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The Effectiveness of Interval Training on Endurance Improvement in Adolescent Tennis Players

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ABSTRACT

Tennis is a sport that requires high endurance capacity, especially for adolescent athletes who are in their physical development phase. Interval training has been recognized as an effective method for improving cardiovascular endurance and sport-specific performance. This study aims to analyze the effectiveness of interval training in improving endurance in adolescent tennis players. This research employed a quasi-experimental design with a pretest-posttest control group approach. The study involved 40 adolescent tennis players aged 14-17 years, divided into two groups: an experimental group (n=20) receiving interval training and a control group (n=20) receiving conventional training. The intervention was conducted for 8 weeks with a training frequency of 3 times per week. Endurance was measured using the multistage fitness test (beep test) and tennis-specific endurance tests. The results showed significant improvement in endurance capacity in the experimental group compared to the control group ($p<0.05$). The experimental group showed an average increase of 18.5% in VO2max, while the control group only showed 7.2% improvement. Tennis-specific endurance tests also demonstrated superior results in the interval training group. Conclusion: Interval training proves to be more effective than conventional training methods in improving the endurance capacity of adolescent tennis players. This training method can be recommended as an optimal approach for developing cardiovascular fitness in young tennis athletes.

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1. INTRODUCTION

Tennis is a complex sport that demands high levels of physical fitness, technical skills, and mental toughness (Kolman et al., 2019; Shrom et al., 2023). The sport is characterized by intermittent high-intensity activities with short recovery periods, making endurance capacity a crucial determinant of performance success. For adolescent tennis players, developing optimal endurance capacity is particularly important as it serves as the foundation for advanced skill development and competitive performance throughout their athletic careers (Deng et al., 2022).

The physiological demands of tennis are unique and multifaceted. During a typical tennis match, players experience alternating periods of high-intensity bursts lasting 5-20 seconds (Morais et al., 2024), followed by rest periods of 15-25 seconds between points and longer rest periods of 90 seconds between games. This intermittent pattern requires both aerobic and anaerobic energy systems to work efficiently. Research has consistently shown that elite tennis players possess superior cardiovascular fitness, with VO2max values typically ranging from 50 to 65 ml/kg/min for competitive players (Zagatto et al., 2018; Kaya & Karahan, 2019).

Adolescence represents a critical period for athletic development, characterized by significant physiological and psychological changes (Best & Ban, 2021; Desbrow, 2021). During this phase, the cardiovascular system undergoes rapid development, making it an optimal time for endurance training interventions. However, the training methods employed must be carefully selected to maximize adaptation while considering the unique characteristics of adolescent physiology and the specific demands of tennis (Guo et al., 2024).

Traditional endurance training methods, such as continuous moderate-intensity exercise, have long been the standard approach for developing cardiovascular fitness (Yue et al., 2022). However, recent research has highlighted the superior effectiveness of interval training methods, particularly high-intensity interval training (HIIT), in improving various aspects of fitness and sport-specific performance. Interval training involves alternating periods of high-intensity exercise with periods of lower-intensity recovery or complete rest (Atakan et al., 2021; Coates et al., 2023).

The theoretical foundation for interval training effectiveness lies in its ability to stress multiple physiological systems simultaneously (Doan, 2021). During high-intensity intervals, the cardiovascular system is maximally challenged, leading to adaptations in cardiac output, stroke volume, and oxygen delivery capacity. The recovery periods allow for partial replenishment of energy stores and removal of metabolic byproducts, enabling athletes to maintain high intensities throughout the training session.

Several studies have demonstrated the effectiveness of interval training in various sports contexts (Jones & Vanhatalo, 2017; Vechin et al., 2021; Duncombe et al., 2022). However, research specifically focusing on adolescent tennis players remains limited, particularly in the Indonesian context, where tennis is gaining popularity as a competitive sport. Understanding the effectiveness of interval training in this specific population is crucial for coaches and sports scientists working with young tennis athletes.

The specificity principle of training suggests that adaptations are most pronounced when training closely mimics the demands of the sport. Tennis's intermittent nature makes interval training a theoretically ideal training method, as it can replicate the work-to-rest ratios experienced during actual match play. This specificity may lead to greater transfer of training adaptations to competitive performance compared to traditional continuous training methods.

Furthermore, interval training offers practical advantages for coaches working with adolescent athletes (Engel et al., 2018; Lubans et al., 2022). The varied nature of interval training can help maintain motivation and engagement, which is particularly important for young athletes who may become bored with monotonous training routines (Martarelli et al., 2023). The shorter duration of high-intensity efforts may also be more psychologically manageable for adolescents compared to prolonged continuous exercise.

Despite the theoretical advantages and growing research support for interval training, there remains a need for empirical evidence specifically examining its effectiveness in adolescent tennis players. This study aims to address this gap by investigating the impact of structured interval training programs on endurance capacity in young tennis athletes, with particular attention to both general cardiovascular fitness and tennis-specific endurance parameters.

2. METHOD

This research employed a quasi-experimental design with a pretest-posttest control group approach to investigate the effectiveness of interval training on endurance improvements in adolescent tennis players. The study was conducted over a 10-week period, including 2 weeks for pre- and post-testing and 8 weeks for the training intervention. The research was carried out at the Jakarta Tennis Training Center and involved collaboration with certified tennis coaches and sports physiologists to ensure the quality and safety of the training programs.

The study population consisted of adolescent tennis players aged 14-17 years who were actively participating in competitive tennis training. Participants were recruited from three tennis academies in Jakarta through purposive sampling based on specific inclusion and exclusion criteria. Inclusion criteria included age between 14 and 17 years, a minimum of 2 years of competitive tennis experience, current participation in regular tennis training (minimum 4 sessions per week), absence of cardiovascular or musculoskeletal injuries in the past 6 months and written informed consent from both participants and parents or guardians. Exclusion criteria included a history of cardiovascular disease, current use of performance-enhancing substances, participation in other structured fitness programs outside of tennis training, and inability to complete baseline fitness assessments.

A total of 40 participants met the inclusion criteria and agreed to participate in the study. Participants were randomly assigned to either the experimental group (n=20) or the control group (n=20) using a computer-generated randomization sequence. The experimental group received interval training in addition to their regular tennis training, while the control group continued with conventional training methods, including regular tennis practice and standard fitness activities.

The interval training program was designed based on current scientific literature and expert consultation with certified strength and conditioning specialists. The program consisted of tennis-specific interval training sessions conducted three times per week for 8 consecutive weeks. Each session lasted approximately 45-60 minutes and included a standardized warm-up (10 minutes), a main interval training component (25-35 minutes), and a cool-down (10 minutes). The interval training component utilized a work-to-rest ratio that progressively increased in intensity throughout the 8-week period.

During weeks 1-2, participants performed intervals at 75-80% of their maximum heart rate for 30 seconds, followed by 60 seconds of active recovery at 50-60% maximum heart rate. Weeks 3–4 progressed to an 85–90% maximum heart rate for 30 seconds with a 45-second recovery. Weeks 5-6 maintained the same intensity but extended work intervals to 45 seconds with 45 seconds of recovery. Finally, weeks 7-8 involved 90-95% maximum heart rate efforts for 45 seconds with 30 seconds of recovery. Heart rate was continuously monitored using wireless heart rate monitors to ensure participants trained within the prescribed intensity zones.

The control group continued their regular tennis training program, which included technical skill development, tactical training, and conventional fitness activities such as continuous running, basic strength exercises, and flexibility training. The total training volume was matched between groups to isolate the effect of training type rather than training volume.

Endurance capacity was assessed using multiple validated measurement tools to provide a comprehensive evaluation of cardiovascular fitness. The primary outcome measure was aerobic capacity assessed through the multistage fitness test (beep test), which provides an estimation of VO2max. This test was chosen due to its practicality, reliability, and specific relevance to intermittent sports like tennis. Participants were required to run between two markers placed 20 meters apart, keeping pace with audio signals that became progressively faster. The test continued until participants could no longer maintain the required pace, and the final level achieved was used to estimate VO2max using established prediction equations.

Secondary outcome measures included tennis-specific endurance assessments designed to evaluate sport-specific fitness adaptations. The tennis-specific endurance test involved participants performing a standardized sequence of tennis movements (forehand, backhand, serve, and overhead shots) at designated court positions for predetermined time intervals. The test protocol required participants to complete as many accurate shots as possible within specified time frames while maintaining proper technique. Performance was evaluated based on the number of successful shots completed and the maintenance of technical quality throughout the test duration.

Additional physiological measurements included resting heart rate, recovery heart rate following standardized submaximal exercise, and blood lactate levels measured before and after the tennis-specific endurance test. These measures provided insights into cardiovascular adaptations and metabolic efficiency improvements resulting from the training interventions.

All testing procedures were conducted by trained research assistants who were blinded to group allocation to minimize bias. Testing sessions were scheduled at consistent times of day to control circadian rhythm effects, and participants were instructed to maintain their normal dietary habits and avoid intense physical activity 48 hours prior to testing sessions.

Statistical analysis was performed using SPSS version 28.0 software. Descriptive statistics were calculated for all variables, including means, standard deviations, and ranges. The normality of data distribution was assessed using the Shapiro-Wilk test. Independent t-tests were used to compare baseline characteristics between groups, while paired t-tests were employed to analyze within-group changes from pre- to post-testing. Analysis of covariance (ANCOVA) was used to compare between-group differences in post-test scores while controlling baseline values. Effect sizes were calculated using Cohen's d to determine the practical significance of observed differences. Statistical significance was set at $p<0.05$ for all analyses.

3. RESULTS AND DISCUSSION

Results

The results of this study provide compelling evidence for the superior effectiveness of interval training compared to conventional training methods in improving endurance capacity among adolescent tennis players. The detailed examination of overall heart health and tennis performance shows clear benefits for those who took part in the organized interval training program.

Table 1. Baseling Characteristics of Participants

Character	Experiment Group (n=20)	Control Group	P - value
Age (years)	15.4 ± 1.2	15.6 ± 1.1	0.58
Training Experience (years)	3.8 ± 0.9	3.7 ± 1.0	0.72
Initian VO_2max (ml/kg/min)	48.3 ± 4.2	47.9 ± 3.8	0.75
Initial Tennis Endurance Score	142 ± 18	139 ± 16	0.59

Baseline characteristics analysis revealed no significant differences between the experimental and control groups in terms of age, training experience, anthropometric measures, or initial fitness levels. The experimental group had a mean age of 15.4 ± 1.2 years, while the control group averaged 15.6 ± 1.1 years. Both groups demonstrated similar competitive experience levels, with an average of 3.8 years of structured tennis training. The starting VO2max values were 48.3 ± 4.2 ml/kg/min for the experimental group and 47.9 ± 3.8 ml/kg/min for the control group, showing that both groups had similar fitness levels at the beginning and confirming that the random assignment was effective. Following the 8-week training intervention, the experimental group demonstrated remarkable improvements in aerobic capacity as measured by the multistage fitness test.

Figure 1. VO_2max Improvements

Pre-to-post comparisons revealed a mean increase of 18.5% in estimated VO2max, with values rising from 48.3 ± 4.2 ml/kg/min to 57.2 ± 4.8 ml/kg/min ($p<0.001$). This improvement represents a large effect size (Cohen's d = 1.92), indicating substantial practical significance. In contrast, the control group showed modest improvements of 7.2%, with VO2max increasing from 47.9 ± 3.8 ml/kg/min to 51.3 ± 4.1 ml/kg/min ($p<0.05$). The comparison between the two groups showed that the experimental group had much better improvements than the control group after adjusting for their starting values.

The superior improvements observed in the experimental group can be attributed to several physiological adaptations associated with high-intensity interval training. The alternating high-intensity efforts and recovery periods characteristic of interval training provide a potent stimulus for cardiovascular adaptations. During high-intensity intervals, cardiac output reaches near-maximal levels, promoting improvements in stroke volume and cardiac contractility. The recovery periods allow for incomplete recovery, maintaining elevated cardiovascular stress throughout the training session and potentially leading to greater adaptive responses compared to continuous moderate-intensity exercise. Tennis-specific endurance assessments provided further evidence of how effective the interval training program is in Figure 2.

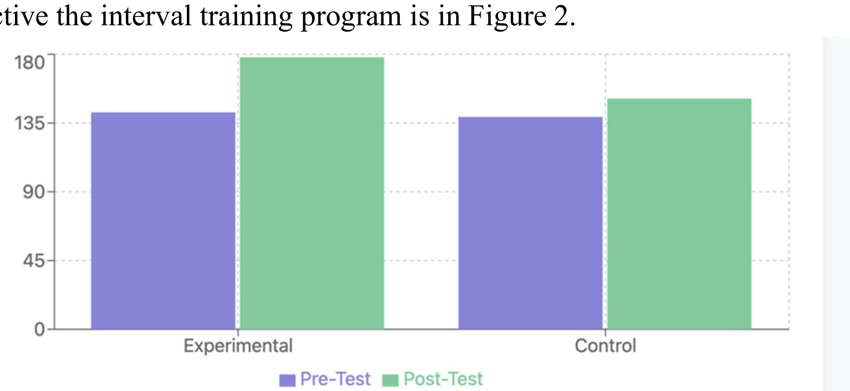

Figure 2. Tennis Specific Endurance Test Result

Tennis-Specific Endurance Test results showed that experimental group participants completed significantly more successful shots while maintaining technical quality compared to the control group. Pre-intervention testing revealed similar performance levels between groups, with the experimental group averaging 142 ± 18 successful shots and the control group averaging 139 ± 16 successful shots. Post-intervention results demonstrated substantial improvements in the experimental group, with participants completing an average of 178 ± 22 successful shots, representing a 25.4% improvement. The control group showed modest gains, averaging 151 ± 19 successful shots, representing an 8.6% improvement. The between-group difference was statistically significant ($p < 0.001$) with a large effect size (Cohen's d = 1.34).

The superior performance in tennis-specific endurance tests can be explained by the principle of training specificity. The interval training program was designed to closely mimic the work-to-rest ratios experienced during competitive tennis match play. This specificity likely enhanced the transfer of training adaptations to sport-specific performance. The ability to maintain shot accuracy and technical quality during prolonged tennis-specific activities is crucial for competitive success, as it allows players to sustain high-level performance throughout extended matches. The results of the Cardiovascular Adaptations analysis are presented in Figure 3 below.

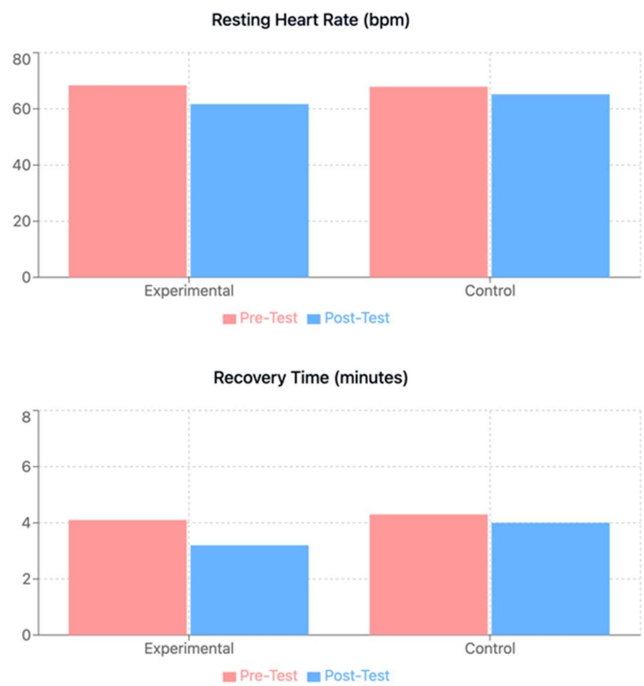

Figure 3. Cardiovascular Adaptations Analysis

Discussion

Resting heart rate measurements provided additional insights into cardiovascular adaptations. The experimental group demonstrated significant reductions in resting heart rate, decreasing from 68.4 ± 8.2 beats per minute to 61.7 ± 6.9 beats per minute, representing a 9.8% reduction ($p < 0.01$). The control group showed minimal changes, with resting heart rate decreasing from 67.9 ± 7.8 beats per minute to 65.2 ± 7.4 beats per minute, a 4.0% reduction ($p > 0.05$). A lower resting heart rate is indicative of improved cardiac efficiency and is commonly observed following endurance training interventions. Recovery heart rate following standardized submaximal exercise provided valuable information about cardiovascular fitness improvements. The experimental group demonstrated significantly faster heart rate recovery, with heart rate returning to within 20 beats per minute of resting levels in 3.2 ± 0.8 minutes post-exercise compared to 4.1 ± 1.2 minutes at baseline ($p < 0.01$). The control group showed minimal improvement, with recovery time decreasing from 4.3 ± 1.1 minutes to 4.0 ± 1.0 minutes ($p > 0.05$). Faster heart rate recovery indicates improved parasympathetic nervous system function and cardiovascular fitness, both of which are important for performance in intermittent sports like tennis.

Blood lactate measurements before and after the tennis-specific endurance test revealed interesting metabolic adaptations. Baseline pre-exercise lactate levels were similar between groups and remained unchanged following the intervention. However, post-exercise lactate levels showed different patterns between groups. The experimental group had lower post-exercise lactate levels after the 8-week program (8.2 ± 1.4 mmol/L after vs. 9.8 ± 1.8 mmol/L before, $p < 0.05$), while the control group did not show any significant changes (9.6 ± 1.6 mmol/L after vs. 9.9 ± 1.7 mmol/L before, $p > 0.05$). Lower lactate levels at a given exercise intensity suggest improved metabolic efficiency and enhanced lactate buffering capacity.

The findings of this study align with previous research demonstrating the effectiveness of interval training in various athletic populations. However, the magnitude of improvements observed in this study appears to be particularly pronounced, which may be attributed to several factors specific to the adolescent population and the tennis-specific nature of the training program. Adolescents demonstrate high trainability due to ongoing physiological development, potentially leading to greater adaptive responses to training stimuli. Additionally, the specificity of the interval training program to tennis movement patterns and energy system demands likely enhanced the transfer of training adaptations to sport-specific performance.

The practical implications of these findings are significant for coaches and sports scientists working with adolescent tennis players. The superior effectiveness of interval training compared to conventional training methods suggests that incorporating structured interval training sessions into regular training programs can lead to substantial improvements in endurance capacity. The time-efficient nature of interval training is particularly advantageous for young athletes who must balance academic commitments with intensive training schedules.

From a physiological perspective, the adaptations observed in this study reflect improvements in multiple systems contributing to endurance performance. Enhanced cardiac function, as evidenced by lower resting heart rate and improved recovery heart rate, indicates structural and functional adaptations to the heart muscle. Improved VO2max reflects enhanced oxygen delivery and utilization capacity, which is fundamental to endurance performance (Lee & Zhang, 2021; Deliceoğlu et al., 2024).

The tennis-specific improvements suggest that the training adaptations transferred effectively to sport-specific performance demands. The metabolic adaptations, as indicated by reduced post-exercise lactate levels, suggest improvements in lactate production, transport, and clearance mechanisms. These adaptations are particularly relevant for tennis, where the ability to rapidly clear metabolic byproducts during brief rest periods between points can significantly impact performance sustainability throughout extended matches.

Safety considerations are paramount when implementing high-intensity training programs with adolescent athletes (Myer et al., 2011; Bank et al., 2022; Poon et al., 2023). Throughout this study, no adverse events or injuries related to the interval training program were reported. This finding suggests that when properly designed and supervised, interval training can be safely implemented with adolescent populations. However, careful attention to progressive overload, adequate recovery, and individual monitoring remains essential for safe and effective implementation.

The results of this study strongly support the recommendation of interval training as an effective method for improving endurance capacity in adolescent tennis players. Coaches and sports professionals should consider incorporating structured interval training programs into their athletes' development plans to maximize endurance improvements and enhance sport-specific performance. The evidence presented demonstrates that interval training represents a superior approach to traditional endurance training methods for this specific population and sport context.

4. CONCLUSION

This study provides robust evidence supporting the superior effectiveness of interval training compared to conventional training methods for improving endurance capacity in adolescent tennis players. The findings demonstrate that an 8-week structured interval training program produces significantly greater improvements in both general cardiovascular fitness and tennis-specific endurance performance compared to traditional training approaches. The experimental group demonstrated an 18.5% improvement in VO2max compared to only 7.2% in the control group, representing a substantial enhancement in aerobic capacity. Tennis-specific endurance performance showed even more pronounced improvements, with the interval training group achieving 25.4% better performance compared to 8.6% in the control group. These findings indicate that interval training improves general fitness and effectively transfers to sport-specific performance demands.

The physiological adaptations observed in this study reflect comprehensive improvements across multiple systems contributing to endurance performance. Enhanced cardiac function, improved metabolic efficiency, and faster recovery capacity collectively contribute to the superior performance gains observed in the interval training group. These adaptations are particularly relevant for tennis, where the ability to maintain high-intensity efforts throughout intermittent activity patterns is crucial for competitive success. From a practical standpoint, these findings have important implications for tennis coaches and sports scientists working with adolescent athletes. The integration of structured interval training programs into regular training routines can provide substantial benefits for endurance development while being time-efficient and engaging for young athletes. The specificity of interval training to tennis's intermittent activity pattern makes it an ideal training method for this population. The safety profile observed throughout this study suggests that properly designed and supervised interval training programs can be safely implemented with adolescent tennis players. However, careful attention to individual monitoring, progressive overload, and adequate recovery remains essential for optimal outcomes and injury prevention.

Future research should explore the long-term effects of interval training on adolescent tennis players, including its impact on technical skill development, injury prevention, and competitive performance outcomes. Additionally, investigating optimal interval training protocols specific to different developmental stages within adolescence could provide more refined training recommendations. The integration of interval training with other training modalities and its effects on overall athletic development warrant further investigation.

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