training and Fartlek training. Interval training, through structured, high-intensity bouts and deliberate recovery, is established as a robust method for improving metabolic efficiency, anaerobic power, and

speed endurance (Foster et al., 2025; Mølmen & Rønnestad, 2024). Conversely, Fartlek training—often termed "speed play"—introduces variable intensity, offering a versatile approach that fosters both aerobic and anaerobic conditioning while enhancing movement adaptability in varied contexts. Although both models aim to improve overall player output, they elicit distinct physiological adaptations that likely impact sport-specific skills in unique ways. Furthermore, research highlights that neuromuscular adaptations, including changes in motor unit recruitment and synchronization, are critical components of these training-induced performance improvements (Duchateau et al., 2006; Kraemer et al., 1996). A comprehensive understanding of how these training modalities specifically modulate muscle activation patterns—the foundational mechanism of neuromuscular efficiency—is essential for developing evidence-based conditioning programs that maximize performance in volleyball players.

Critical Examination of Existing Literature

Each training model incorporates distinct patterns of

workload, recovery, and movement variability, thereby eliciting specific physiological and neuromuscular adaptations essential for high-performance sports. Interval training typically involves highly structured bouts of intense exercise interspersed with precise recovery periods, which are well-documented to enhance metabolic efficiency, anaerobic power, and speed endurance by maximizing cardiovascular stress and mitochondrial adaptations (Gibala, 2020; Tschakert & Hofmann, 2013). In contrast, Fartlek training—often termed “speed play”—integrates continuous, variable-intensity exercise, which offers a versatile stimulus that promotes aerobic and anaerobic conditioning while fostering movement adaptability and sport-specific endurance in unpredictable environments (Gautam et al., 2024; Seiler, 2010). While both methods improve overall player output, recent evidence suggests they do so through different mechanistic pathways: HIIT often maximizes cardiovascular and lactate tolerance adaptations (Wulandari et al., 2026), whereas Fartlek may provide greater benefits for dynamic movement adaptability and endurance under varied intensity (Alzubaidi, 2025; Seiler, 2010).

Volleyball performance is inherently dependent on a complex range of physical and technical skills, such as explosive sprinting, jumping, blocking, and rapid change-of-direction maneuvers. These actions demand rapid force production, efficient energy utilization, and precise neuromuscular coordination (Sheppard et al., 2009). The successful execution of these technical skills is governed by the activation patterns of key muscle groups, notably the deltoid, biceps brachii, triceps brachii, rectus abdominis, quadriceps, and gastrocnemius.

To rigorously evaluate these training-induced adaptations, electromyography (sEMG) serves as a critical diagnostic tool. sEMG enables researchers and sport scientists to quantify muscle activation patterns during dynamic, sport-specific movements—such as the spike jump or reception—providing objective data on motor unit recruitment, activation intensity, and neuromuscular efficiency (Holonec et al., 2024; Luca, 1997). By integrating EMG analysis, coaches can better understand not only the intensity of muscular effort but also the coordination and timing required for efficient performance, thereby refining conditioning strategies to enhance volleyball-specific neuromuscular adaptations (Aedo-Muñoz et al., 2020; Chen et al., 2025; Torres-Banduc et al., 2021).

Identification of Research Gaps

Despite their widespread use, there remains a notable gap in understanding the comparative effectiveness of these training

approaches in maximizing volleyball-specific skills, particularly when examined through a scientific and physiological lens. Although previous studies have demonstrated the effectiveness of both interval and Fartlek training in improving volleyball performance (Gabbett, 2008; Marques et al., 2008), there is a lack of research comparing their relative effectiveness using integrated physiological measures. Furthermore, the underlying mechanism of these differences, particularly in terms of muscular activation, remains inadequately explored.

Rationale for the Research

Since muscle activation is fundamental to all movement and performance outcomes, it is essential to investigate how different training modalities affect neuromuscular responses. By integrating performance metrics with physiological data—specifically using electromyographic analysis—this research aims to substantiate performance outcomes with objective data. This approach is expected to contribute to evidence-based training practices and enhance the scientific understanding of sport-specific conditioning, providing a comprehensive evaluation of training effectiveness.

Objectives of the Study

This study aimed to design and implement Fartlek and interval training programmes for adolescent female volleyball players and to examine their comparative effects on selected performance, physiological, and neuromuscular variables. Specifically, the study sought to investigate the individual impact of Fartlek training and interval training on core areas of volleyball-related physical fitness, including speed, strength, and endurance, and to compare the differences in adaptation produced by the two training methods. In addition, the study aimed to analyze muscular activation data obtained through electromyography (EMG) in order to determine whether the observed performance and physiological changes were supported by differences in muscle activation responses across the training conditions. Based on these objectives, the study tested three null hypotheses. First, it was hypothesized that there would be no significant difference between Fartlek training and interval training in improving volleyball-related physical fitness variables, including speed, strength, and endurance. Second, it was hypothesized that there would be no significant difference between Fartlek training and interval training in enhancing volleyball performance skills. Third, it was hypothesized that there would be no significant difference in EMG-derived muscular activation data between volleyball players trained through Fartlek training and those trained through interval training.

MATERIALS AND METHODS

Study Participants

This study involved 45 adolescent female volleyball players aged 14–17 years. The participants were recruited based on their active involvement in volleyball training and their physical readiness to participate in structured conditioning interventions. All participants were apparently healthy, free from musculoskeletal injury, and had no reported medical condition that could limit their participation in high-intensity physical training or surface electromyography (sEMG) assessment. The participants were randomly assigned into three equal groups, each consisting of 15 players. Group A served as Experimental Group 1 and received Fartlek training. Group B served as Experimental Group 2 and received interval training. Group C served as the control group and did not receive any additional specialized training during the intervention period. Random

assignment was applied to minimize selection bias and to ensure comparability among the groups before the intervention.

This study employed a descriptive quantitative research design aimed at characterizing and standardizing lower-limb explosive power and VO_2max among volleyball athletes in a defined age group. The descriptive design was selected as it enables systematic documentation of naturally occurring performance characteristics without experimental manipulation of independent variables, which is appropriate for establishing population-specific normative data.

Data collection was organized in a single session per participant. Prior to testing, all participants completed a standardized 15-minute warm-up protocol consisting of light jogging, dynamic stretching, and sport-specific movement patterns. Testing was conducted during morning hours (07.00–

11.00 local time) in standardized facilities at the respective institutions to ensure environmental consistency. The Standing Board Jump Test was administered first to assess lower-limb explosive power, given that it requires maximal neuromuscular output without aerobic demand. Following a minimum 10-minute rest period to attenuate residual fatigue effects, participants performed the 20-Meter Multistage Fitness Test to estimate $VO_2\max$. All testing was supervised by trained research assistants who had completed a calibration protocol prior to the study to ensure inter-rater reliability.

Study organization

The following variables were analyzed to determine the comparative effectiveness of the two training methods. The study employed a three-group true experimental pre-test and post-test design. This design was selected to compare the effects of Fartlek training and interval training on selected physiological and neuromuscular variables among adolescent female volleyball players. The study consisted of two experimental groups and one control group. Experimental Group 1 received Fartlek training, Experimental Group 2 received interval training, and the control group continued usual activities without any additional specialized training intervention. The overall experimental design of the study is illustrated in Figure 1.

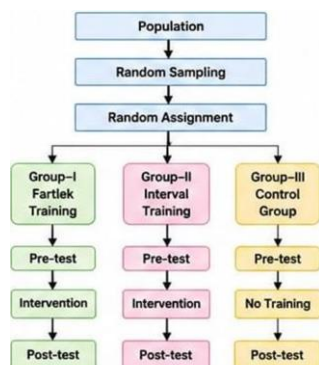


Figure 1. Experimental research design of the study.

Table 1. Experimental Research Design

Group	Assignment	Pre-test	Intervention	Post-test
Experimental Group 1 (E1)	Random assignment (R)	Q1	X1: Fartlek training	Q2
Experimental Group 2 (E2)	Random assignment (R)	Q1	X2: Interval training	Q2
Control Group (C)	Random assignment (R)	Q1	—: No special training intervention	Q2

Notes. R = random assignment; E1 = Experimental Group 1; E2 = Experimental Group 2; C = control group; Q1 = pre-test; Q2 = post-test; X1 = Fartlek training; X2 = interval training; — = no special training intervention.

The independent variable in this study was the training intervention, consisting of Fartlek training and interval training. The dependent variables included selected physiological and neuromuscular outcomes. The physiological variables were $VO_2\max$, resting heart rate, and muscular endurance. $VO_2\max$ was measured using the Cooper 12-minute run test, resting heart rate was measured in beats per minute, and muscular endurance was assessed using sit-up and/or push-up performance tests. Neuromuscular activation was assessed using non-invasive surface electromyography. The sEMG analysis focused on the cumulative muscle activation patterns of the deltoid, biceps brachii, triceps brachii, rectus abdominis, quadriceps, and gastrocnemius muscles. These muscles were selected because

of their functional relevance to volleyball-specific movements, including jumping, spiking, blocking, rapid directional changes, and court-based locomotor actions.

Intervention Development and Implementation

Table 2. Summary of the intervention protocol and measurement procedures

Component	Fartlek Training Group	Interval Training Group	Control Group
Group status	Experimental Group 1	Experimental Group 2	Control Group
Intervention duration	4 weeks	4 weeks	4 weeks
Session duration	45 minutes per day	45 minutes per day	No additional specialized training
Training structure	Continuous variable-intensity training Jogging, sprinting, walking, and volleyball-specific game-like movements	Structured high-intensity interval training Sprint intervals, jumping exercises, and court-like movement patterns	Usual activities only
Main training activities	Alternation of low-, moderate-, and high-intensity activities	Repeated high-intensity efforts followed by planned recovery	No Fartlek or interval training intervention
Intensity pattern			Not applicable
Rest interval	No fixed rest interval	Work-to-rest ratio of 1:1	Not applicable
Training emphasis	Speed play, movement variability, continuous transitions, and game-like adaptation	High-intensity effort, repeated sprinting, jumping, and structured recovery	Maintenance of usual activities
Training rationale	To simulate the intermittent and unpredictable movement demands of volleyball	To improve physiological responses through structured high-intensity efforts and recovery periods	To provide a comparison condition without additional training stimulus
Pre-test procedure	Conducted before the intervention	Conducted before the intervention	Conducted before the intervention
Post-test procedure	Conducted after the 4-week intervention	Conducted after the 4-week intervention	Conducted after the 4-week period
sEMG data collection	Surface electromyographic data collected with trained personnel	Surface electromyographic data collected with trained personnel	Surface electromyographic data collected with trained personnel
sEMG outcome indicator	Cumulative average of sEMG signal amplitudes representing muscular activation responses	Cumulative average of sEMG signal amplitudes representing muscular activation responses	Cumulative average of sEMG signal amplitudes representing muscular activation responses

Table 2 summarizes the structure of the four-week intervention protocol and the measurement procedures applied across the three study groups. Both experimental groups completed 45-minute daily training sessions, but they differed in training characteristics: the Fartlek group performed continuous variable-intensity activities without fixed rest intervals, whereas the interval training group followed structured high-intensity activities with a 1:1 work-to-rest ratio. The control group continued usual activities without additional specialized training. Pre-test and post-test measurements were administered to all groups, and surface electromyography data were collected to determine cumulative

muscular activation responses, allowing comparison of physiological and neuromuscular adaptations across the training conditions.

Test and measurements

The selected physiological and neuromuscular variables were measured using standardized field tests and instrumental assessment procedures. All measurements were conducted during the pre-test and post-test phases to determine changes following the four-week intervention. The physiological variables included $VO_2\text{max}$, resting heart rate, and muscular endurance, whereas the neuromuscular variable was represented by surface electromyography (sEMG)-derived muscle activation. $VO_2\text{max}$ was assessed using the Cooper 12-minute run test. Participants were instructed to cover the maximum possible distance within 12 minutes, and the result was used to estimate aerobic capacity. Resting heart rate was measured in beats per minute (bpm) before physical activity, with participants positioned in a rested condition to ensure measurement consistency. Muscular endurance was assessed using repetition-based exercise tests,

including sit-up and/or push-up performance, with the total number of correctly completed repetitions recorded as the outcome score.

Neuromuscular activation was measured using non-invasive surface electromyography. The sEMG assessment was used to record the electrical activity produced by muscle contractions during selected volleyball-related movements and training activities. The muscles assessed included the deltoid, biceps brachii, triceps brachii, rectus abdominis, quadriceps, and gastrocnemius. These muscle groups were selected because of their functional involvement in volleyball-specific actions such as jumping, spiking, blocking, arm swing execution, trunk stabilization, and rapid court movement. The cumulative average of sEMG signal amplitudes, expressed in microvolts (μV), was used as the indicator of muscular activation. All measurements were conducted under the supervision of trained personnel to ensure standardization, accurate recording, and participant safety. The same testing procedures were applied during both pre-test and post-test sessions to maintain consistency and reduce measurement bias.

Table 3. Measurement instruments and outcome indicators

Variable	Test/Instrument	Unit/Outcome Indicator	Purpose of Measurement
$VO_2\text{max}$	Cooper 12-minute run test	Estimated $VO_2\text{max}$ / aerobic capacity	To assess cardiovascular endurance and aerobic fitness
Resting heart rate	Pulse measurement	Beats per minute (bpm)	To assess cardiovascular efficiency at rest
Muscular endurance	Sit-up and/or push-up test	Number of correct repetitions	To assess endurance capacity of working muscles
Muscle activation	Surface electromyography (sEMG)	Signal amplitude in microvolts (μV)	To assess neuromuscular activation of selected muscle groups
Targeted muscle groups	sEMG recording of deltoid, biceps brachii, triceps brachii, rectus abdominis, quadriceps, and gastrocnemius	Cumulative average sEMG amplitude	To examine muscle activation responses associated with volleyball-specific training

Statistical analysis

The collected data were analyzed using descriptive and inferential statistical procedures to determine the comparative effects of Fartlek training, interval training, and the control condition on physiological and neuromuscular outcomes. Descriptive statistics were first employed to calculate the pre-test and post-test mean scores for each group. These analyses were used to summarize changes in $VO_2\text{max}$, resting heart rate, muscular endurance, and surface electromyography (sEMG)-derived muscle activation following the four-week intervention period. To examine differences among the three groups while controlling for baseline pre-test scores, analysis of covariance (ANCOVA) was applied. ANCOVA was considered appropriate because the study used a pre-test and post-test experimental design and aimed to compare post-intervention outcomes after adjusting for initial group differences. This procedure enabled a more accurate evaluation of whether the observed improvements were attributable to the training interventions. The F-ratio was used to determine the statistical significance of group differences. The level of significance was set at 0.05. The calculated F-values were compared with the critical table value of 3.22. A calculated F-value greater than the critical value was interpreted as indicating a statistically significant difference among the groups.

The ANCOVA results showed significant differences among the groups for all measured variables. For $VO_2\text{max}$, the obtained F-value was 15.98, indicating a significant difference among the groups, with the Fartlek training group demonstrating the greatest improvement. For resting heart rate, the obtained F-value was 12.00, showing a significant reduction across groups, with the largest decrease observed in the Fartlek training group. For muscular endurance, the obtained F-value was 18.75, indicating

a significant group difference, again favoring the Fartlek training group. Similarly, the ANCOVA result for sEMG signal amplitude showed an F-value of 20.25, confirming a significant difference in muscular activation among the groups, with the Fartlek training group achieving the highest post-test activation response.

Overall, the statistical analysis confirmed that both Fartlek training and interval training produced positive adaptations compared with the control condition. However, the Fartlek training group consistently demonstrated superior improvements across physiological and neuromuscular variables. These findings indicate that Fartlek training was more effective than interval training in enhancing $VO_2\text{max}$, reducing resting heart rate, improving muscular endurance, and increasing sEMG-based muscular activation among adolescent female volleyball players.

Ethical Considerations

This study received ethical approval from the Research Ethics Committee of Ganeasr college of Arts& Science (Affiliated to Bharathidasan university, Tiruchirapalli, India) through ethical clearance letter No. BDU2220092779722/PhD/Physical Education/25, dated 18.9.2025. All procedures were conducted in accordance with ethical principles for research involving human participants. Written informed consent was obtained from all participants and, because the participants were aged 14–17 years, additional written consent was obtained from their parents or legal guardians. Participants were informed about the study objectives, training procedures, measurement protocols, potential risks, confidentiality of data, and their right to withdraw from the study at any time without penalty. All data were anonymized and used only for academic purposes, while all training and testing procedures were supervised by qualified personnel to ensure participant safety.

RESULTS

This section presents the comparative outcomes of Fartlek training, interval training, and the control condition on selected physiological and neuromuscular variables among adolescent female volleyball players. The results are reported objectively using pre-test and post-test mean scores, ANCOVA results, and effect size estimates. The measured variables included VO₂max, resting heart rate, muscular endurance, and surface electromyography (sEMG)-derived muscle activation.

Changes in Physiological and Neuromuscular Variables

Table 4 presents the pre-test and post-test mean scores for VO₂max, resting heart rate, muscular endurance, and sEMG signal amplitude across the three study groups. The results show that both experimental groups improved after the four-week intervention; however, the Fartlek training group consistently demonstrated greater positive changes than the interval training group and the control group.

Table 4. Pre-test and post-test mean scores of physiological and neuromuscular variables across groups

Variable	Group	Training Method	Pre-test Mean	Post-test Mean	Mean Change
VO ₂ max	Experimental Group 1	Fartlek training	42.10	48.75	+6.65
VO ₂ max	Experimental Group 2	Interval training	41.85	46.20	+4.35
VO ₂ max	Control Group	No special training	42.00	42.50	+0.50
Resting heart rate	Experimental Group 1	Fartlek training	78 bpm	70 bpm	-8 bpm
Resting heart rate	Experimental Group 2	Interval training	79 bpm	73 bpm	-6 bpm
Resting heart rate	Control Group	No special training	78 bpm	77 bpm	-1 bpm
Muscular endurance	Experimental Group 1	Fartlek training	25 reps	34 reps	+9 reps
Muscular endurance	Experimental Group 2	Interval training	24 reps	32 reps	+8 reps
Muscular endurance	Control Group	No special training	25 reps	26 reps	+1 rep
sEMG signal amplitude	Experimental Group 1	Fartlek training	120 µV	165 µV	+45 µV
sEMG signal amplitude	Experimental Group 2	Interval training	118 µV	145 µV	+27 µV
sEMG signal amplitude	Control Group	No special training	119 µV	122 µV	+3 µV

Table 4 indicates that the Fartlek training group achieved the highest improvement in VO₂max, increasing from 42.10 to 48.75. The interval training group also improved, increasing from 41.85 to 46.20, whereas the control group showed only a marginal change. Resting heart rate decreased most substantially in the Fartlek training group, from 78 bpm to 70 bpm, suggesting improved cardiovascular efficiency. Muscular endurance also increased more prominently in the Fartlek group, with a gain of 9 repetitions. The largest neuromuscular improvement was observed in sEMG signal amplitude, where the Fartlek group increased from 120 µV to 165 µV, indicating greater post-intervention muscular activation.

comparing pre-test and post-test scores across the three groups. This comparison was intended to provide a visual overview of the magnitude of improvement following the four-week intervention and to identify whether Fartlek training and interval training produced different patterns of adaptation compared with the control condition.

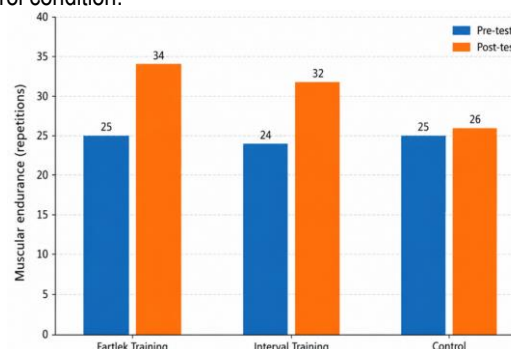


Figure 4. Pre-test and Post-test Comparison of Muscular Endurance Across Groups

Figure 4 illustrates the pre-test and post-test differences in muscular endurance among the Fartlek training, interval training, and control groups. The Fartlek training group showed the greatest improvement, increasing from 25 to 34 repetitions, followed by the interval training group, which increased from 24 to 32 repetitions. In contrast, the control group showed only a minimal increase from 25 to 26 repetitions. These findings indicate that both training interventions improved muscular endurance, but Fartlek training produced the most pronounced gain. The visual pattern supports the statistical findings that structured and variable-intensity conditioning, particularly Fartlek training, contributed more substantially to muscular endurance development than usual activity alone. To further examine the neuromuscular effects of the training interventions, sEMG signal amplitude was analyzed before and after the four-week training period. This visual comparison was used to identify changes in cumulative muscular activation across the Fartlek training, interval training, and control groups. Higher sEMG signal amplitude reflects greater muscle activation response, which may indicate improved neuromuscular engagement following the

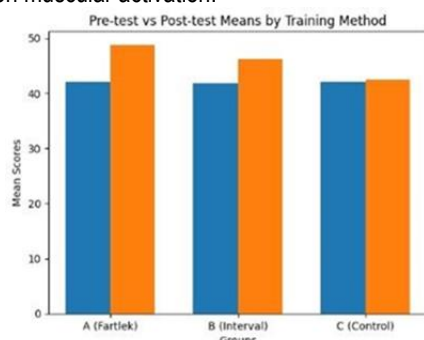


Figure 2. Pre-test and post-test comparison of VO₂max across groups

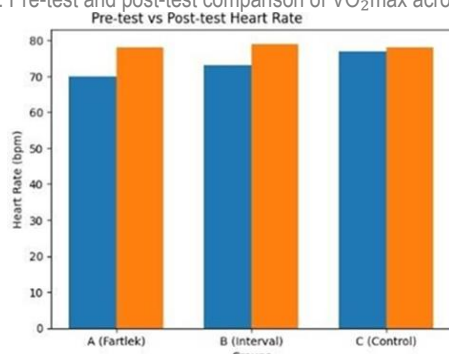


Figure 3. Pre-test and post-test comparison of resting heart rate across groups. Before conducting inferential statistical analysis, changes in muscular endurance were first examined descriptively by

training intervention.

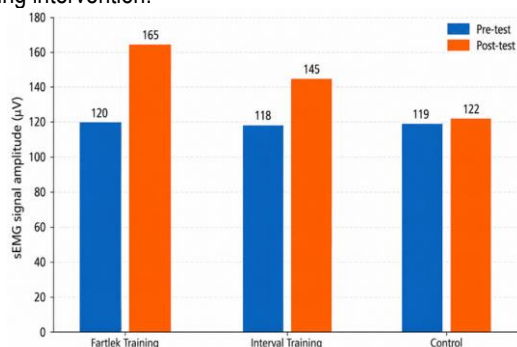


Figure 5. Pre-test and Post-test Comparison of sEMG Signal Amplitude Across Groups

Figure 5 presents the pre-test and post-test comparison of sEMG signal amplitude among the three study groups. The Fartlek

training group demonstrated the largest increase in sEMG amplitude, rising from 120 µV to 165 µV, followed by the interval training group, which increased from 118 µV to 145 µV. In contrast, the control group showed only a minimal change, increasing from 119 µV to 122 µV. These findings indicate that both training interventions enhanced muscular activation; however, Fartlek training produced the most substantial neuromuscular response. The visual pattern supports the statistical evidence that Fartlek training was more effective than interval training and the control condition in improving sEMG-derived muscular activation among adolescent female volleyball players.

Statistical Evaluation Using ANCOVA

Analysis of covariance was conducted to determine whether significant differences existed among the three groups after adjusting for baseline pre-test scores. The ANCOVA results are presented in Table 3.

Table 5. ANCOVA results for physiological and neuromuscular variables

Variable	Source of Variance	SS Between Groups	SS Within Groups	df Between	df Within	F-value	Critical Value	Significance
VO ₂ max	Between groups	120.50	158.40	2	42	15.98	3.22	Significant
Resting heart rate	Between groups	96.00	168.00	2	42	12.00	3.22	Significant
Muscular endurance	Between groups	150.00	168.00	2	42	18.75	3.22	Significant
sEMG muscle activation	Between groups	4050.00	4200.00	2	42	20.25	3.22	Significant

Table 5 shows that all calculated F-values exceeded the critical value of 3.22 at the 0.05 significance level. For VO₂max, the obtained F-value was 15.98, indicating a statistically significant difference among the groups. Resting heart rate also showed a significant group difference, with an F-value of 12.00. Muscular endurance demonstrated a significant difference among groups, with an F-value of 18.75. The highest F-value was observed for sEMG muscle activation, with an F-value of 20.25, indicating the strongest statistical differentiation among the groups for neuromuscular response. These findings confirm that the training interventions produced significant physiological and neuromuscular adaptations, with the Fartlek training group demonstrating the most favorable outcomes.

Effect Size Analysis

Effect size was calculated using eta squared (η^2) to determine the magnitude of the intervention effects. Eta squared was calculated by dividing the between-group sum of squares by the total sum of squares. The interpretation followed conventional thresholds, where 0.01 indicates a small effect, 0.06 indicates a

medium effect, and 0.14 or above indicates a large effect.

Table 6. Effect size values for physiological and neuromuscular variables

Variable	SS Between Groups	SS Total	η^2	Effect Size Interpretation
VO ₂ max	120.50	278.90	0.43	Large effect
Resting heart rate	96.00	264.00	0.36	Large effect
Muscular endurance	150.00	318.00	0.47	Large effect
sEMG muscle activation	4050.00	8250.00	0.49	Large effect

To complement the statistical significance testing, effect size analysis was conducted to determine the practical magnitude of the intervention effects across the measured variables. Eta squared (η^2) was used to quantify the proportion of variance explained by group differences in VO₂max, resting heart rate, muscular endurance, and sEMG-derived muscle activation. This analysis provides a clearer understanding of whether the observed differences among the Fartlek training, interval training, and control groups were not only statistically significant but also practically meaningful.

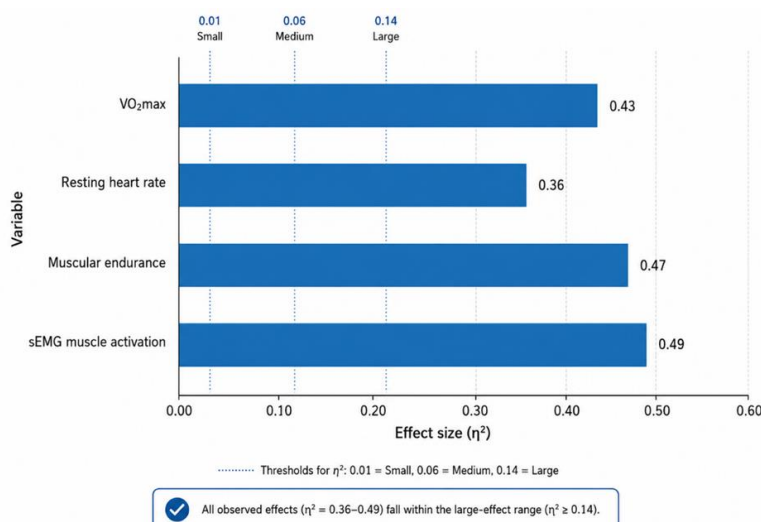


Figure 6. Effect Size Analysis Across Physiological and Neuromuscular Variables

Figure 6 presents the eta squared (η^2) effect size values for all measured physiological and neuromuscular variables. The effect size values ranged from 0.36 to 0.49, indicating that all variables fell within the large-effect category. The largest effect was observed for sEMG muscle activation ($\eta^2 = 0.49$), followed by muscular endurance ($\eta^2 = 0.47$), VO_2max ($\eta^2 = 0.43$), and resting heart rate ($\eta^2 = 0.36$). These findings indicate that the intervention produced substantial practical effects across all outcomes, with the strongest impact occurring in neuromuscular activation. Overall, the effect size results strengthen the statistical findings by demonstrating that the differences among groups were not only significant but also meaningful in practical sport training contexts.

Summary of Major Findings

The results demonstrate that Fartlek training produced the

greatest improvements across physiological and neuromuscular variables. The Fartlek group showed the highest increase in VO_2max , the greatest reduction in resting heart rate, the largest gain in muscular endurance, and the strongest increase in sEMG-derived muscle activation. Although interval training also produced positive changes compared with the control condition, its effects were consistently lower than those observed in the Fartlek training group. The control group showed only minimal changes across all measured variables. Overall, the statistical findings indicate that Fartlek training was more effective than interval training in enhancing physiological fitness and neuromuscular activation among adolescent female volleyball players.

DISCUSSION

Principal Findings

This study examined whether Fartlek and interval training improve physiological fitness and neuromuscular activation in adolescent female volleyball players compared with a control condition. The reported results support the hypothesis that training interventions are associated with improvement: adjusted group differences were statistically significant for VO_2max , resting heart rate, muscular endurance, and sEMG-derived muscle activation. The reported pattern also favored Fartlek training, with the largest changes described for that group. However, the omnibus ANCOVA results establish that at least one group differed from another for each outcome; without reported post-hoc comparisons and confidence intervals, they do not by themselves confirm that every Fartlek–interval contrast was statistically significant. Consistent with these observations, previous research has indicated that Fartlek protocols can induce cardiovascular adaptations comparable to traditional high-intensity interval training, while the integration of active recovery periods facilitates sustained heart rate elevation throughout the session (Bhutada & Ladha, 2024, p. 14). Furthermore, the inherent flexibility and unordered intensity fluctuations characteristic of Fartlek sessions allow participants to effectively challenge both aerobic and anaerobic pathways, often leading to superior gains in maximum oxygen consumption (Nadimikeri & Joshi, 2022, p. 152).

The reported η^2 values, ranging from 0.36 to 0.49, suggest potentially substantial group effects. This indicates that the findings may be practically relevant, not merely statistically detectable. Nevertheless, statistical significance and effect magnitude do not establish that changes were meaningful in competition or durable over time. No thresholds for meaningful change, uncertainty intervals, or direct volleyball skill outcomes are provided in the results presented here. In particular, improved sEMG amplitude should be interpreted as a change in the measured electrical signal, not as conclusive evidence of superior coordination or match performance. The findings therefore support the potential value of both training approaches, while the extent of their practical transfer remains to be tested. Furthermore, future investigations should incorporate longitudinal assessments to determine if the reported neuromuscular and aerobic enhancements translate into sustained performance advantages throughout a competitive volleyball season. Furthermore, given the study's focus on short-term training adaptations, it remains to be seen whether these improvements in physiological and neuromuscular parameters translate into

tangible gains in sport-specific metrics such as linear speed or agility (Gao et al., 2025, p. 1629062).

Comparison with International Evidence

The findings are consistent with broader evidence that interval-based conditioning can improve physical capacities relevant to volleyball. A six-week pilot comparison involving volleyball players reported improvements in power with both Fartlek and high-intensity interval training, while the interval-training group showed a larger improvement in VO_2max than the Fartlek group (Gautam et al., 2024; Purkhús et al., 2016; Wulandari et al., 2026). This differs from the current study's reported overall advantage for Fartlek and cautions against treating one method as universally superior. The pilot involved only 15 national-level players and measured VO_2max and power; differences in sample composition, training content, and outcome selection may help explain the contrasting pattern.

Evidence from other volleyball populations also supports the effectiveness of interval approaches but does not establish that they outperform Fartlek. In a study of collegiate players, both running-based and jump-based interval training improved cardiorespiratory fitness, power, and motor performance, while the relative advantages differed by outcome: jump-based intervals favored jumping measures, whereas running-based intervals favored sprint speed (Venegas-Carro et al., 2023, p. 1; Zhao & Lu, 2024). A separate study of male volleyball players reported improved endurance following high-intensity interval training (Wu, 2023). These findings suggest that adaptations depend partly on the specific exercise mode and the quality being assessed. Fartlek's changing pace and less rigid structure may offer a broader stimulus, but whether that variability accounts for the current pattern cannot be determined without detailed information about intensity, work-to-rest ratios, session frequency, and training fidelity.

The neuromuscular findings are also plausible in light of volleyball EMG research, although the available studies differ substantially from this intervention. Six weeks of plyometric training in male collegiate volleyball athletes was associated with changes in sEMG measures during blocking, alongside improvements in blocking agility and jump height (Gaur et al., 2026; Ramírez-Campillo et al., 2021, p. 491; Wang et al., 2020). Research in female volleyball players has likewise used sEMG to characterize muscle activity during drop jumps, illustrating the value of measuring neuromuscular responses in sport-specific tasks (Torres-Banduc et al., 2021, p. 724070). However, these studies assessed different training exposures, populations,

muscles, and movement tasks. They support the relevance of neuromuscular measurement, not a direct conclusion that Fartlek training produces greater activation than interval training across settings. Moreover, the absence of data regarding sport-specific performance transfer in the current analysis mirrors a recurring limitation in existing literature, where physiological gains frequently fail to correlate with improved competitive outcomes (Stöggl & Björklund, 2017, p. 566). Furthermore, the discrepancy between observed physiological adaptation and actual sport-specific performance underscores the necessity of quantifying individual responses to training intensity and recovery duration within the context of competitive team sport demands (Rodríguez-Fernández et al., 2022, p. 49; Stanković et al., 2023, p. 85).

Population and context are important when comparing results. Studies involving male collegiate or elite athletes may not transfer directly to adolescent female players, whose training history, biological maturation, and competitive demands may differ. Intervention duration and workload, the inclusion of regular team practice, and whether training is individualized can also affect adaptation. Differences in sEMG electrode placement, normalization, signal processing, and the movement performed during measurement may limit direct comparison between studies. Accordingly, the current findings extend the literature by examining physiological and neuromuscular outcomes together in adolescent female volleyball players, but they require replication with clearly reported protocols and comparable measurements.

Theoretical, Methodological, and Practical Implications

The results are compatible with the view that intermittent sports conditioning should address both physiological capacity and the ability to produce repeated muscular actions. Fartlek training may provide changing intensities that engage different demands within a session, while structured interval training provides a more prescribed stimulus. The current results suggest that either approach may be beneficial and that a variable training format may be promising for the outcomes measured. They do not, however, demonstrate that variability itself caused the apparent advantage: the comparison would require training-load data and a design that isolates variability from differences in intensity, volume, and exercise content. Additionally, future investigations should account for the role of individual biological maturation, as developmental stages may independently influence neuromuscular adaptations regardless of the specific conditioning modality. Furthermore, future research must systematically document training adherence and control for confounding variables such as nutritional status, sleep quality, and menstrual cycle phase to ensure the precision and reliability of the observed performance effects (Hu et al., 2025, p. 1678876).

Methodologically, the use of a control group and baseline-adjusted group comparisons strengthens interpretation relative to a simple pre-post comparison. Combining physiological measures with sEMG also provides a wider view of possible adaptation than relying on a single fitness test (Krämer et al., 2018, p. 641; Pareja-Blanco et al., 2020, p. 1772; Taipale et al., 2023, p. 679). At the same time, the effect-size calculations should be interpreted cautiously. The manuscript describes η^2 as the ratio of between-group to total sums of squares, but it does not specify the sums-of-squares type or whether the values correspond to an adjusted ANCOVA effect size. Reporting the calculation method, confidence intervals, and adjusted group

means would make the magnitude and precision of the effects easier to evaluate. In addition, integrating longitudinal tracking of neuromuscular efficiency alongside standardized performance markers would clarify whether the observed adaptations persist over an entire competitive season. By assessing these longitudinal changes, researchers can better delineate whether the observed performance gains represent transient physiological responses to acute training stimuli or sustained, long-term adaptations relevant to athletic development.

For coaches, the findings support considering both Fartlek and interval training as components of conditioning for adolescent female volleyball players, rather than replacing technical or tactical practice with either method. Choice of approach should reflect the training objective, athlete readiness, available time, and the balance of workload across the season. Since the present results do not establish long-term retention, injury effects, cost-effectiveness, or improved match outcomes, implementation should be monitored and adjusted to the athletes' responses. Claims of transfer to spiking, jumping, agility, or overall volleyball performance should remain provisional unless those outcomes are measured directly.

Strengths and Limitations

A principal strength is the comparison of two training approaches with a control condition, alongside baseline-adjusted analyses of several physiological and neuromuscular outcomes. The inclusion of sEMG is another strength because it adds a measure of muscle electrical activity to conventional fitness outcomes. These features make the study relevant to the practical question of how alternative conditioning approaches may relate to more than one dimension of performance. However, the reliance on a relatively small, homogeneous cohort limits the generalizability of these findings across different competitive levels or broader athletic populations.

Important limitations constrain the conclusions. The results provided do not specify the sample size and allocation by group, recruitment strategy, randomization procedure, intervention dose and duration, adherence, or whether other training was standardized. Without these details, selection bias, unequal exposure, and confounding by routine team practice cannot be ruled out. In adolescent athletes, maturation and baseline training history may also influence outcomes. The methods summarized here do not report assessor blinding, missing-data patterns or handling, or follow-up testing. Their absence from the reported information should not be taken to mean that these procedures were not undertaken, but it prevents readers from judging their influence.

Measurement and analysis also warrant caution. sEMG is sensitive to electrode placement, skin preparation, normalization procedures, and task execution; these details are needed to assess reproducibility and to distinguish changes in the signal from changes in functional performance. Four outcomes were tested, and the analysis as presented does not describe adjustment for multiple comparisons or post-hoc tests. The reported large η^2 estimates are potentially important, but without confidence intervals and transparent specification of the effect-size calculation, their precision and comparability are uncertain. A statistically significant omnibus result does not establish which pairs of groups differ or whether changes exceed a practically meaningful threshold.

Finally, findings from one sample of adolescent female volleyball players may not generalize to athletes of different ages, competitive levels, sexes, or cultural and training contexts. These limitations do not negate the observed group-level pattern; they

mean it should be treated as promising rather than definitive. Clearer reporting, larger and more representative samples, standardized measurement, and replication can reduce these uncertainties.

Future Research

Future studies should recruit adequately powered samples of adolescent female volleyball players across multiple clubs and countries, with transparent eligibility criteria and documentation of age, maturation, competitive level, and previous training. Randomized, preferably multicentre trials should compare Fartlek, interval, and usual-training conditions while matching or reporting total workload, intensity, frequency, and concurrent practice. Interventions lasting at least a full training block, followed by retention testing several months later, would help determine whether adaptations persist beyond the immediate post-test. Research should also measure volleyball-specific transfer directly, including jump and spike performance, agility,

repeated-effort ability, and match-relevant indicators, alongside VO_2max , resting heart rate, muscular endurance, and carefully standardized sEMG. Potential mechanisms—such as aerobic adaptation, fatigue resistance, and changes in recruitment during sport-specific tasks—could be examined, with training history, maturation, and baseline fitness tested as possible moderators. Studies should pre-register primary outcomes, report adjusted group differences with confidence intervals, address multiplicity and missing data, and document adherence and assessor blinding where feasible. Finally, implementation studies should examine coach and athlete acceptability, equipment and staffing requirements, feasibility within regular practice, and injury or fatigue monitoring. Cost-effectiveness analyses could determine whether either approach offers meaningful benefits relative to its time and resource demands. Replication across different competitive and cultural settings is needed before recommending Fartlek as generally superior to interval training.

CONCLUSION

The present study contributes significantly to the field of sports training by establishing a scientific link between training methodologies and muscular activation patterns. By integrating electromyographic analysis with performance skill assessment, the study provides a deeper understanding of the physiological and anatomical mechanisms underlying performance enhancement in volleyball. Within the scope of this investigation, the study examined the cumulative muscular activation of key muscle groups, including the deltoid, biceps brachii, triceps brachii, rectus abdominis, quadriceps, and gastrocnemius. The findings clearly demonstrate that Fartlek training produces greater muscular activation and improved neuromuscular coordination compared to Interval training. This enhanced coordination is a critical factor contributing to improved volleyball performance skills such as jumping, spiking, and agility. The study concludes that Fartlek training is more effective than

Interval training in improving volleyball performance because of its dynamic and variable nature, which closely replicates game conditions. The electromyographic evidence provides a strong anatomical and physiological justification for this superiority, highlighting the role of coordinated muscle activation in optimizing athletic performance. Moreover, the study opens new avenues for future research by emphasizing the importance of integrating biomechanical and physiological data in evaluating training effectiveness. The findings encourage further exploration into muscle-specific activation patterns and their direct relationship with skill execution in sports. In conclusion, the present study not only identifies the relative effectiveness of Fartlek training but also provides a scientific rationale for its superiority, thereby contributing valuable insights for coaches, trainers, and researchers in the domain of sports science.

DECLARATIONS

Ethical Approval

This study received ethical approval from the Research Ethics Committee of Ganesar College of Arts and Science, affiliated with Bharathidasan University, Tiruchirappalli, India, through Ethical Clearance Letter No. BDU2220092779722/PhD/Physical Education/25, dated 18 September 2025. All procedures involving human participants were conducted in accordance with applicable ethical principles and institutional requirements.

Consent to Participate

Written informed consent was obtained from all participants prior to their participation in the study. Because the participants were adolescents aged 14–17 years, additional written informed consent was obtained from their parents or legal guardians. Participants and their parents or legal guardians were informed about the study objectives, training procedures, measurement protocols, potential risks, confidentiality of data, and the right to withdraw from the study at any time without penalty.

Consent for Publication

Written consent for publication was obtained from the participants and their parents or legal guardians, where applicable, for the publication of the study findings. No personally identifiable information, photographs, or individual-level information that could directly identify participants is included in

this manuscript.

Author Contributions (CRediT)

Asha Devi T.: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, and Project Administration.

Uma V.: Methodology, Investigation, Data Curation, Validation, and Writing – Review & Editing.

Suresh Kumar M.: Investigation, Data Curation, Formal Analysis, Visualization, and Writing – Review & Editing.

Ivin Jebakumar K.: Conceptualization, Supervision, Validation, Writing – Review & Editing, and Project Administration.

All authors contributed to the interpretation of the results, reviewed the manuscript critically, approved the final version, and agreed to be accountable for all aspects of the work.

Funding

This research received no specific grant or financial support from any funding agency in the public, commercial, or not-for-profit sectors. The study was conducted as part of the authors' academic and research activities.

Conflict of Interest

The authors declare that they have no conflict of interest related to the research, authorship, or publication of this article.

Data Availability

The data generated and analyzed during this study are not

publicly available because they contain research data obtained from adolescent participants and may include potentially identifiable individual-level information. The data may be made available from the corresponding author upon reasonable request, subject to appropriate ethical, privacy, and institutional restrictions.

Acknowledgements

The authors would like to express their gratitude to Ganesar College of Arts and Science, affiliated with Bharathidasan University, Tiruchirappalli, India, for institutional support. The authors also sincerely thank the participating adolescent female volleyball players and their parents or legal guardians for their cooperation and participation in the study.

References

- Aedo-Muñoz, E., Contreras, V. T., Reyes, C. R., Wimmer, C. H., Brito, C. J., Miarka, B., Velasco-Bucheli, R., Bello, F. D., & Valenzuela, T. H. (2020). Power and electromyographic activity in college volleyball players. *Pensar en Movimiento Revista de Ciencias del Ejercicio y la Salud*, 18(1). <https://doi.org/10.15517/pensarmov.v18i1.37753>
- Alzubaidi, A. (2025). The Effect of Using Fartlek Training Method on Developing Speed, Strength Endurance, and Court Defense Skill Performance in Volleyball. *Jurnal Nakula Pusat Ilmu Pendidikan Bahasa Dan Ilmu Sosial*, 3(3), 329–337. <https://doi.org/10.61132/nakula.v3i3.1837>
- Amiri, S., Mohammadi, H., Watt, P., Shakiba, E., & Shahrjerdi, S. (2025). The Impact of a Structured Volleyball-Specific Fitness Training on the Performance of Female Volleyball Players. *Women in Sport and Physical Activity Journal*, 33(1). <https://doi.org/10.1123/wspaj.2025-0058>
- Bhutada, A., & Ladha, N. (2024). Effectiveness of 4-week Fartlek Training on Cardiovascular Endurance and Speed among Amateur Basketball Players. *International Journal of Health Sciences and Research*, 14(10), 11–16. <https://doi.org/10.52403/ijhsr.20241002>
- Chen, C., Zhong, J., Zhu, Z., Wang, Y., Huang, K., Yuan, H., Deng, M., & ShangGuan, Y. (2025). Position-specific neuromuscular activation and biomechanical characterization of the snap jump in elite male volleyball players: a comparative study of outside and opposite hitters. *Journal of Men s Health*, 21(6), 129. <https://doi.org/10.22514/jomh.2025.089>
- Duchateau, J., Semmler, J. G., & Enoka, R. M. (2006). Training adaptations in the behavior of human motor units. *Journal of Applied Physiology*, 101(6), 1766–1775. <https://doi.org/10.1152/jappphysiol.00543.2006>
- Foster, C., Casado, A., Bok, D., Hofmann, P., Bakken, M., Tjelta, A. R., Manso, J., Boulosa, D., & Koning, J. J. de. (2025). History and perspectives on interval training in sport, health, and disease. *VU Research Portal*, 50, 1–16. <https://doi.org/10.1139/apnm-2023-0611>
- Gabbett, T. J. (2008). Do Skill-Based Conditioning Games Offer a Specific Training Stimulus for Junior Elite Volleyball Players? *The Journal of Strength and Conditioning Research*, 22(2), 509–517. <https://doi.org/10.1519/jsc.0b013e3181634550>
- Gao, Y., Yang, Y., Xian, C., & Wang, Z. (2025). Comparative study of functional training and traditional resistance training on lower-limb strength performance in male adolescent volleyball players: a randomized controlled trial. *Frontiers in Physiology*, 16, 1629055. <https://doi.org/10.3389/fphys.2025.1629055>
- Gaur, T., Anand, P., & Siwach, P. (2026). Effect of Plyometric Training on Lower Limb Explosive Power, Strength, and Vertical Jump in Volleyball Players: A Systematic Review. *International Journal of Science and Research (IJSR)*, 1382–1391. <https://doi.org/10.21275/mr26317092055>
- Gautam, N., Pal, S., & Rakheja, H. (2024). Comparative Study of the Effectiveness of Fartlek Training and High-intensity Interval Training on VO2 max and Power on Volleyball Players: A Pilot Study. *Journal Of Clinical And Diagnostic Research*. <https://doi.org/10.7860/jcdr/2024/75484.19995>
- Gibala, M. J. (2020). Physiological basis of interval training for performance enhancement. *Experimental Physiology*, 106(12), 2324–2327. <https://doi.org/10.1113/ep088190>
- Hernández-Martínez, J., Guzmán-Muñoz, E., Ramírez-Campillo, R., Herrera-Valenzuela, T., Branco, B. H. M., Avila-Valencia, S., Carter-Beltrán, J., Aravena-Sagardia, P., Méndez-Cornejo, J., & Valdés-Badilla, P. (2023). Effects of different plyometric training frequencies on physical performance in youth male volleyball players: a randomized trial. *Frontiers in Physiology*, 14, 1270512. <https://doi.org/10.3389/fphys.2023.1270512>
- Holonec, R., Grindei, L., & Rápolti, L. (2024). A Comprehensive Investigation of Volleyball Movements Using Electromyography and Visual Tracking Techniques. 1–4. <https://doi.org/10.1109/ehb64556.2024.10805651>
- Hu, R., Zhao, M., Shen, X., & Wang, Z. (2025). The effects of an 8-week complex training program on lower limb explosive power and movement agility in adolescent female badminton players. *Frontiers in Physiology*, 16, 1678866. <https://doi.org/10.3389/fphys.2025.1678866>
- Jaworski, J., Lech, G., Ambroży, T., & Żak, M. (2020). Identification of coordination motor abilities determining the sports skill level in elite male badminton players. *Human Movement*, 22(1), 9–15. <https://doi.org/10.5114/hm.2021.98459>
- Kraemer, W. J., Fleck, S. J., & Evans, W. J. (1996). Strength and Power Training. *Exercise and Sport Sciences Reviews*, 24. <https://doi.org/10.1249/00003677-199600240-00014>
- Krämer, A., Kümmel, J., Gollhofer, A., Armbrrecht, G., Ritzmann, R., Belavý, D. L., Felsenberg, D., & Grüber, M. (2018). Plyometrics Can Preserve Peak Power During 2 Months of Physical Inactivity: An RCT Including a One-Year Follow-Up. *Frontiers in Physiology*, 9, 633. <https://doi.org/10.3389/fphys.2018.00633>
- Lin, G., Deng, B., Li, Y., Yan, R., Li, D., He, J., Zhang, X., & Jian, S. (2025). Less training, better improvement: effects of velocity-based complex training on lower-limb maximal strength and explosive performance in highly-trained volleyball athletes. *BMC Sports Science Medicine and Rehabilitation*, 17(1), 312. <https://doi.org/10.1186/s13102-025-01364-3>
- Luca, C. J. D. (1997). The Use of Surface Electromyography in Biomechanics. *Journal of Applied Biomechanics*, 13(2), 135–163. <https://doi.org/10.1123/jab.13.2.135>
- Marques, M. C., Tillaar, R. van den, Vescovi, J. D., & González-Badillo, J. J. (2008). Changes in Strength and Power Performance in Elite Senior Female Professional Volleyball Players During the In-Season: A Case Study. *The Journal of Strength and Conditioning Research*, 22(4), 1147–1155. <https://doi.org/10.1519/jsc.0b013e31816a42d0>
- Mølmen, K. S., & Rønnestad, B. R. (2024). A narrative review exploring advances in interval training for endurance athletes. *TSpace*, 49(7), 1008–1013. <https://doi.org/10.1139/apnm-2023-0603>
- Nadimikeri, K., & Joshi, A. (2022). Effectiveness of Fartlek Training on Maximum Oxygen Consumption and Resting Heart Rate in Young Obese Males: An Experimental Study. *International Journal of Health Sciences and Research*, 12(6), 147–153. <https://doi.org/10.52403/ijhsr.20220619>

- Pareja-Blanco, F., Alcázar, J., Sánchez-Valdepeñas, J., Cornejo-Daza, P. J., Piqueras-Sanchiz, F., Mora-Vela, R., Sánchez-Moreno, M., Bachero-Mena, B., Ortega-Becerra, M., & Alegre, L. M. (2020). Velocity Loss as a Critical Variable Determining the Adaptations to Strength Training. *RUIdeRA - Institutional University Repository (University of Castilla-La Mancha)*, 52(8), 1752–1762. <https://doi.org/10.1249/mss.0000000000002295>
- Purkhús, E., Krstrup, P., & Mohr, M. (2016). High-Intensity Training Improves Exercise Performance in Elite Women Volleyball Players During a Competitive Season. *The Journal of Strength and Conditioning Research*, 30(11), 3066–3072. <https://doi.org/10.1519/jsc.0000000000001408>
- Ramírez-Campillo, R., Andrade, D. C., Nikolaidis, P. T., Moran, J., Clemente, F. M., Chaabène, H., & Comfort, P. (2021). Effects of plyometric jump training on vertical jump height of volleyball players: a systematic review with meta-analysis of randomized-controlled trial. *PubMed*, 19(3), 489–499. <https://doi.org/10.25932/publishup-52589>
- Ramírez-Campillo, R., García-de-Alcaráz, A., Chaabène, H., Moran, J., Negra, Y., & Granacher, U. (2021). Effects of Plyometric Jump Training on Physical Fitness in Amateur and Professional Volleyball: A Meta-Analysis. *Frontiers in Physiology*, 12, 636140. <https://doi.org/10.3389/fphys.2021.636140>
- Rebello, A., Pereira, J. R., Cunha, P., Coelho-e-Silva, M. J., & Valente-dos-Santos, J. (2024). Training stress, neuromuscular fatigue and well-being in volleyball: a systematic review. *BMC Sports Science Medicine and Rehabilitation*, 16(1). <https://doi.org/10.1186/s13102-024-00807-7>
- Rodríguez-Fernández, A., Lago-Rodríguez, Á., Ramírez-Campillo, R., Sánchez, M., & Sánchez-Sánchez, J. (2022). Cardiopulmonary-versus neuromuscular-based high-intensity interval training during a pre-season in youth female basketball players. *Human Movement*, 24(2), 44–51. <https://doi.org/10.5114/hm.2023.115832>
- Seiler, S. (2010). What is Best Practice for Training Intensity and Duration Distribution in Endurance Athletes? *International Journal of Sports Physiology and Performance*, 5(3), 276–291. <https://doi.org/10.1123/ijspp.5.3.276>
- Sheppard, J. M., Gabbett, T. J., & Stanganelli, L. C. R. (2009). An Analysis of Playing Positions in Elite Men's Volleyball: Considerations for Competition Demands and Physiologic Characteristics. *The Journal of Strength and Conditioning Research*, 23(6), 1858–1866. <https://doi.org/10.1519/jsc.0b013e3181b45c6a>
- Stanković, M., Djordjevic, D., Trajković, N., & Milanović, Z. (2023). Effects of High-Intensity Interval Training (HIIT) on Physical Performance in Female Team Sports: A Systematic Review. *Sports Medicine - Open*, 9(1), 78. <https://doi.org/10.1186/s40798-023-00623-2>
- Stöggli, T., & Björklund, G. (2017). High Intensity Interval Training Leads to Greater Improvements in Acute Heart Rate Recovery and Anaerobic Power as High Volume Low Intensity Training. *Frontiers in Physiology*, 8, 562. <https://doi.org/10.3389/fphys.2017.00562>
- Taipale, R. S., Ihalainen, J. K., Hackney, A. C., & Häkkinen, K. (2023). Perspectives on Concurrent Strength and Endurance Training in Healthy Adult Females: A Systematic Review. *Sports Medicine*, 54(3), 673–696. <https://doi.org/10.1007/s40279-023-01955-5>
- Torres-Banduc, M. A., Ramírez-Campillo, R., Andrade, D. C., Calleja-González, J., Nikolaidis, P. T., McMahon, J. J., & Comfort, P. (2021). Kinematic and Neuromuscular Measures of Intensity During Drop Jumps in Female Volleyball Players. *Frontiers in Psychology*, 12, 724070. <https://doi.org/10.3389/fpsyg.2021.724070>
- Tschakert, G., & Hofmann, P. (2013). High-Intensity Intermittent Exercise: Methodological and Physiological Aspects. *International Journal of Sports Physiology and Performance*, 8(6), 600–610. <https://doi.org/10.1123/ijspp.8.6.600>
- Venegas-Carro, M., Herring, J. T., Riehle, S., & Krämer, A. (2023). Jumping vs. running: Effects of exercise modality on aerobic capacity and neuromuscular performance after a six-week high-intensity interval training. *PLoS ONE*, 18(2). <https://doi.org/10.1371/journal.pone.0281737>
- Wang, M., Chen, K.-C., Hung, M.-H., Chang, C.-Y., Ho, C.-S., Chang, C.-H., & Lin, K.-C. (2020). Effects of Plyometric Training on Surface Electromyographic Activity and Performance during Blocking Jumps in College Division I Men's Volleyball Athletes. *Applied Sciences*, 10(13), 4535. <https://doi.org/10.3390/app10134535>
- Wu, X. (2023). High-Intensity Interval Training Impacts On Endurance Of Volleyball Players. *Revista Brasileira de Medicina Do Esporte*, 29. https://doi.org/10.1590/1517-8692202329012023_0047
- Wulandari, F. Y., Pambudi, N. A., Jatmikanto, R. S., Hafidz, A., Fajar, M. K., Daulay, D. A. A., Widohardhono, R., Andriana, L. M., & S, A. (2026). High-Intensity Interval Training Outperforms Fartlek and Continuous Training in Aerobic and Running-Mechanics Adaptations: Evidence from Athletics Education. *Physical Education Theory and Methodology*, 26(1), 193–205. <https://doi.org/10.17309/tmf.2026.1.19>
- Zhao, X., & Lu, M. (2024). The Impact of Running-Based and Drop Jumping Interval Interventions on Cardiorespiratory Fitness and Anaerobic Power of Collegiate Volleyball Players: A Comparative Analysis of Inter-Individual Variability in the Adaptive Responses. *Journal of Sports Science and Medicine*, 23(4), 863–871. <https://doi.org/10.52082/jssm.2024.863>