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<https://doi.org/10.55040/wgyhje81>

Effectiveness of game-based physical training on aerobic and anaerobic capacity in volleyball players aged 15-18 years: a randomized controlled trial

Eficacia del entrenamiento físico basado en juegos sobre la capacidad aeróbica y anaeróbica en jugadores de voleibol de 15 a 18 años: un ensayo controlado aleatorizado

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Editorial schedule: Article received 17/04/2026 Accepted: 20/06/2026 Published: 01/08/2026

<https://doi.org/10.55040/wgyhje81>

To cite this article use the following reference:

Andriansyah; Sumaryanto; Ngatman; Prabowo, T.A. (2026). Effectiveness of game-based physical training on aerobic and anaerobic capacity in volleyball players aged 15-18 years: a randomized controlled trial. *Sportis Sci J*, 12 (4), 1-22
<https://doi.org/10.55040/wgyhje81>

Author contribution: study design is A.A. & S.S., data collection is A.A. & N.N., statistical analysis is T.A.P, manuscript preparation is T.A.P, Funds Collection is S.S. & N.N

Funding: There is no funding in this research

Conflict of interest: All authors have no conflict of interest

Ethical aspects: The researcher explained the research objectives, training program and test procedures to the respondents and the respondents filled out the informed consent form voluntarily

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Abstract

Volleyball is an intermittent sport that requires both aerobic and anaerobic capacity; therefore, training approaches should match these physiological demands. This study aimed to analyze the effectiveness of game-based physical training on aerobic and anaerobic endurance in volleyball players aged 15-18 years. The study employed a randomized controlled trial design with a pretest-posttest format involving two groups. A total of 48 volleyball players aged 15-18 years (24 males and 24 females) were randomly assigned to an intervention group (game-based physical training) and a control group (conventional training). The intervention was conducted over 8 weeks (24 sessions) with an intensity of 65-85%. Aerobic endurance was measured using the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1), while anaerobic endurance was assessed using the 10 × 20-meter Repeated Sprint Ability test with Total Sprint Time as the indicator. Data were analyzed using multivariate analysis of covariance (MANCOVA). The results showed a significant group effect on the combined posttest scores of aerobic and anaerobic capacity ($p < 0.001$; partial $\eta^2 = 0.738$). Univariate analysis revealed that the group significantly affected both posttest aerobic capacity ($p < 0.001$; partial $\eta^2 = 0.508$) and posttest anaerobic capacity ($p < 0.001$; partial $\eta^2 = 0.687$). Game-based physical training was more effective than conventional training in improving aerobic and anaerobic endurance in volleyball players aged 15-18 years. Future studies should employ more comprehensive designs, objective measurements, and longer intervention periods.

Keywords: physical training, game-based training, endurance capacity, youth volleyball athletes, volleyball training methods.

Resumen

El voleibol es un deporte intermitente que requiere capacidad tanto aeróbica como anaeróbica; por lo tanto, los enfoques de entrenamiento deben ajustarse a estas demandas fisiológicas. Este estudio tuvo como objetivo analizar la efectividad del entrenamiento físico basado en el juego sobre la resistencia aeróbica y anaeróbica en jugadores de voleibol de 15 a 18 años. El estudio empleó un diseño de ensayo controlado aleatorizado con un formato pretest-posttest que involucró a dos grupos. Un total de 48 jugadores de voleibol de 15 a 18 años (24 hombres y 24 mujeres) fueron asignados aleatoriamente a un grupo de intervención (entrenamiento físico basado en el juego) y a un grupo de control (entrenamiento convencional). La intervención se llevó a cabo durante 8 semanas (24 sesiones) con una intensidad del 65-85%. La resistencia aeróbica se midió utilizando la Prueba de Recuperación Intermitente Yo-Yo Nivel 1 (YYIR1), mientras que la resistencia anaeróbica se evaluó utilizando la prueba de Capacidad de Sprint Repetido de 10 × 20 metros con Tiempo Total de Sprint como indicador. Los datos se analizaron utilizando un análisis multivariado de covarianza (MANCOVA). Los resultados mostraron un efecto de grupo significativo en las puntuaciones post-test combinadas de capacidad aeróbica y anaeróbica ($p < 0,001$; η^2 parcial = 0,738). El análisis univariado reveló que el grupo afectó significativamente tanto la capacidad aeróbica post-test ($p < 0,001$; η^2 parcial = 0,508) como la capacidad anaeróbica post-test ($p < 0,001$; η^2 parcial = 0,687). El entrenamiento físico basado en juegos fue más efectivo que el entrenamiento convencional para mejorar la resistencia aeróbica y anaeróbica en jugadores de voleibol de 15 a 18 años. Los estudios futuros deberían emplear diseños más completos, mediciones objetivas y períodos de intervención más prolongados.



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Palabras clave: entrenamiento físico, entrenamiento basado en juegos, capacidad de resistencia, jóvenes atletas de voleibol, métodos de entrenamiento de voleibol.

Introduction

Volleyball is a team sport that requires the simultaneous integration of technical skills, tactical understanding, and physical conditioning. During matches, players must perform jumps, short sprints, changes of direction, rapid reactions, and repeated attack-defense transitions within short periods (Permana et al., 2025; Afifah et al., 2025). This fast and intermittent nature means that volleyball performance is highly influenced by athletes' physical readiness, particularly during phases requiring explosive responses while maintaining stability throughout sets and matches. Recent studies also emphasize that success in volleyball is determined not only by mastery of technical skills but also by the quality of physical attributes that support effective and repeated execution of those skills (Oliveira et al., 2025; Negaresh et al., 2025).

Among various physical components, aerobic and anaerobic endurance play important roles in supporting the performance of volleyball players aged 15-18 years. Anaerobic endurance is required to sustain high-intensity actions such as jumping, blocking, spiking, and short explosive movements (Başandaç et al., 2025). Meanwhile, aerobic endurance contributes to faster recovery between rallies, maintaining game intensity, and preserving performance quality throughout the match (Munandar et al., 2023). Recent research in youth volleyball indicates that game demands involve simultaneous contributions from both energy systems; therefore, training approaches emphasizing only one aspect may be suboptimal for developing young athletes' performance (Bilici & Topateş, 2025; Widowati et al., 2025).

Despite the multidimensional physical demands of volleyball, training practices in the field are still often dominated by conventional approaches that tend to be coach-centered, repetitive, and focused on technique training or drills separated from game context. Previous research describes conventional training groups as programs emphasizing coach direction, individual feedback, and technical drills (Biçer, 2021; Longakit et al., 2025), whereas game-based groups engage in more play-oriented training activities (Wubale et al., 2023). Logically, such conventional approaches may produce



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lower stimulus relative to the complexity of real match demands, particularly when training aims to develop physical capacity that must emerge alongside decision-making and sport-specific movement. Additionally, recent studies on youth volleyball athletes indicate that repetitive training methods often fail to fully capture the multidimensional demands of modern volleyball (Bilici & Topateş, 2025).

As an alternative, game-based physical training offers a more contextual approach by integrating physical, technical, and situational game elements within a single training session. Recent literature shows that game-based or small-sided training interventions can increase participant engagement, enjoyment, and contribute positively to fitness components, particularly aerobic performance (de Oliveira Castro et al., 2022; Mo et al., 2024). A meta-analysis in children and adolescents reported that physical game programs improve enjoyment compared to traditional learning (Li et al., 2023), while a systematic review of small-sided game interventions demonstrated improvements in aerobic fitness in youth populations (Li et al., 2024). These findings support the assumption that game-based training is a promising, adaptive, and engaging approach for adolescent athletes.

In volleyball contexts, empirical support for game-based training is also growing. Previous research involving male youth volleyball players showed that a 12-week game-based approach effectively improved general physical abilities compared to traditional training (Wubale et al., 2023). Furthermore, game-based training was found to be more effective than drill-based training in improving technical skills among volleyball players aged 15-16 years (Wubale et al., 2025). In addition, a development study that produced a Game-Based Physical Training Model for volleyball athletes aged 15-18 years demonstrated that the model was valid and effective in improving motivation and smash ability (Andriansyah et al., 2025). Thus, the game-based training model used in this study has an initial conceptual and empirical foundation and is suitable for further testing on more specific physiological indicators.

However, a clear research gap remains. Development studies on Game-Based Physical Training have focused on motivation and smash ability rather than aerobic and anaerobic endurance as primary physiological outcomes (Andriansyah et al., 2025). On the other hand, recent youth volleyball studies emphasize the importance of developing aerobic and anaerobic capacity, while also noting that direct comparisons of different

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training methods in youth volleyball athletes remain limited (Bilici & Topateş, 2025). Therefore, scientific evidence regarding whether game-based physical training is more effective than conventional training in improving these two endurance components among volleyball players aged 15-18 years is still insufficient.

Based on these conditions, this study offers novelty in several aspects. First, the study does not focus on model development but on further effectiveness testing of an already developed model. Second, it specifically places aerobic and anaerobic endurance as primary outcomes, thereby extending evidence of game-based training benefits from motivational and skill domains to physiological aspects. Third, the study employs a Randomized Controlled Trial design, providing stronger methodological rigor in comparing game-based physical training with conventional training among youth volleyball athletes. Inferentially, the combination of these three aspects positions this study to contribute new insights to the literature on youth athlete physical development in volleyball.

Therefore, this study aims to analyze the effectiveness of game-based physical training on aerobic and anaerobic endurance in volleyball players aged 15-18 years and to compare it with conventional training using a Randomized Controlled Trial design. The study is based on the hypothesis that the group receiving game-based physical training will show greater improvements in aerobic and anaerobic endurance compared to the conventional training group. The findings are expected to provide stronger scientific evidence for coaches, teachers, and sport practitioners in selecting effective, contextual physical training models suitable for adolescent volleyball athletes.

Method

Research Design

This study employed a Randomized Controlled Trial (RCT) design with two parallel groups and a pretest-posttest measurement structure. The study aimed to analyze the effectiveness of game-based physical training compared with conventional training on aerobic and anaerobic endurance in volleyball players aged 15-18 years. The entire research process was conducted within a youth volleyball training setting in Indonesia according to a schedule determined by the researchers and supervising coaches.



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Prior to data collection, ethical approval was obtained from Universitas Negeri Yogyakarta (approval number: B/0647/UN34.16/PT.01.03/2026). Before participation, all candidates and their parents/guardians received detailed explanations regarding the study objectives, benefits, procedures, duration of the training program, potential risks during training and testing, and participants' right to withdraw at any time without consequences. Written informed consent was obtained from parents/guardians, and participants provided assent to take part in the study.

Before the pretest, all participants attended an orientation and familiarization session. During this stage, researchers explained the study schedule, training procedures, test order, warm-up and cool-down procedures, and safety rules during the intervention. Familiarization ensured that participants understood the research flow, recognized testing procedures, and minimized procedural errors during measurements. After familiarization, participants underwent baseline measurements (pretest) for all main study variables: aerobic endurance and anaerobic endurance. Baseline measurements were conducted under standardized conditions, including identical equipment, test order, assessors, and relatively uniform testing times.

After obtaining all pretest data, participants were randomly assigned to two groups using a 1:1 allocation ratio. Because the study included equal numbers of male and female participants, randomization considered sex to maintain balanced group distribution. Group allocation was conducted after completion of pretest measurements to prevent influencing baseline results. The first group was assigned to the game-based physical training intervention, and the second group was assigned to conventional training.

Due to the nature of the intervention, blinding participants and coaches was not feasible. However, efforts were made to minimize bias by separating training implementation from testing procedures as much as possible. Pretest and posttest measurements were conducted using identical procedures for both groups to ensure objective and fair comparisons.

The intervention lasted 8 weeks with a frequency of three sessions per week, totaling 24 training sessions. The experimental group followed the game-based physical training program, whereas the control group followed conventional training over the same period. Both groups received equal training frequency, intervention duration, and



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schedule to ensure that observed differences reflected the training approach rather than the training dose. Attendance was recorded at each session, and researchers and coaches monitored participation, adherence, and any issues during training.

To maintain treatment consistency, participants were instructed not to engage in additional physical training outside the prescribed program during the study period. Regular technical training activities were allowed provided they did not impose unequal additional loads between groups. Absences, temporary discontinuation, or any events potentially affecting results were documented throughout the intervention.

At the end of week eight, all participants completed posttest measurements using the same instruments, test order, conditions, and assessors as in the pretest. This ensured accurate comparison of changes between the game-based physical training group and the conventional training group. The participant flow from recruitment, baseline measurement, randomization, intervention, and posttest assessment can be presented in a study flow diagram to clarify participation and analysis processes (Hopewell et al., 2025).

Research Samples

A total of 48 volleyball players aged 15-18 years participated in this study, consisting of 24 males and 24 females. After randomization, 24 participants were allocated to the intervention group and 24 to the control group. All participants had structured volleyball training experience for approximately 20-24 months and only competed at the district/city level, this shows a relatively homogeneous competition background. In terms of developmental characteristics, the sample is representative of late adolescent athletes based on chronological age; however, biological maturation was not assessed directly. Additionally, no participants reported injuries that limited training or testing at the time of recruitment.

Each group consisted of 12 males and 12 females. Baseline characteristics of participants in the intervention group included an average age of approximately 17.6 years, height ranging from 164-181 cm, body weight 49-70 kg, and BMI 18.22-21.37. In the control group, the average age was approximately 17.5 years, height ranged from 162-182 cm, body weight 51-72 kg, and BMI 19.43-21.74. The distribution of characteristics by sex within each group showed relatively comparable patterns. The distribution of characteristics based on gender in each group shows a relatively comparable pattern.



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Overall, the similarity of participants' age ranges, training experiences, competitive levels, and baseline anthropometric profiles supports comparison of the two groups and facilitates interpretation of intervention effects in a relatively uniform youth volleyball population.

Intervention program

The intervention was conducted over 8 weeks with a total of 24 training sessions, resulting in a frequency of three sessions per week for both groups. Training sessions were held on Mondays, Wednesdays, and Fridays from 03:30 to 05:00 p.m. Both groups trained simultaneously for 90 minutes per session with an intensity of 65-85%. Equalizing training frequency and duration ensured that differences in outcomes reflected differences in training approach rather than exposure volume.

The intervention group adopted the game-based physical training model developed in previous research (Andriansyah et al., 2025), whereas the control group followed a conventional training approach modified from Wubale et al., (2023). The training programs for both groups are presented below.

Table 1. Training program for research groups

Week	Intervention Group (Game-Based Physical Training)	Focus	Control Group (Conventional Training)
1-2	Volley Target Hunt; Jump and Catch	Coordination, motivation, basic smash, vertical jump	Basic technical drills, passing, setting, serving, basic footwork
3-4	Smash Zone Challenge; Jump Volley Race	Smash technique, accuracy, competitive motivation, lower-limb stability	Controlled smash drills, wall drills, partner drills, blocking practice
5-6	Obstacle Smash Game; Explosive Square Drill	Intensity, power, concentration, muscular endurance, explosiveness	Technique drills + simple repetition-based conditioning
7-8	Mini Volleyball Game; Smash Point Rally	Match simulation, technique application, accuracy, power, endurance	Conventional technical- tactical training and attack pattern repetition

Outcome measures



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The primary outcomes of this study were aerobic endurance and anaerobic endurance. Aerobic endurance was assessed using the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1), whereas anaerobic endurance was evaluated using the 10 × 20 m repeated sprint test with fatigue index. The selection of these tests was based on their suitability for volleyball, an intermittent sport requiring repeated high-intensity efforts interspersed with short recovery periods, as well as the ability to maintain performance during rallies and game transitions. Both YYIR1 and repeated sprint tests have previously been used in studies involving adolescent and collegiate volleyball athletes, demonstrating practical and methodological relevance for the present study (Siquier-Coll et al., 2024; Bilici & Topateş, 2025; Wei et al., 2025).

The Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) is a field test designed to assess an athlete's ability to perform repeated high-intensity exercise with short recovery intervals, making it highly appropriate for intermittent team sports such as volleyball. Participants performed repeated 2 × 20 m shuttle runs following audio signals, interspersed with 10 seconds of active recovery involving walking before the next repetition. Running speed increased progressively until the participant was unable to maintain the required pace. In volleyball studies, the standard YYIR1 protocol typically begins at 10 km·h⁻¹ and increases gradually, with termination occurring when players fail to reach the line twice consecutively. The main outcome recorded is the total distance covered (Kilic-Toprak et al., 2015; Trajković et al., 2020; Rubiyatno et al., 2023).

Repeated sprint ability (RSA) was used to measure the athlete's capacity to maintain maximal sprint performance across repeated efforts with short recovery intervals. Participants completed 10 maximal sprints over 20 meters with standardized recovery intervals between repetitions. The 10 × 20 m protocol is widely used to assess RSA in intermittent sports, and in the present study, performance was analyzed using Total Sprint Time (Hazir et al., 2019; Eryilmaz & Kaynak, 2019). The 20-meter distance is also relevant in volleyball, as it reflects short acceleration phases that are more representative of on-court movement demands than longer sprint distances (Bilici & Topateş, 2025).

Statistical Analysis



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Data were analyzed using IBM SPSS Statistics version 27 (George & Mallery, 2021). The primary analysis examined the effect of the intervention on two dependent variables, namely aerobic endurance (YYIR1 total distance) and anaerobic endurance (RSA total sprint time), using multivariate analysis of covariance (MANCOVA), with pretest scores entered as covariates. Effect size was reported using partial eta squared (η^2), and statistical significance was set at $p < 0.05$. Prior to the main analysis, the assumptions of normality and homogeneity were tested as prerequisites for conducting MANCOVA. Normality was assessed using the Shapiro-Wilk test for each variable across groups and sex categories. The results showed that all pretest and posttest variables had significance values greater than 0.05, indicating that the data were normally distributed (Bernadett & Csaba, 2024). Homogeneity assumptions were also examined before conducting the multivariate analysis to ensure the suitability of the data for subsequent parametric testing.

Results

This research data was collected through pretest and posttest, then continued by testing the influence between groups. Following confirmation of normality, homogeneity was tested using Levene's Test of Equality of Error Variances, which showed significance values greater than 0.05. Additionally, Box's Test of Equality of Covariance Matrices indicated Box's $M = 57.852$, $F = 5.897$, $Sig = 0.172$, suggesting that the data originated from homogeneous populations. After meeting these assumptions, the primary MANCOVA analysis was conducted (Table 2).

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Table 2. Results of the relationship between variables with the pretest as a covariate

Effect		F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	5.006 ^b	2.000	41.000	0.011	0.196
	Wilks' Lambda	5.006 ^b	2.000	41.000	0.011	0.196
Pretest_Aerobics	Pillai's Trace	3.843 ^b	2.000	41.000	0.030	0.158
	Wilks' Lambda	3.843 ^b	2.000	41.000	0.030	0.158
Pretest_Anaerobics	Pillai's Trace	31.564 ^b	2.000	41.000	0.000	0.606
	Wilks' Lambda	31.564 ^b	2.000	41.000	0.000	0.606
Group	Pillai's Trace	57.808 ^b	2.000	41.000	0.000	0.438
	Wilks' Lambda	57.808 ^b	2.000	41.000	0.000	0.438
Sex	Pillai's Trace	11.698 ^b	2.000	41.000	0.000	0.363
	Wilks' Lambda	11.698 ^b	2.000	41.000	0.000	0.363
Group*Sex	Pillai's Trace	5.707 ^b	2.000	41.000	0.007	0.218
	Wilks' Lambda	5.707 ^b	2.000	41.000	0.007	0.218

Based on Table 2, the multivariate analysis using Pillai's Trace indicated that after controlling for pretest aerobic and pretest anaerobic scores, there was a significant effect of group on the combined posttest scores of aerobic and anaerobic endurance, $F = 57.808$, $p < 0.001$, partial $\eta^2 = 0.438$. In addition, sex also showed a significant multivariate effect, $F = 11.698$, $p < 0.001$, partial $\eta^2 = 0.363$. The interaction between group and sex was also significant, $F = 5.707$, $p = 0.007$, partial $\eta^2 = 0.218$. These results indicate that the intervention's effectiveness on combined aerobic and anaerobic endurance outcomes differed by sex. Subsequently, follow-up univariate analyses were conducted, as presented in Table 3.

Table 3. Results based on Tests of Between-Subjects Effects

Source		df	Mean Square	F	Sig.	Partial Eta Squared
Pretest_Aerobics	Posttest_Aerobics	1	45381.380	7.745	0.008	0.156
	Posttest_Anaerobics	1	0.003	0.009	0.927	0.000
Pretest_Anaerobics	Posttest_Aerobics	1	3044.379	0.520	0.475	0.012
	Posttest_Anaerobics	1	19.646	64.334	0.000	0.605
Group	Posttest_Aerobics	1	254256.376	43.390	0.000	0.408
	Posttest_Anaerobics	1	28.201	92.352	0.000	0.487
	Posttest_Aerobics	1	137478.815	23.462	0.000	0.358
	Posttest_Anaerobics	1	0.002	0.006	0.938	0.000
Group*Sex	Posttest_Aerobics	1	62461.051	10.659	0.002	0.202
	Posttest_Anaerobics	1	0.070	0.229	0.635	0.005



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Based on Table 3, the follow-up univariate analysis showed that after controlling for pretest scores, there was a significant effect of group on posttest aerobic endurance, $F = 43.390$, $p < 0.001$, partial $\eta^2 = 0.408$, and on posttest anaerobic endurance, $F = 92.352$, $p < 0.001$, partial $\eta^2 = 0.487$. Sex had a significant effect on posttest aerobic endurance, $F = 23.462$, $p < 0.001$, partial $\eta^2 = 0.358$, but not on posttest anaerobic endurance, $F = 0.006$, $p = 0.938$. The interaction between group and sex was significant for posttest aerobic endurance, $F = 10.659$, $p = 0.002$, partial $\eta^2 = 0.202$, but not significant for posttest anaerobic endurance, $F = 0.229$, $p = 0.635$. These findings indicate that the intervention's effectiveness for aerobic endurance differed by sex, whereas its effect on anaerobic endurance was relatively consistent across males and females. The study then presents estimated mean values by group, as shown in Table 4.

Table 4. Results of mean differences by group in the study

Dependent Variable		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Posttest_Aerobics	Intervention Group	1265.348 ^a	16.029	1233.000	1297.696
	Control Group	1112.360 ^a	16.029	1080.012	1144.708
Posttest_Anaerobics	Intervention Group	41.809 ^a	0.116	41.575	42.042
	Control Group	43.420 ^a	0.116	43.187	43.654

Estimated marginal means (Table 4) showed that after controlling for pretest aerobic and anaerobic scores, the intervention group had higher posttest aerobic endurance compared to the control group (1265.35 m vs. 1112.36 m). This indicates that the game-based physical training program was more effective in improving aerobic endurance than conventional training.

For anaerobic endurance, the intervention group also demonstrated better performance compared to the control group (41.81 s vs. 43.42 s). Because anaerobic performance was expressed as total sprint time, lower values indicated better performance. Thus, the intervention group showed superior anaerobic endurance compared to the control group.



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Table 5. Results of mean differences based on group and gender

Dependent Variable			Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Posttest_Aerobics	Intervention Group	Male	2566.697 ^a	259.257	2043.496	3089.898
		Female	-36.001 ^a	260.549	-561.810	489.808
	Control Group	Male	2327.133 ^a	262.060	1798.275	2855.991
		Female	-102.413 ^a	260.376	-62.872	423.046
Posttest_Anaerobics	Intervention Group	Male	41.707 ^a	1.872	37.930	45.484
		Female	41.911 ^a	1.881	38.115	45.706
	Control Group	Male	43.227 ^a	1.892	39.409	47.045
		Female	43.613 ^a	1.880	39.820	47.407

Table 5 shows that for anaerobic endurance, the intervention group achieved lower posttest values than the control group for both males (41.71 s vs. 43.23 s) and females (41.91 s vs. 43.61 s). Since lower total sprint time reflects better repeated sprint performance, these findings confirm that game-based physical training was more effective than conventional training in improving anaerobic endurance, with consistent effects across sexes.

For aerobic endurance, the estimated marginal means indicated a pattern of differences between group and sex. However, the adjusted means for female participants were negative, which are not theoretically possible for YYIR1 distance scores. Therefore, these values should not be interpreted literally and suggest that interpretation of the aerobic interaction based on estimated marginal means should be conducted cautiously. Nevertheless, the univariate analysis still demonstrated a significant interaction between group and sex for posttest aerobic endurance, indicating differential responses to the intervention between males and females.

Discussion

The findings of this study indicate that game-based physical training was more effective than conventional training in improving aerobic and anaerobic endurance among volleyball players aged 15-18 years. The results also suggest that responses in the aerobic variable appeared to be influenced by sex, whereas the intervention effect on the anaerobic variable tended to be more consistent across males and females. These findings



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not only support the use of training approaches that are more contextualized to match demands but also highlight the importance of understanding training effects in youth athletes on a more individualized basis.

The improvement in aerobic endurance observed in the game-based training group can be explained by the nature of this approach, which places players in intermittent, repetitive, and game-specific movement situations. Consequently, the physiological stimulus is more closely aligned with the actual demands of volleyball competition. These findings are consistent with research involving adolescent female volleyball players, which demonstrated that high-intensity, game-based functional interventions improved physiological capacity and sport performance (Bilici & Topateş, 2025). Similarly, research involving adolescent male volleyball players reported improvements in physical performance following a 12-week game-based training program (Wubale et al., 2023). Broader support is provided by systematic reviews and meta-analyses in youth team-sport athletes, concluding that small-sided games and game-based formats are generally effective for improving aerobic fitness and intermittent high-intensity endurance (Li et al., 2023). However, recent findings also indicate that improvements in aerobic capacity do not necessarily imply that game-based approaches are universally superior to all other methods (Liu et al., 2026), as effectiveness depends heavily on task design, duration, frequency, and participant characteristics.

For anaerobic endurance, represented in this study by Total Sprint Time in the 10 × 20 m RSA test, the intervention group also demonstrated superior results compared with the control group. This outcome is plausible because game-based training requires repeated short accelerations, decelerations, directional changes, jumps, and rapid transitions, thereby simultaneously stressing anaerobic energy systems and recovery capacity between efforts. These findings are consistent with sprint interval training research in collegiate volleyball players that reported improvements in repeated sprint ability (Wei et al., 2025), as well as studies in rugby athletes demonstrating that repeated sprint training improves both aerobic and anaerobic capacity (Wang et al., 2025). A recent meta-analysis in youth team-sport athletes also found that small-sided game formats improve sprint acceleration and intermittent endurance (Liu et al., 2026). Nevertheless, these results do not indicate that game-based training is always superior to all other high-



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intensity training models, as studies in adolescent female volleyball players have shown that different active interventions may produce improvements without consistent differences across all variables (Bilici & Topateş, 2025).

The superiority of game-based training in this study may not only stem from physiological factors but also from greater athlete engagement during training. The training model used in this research was designed to integrate movement, small competitions, targets, and match simulations over an 8-week (24-session) period (Andriansyah et al., 2025), thereby creating a more meaningful training context beyond repetitive technical drills. This interpretation aligns with meta-analytic evidence indicating that game-based interventions in children and adolescents increase enjoyment (Mo et al., 2024), as well as systematic reviews showing that gamification and game-based approaches improve motivation, autonomy, learning climate, and engagement (Sal-de-Rellán et al., 2025). However, the literature also emphasizes that game-based approaches are not automatically superior for all outcomes; benefits may diminish if activity design is inadequate, affective-motivational components are neglected, or intervention duration is too short and insufficiently structured (Sal-de-Rellán et al., 2025). Thus, the positive results of this study are likely attributable not merely to the presence of games but to their systematic, progressive, and volleyball-specific design.

The finding that aerobic responses appeared to be influenced by sex should be interpreted cautiously. Biologically, previous studies have demonstrated that during adolescence, physical performance development differs between males and females, with gaps often widening during early-to-mid adolescence before stabilizing in older age groups (Lesinski et al., 2020; Albaladejo-Saura et al., 2022; Romero-García et al., 2023). Research in youth volleyball players has also reported sex differences across several physical fitness tests (Oliveira et al., 2025). Therefore, it is not surprising that aerobic responses to the intervention were not entirely uniform. Nevertheless, prior evidence also indicates that physical development in youth athletes is not always linear, and not all performance components improve in proportion to age, maturation, or sex differences (Tingelstad et al., 2025). Accordingly, the observed interaction effect in aerobic endurance should be interpreted as an indication of variability in responses by sex rather than as a basis for broad generalization without further validation in larger samples.



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Within the broader literature, these findings reinforce the idea that context-specific training approaches can be effective alternatives for youth athletes but should not necessarily be viewed as universally superior. Meta-analytic evidence in youth athletes suggests that high-intensity interval training (HIIT) does not always outperform sport-specific drills in improving aerobic or anaerobic endurance (Matzka et al., 2025). Similarly, systematic reviews in basketball indicate that small-sided games are at least comparable to non-game-based training for aerobic performance and change-of-direction ability, and may be superior for certain physical qualities (Zhang et al., 2025). Recent findings in youth athletes also suggest that both small-sided games and running-based HIIT can produce similar aerobic improvements, although small-sided games may provide additional benefits for sprint performance or coordination, along with lower perceived exertion (Panasc et al., 2026). Therefore, the present results should not be interpreted as evidence that conventional training is inferior, but rather that in the context of youth volleyball and the specific program design used, game-based physical training offers meaningful additional benefits for the outcomes examined. This interpretation strengthens the study by acknowledging that training effects depend on context, program design, and athlete characteristics.

The practical implications of this study suggest that coaches, teachers, and extracurricular volleyball instructors do not need to rely solely on monotonous conventional training to develop aerobic and anaerobic capacity. Structured game-based programs may serve as a more applicable alternative, allowing physical conditioning to develop while maintaining technical execution, decision-making, competition elements, and athlete engagement. In the 15-18-year age group, this approach has the potential to improve training quality while sustaining motivation, particularly when games are progressively structured and outcomes are monitored using simple instruments such as YYIR1 and RSA 10 × 20 m total sprint time. From an implementation perspective, the findings also suggest that coaches may consider individual adjustments for aerobic development, whereas anaerobic improvements appear to be more uniformly applicable across sexes.

Several limitations should be acknowledged. The sample size was relatively small and consisted of athletes from a homogeneous competition level, which limits



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generalization to broader athlete populations. The eight-week intervention duration was sufficient to capture early adaptations but insufficient to confirm long-term stability of training effects. Additionally, the study focused on two primary outcomes and did not examine other indicators such as internal and external load, match performance metrics, or detailed physiological markers. Future research should therefore replicate these findings using larger samples, longer intervention periods, and more comprehensive measurement approaches.

Conclusion

This study concludes that game-based physical training is more effective than conventional training in improving aerobic and anaerobic endurance among volleyball players aged 15-18 years. For aerobic endurance, improvements showed a tendency for sex-related differences, suggesting that aerobic training adaptations in youth athletes should be considered more individually. In contrast, for anaerobic endurance measured through RSA 10 × 20 m total sprint time, game-based physical training produced better results than conventional training, with relatively consistent effects across males and females. Therefore, game-based physical training can be recommended as an effective, contextual, and practical approach to support the development of physical capacity in adolescent volleyball players.

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