PEDAGOGICAL ACADEMY:
SCIENTIFIC NOTES

PHYSICAL EDUCATION AND SPORTS

UDC 796.342:796.015.5

DOI https://doi.org/10.5281/zenodo.17189026

# Effectiveness of high-intensity interval training in increasing endurance in singles tennis

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**Accepted: 11.09.2025 | Published: 24.09.2025**

***Abstract.*** *The* ***purpose of this article*** *is to evaluate the effectiveness of high-intensity interval training in developing endurance and maintaining the playing capacity of tennis players, as well as to develop scientifically grounded recommendations for its application in the training process.* ***Methods****. The study used a systematic analysis to investigate the physiological mechanisms of high-intensity interval training on the bodies of athletes and to evaluate its effectiveness based on available experimental data. Methods of generalization and comparative analysis were applied to identify the most effective high-intensity interval training protocols, as well as to compare the results of using different approaches (HIIT, RST, IIT) in the training of tennis players and athletes in related sports. The synthesis method was employed to formulate practical recommendations for integrating high-intensity interval training.* ***Results****. It was determined that high-intensity interval training is a universal and effective tool for developing both aerobic and anaerobic endurance. The analysis of studies has shown that high-intensity interval training significantly increases* $VO_2$*peak and general endurance.*

*Combining it with other methods, such as RST and IIT, allows for targeted improvement of qualities specific to tennis, including recovery speed and repeated sprint ability. It was concluded that the effectiveness of training depends on an integrated approach that considers the athlete's age, skill level, and individual characteristics.* ***Conclusions.*** *It is emphasized in the conclusions that high-intensity interval training is a fundamental component of modern physical training in tennis. Its value lies not only in its physiological impact but also in its ability to simulate game loads, which allows for an optimal combination of developing physical qualities with maintaining technical and tactical mastery. It makes it a key tool for coaches who seek to use training time as effectively as possible, as well as a holistic strategy for achieving the highest athletic results.*

***Keywords:*** *sports training, physical performance, endurance, training process, physiological mechanisms, RST, IIT.*

## Ефективність інтервальних тренувань високої інтенсивності у підвищенні витривалості в одиночному тенісі

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***Анотація. Метою*** *статті є оцінка ефективності застосування високоінтенсивних інтервальних тренувань у розвитку витривалості та підтриманні ігрової працездатності тенісистів, а також розробка науково обґрунтованих рекомендацій для їх застосування у тренувальному процесі.* ***Методи****. У роботі використано системний аналіз для дослідження фізіологічних механізмів впливу високоінтенсивних інтервальних тренувань на*

*організм спортсменів та оцінки його ефективності на основі наявних експериментальних даних. Методи узагальнення та порівняльного аналізу застосовано для виявлення найбільш ефективних протоколів високоінтенсивних інтервальних тренувань, а також для зіставлення результатів застосування різних підходів (HIIT, RST, IIT) у тренуванні тенісистів та спортсменів в інших видах спорту. Метод синтезу використано для формування практичних рекомендацій щодо інтеграції високоінтенсивних інтервальних тренувань. У* ***результатах*** *визначено, що високоінтенсивні інтервальні тренування є універсальним та ефективним інструментом для розвитку як аеробної, так і анаеробної витривалості. Аналіз досліджень показав, що високоінтенсивні інтервальні тренування значно підвищують показники $VO_2peak$ та загальну витривалість, тоді як поєднання з іншими методами, такими як RST та IIT, дозволяє цілеспрямовано покращувати специфічні для тенісу якості, зокрема швидкість відновлення та повторювану спринтерську здатність. Зроблено висновок, що ефективність тренувань залежить від інтегрованого підходу, який враховує вік, рівень підготовленості та індивідуальні особливості спортсмена. У* ***висновках*** *наголошено, що високоінтенсивні інтервальні тренування є фундаментальним компонентом сучасної фізичної підготовки в тенісі. Його цінність полягає не лише у фізіологічному впливі, але й у здатності моделювати ігрові навантаження, що дозволяє оптимально поєднати розвиток фізичних якостей із підтриманням техніко-тактичної майстерності. Це робить його цілісною стратегією для досягнення найвищих спортивних результатів, а також ключовим інструментом для тренерів, які прагнуть максимально ефективно використовувати тренувальний час.*

***Ключові слова****: спортивна підготовка, фізична працездатність, витривалість, тренувальний процес, фізіологічні механізми, RST, IIT.*

**Problem statement.** Modern singles tennis is one of the most physically demanding sports, characterized by short-term explosive movements, high-speed movements, multiple repetitive sprints and short rest periods. The effectiveness of a player during a long match largely depends on the level of his specific endurance, which allows him to maintain a high intensity of game actions and quickly recover between rallies. Despite the prominent role of endurance, traditional approaches to its development, based on long-term loads of low and moderate intensity, do not always fully correspond to the intermittent nature of a tennis match. High-intensity interval training (HIIT) has gained popularity as an effective method for developing both aerobic and anaerobic endurance in various sports. However, despite the significant amount of research on HIIT, the issue of its targeted application and objective effectiveness in the context of tennis player training remains insufficiently studied. There are no unified, scientifically based protocols for implementing such training within the training process, which complicates its practical application for coaches and athletes. Thus, there is a scientific and practical need to analyze and summarize the existing research on the use of HIIT in tennis, to identify its advantages and limitations, and to develop specific recommendations.

**Analysis of recent research and publications.** Modern studies confirm that in tennis, a combination of aerobic and anaerobic energy supply mechanisms plays a crucial role, as matches involve both short, explosive movements and prolonged exertion. In conditions of long matches, which are accompanied by repeated intense actions, the development of endurance, the ability to quickly recover, and maintaining a stable level of playing performance become especially important. In this context, HIIT is gaining increasing attention, which enables a comprehensive impact on the body's physiological systems. A systematic review by D. Durmuş, H. Ödemiş and M. Söğüt [1] shows that the use of HIIT in tennis effectively develops both aerobic and anaerobic endurance.

Ukrainian authors also emphasize that the combination of explosive actions with effective recovery determines the performance of tennis players.

N. V. Kichenok [2] emphasizes the need to form a strong physiological base that provides resistance to fatigue, while A. V. Yefremenko, S. S. Pyatisotska, V. M. Pavlenko, T. V. Shutieieva, Ya. B. Kraynik and O. Yu. Nasonkina [3] proved the positive effect of special physical training with elements of athletics on the development of young athletes. Research by W. Yang, L. Yin, E. T.-C. Poon, I. M. K. Ho, H. Liu, B. Qi, Q. Li, Y. Li [4] deepens this direction, emphasizing the importance of speed endurance, without which it is impossible to perform multiple accelerations and changes of direction, characteristic of a tennis match. At the same time, the benefits of HIIT are confirmed in sports with different dynamics. Thus, M. Stankovic, D. Djordjevic, N. Trajkovic and Z. Milanovic [5] showed its effectiveness in women's team sports. A meta-analysis by H.-P. Wiesinger, W. G. Hopkins, N. Haller, J. Blumkaitis, T. Strepp, and T. L. Stöggl [6] found significant improvements in endurance and functional readiness indicators in elite athletes. These findings are consistent with the results of Ukrainian researchers G. Lisenchuk, I. Khmelnytska, K. Bogatyrev, B. Kokarev, S. Kokareva, V. Derkach, I. Martsinkovsky, S. Krupenya and M. Cieślicka [7], who showed that the integration of HIIT with modern fitness technologies significantly increases the fitness of highly qualified football players. Similar effects have been recorded in basketball (S. Cao, Z. Li, Z. Wang, S. K. Geok and J. Liu [8]), swimming (S. Amara, R. Hammami, R. Zacca, J. Mota, Y. Negra and S. Gaied Chortane [9]) and wrestling (S. Kolimechkov, R. Makaveev, D. Zaykova and L. Petrov [10]), which allows us to consider HIIT as a universal means of developing exceptional endurance.

However, the most valuable studies are those devoted to the training process in tennis. Thus, J. Fernandez-Fernandez, R. Zimek, T. Wiewelhove and A. Ferrauti [11] found that HIIT more effectively develops $VO_2$peak and general endurance. At the same time, repeated sprint training (RST) contribute to the development of explosive power to a greater extent. Further work, in particular, by J. Morais, B. Kilit, E. Arslan, J. Bragada, Y. Soylu, D. Marinho [12], confirmed that the combination of HIIT and RST increases the general physical fitness of young tennis

players. Still, it is RST that provides higher indicators of speed and agility. At the same time, a study by V. Pialoux, C. Genevois, A. Capoen, S. C. Forbes, J. Thomas and I. Rogowski [13] demonstrated that a game format («playing HIIT») creates a higher level of physiological load, but is accompanied by a decrease in the accuracy of hits. Interesting results were obtained by R. E. Reigal, S. Barrero, J. P. Morillo-Baro, V. Morales-Sánchez, R. Juárez-Ruiz de Mier and A. Hernández-Mendo [14], who combined HIIT with cognitive load and showed that under such conditions the accuracy of serves is maintained, although the speed is reduced. Finally, D. Suárez Rodríguez, M. Del Valle Soto [15] found that HIIT provides a higher number of hits and a higher intensity, while intermittent interval training (IIT) better maintains technical stability.

Thus, the generalization of modern research allows us to conclude that HIIT is an effective means of developing both physiological and playing qualities of tennis players; however, no protocol can be considered universal. The most effective strategy is to combine HIIT with RST, IIT, or game formats, taking into account the age of the athletes, their level of fitness, and the specific tasks of the training process.

**Identification of previously unresolved parts of the overall problem**. Analysis of scientific sources on the modern practice of training tennis players allows us to highlight some incompletely resolved parts of the general problem:

1. Fragmentation and inconsistency of data: Existing studies, although confirming the effectiveness of HIIT, often have a narrow focus (specific protocols, populations) or demonstrate contradictory results regarding the impact on specific tennis endurance. It creates a need for a systematic review of practical cases to generalize and identify patterns.

2. Lack of standardized protocols: Scientifically based methods and programs for implementing HIIT in micro- and macrocycles of training of tennis players of different skill levels have not been developed and are not unified.

3. The impact on playing performance has been poorly studied; in particular, it has not been sufficiently studied how exactly the integration of HIIT training

affects its specific indicators, such as the speed of recovery between rallies, the accuracy of blows and tactical efficiency in conditions of fatigue.

**Formulation of the article's goals (task setting).** The purpose of the article is to conduct a comprehensive assessment of the effectiveness of HIIT as a means of increasing the endurance and playing performance of tennis players, as well as to develop scientifically based recommendations for their use in the training process.

To achieve the set goal, the following tasks were defined:

1. To determine the physiological mechanisms of the influence of HIIT on the development of endurance in playing sports.

2. To identify and summarize the most effective HIIT protocols used in the training of tennis players and athletes in related sports.

3. To assess the impact of HIIT training on specific indicators of tennis players' performance (recovery speed, accuracy, technical and tactical actions).

4. To formulate practical recommendations for integrating HIIT training into the training process of tennis players of different skill levels.

**Research results.** Energy supply in singles tennis has a complex, combined nature, combining both aerobic and anaerobic processes. During the match, players perform multiple explosive accelerations, changes in direction of movement and high-speed strikes, the duration of which is usually 3–15 seconds. These actions are provided mainly by the anaerobic system, in particular the creatine phosphate mechanism. However, the total duration of the match, which can reach several hours, as well as frequent, albeit short, pauses between rallies, requires a high level of aerobic performance. It is the aerobic system that is responsible for adequate recovery after high-intensity efforts, maintaining playing efficiency and preventing the accumulation of fatigue. Thus, to achieve success in modern tennis, an athlete must have both systems well developed, and the training process must be aimed at their comprehensive development. The physiological requirements of tennis are determined by the interval nature of work and constant changes in the intensity of the load. The average length of a game is 8 seconds, with a 20-second rest between

each game. It requires players to perform explosive movements repeatedly and recover quickly. However, traditional approaches to endurance training do not fully capture the interval and alternating nature of tennis training.

It is where HIIT training comes in. Unlike continuous training, HIIT mimics the specific physical demands of a tennis match: short bursts of effort interspersed with periods of partial rest. A systematic review of the scientific literature on the use of HIIT in tennis has shown that it is effective in developing both aerobic and anaerobic endurance [1, p. 48]. Studies have shown that players who incorporate HIIT into their training program demonstrate significant improvements in aerobic capacity, which is a key factor in maintaining high performance throughout the match.

HIIT is now considered a universal method for developing endurance and performance not only in tennis, but also in many other sports [5], which indicates the versatility of this method. In particular, in football, the use of HIIT in combination with innovative fitness technologies (TRX, Tabata, Strenflex, etc.) has contributed to a significant increase in the physical fitness of players and high-level team achievements [7, p. 30-35]. In basketball, six-week sprint HIIT exercises have demonstrated an improvement in specific endurance and the ability to perform multiple sprints in young female athletes [5]. In swimming, the combination of HIIT with strength training in the gym has proven its effectiveness in increasing muscle strength, technique and results in the 100-meter butterfly [9, p. 85]. In wrestling, the HIIT Tabata protocol with kettlebells significantly improved the endurance of freestyle wrestlers, confirming the versatility of the method for power disciplines as well [10, p. 467-468].

It is worth emphasizing that endurance is one of the key physical qualities that determines the level of a tennis player's playing efficiency and their ability to perform work without changing the intensity indicators, accuracy of movements, etc. [4, p. 225-228]. Its role is not limited to long matches; it also provides the ability to quickly recover between rallies, sets, and throughout the tournament. It helps to

maintain a high level of technical and tactical actions even in conditions of cumulative fatigue. It is essential in modern tennis, where the intensity of playing actions and the number of competitions are increasing. For example, according to domestic researchers [3, p. 7], physical training aimed at developing endurance significantly affects the competitive activity of young tennis players.

In addition, an essential component is speed endurance, which allows you to repeatedly perform short accelerations and sharp changes in direction of movement, which are an integral part of singles tennis [4, p. 224]. Thus, endurance in tennis is a complex quality that combines both a general aerobic base and game-specific components. Therefore, incorporating HIIT into the training process requires careful planning and adaptation to the specific needs of tennis. It is generally accepted that the effectiveness of HIIT training depends on several factors, including the intensity and duration of intervals, as well as the length and nature of recovery periods. For tennis players, HIIT training often includes court-specific exercises, such as sprints to the T-line, movements from one corner to another, or a series of quick shots that simulate game situations [1, p. 47]. It helps not only to increase aerobic and anaerobic endurance, but also to develop speed-strength qualities necessary for robust and accurate blows. This approach significantly improves speed performance and repetitive sprinting ability, which is critically important for successful competitive activity. In modern tennis, HIIT is implemented in various forms, depending on the age of the athletes, their level of fitness, and training goals. The use of interval protocols can include both classic endurance models and repetitive sprints, game formats with a racket and ball, as well as combinations with cognitive tasks or alternating intense and moderate intervals. Each of these approaches is aimed at developing individual components of fitness, including aerobic endurance, speed, strength, agility, or technical stability (Table 1).

**Table 1**

*Characteristics of different forms of HIIT training process in tennis players*

| Training format | Players | Protocol | Main indicators | Result |
|---|---|---|---|---|
| HIIT vs. RST | Competitive tennis players | Comparison of HIIT (intervals of 15–30 s, high intensity) and RST (short repeated sprints) | $VO_2$peak, speed, endurance | Both forms increased aerobic capacity, HIIT developed endurance more, and RST – speed qualities |
| On-Court HIIT vs. RST | Young tennis players (13–14 years old) | 8 weeks, 2–3 training sessions/week; comparison of HIIT on the court and RST | $VO_2$peak, speed, agility, jumping ability, internal load | Both methods improved aerobic capacity; HIIT improved endurance, RST improved speed and agility |
| Game-based HIIT vs. Nonplaying Aerobic Training | Young tennis players (~13 years old) | *G*ame-based HIIT (using a racket and ball) vs. traditional running training | $VO_2$peak, recovery rate, and accuracy of strokes | HIIT improved physiological parameters, but the accuracy of strokes decreased; nonplaying training preserved technique better |
| Combined HIIT + Stroop | Recreational tennis players (~21 years old) | Combining HIIT with the cognitive Stroop test | Strength, speed and accuracy of serves | Improvement of strength and speed, accuracy of serves remained, but pace decreased slightly |
| HIIT vs. IIT | Young tennis players | Comparison of two types of interval training: HIIT and IIT | Intensity, fatigue, and accuracy of strokes | HIIT provided greater intensity and number of strokes, and IIT better preserved technical stability |

Source: formed by the author based on [11-15]

Based on the presented data, several approaches to implementing HIIT in the training process of tennis players can be distinguished today, depending on the training goals and the level of fitness of the athletes.

A comparison of HIIT and RST showed that HIIT is more effective for the development of aerobic endurance, as indicated by the maximum oxygen consumption indicator ($VO_2$peak), which is critically important for maintaining

performance during a long match. At the same time, RST better develops the ability to perform multiple explosive accelerations and agility, which makes it valuable in the context of short rallies and changes in direction of movement. Thus, both methods have different specializations, and their combination can give a comprehensive result.

A comparison of HIIT and IIT revealed that HIIT provides a higher intensity of exercise performance and a greater number of strokes, which contribute to the development of anaerobic power. At the same time, IIT allows you to maintain accuracy and technical stability, as it provokes fatigue to a lesser extent. It indicates the feasibility of using IIT for technique development, while HIIT should be used for the development of functional fitness.

Studies of game-based HIIT and non game-based HIIT have shown that the game format of interval training creates a higher physiological load and better simulates the specifics of the match. However, excessive intensity in this case can negatively affect the accuracy of strokes, which is a significant limitation. Therefore, at the stage of training young tennis players, it is advisable to use a combination of «game» and «non-game» protocols, depending on the goals of the lesson.

In general, a comparative analysis of different training formats confirms that there is no universal HIIT protocol suitable for all categories of athletes. The choice of a specific approach should depend on age, skill level and current training objectives. HIIT remains the basic means for developing endurance, while RST, IIT and playful HIIT can act as a supplement aimed at developing specific qualities.

The general analysis of the presented studies indicates that HIIT holds a leading position in the physical training of tennis players; however, its effectiveness depends on the format of application and its combination with other methods. Each of the considered approaches (HIIT, RST, IIT and game-based HIIT) has its own strengths and may be appropriate in certain conditions. Therefore, the task of transforming the obtained scientific conclusions into specific practical recommendations for the training process arises.

*Combining HIIT and RST protocols.* To develop comprehensive physical fitness, it is advisable to combine HIIT (development of $VO_2$peak, aerobic endurance) with RST (ability to perform multiple accelerations, agility). This approach allows you to prepare an athlete for long matches and explosive rallies simultaneously.

*Using IIT for technical and tactical tasks.* IIT should be included in periods when the priority is to maintain the accuracy of blows and technical stability, especially in recovery microcycles or before competitive performances.

*HIIT with game elements as a specific imitation of a match.* The HIIT game format is an effective means of training experienced athletes, as it creates a load close to real conditions. In training young tennis players, it is recommended to combine «game» and «non-game» HIIT, depending on age and individual characteristics.

*Balance between physical and technical training.* High-intensity interval loads can temporarily reduce the quality of technical actions. Therefore, HIIT should be combined with separate sessions focused on improving technique and tactics.

*Exercise specification.* HIIT protocols in tennis should include exercises from the court (T-line sprints, corner-to-corner moves, series of shots), which increase efficiency and make training as close as possible to match conditions.

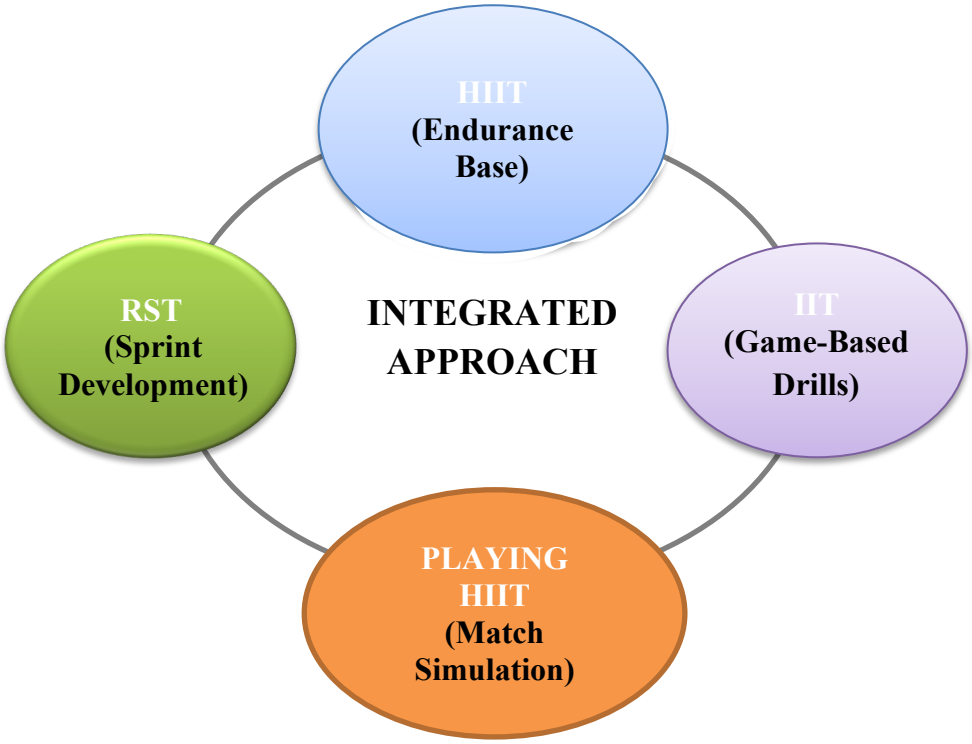
*Individualization of the load.* The frequency of HIIT sessions (2–3 times a week) and their duration (15–25 minutes) should be selected taking into account the level of fitness, playing style and competition calendar.

Thus, the practical application of HIIT in tennis requires an integrated approach: HIIT serves as the basis for the development of endurance and anaerobic power, while RST, IIT and playfull HIIT serve as additional tools that allow for a targeted influence on individual aspects of the athlete's fitness. Schematically, this integrated approach can be depicted as follows (Fig. 1).


ISSN: 2786-9458

**Figure 1**

*Model of an integrated approach to tennis player training*




Source: formed by the author

**Conclusions.** Thus, HIIT is a key tool for developing endurance and increasing the playing efficiency of tennis players. Its value lies not only in the influence on physiological indicators, but also in the ability to model specific conditions of competitive activity, which has both theoretical significance for the further development of sports training concepts and practical value in the form of creating individualized training programs aimed at increasing the performance of tennis players.

It has been established that none of the HIIT protocols is universal; the most significant effect can be achieved by combining different approaches and their flexible adaptation to the athlete's age, level of fitness, and tasks. Thus, HIIT is the foundation of a modern system of training tennis players, which allows you to optimally combine the development of physical qualities with the maintenance of technical and tactical skills.

Prospects for further research are related to the need to create standardized HIIT protocols for tennis players of different skill levels, determine their long-term impact on playing activity, and find the optimal ratio between intensive and technical-tactical training. It opens up opportunities for the formation of a more holistic and scientifically based model of athlete training that can meet the challenges of modern tennis.

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