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Impact of Tabata Training Under Digital Monitoring on Physical Fitness in High-Level University Tennis Athletes

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Abstract:
Background: The increasing demand for improved physical conditioning in university tennis athletes has highlighted the need for training methods that effectively enhance endurance, explosiveness, and agility. Chinese university tennis players often face constraints such as limited training time and insufficient focus on physical conditioning, which adversely affect their competitive performance. This study investigates the impact of Tabata training under

digital monitoring on the physical fitness of high-level university tennis athletes, offering novel insights into optimizing training efficacy.
Methods: This experimental study involved 20 university tennis athletes who participated in an 8-week training intervention. The experimental group underwent Tabata training, while the control group adhered to traditional training methods. Both groups were assessed before and after the intervention on 11 physical fitness parameters, including strength, speed, agility, and endurance. Data were analyzed using SPSS, with paired t-tests conducted to examine changes in performance.
Results: a. Speed: The experimental group exhibited significant improvements in the 20-meter sprint ($P < 0.05$), with no significant differences in the 5-meter and 10-meter sprints ($P > 0.05$). b. Strength: Significant improvements were observed across all strength parameters except for half-squat at half-body weight ($P < 0.05$). c. Agility: The experimental group showed highly significant improvements in agility ($P < 0.001$). d. Endurance: The experimental group demonstrated a highly significant increase in endurance ($P < 0.001$).
Conclusion: An 8-week regimen of Tabata training significantly enhanced the physical performance of high-level university tennis athletes, particularly in agility and endurance. These findings affirm the effectiveness of Tabata training in improving athletic fitness.
Keywords: Digital Monitoring, Tennis, Tabata Training, Athletes, Physical Fitness Training

1 Introduction

Tennis is a sport that demands exceptional physical conditioning, particularly in the areas of endurance, explosiveness, agility, and cardiovascular function [1]. As the competitive level of tennis continues to rise, physical conditioning has emerged as a critical determinant of athletic performance. One of the primary challenges faced by tennis players is optimizing the efficiency and scientific rigor of physical training within limited timeframes [2]. Traditional training methods often involve prolonged exercises and repetitive routines, which may not effectively enhance overall fitness in a time-constrained setting [3].

High-Intensity Interval Training (HIIT) has been established as an effective method for improving athletic performance. Among its variations, the Tabata training method alternates between brief bursts of high-intensity exercise and rest periods. This approach has been shown to significantly enhance both aerobic and anaerobic capacities [4]. Previous studies indicate that Tabata training is particularly effective in improving explosive strength, endurance, and cardiovascular function, with applications across sports such as athletics, soccer, and basketball [5]. However, research examining the specific application of Tabata training for tennis players is limited, particularly in terms of systematic training programs designed to meet the unique demands of tennis [6, 7].

The advancement of digital monitoring technologies has facilitated the integration of real-time tracking into athletes' conditioning regimens [8]. When coupled with Tabata training, digital monitoring enables the continuous assessment of physical performance, facilitating personalized adjustments and optimizing training outcomes [9]. Despite the potential advantages, current research predominantly focuses on other sports, with limited attention given to the combination of digital monitoring and Tabata training in tennis [10]. While digital devices can track basic fitness indicators, the use of real-time data to tailor individualized training plans remains an underexplored area [11].

This study aims to investigate the impact of the Tabata training method under digital monitoring on the physical fitness of high-level university tennis players. By employing digital devices to track physical performance in real-time, this study seeks to evaluate the effectiveness of Tabata training in improving key fitness indicators. The experimental design compares pre- and post-intervention performance changes between experimental and control groups, providing insights into the potential of Tabata training in enhancing tennis players' physical fitness.

2 Methods

2.1 Participants

This study recruited high-level university tennis team athletes as participants. Following screening, a total of 20 participants (14 males and 6 females) were included. Participants were randomly and evenly assigned to either the experimental group or the control group, with 10 individuals in each group. Inclusion criteria were as follows: (1) age between 18 and 25 years; (2) tennis skill level of at least a second-level athlete, with participation in provincial or higher-level competitions; (3) no involvement in other physical training during the study period; and (4) no history of injuries in the preceding six months, with normal auditory and visual abilities. All participants provided informed consent and received compensation upon completion of the study. As shown in Table 1, no significant differences were observed between the two groups in baseline characteristics, including age, height, weight, and athletic level distribution (Table 1).

Table 1. Baseline Characteristics of the Experimental and Control Groups

	Age	Height	Weight	Years of Exercise
EG	20.9±0.876	176.5±4.65	69.25±12.682	8.7±2.946
CG	20.9±2.132	174.3±11.1	64.45±11.954	9.2±2.251
t	0	0.580	0.871	-0.426
P	1	0.569	0.395	0.675

EG = Experimental group; CG = control group

2.2 Experimental Design

2.2.1 Study Design

Participants underwent physical fitness assessments at baseline and after the intervention. Following the initial assessment, the experimental group engaged in Tabata training, while the control group continued with traditional physical training routines. The intervention spanned eight weeks, with training sessions held three times per week. The training protocol was divided into three progressive phases—experience, strengthening, and advanced stages—designed to match the increasing demands of the program. Digital monitoring devices were utilized during training sessions to ensure that exercise intensity met the standards for Tabata training. Post-intervention assessments were conducted, and pre- and post-intervention data were compared.

2.2.2 Experimental Protocol and Equipment

（1）Training Protocol

The Tabata training protocol consisted of eight sets of exercises per session, each lasting 20 seconds of high-intensity effort followed by 10 seconds of rest, for a total duration of four minutes. Exercise intensity was targeted at over 90% of maximum heart rate. The intervention was divided into three progressive phases (Table 2).

Table 2. Tabata Training Design Table

Week	Training Content
Experience Phase	Week1: High knees, lunge jumps, push-ups, etc.
	Week2: High knees, squat crunches, jumping jacks, etc.
Strengthening Phase	Week3: Mountain climbers, skiers, squat crunches, etc.
	Week4: Mountain climbers, skiers, cross-body high-fives, etc.
	Week5: Twisting mountain climbers, side skiers, etc.
Advanced Phase	Week6: Twisting mountain climbers, shuttle runs, etc.
	Week7: Twisting mountain climbers, weighted Russian twists, etc.
	Week8: Twisting mountain climbers, weighted Bulgarian squats, etc.

(2) Digital Monitoring Equipment

Heart rate and exercise intensity were monitored using the “Fitness Training” application on the Apple Watch. Heart rate data were recorded in real time to ensure that participants reached at least 90% of their maximum heart rate by the sixth set of each training session. Adjustments to exercise intensity were made based on these data to maintain adherence to the protocol.

2.2.3 Experimental Indicators and Requirements

The specific experimental indicators and corresponding requirements are outlined in Table 3.

Table 3. Experimental Indicators

Physical Fitness	Test Method	Assessment Criteria
Strength	Half-body weight bench press Half-body weight squat Half-body weight pull	Maximum repetitions in 1 minute
	Closed-position forehand medicine ball throw Closed-position backhand medicine ball throw	Two attempts, record the farthest distance
Speed	5-meter sprint 10-meter sprint 20-meter sprint	Two attempts, record the shortest time
Agility	Hexagon jump Illinois agility run	Shortest time
Endurance	YoYo endurance test	Highest level reached during the beep test

2.2.4 Testing Equipment and Requirements

The specific testing equipment and requirements are detailed in Table 4.

Table 4. Testing Equipment and Requirements

Test Equipment	Test Venue	Test Requirements	Test Equipment
Half-body weight bench press, pull, squat	Barbell plates, barbell rod, weighing scale	Gym, small strength training room	Half-body weight bench press, pull, squat
Closed-position forehand and backhand medicine ball throw	6 kg medicine ball, measuring tape	Tennis court or playground	Closed-position forehand and backhand medicine ball throw

5m, 10m, 20m sprints	Measuring tape, whistle, marker plates	Tennis court	5m, 10m, 20m sprints
Hexagon jump	Hexagon jump equipment (side length 27.5 cm), whistle	Tennis court	Hexagon jump
Illinois agility run	Cones, measuring tape, whistle	Tennis court	Illinois agility run
YoYo endurance test	Speakers, measuring tape, cones	Track and field	YoYo endurance test

2.3 Statistical Analysis

Data were categorized and organized using Excel software. Statistical analysis of pre- and post-test physical fitness indicators for both the experimental and control groups was performed using SPSS version 23.0. Independent sample t-tests and paired sample t-tests were employed for statistical comparisons. A significance level of $P < 0.05$ was considered statistically significant, $P > 0.05$ indicated no significant difference, and $P < 0.001$ indicated extreme statistical significance.

3 Results

3.1 Baseline Physical Fitness Data of the Two Groups

Table 5. Baseline Physical Fitness Data of the Two Groups

Category	Item	Experimental Group (n = 10)	Control Group (n = 10)	P-value
Speed	5m Sprint (s)	1.59 ± 0.15	1.51 ± 0.21	0.307
	10m Sprint (s)	2.34 ± 0.21	2.23 ± 0.15	0.210
	20m Sprint (s)	3.93 ± 0.36	3.64 ± 0.37	0.092
Strength	Half-body weight bench press (reps)	16.2 ± 10.78	21.7 ± 14.6	0.351
	Half-body weight squat (reps)	51.6 ± 10.23	51.0 ± 13.98	0.914
	Half-body weight pull (reps)	16.6 ± 11.85	26.4 ± 13.56	0.102
	Forehand medicine ball throw (m)	7.52 ± 2.65	6.08 ± 2.14	0.198
	Backhand medicine ball throw (m)	7.84 ± 2.32	6.28 ± 1.91	0.117
Agility	Illinois agility run (s)	17.77 ± 1.13	16.86 ± 1.14	0.087
	Hexagon jump (s)	15.17 ± 1.32	14.02 ± 1.50	0.087
Endurance	YoYo endurance test (level)	15.3 ± 1.37	15.81 ± 1.49	0.606

Baseline physical fitness data for the experimental and control groups are presented in Table 5. No significant differences were observed between the two groups in any of the physical fitness tests (P > 0.05). Specifically, the following results were obtained:

Speed: No significant differences were found in the 5-meter, 10-meter, and 20-meter sprint times between the experimental and control groups (P > 0.05).

Strength: No significant differences were observed in strength measures, including half-body weight bench press, squat, pull, and forehand/backhand medicine ball throws (P > 0.05).

Agility: No significant differences were noted in the Illinois agility run and hexagon jump times (P > 0.05).

Endurance: No significant differences were observed in the YoYo endurance test results (P > 0.05).

3.2 Comparison of Pre- and Post-test Data in the Experimental Group

After 8 weeks of Tabata training under digital monitoring, the experimental group underwent post-testing for 11 physical fitness indicators. The results are summarized in Table 6.

Table 6. Pre- and Post-test Results in the Experimental Group

Category	Item	Pre - test (Mean ± SD)	Post-test (Mean ± SD)	P-value
Speed	5m Sprint (s)	1.59 ± 0.15	1.58 ± 0.19	0.590
	10m Sprint (s)	2.34 ± 0.21	2.29 ± 0.18	0.270
	20m Sprint (s)	3.93 ± 0.36	3.71 ± 0.35	0.020
Strength	Half-body weight bench press (reps)	16.2 ± 10.78	18.8 ± 11.47	0.030
	Half-body weight squat (reps)	51.6 ± 10.23	52.0 ± 9.51	0.800
	Half-body weight pull (reps)	16.6 ± 11.85	19.6 ± 12.26	0.026
	Forehand medicine ball throw (m)	7.52 ± 2.65	8.33 ± 2.36	0.001
	Backhand medicine ball throw (m)	7.84 ± 2.32	8.58 ± 2.25	0.000
Agility	Illinois agility run (s)	17.77 ± 1.13	16.89 ± 1.26	0.000
	Hexagon jump (s)	15.17 ± 1.32	15.05 ± 1.25	0.004
Endurance	YoYo endurance test (level)	15.3 ± 1.37	15.81 ± 1.49	0.000

After 8 weeks of Tabata training under digital monitoring, the experimental group exhibited significant improvements in multiple physical fitness measures. Specifically, the Illinois agility run (P < 0.001), hexagon jump (P = 0.004), forehand (P = 0.001) and backhand (P < 0.001) medicine ball throws, and the YoYo endurance test (P < 0.001) showed substantial improvement. While the 20-meter sprint (P = 0.020), half-body weight bench press (P = 0.030), and pull (P = 0.026) also showed statistically significant improvements, these results did not reach the same level of significance as the other tests. No significant changes were observed in the 5-meter sprint (P = 0.590), 10-meter sprint (P = 0.270), or half-body weight squat (P = 0.800).

These findings suggest that Tabata training, especially when coupled with digital monitoring, has a pronounced effect on enhancing strength, agility, and endurance in high-level university tennis players.

3.2.1 Comparison of Strength Test Results in the Experimental Group

The strength test results for the experimental group are summarized in Table 7.

Table 7. Strength Test Results in the Experimental Grou

Group	Half-body Weight Bench Press (reps)	Half-body Weight Squat (reps)	Half-body Weight Pull (reps)	Closed-position Forehand Medicine Ball Throw (m)	Closed-position Backhand Medicine Ball Throw (m)
Pre-test	16.2 ± 10.78	51.6 ± 10.23	16.6 ± 11.85	7.52 ± 2.65	7.84 ± 2.32
Post-test	18.8 ± 11.47	52.0 ± 9.51	19.6 ± 12.26	8.33 ± 2.36	8.58 ± 2.25
P-value	0.03	0.800	0.026	0.001	0.000

Significant improvements were observed in the half-body weight bench press, with a pre-test score of 16.2 ± 10.78 repetitions and a post-test score of 18.8 ± 11.47 repetitions ($P = 0.03$). However, no significant difference was found in the half-body weight squat, with pre-test and post-test scores of 51.6 ± 10.23 repetitions and 52.0 ± 9.51 repetitions, respectively ($P = 0.800$). In contrast, the half-body weight pull showed a significant improvement, with pre-test and post-test scores of 16.6 ± 11.85 repetitions and 19.6 ± 12.26 repetitions, respectively ($P = 0.026$). Both the forehand and backhand closed-position medicine ball throws showed substantial improvements, with the forehand throw increasing from 7.52 ± 2.65 meters to 8.33 ± 2.36 meters ($P = 0.001$), and the backhand throw improving from 7.84 ± 2.32 meters to 8.58 ± 2.25 meters ($P < 0.001$).

3.2.2 Comparison of Speed Test Results in the Experimental Group

Table 8. Speed Test Results in the Experimental Group

Group	5m Sprint (s)	10m Sprint (s)	20m Sprint (s)
Pre-test	1.59 ± 0.15	2.34 ± 0.211	3.93 ± 0.36
Post-test	1.58 ± 0.193	2.29 ± 0.182	3.71 ± 0.346
P-value	0.59	0.27	0.02

As shown in Table 8, there were no significant improvements in the 5-meter sprint, with pre-test and post-test times of 1.59 ± 0.15 seconds and 1.58 ± 0.193 seconds, respectively ($P = 0.59$). Similarly, the 10-meter sprint showed no significant difference, with pre-test and post-test times of 2.34 ± 0.211 seconds and 2.29 ± 0.182 seconds ($P = 0.27$). However, the 20-meter sprint demonstrated significant improvement, with pre-test and post-test times of 3.93 ± 0.36 seconds and 3.71 ± 0.346 seconds, respectively ($P = 0.02$).

3.2.3 Comparison of Agility Test Results in the Experimental Group

Table 9. Agility Test Results in the Experimental Group

Group	Illinois Agility Run (s)	Hexagon Jump (s)
Pre-test	17.77 ± 1.13	15.17 ± 1.32
Post-test	16.89 ± 1.26	15.05 ± 1.25
P-value	0.000	0.004

Table 9 displays the results of the agility tests. The Illinois agility run showed a highly significant improvement, with pre-test and post-test times of 17.77 ± 1.13 seconds and 16.89 ± 1.26 seconds, respectively ($P < 0.001$). The hexagon jump also showed significant improvement, with pre-test and post-test times of 15.17 ± 1.32 seconds and 15.05 ± 1.25 seconds (P = 0.004).

3.2.4 Comparison of Endurance Test Results in the Experimental Group

Table 10. Endurance Test Results in the Experimental Group

Group	YoYo Endurance Test (level)
Pre-test	15.3 ± 1.37
Post-test	15.81 ± 1.49
P-value	0.000

The results for the YoYo endurance test are presented in Table 10. The experimental group showed a highly significant improvement in endurance, with pre-test and post-test results of 15.3 ± 1.37 and 15.81 ± 1.49 levels, respectively (P < 0.001).

These results suggest that Tabata training under digital monitoring significantly enhanced the strength, speed, agility, and endurance of athletes in the experimental group, with the most pronounced improvements observed in strength, agility, and endurance parameters.

3.3 Comparison of Pre-test and Post-test Data in the Control Group

Table 11. Control Group Pre-test and Post-test Results

Category	Item	Pre-test	Post-test	P-value
Speed	5m Sprint (s)	1.51 ± 0.22	1.52 ± 0.23	0.640
	10m Sprint (s)	2.24 ± 0.15	2.34 ± 0.19	0.049
	20m Sprint (s)	3.65 ± 0.37	3.79 ± 0.44	0.162
Strength	50% Bodyweight Bench Press (reps)	21.7 ± 14.63	23.2 ± 15.01	0.152
	50% Bodyweight Half Squat (reps)	51.0 ± 13.98	50.7 ± 13.69	0.708
	50% Bodyweight Deadlift (reps)	26.4 ± 13.56	27.1 ± 15.19	0.519
	Closed-grip Forehand Medicine Ball Throw (m)	6.08 ± 2.14	6.26 ± 2.10	0.011
	Closed-grip Backhand Medicine Ball Throw (m)	6.28 ± 1.90	6.52 ± 1.84	0.000
Agility	Illinois Agility Run (s)	16.86 ± 1.13	17.16 ± 1.19	0.266
	Hexagon Jump (s)	14.02 ± 1.50	14.25 ± 1.13	0.392
Endurance	Yo-Yo Endurance Test (level)	14.89 ± 1.75	14.98 ± 1.67	0.618

The data presented in Table 11 suggest that, following continued participation in traditional physical training, the control group exhibited no significant changes across most test indicators. Paired sample t-tests performed on the pre-test and post-test results revealed that, except for the significant improvements observed in the closed-grip medicine ball throws (both forehand and backhand), which showed statistically significant changes (P = 0.011 and

P = 0.000, respectively), all other variables demonstrated P-values greater than 0.05, indicating no significant effects. Additionally, some variables even showed a decline in performance when comparing pre-test and post-test results. The observed improvements in the closed-grip forehand and backhand throws may be attributed to participants' increased familiarity with the test procedures following the pre-test, as well as the similarity between the mechanics of the throws and the explosive movements involved in tennis forehand and backhand strokes.

3.3.1 Comparison of Strength Test Results in the Control Group

Table 12. Control Group Strength Test Results

Item	50% Bodyweight Bench Press (reps)	50% Bodyweight Half Squat (reps)	50% Bodyweight Deadlift (reps)	Closed-grip Forehand Medicine Ball Throw (m)	Closed-grip Backhand Medicine Ball Throw (m)
Pre-test	21.7 ± 14.63	51.0 ± 13.98	26.4 ± 13.56	6.08 ± 2.14	6.28 ± 1.90
Post-test	23.2 ± 15.01	50.7 ± 13.69	27.1 ± 15.19	6.26 ± 2.10	6.52 ± 1.84
P-value	0.152	0.708	0.519	0.011	0.000

Analysis of Table 12 reveals that the control group's pre-test performance in the 50% bodyweight bench press was 21.7 ± 14.63 repetitions, while post-test performance increased to 23.2 ± 15.01 repetitions, but this difference was not statistically significant (P = 0.152). Similarly, for the 50% bodyweight half squat, pre-test results of 51.0 ± 13.98 repetitions and post-test results of 50.7 ± 13.69 repetitions showed no significant change (P = 0.708). Likewise, the 50% bodyweight deadlift demonstrated no significant difference, with pre-test and post-test results of 26.4 ± 13.56 and 27.1 ± 15.19 repetitions, respectively (P = 0.519). In contrast, significant improvement was observed in the closed-grip forehand medicine ball throw, which increased from 6.08 ± 2.14 meters to 6.26 ± 2.10 meters (P = 0.011), while the closed-grip backhand throw showed a more pronounced improvement from 6.28 ± 1.90 meters to 6.52 ± 1.84 meters ($P < 0.001$).

3.3.2 Comparison of Speed Test Results in the Control Group

Table 13. Control Group Speed Test Results

Item	5m Sprint (s)	10m Sprint (s)	20m Sprint (s)
Pre-test	1.51 ± 0.22	2.24 ± 0.15	3.65 ± 0.37
Post-test	1.51 ± 0.22	2.34 ± 0.19	3.79 ± 0.44
P-value	0.640	0.049	0.162

Table 13 shows that for the 5m sprint, the pre-test time was 1.51 ± 0.22 seconds, and the post-test time was 1.52 ± 0.23 seconds, with no significant change (P = 0.640). The 10m sprint revealed a pre-test time of 2.24 ± 0.15 seconds and a post-test time of 2.34 ± 0.19 seconds, with a marginally significant difference (P = 0.049), although this was not considered a substantial effect. For the 20m sprint, the pre-test time was 3.65 ± 0.37 seconds, and the post-test time was 3.79 ± 0.44 seconds, with no significant change (P = 0.162).

3.3.3 Comparison of Agility Test Results in the Control Group

Table 14. Control Group Agility Test Results

Item	Illinois Agility Run (s)	Hexagon Jump (s)
Pre-test	16.86 ± 1.13	14.02 ± 1.50
Post-test	17.16 ± 1.19	14.25 ± 1.13
P-value	0.266	0.392

Analysis of Table 14 indicates that the pre-test performance in the Illinois Agility Run was 16.86 ± 1.13 seconds, and the post-test time was 17.16 ± 1.19 seconds, with no significant difference (P = 0.266). Similarly, for the hexagon jump, the pre-test time was 14.02 ± 1.50 seconds, and the post-test time was 14.25 ± 1.13 seconds, showing no significant difference (P = 0.392).

3.3.4 Comparison of Endurance Test Results in the Control Group

Table 15. Control Group Endurance Test Results

Item	Yo-Yo Endurance Test (level)
Pre-test	14.89 ± 1.75
Post-test	14.98 ± 1.67
P-value	0.618

Analysis of Table 15 reveals that the pre-test performance in the Yo-Yo endurance test was 14.89 ± 1.75, and the post-test performance was 14.98 ± 1.67, with no significant change (P = 0.618).

These results indicate that while some improvements were observed in specific strength and speed measures (particularly the closed-grip medicine ball throws), the control group did not experience significant changes in most of the other performance indicators after the traditional training program.

3.4 Comparison of Pre- and Post-Test Data Between the Experimental and Control Groups

After 8 weeks of Tabata training under digital monitoring, the experimental group exhibited significant improvements in most of the 11 test items, while the control group showed minimal changes, with some indicators even regressing. These findings suggest that Tabata training is more effective in enhancing the physical fitness of high-level university tennis players compared to traditional training methods.

Table 16. Change Rate Table

Category	Indicator	Experimental Group Pre-Test	Experimental Group Post-Test	Change Rate (%)	Control Group Pre-Test	Control Group Post-Test	Change Rate (%)
Speed	5m Sprint (s)	1.59±0.15	1.58±0.19	-0.63%	1.51±0.21	1.52±0.23	-0.66%
	10m Sprint (s)	2.34±0.21	2.29±0.18	2.13%	2.23±0.15	2.34±0.19	-4.93%
	20m Sprint (s)	3.93±0.36	3.71±0.35	5.6%	3.64±0.37	3.79±0.44	-4.12%
Strength	1/2 Bodyweight Bench Press (reps)	16.2±10.78	18.8±11.47	16.04%	21.7±14.6	23.2±15.01	6.91%
	1/2 Bodyweight	51.6±10.23	52.0±9.51	0.78%	51.0±13.98	50.7±13.69	-0.59%

	Squat (reps)						
	1/2 Bodyweight Deadlift (reps)	16.6±11.85	19.6±12.26	18.07%	26.4±13.56	27.1±15.19	2.65%
	Closed-Hand Forehand Medicine Ball Throw (m)	7.52±2.65	8.33±2.36	10.77%	6.08±2.14	6.26±2.10	2.96%
	Closed-Hand Backhand Medicine Ball Throw (m)	7.84±2.32	8.58±2.25	9.44%	6.28±1.91	6.52±1.84	3.82%
Agility	Illinois Agility Run (s)	17.77±1.13	16.89±1.26	4.95%	16.86±1.14	17.16±1.19	-1.78%
	Hexagon Jump (s)	15.17±1.32	15.05±1.25	7.9%	14.02±1.5	14.25±1.13	-1.64%
Endurance	YoYo Endurance Run (level)	15.3±1.37	15.81±1.49	3.33%	15.81±1.49	14.98±1.67	-5.24%

(1) Experimental Group Post-Tabata Training Results

The experimental group demonstrated significant improvements across multiple areas of physical fitness, including speed, strength, agility, and endurance:

1.Speed: The 5-meter sprint time decreased by 0.63%, the 10-meter sprint time increased by 2.13%, and the 20-meter sprint time improved by 5.6%.

2.Strength: Performance in the 1/2 bodyweight bench press improved by 16.04%, the squat increased by 0.78%, the deadlift rose by 18.07%, and both forehand and backhand medicine ball throws increased by 10.77% and 9.44%, respectively.

3.Agility: The Illinois Agility Run time decreased by 4.95%, and the hexagon jump time decreased by 7.90%.

4.Endurance: The YoYo Endurance Run level increased by 3.33%.。

(2) Control Group Pre- and Post-Test Comparison

The control group, which engaged in traditional training, exhibited minimal progress, with several indicators showing regression:

1.Speed: The 5-meter sprint time decreased by 0.66%, the 10-meter sprint time decreased by 4.93%, and the 20-meter sprint time decreased by 4.12%.

2.Strength: The bench press improved by 6.91%, the squat decreased by 0.59%, the deadlift increased by 2.65%, and both forehand and backhand medicine ball throws increased by 2.96% and 3.82%, respectively.

3.Agility: The Illinois Agility Run time increased by 1.78%, and the hexagon jump time increased by 1.64%.

4.Endurance: The YoYo Endurance Run level decreased by 5.24%.

The experimental group demonstrated superior improvements across all physical fitness indicators, with notably higher change rates compared to the control group. While no significant progress was noted in the 5-meter sprint and 1/2 bodyweight squat, and some regression was observed in the 5-meter sprint, the experimental group showed considerable improvements in the 1/2 bodyweight bench press and deadlift. These results indicate that Tabata training significantly enhances the physical fitness of high-level tennis players in universities compared to traditional training methods.

4 Discussion

4.1 Impact of Digital Monitoring Tabata Training on Strength in High-Level University Tennis Athletes

The results of this study demonstrate that after 8 weeks of digital monitoring-based Tabata training, the experimental group exhibited significant improvements in strength, with the exception of the 1/2 bodyweight squat ($p > 0.05$). Statistically significant differences ($p < 0.05$) were observed in the 1/2 bodyweight bench press, 1/2 bodyweight deadlift, and both the closed-hand forehand and backhand medicine ball throws, with the most substantial improvement noted in the closed-hand backhand medicine ball throw ($p < 0.001$). The bench press, deadlift, and squat are considered fundamental strength movements in fitness training and are commonly utilized by athletes across various sports to develop strength [12]. Among these, the bench press is a key exercise for building chest and upper limb strength, and using 1/2 bodyweight as the load for this exercise is regarded as a scientifically rigorous benchmark. The closed-hand forehand and backhand medicine ball throws also play a critical role in enhancing the strength and speed of an athlete’s forehand and backhand strokes.

Further analysis revealed that, aside from the 1/2 bodyweight squat, the most pronounced improvements were observed in the 1/2 bodyweight deadlift, bench press, and both forehand and backhand medicine ball throws. These findings align with those reported by Li Zhaoqian, who employed HIIT training to enhance strength in female university students [13]. However, Li’s study used standing long jump exercises to assess lower body strength, a test that evaluates both technique and explosive power. The strength characteristics of female university students differ considerably from those of high-level tennis athletes, who require more targeted strength, particularly in the forehand and backhand strokes. This underscores the importance of tailoring strength training methods to the specific needs of tennis athletes. Selecting scientifically grounded and effective training methods, based on individual performance metrics, is crucial not only to avoid muscle overuse injuries but also to optimize training outcomes.

4.2 Impact of Digital Monitoring Tabata Training on Speed in High-Level University Tennis Athletes

The results of this study indicate that, after 8 weeks of Tabata training under digital monitoring, the experimental group exhibited improvements in speed performance, particularly in the 20-meter sprint ($p < 0.05$). However, no significant differences were observed in the 5-meter sprint and 10-meter sprint ($p > 0.05$). These results are consistent with those reported by Yang Xiang in his study on the effects of HIIT training on the physical fitness of sprint athletes in sports schools[14]. A standard tennis court measures 23.77 meters in length and 10.97 meters in width, which is smaller than the playing fields used in sports such as soccer and basketball. The specialized speed required for tennis involves executing rapid individual movements, such as reacting to and anticipating a return shot, quick footwork, and ball striking velocity. Success in tennis demands not only fast reflexes but also quick decision-making, rapid starts, swift foot movements, and efficient execution of actions during a high-paced, dynamic game. As such, tennis players must exhibit high levels of displacement speed and reaction time [15]. For this reason, the study employed the 5-meter, 10-meter, and 20-meter sprints as indicators of speed performance.

Further analysis revealed that, despite some improvements, the changes in speed performance across all tests for the experimental group were minimal. This suggests that short-distance sprints cannot be significantly improved over a relatively brief period, such as the 8-week duration of Tabata training. Short sprints primarily rely on the phosphagen energy system, which is indicative of an athlete's anaerobic capacity [16]. Consequently, tennis players need prolonged training regimens to enhance their speed. Effective training should combine short-distance sprint exercises to improve quick movements with multi-ball drills designed to enhance response times in returning shots. This approach will facilitate the development of the players' ability to accurately judge the trajectory of the ball and execute effective returns, while stimulating the central nervous system to improve reaction speed and reflexes.

4.3 Impact of Digital Monitoring Tabata Training on Agility in High-Level University Tennis Athletes

The findings of this study indicate that 8 weeks of Tabata training under digital monitoring significantly improved agility performance in the experimental group. Statistically significant improvements were observed in the Illinois Agility Test ($p < 0.05$), with highly significant differences noted in the Hexagon Jump ($p < 0.001$). Agility is defined as the ability to respond rapidly and accurately to sudden changes in movement or direction. The Hexagon Jump, endorsed by the American Council on Exercise as an effective tool for agility training, enhances multi-joint mobility in the lower limbs and is widely used in tennis-specific training. It is frequently employed as a pre-competition evaluation in tennis tournaments [17, 18]. Similarly, the Illinois Agility Test is a widely recognized assessment with a standardized grading system [19], providing benchmarks for male and female athletes. This test evaluates acceleration, deceleration, directional changes, and explosive power—all critical skills in tennis that mimic the dynamic movements required during matches.

Existing research on the effects of Tabata training on agility is limited, with most studies focusing on adolescent basketball players. A meta-analysis by Zhang Zhiyong et al. [20] reported no significant improvements in agility with high-intensity interval training (HIIT), which contrasts with the findings of this study. The meta-analysis included only five studies on agility, potentially limiting its conclusions. In this study, significant improvements were observed in both the Hexagon Jump and Illinois Agility Test results among participants in the experimental group. At baseline, common errors, such as stepping on lines or knocking over cones, were prevalent. These errors were almost entirely eliminated in post-test evaluations, with participants completing the required movements more precisely. Analysis of variance revealed significant reductions in Hexagon Jump times and Illinois Agility Test scores, with the Hexagon Jump showing the most pronounced improvements.

4.4 Impact of Digital Monitoring Tabata Training on Endurance in High-Level University Tennis Athletes

The results of this study demonstrated highly significant improvements in endurance performance ($p < 0.001$) in the experimental group following 8 weeks of Tabata training under digital monitoring. In tennis, most technical movements, such as serving and groundstrokes, involve explosive actions of short duration. However, for high-level university tennis players, where opponents often possess comparable technical skills and matches lack time constraints, endurance becomes a critical determinant of performance. While explosive power provides an advantage in isolated movements, the ability to sustain consistent performance over extended matches is vital.Previous research on HIIT has primarily focused on populations with obesity or overweight conditions, demonstrating improvements in endurance, fat reduction, and strength [21-23]. Tabata training, as an advanced form of HIIT, is particularly suited for individuals with higher fitness levels, such as elite athletes, due to its intense demands.

In this study, the Yo-Yo Intermittent Recovery Test, commonly known as the "beep test," was used to assess endurance. Initially developed for elite soccer players, the test was introduced to China in 2003 and has since become a standard endurance assessment across various sports. Participants performed 20-meter shuttle runs synchronized with rhythmic cues, with a 5-second rest interval between runs. The interval shortened progressively, increasing the speed required for each level [24, 25]. Analysis revealed a significant improvement in Yo-Yo test scores in the experimental group. This can be attributed to the brief recovery periods characteristic of Tabata training, which challenge the body's aerobic system to operate at higher intensities while permitting partial recovery. The intense workload places considerable demands on the respiratory and cardiovascular systems [26, 27], leading to improved aerobic endurance. These findings suggest that Tabata training is an effective and feasible method for enhancing endurance in tennis players.

Tabata training, as a form of HIIT, has shown significant effects on physical fitness in tennis athletes. This study utilized digital monitoring devices to ensure precise control of training intensity, revealing that the experimental group demonstrated significant improvements in 9 out of 11 physical fitness tests, particularly in agility, endurance, and strength. However, improvements in speed performance were limited, with no significant changes observed in the 5m and 10m sprints or the 1/2 bodyweight squat. These findings suggest that while Tabata training has a pronounced positive impact on agility and endurance in high-level tennis players, its effect on speed is less substantial. Therefore, future training regimens should align with the specific demands of tennis, integrating physical conditioning with technical training for optimal performance.

5 Conclusion

Following 8 weeks of Tabata training under digital monitoring, the experimental group exhibited significant improvements in key physical fitness parameters, including strength, speed, agility, and endurance. Notable gains were observed in exercises such as the half-bodyweight bench press, pull-ups, medicine ball throws, 20-meter sprints, hexagon jumps, and the Yo-Yo endurance test. When compared to the control group, these enhancements were more pronounced, suggesting that Tabata training has a substantial impact on improving the physical fitness of high-level university tennis athletes. Additionally, the integration of digital monitoring not only increased training efficiency but also facilitated real-time data analysis, providing advantages in terms of timeliness and precision over traditional training methods. These findings offer scientific evidence supporting the use of Tabata training to enhance athletes' physical qualities.

6 Limitations

One limitation of the study was the exclusion of flexibility as a fitness parameter in the test design. This omission stemmed from the lack of research exploring the effects of Tabata training on flexibility and the experimental constraints that prevented flexibility monitoring. Future research could extend the duration of the training program to better capture the effects on speed, endurance, and agility, ensuring that the full potential of Tabata training is realized. Additionally, incorporating more advanced digital technologies, such as digital sensors and specialized equipment, could enhance data acquisition and improve the precision of training monitoring. This study relied solely on smartwatches for data collection, which limited real-time data acquisition and the overall accuracy of monitoring. Future studies should also explore flexibility testing, balance training across different physical attributes, and tailor

Tabata training programs to the specific needs of tennis athletes for more comprehensive physical development.

Disclosure:

Authors'contribution:

YunZhong Luo: Selecting the topic, setting the framework, writing, unifying and revising the manuscript.

Liang Deng:categorize and analyze information

Kai Chen::categorize and analyze information

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