The Effect of On-Court vs. Off-Court Interval Training on Skilled Tennis Performance and Tolerance to Fatigue in Young Male Tennis Players

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ABSTRACT

Srihirun K, Boonrod W, Mickleborough TD, Suksom D. The Effect of On-Court vs. Off-Court Interval Training on Skill Tennis Performance and Fatigue in Tennis Training. JEPonline 2014;17(5):11-20. The aim of this study was to investigate the effect of on-court vs. off-court interval-training on skilled tennis performance and tolerance to fatigue in young tennis players. Twenty male tennis players (aged 16.6 ± 0.6 yrs) were randomly assigned to two groups: (a) an on-court interval-training (On-INT; N = 10) group; and (b) an off-court interval-training (Off-INT; N = 10) group. The On-INT group (tennis skill specific interval training in the field) was subjected to 4 sets of 6 repetitions of 10 sec of high-intensity exercise, alternating with 10 sec of active recovery (footwork). The Off-INT (running interval training on treadmill) group was subjected to 4 sets of 6 repetitions of 10 sec of high-intensity exercise performed by running at 90-100% of peak treadmill speed (PTS), alternating with 10 sec of running at 30-40% of PTS. Both the On-INT and the Off-INT groups trained for 3 days·wk⁻¹ for 8 wks. After interval training, both On-INT and Off-INT groups had significantly (P<0.05) increased their VO₂ max (10.68% and 6.66%, respectively. However, the percentage of groundstroke accuracy score and mean time to fatigue were significantly increased (P<0.05) only in the On-INT group. This study has shown that while both On-INT and Off-INT are effective in the improvement of aerobic capacity, only the On-INT was effective in improving skilled tennis performance and tolerance to fatigue.

Key Words: The Loughborough Intermittent Tennis Test (LITT), Aerobic Capacity, Groundstroke Accuracy, Time to Volitional Fatigue
INTRODUCTION

Tennis is a sport that has been characterized as having a mixture of short bouts of high-intensity intermittent exercise and longer periods of lower intensity activity (27). Typically, match time in tennis is comprised of repetitive ballistic actions. If played in hot and humid conditions, it can disturb the body’s homeostatic control mechanisms that lead to fatigue and a subsequent decrease in performance (17).

Interval training encompasses high-intensity exercise that is equal or superior to maximal lactate steady-state velocity. When interspersed with recovery periods of light exercise or rest, interval training can be used to improve aerobic performance and overall fitness in endurance sports (3). Previous studies have shown that interval training improves VO$_2$ max (1), peak-power output (27), the lactate threshold (6), and time-trial performance (31) in a variety of sports. Additionally, it has been shown that mean power output and fatigability after a cycle ergometer intermittent exercise test can be improved by interval training (30). Within the sport of tennis, coaches are increasingly utilizing an integrated approach to conditioning and skill training, such as game-specific on-court exercises that include both technical and tactical drills that form a part of their sport-specific conditioning program (4-5,27). In fact, it has been reported that on-court tennis-specific interval training improves aerobic fitness to a similar extent as off-court interval training performed on a treadmill (10).

To our knowledge, no studies to date have compared the effect of on-court and off-court interval training on skilled tennis performance and tolerance to fatigue. Therefore, the aim of the present study was to determine the effects of on-court versus off-court interval training on skilled tennis performance and tolerance to fatigue in young tennis players. We hypothesized that on-court interval training would significantly improve physical fitness, skilled tennis performance, and tolerance to fatigue compared with off-court interval training.

METHODS

Subjects

Twenty high school male tennis players (mean ± SD: age = 16.6 ± 0.6 yrs; height = 171.4 ± 6.99 cm; body mass = 63 ± 10.9 kg; body fat = 13.9 ± 6.2%; mean tennis training practice = 6.55 ± 1.23 yrs) gave their written informed consent to participate in this study, which was approved by the Ethical Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Bangkok, Thailand. The inclusion criteria included male tennis players in national youth level, who had played tennis for at least 5 yrs and had not performed any interval training in the past 6 months. Exclusion criteria included a history of any chronic disease (such as hypertension, diabetes, coronary heart disease, and asthma).

Procedures

Before training, all subjects were required to attend a laboratory “familiarization visit” to introduce the testing and training procedures used for the baseline measures. The players completed baseline tests for body composition, VO$_2$ max (maximal oxygen consumption), and skilled tennis performance. Then, they were randomly divided into 2 training groups: (a) an on-court interval-training (On-INT; N = 10) group; and (b) an off-court interval-training (Off-INT; N = 10) group. The On-INT group (tennis skill specific interval training in the field) was subjected to 4 sets of 6 repetitions of 10 sec of high-intensity exercise, alternating with 10 sec of active recovery (footwork). The Off-INT (running interval training on treadmill) group was subjected to 4 sets of 6 repetitions of 10 sec of high-intensity
exercise performed by running at 90-100% of peak treadmill speed (PTS), alternating with 10 sec of running at 30-40% of PTS. Both the On-INT and the Off-INT groups trained for 3 days·wk⁻¹ for 8 wks. After the training period, post-training tests were conducted using the same protocol as the pre-training test.

Experimental Protocol
Physiological Fitness
Maximal oxygen consumption (VO₂ max) was performed using a cardiopulmonary gas exchange system (Metamax 3B, Cortex, Leipzig, Germany). The subjects were asked to run on a treadmill (Landice, USA) while the grade and intensity were increased every 3 min until exhaustion. Criteria for determination of VO₂ max included a plateau in VO₂ despite an increase in workload during the last 1 min, a respiratory exchange ratio >1.1, and an exercise heart rate (HR) >90% of predicted HR max (15).

The Skill Tennis Performance after The Loughborough Intermittent Tennis Test
The Loughborough Intermittent Tennis Test (LITT) was used to assess the subjects’ skill level. The LITT consisted of bouts of maximal hitting of tennis balls of 4 min duration with 40 sec seated recovery between bouts until volitional fatigue. The players were required to hit returns at maximum effort, within the singles court but further than the service line, towards either target A or B (Figure 1). A 1.5 x 1.5 m target was placed in the rear corner of both singles court areas. The tennis ball serving machine fed balls in a random fashion at a frequency of 30 balls·min⁻¹. The on-site scoring and a video recorder were used to record the players’ ability to return the tennis ball landing into the target areas. Tennis performance (ground stroke accuracy, consistency, and errors-scores) on the LITT were recorded throughout the test. Scores for each player were converted into percentages, whereby ‘ground stroke consistency’ + ‘ground stroke accuracy’ + ‘ground stroke error’ = 100%. The mean percentage scores were calculated for each parameter (7).

Figure 1. The Loughborough Intermittent Tennis Test (7).
**Time to Volitional Fatigue during the LITT**
During the LITT, the subjects were required to hit returns at maximum effort until volitional exhaustion. Fatigue was considered to have occurred when the required hitting frequency was not maintained for two consecutive feeds from the tennis ball serving machine or when the players stopped voluntarily (7).

**Time to Volitional Fatigue on the Treadmill Test**
The test started at a running speed of 8 km·h⁻¹ with a stepwise 0.5 km·h⁻¹ speed increment every 30 sec until the subject stopped due to volitional exhaustion (25). If the last stage was not fully completed, the peak treadmill speed (PTS) was calculated using the formula developed by Kuipers et al. (1985) (18): \( PTS = S_f + (t/30 \times 0.5) \), where \( S_f \) was the last completed speed in km·hr⁻¹ and \( t \) was the time in seconds of the uncompleted stage.

**On-Court Interval Training Protocol**
The subjects were required to perform forehand and backhand strokes in different positions on the tennis court. Ball location followed a fixed order, which was previously explained to the subjects. An experienced professional coach hand-fed new tennis balls to the player at a frequency of approximately one ball every 2 sec ± 100 cm over the net. The subjects performed movement and stroke patterns A (Figure 2A) that included 2 sets of 6 repetitions of 10 sec of high-intensity exercise using forehand and backhand strokes while moving forward as fast as possible and hitting the ball with maximal effort and maintaining stroke accuracy, which was alternated with 10 sec of active recovery (footwork) and 3 min of rest between the sets. Then, the subjects performed movement and stroke patterns B (Figure 2B) that included 2 sets of 6 repetitions of 10 sec of high-intensity exercise using forehand and backhand strokes while moving backward as fast as possible and hitting the ball with maximal effort and maintaining stroke accuracy, which was alternated with 10 sec of active recovery (footwork) and 3 min of rest between the sets.

**Off-Court Interval Training Protocol**
During the off-court sessions, subjects were required to perform interval running on a treadmill. The subjects performed 4 sets of 6 repeated 10-sec sprints at 90-100% of peak treadmill speed (PTS) alternating 10-sec active recovery.

**Figure 2. A: Moving Forward Interval Training, B: Moving Backward Interval Training.** 1,3 = Forehand moving forward, 2,4 = Backhand moving forward. Both on-court interval-training (On-INT) and off-court interval-training (Off-INT) were equal in training intensity, given that there were no statistically significant differences in the subjects' %HR max, blood lactate concentration, and rating of perceived exertion (RPE) in each set of training.
Statistical Analyses
The data were analyzed using SPSS version 17 for Windows statistical software package (SPSS Inc., Chicago, USA). For each shot of ground stroke the subjects’ raw scores were converted into ‘consistency’, ‘accuracy’, and ‘out’ percentages as a means of generating the dependent variables. The assessment of VO\textsubscript{2} max, skill tennis performance, and time to volitional fatigue, and the difference in the mean values between the pre-training and post-training, were analyzed using paired \( t \) tests. The independent \( t \) tests were used to determine the significance between groups. A \( P \)-value of \( \leq 0.05 \) was considered to be statistically significant.

RESULTS

Physiological Characteristics
Physical characteristics of the subjects are summarized in Table 1. After 8 wks of training there were no significant differences (\( P>0.05 \)) in body weight, body fat, resting heart rate and blood pressure between the On-INT and Off-INT groups. However, it was found that VO\textsubscript{2} max was significantly increased (\( P<0.05 \)) in the On-INT and Off-INT groups.

Table 1. Pre-Training and Post-Training Subject Characteristics.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>On-INT group (N = 10)</th>
<th>Off-INT group (N = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Training</td>
<td>Post-Training</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>16.6 ± 0.5</td>
<td>-</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.4 ± 7.9</td>
<td>-</td>
</tr>
<tr>
<td>Tennis Practice (yr)</td>
<td>6.5 ± 1.3</td>
<td>-</td>
</tr>
<tr>
<td>Body Weight (kg)</td>
<td>62.0 ± 12.6</td>
<td>62.6 ± 12.8</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>15.2 ± 8.1</td>
<td>15.0 ± 7.2</td>
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<tr>
<td>Resting Heart Rate (beats·min(^{-1}))</td>
<td>76.8 ± 7.2</td>
<td>75.5 ± 7.8</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>116.6 ± 10.7</td>
<td>117.6 ± 10.6</td>
</tr>
<tr>
<td>Diastolic BP (mmHg)</td>
<td>70.2 ± 9.1</td>
<td>74.7 ± 5.6</td>
</tr>
<tr>
<td>VO\textsubscript{2} Max (mL·kg(^{-1})·min(^{-1}))</td>
<td>38.4 ± 7.3</td>
<td>42.30 ± 7.56*</td>
</tr>
</tbody>
</table>

Data are mean ± SD. *Statistical difference from pre-training at \( P<0.05 \), On-INT = On-court interval training, Off-INT = Off-court interval training

Tennis Performance on the Loughborough Intermittent Tennis Test
The amount of total tennis ball hitting significantly increased (\( P<0.05 \)) in the On-INT and Off-INT groups. However, the percentage of groundstroke accuracy was significantly increased (\( P<0.05 \)) and the percentage of groundstroke stroke error was significantly reduced (\( P<0.05 \)) only in the On-INT group. There was no significant difference (\( P>0.05 \)) in the percentage of groundstroke consistency score between pre-training and post-training in both groups (Table 2).
Table 2. The Skilled Tennis Performance after the Loughborough Intermittent Tennis Test.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>On-INT group (N = 10)</th>
<th>Off-INT group (N = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Training</td>
<td>Post-Training</td>
</tr>
<tr>
<td>Total Tennis Ball Hitting (ball)</td>
<td>466.8 ± 143.6</td>
<td>596.1 ± 163.6*</td>
</tr>
<tr>
<td></td>
<td>399.0 ± 105.8</td>
<td>471.6 ± 117.4*</td>
</tr>
<tr>
<td>Percentage Scores of Groundstroke Accuracy (%)</td>
<td>16.0 ± 7.5</td>
<td>20.0 ± 6.1*</td>
</tr>
<tr>
<td></td>
<td>14.6 ± 4.8</td>
<td>16.7 ± 2.9</td>
</tr>
<tr>
<td>Percentage Scores of Groundstroke Consistency (%)</td>
<td>52.1 ± 0.5</td>
<td>52.0 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>51.9 ± 0.1</td>
<td>51.9 ± 0.1</td>
</tr>
<tr>
<td>Percentage Scores of Groundstroke Error (%)</td>
<td>31.6 ± 8.8</td>
<td>26.3 ± 6.7*</td>
</tr>
<tr>
<td></td>
<td>31.7 ± 7.2</td>
<td>25.8 ± 4.0</td>
</tr>
</tbody>
</table>

Data are mean ± SD. *Statistical difference from pre-training at P<0.05, On-INT = On-court interval training, Off-INT = Off-court interval training

Time to Volitional Fatigue Data
Only the On-INT group significantly increased (P<0.05) time to volitional fatigue during the LITT and on treadmill test after 8 wks of training. There were no significant differences (P>0.05) in time to volitional fatigue on the LITT and treadmill test in the Off-INT training after 8 wks of training (Figure 3).

Time to Volitional Fatigue on LITT Test

Time to Volitional Fatigue on Treadmill test

Figure 3. The Mean Time to Volitional Fatigue after The Loughborough Intermittent Tennis Test (LITT) and Treadmill Test. Data are mean ± SD. *Statistical difference from pre-training at P<0.05, On-INT = On-court interval training, Off-INT group = Off-court interval training, LITT test = The Loughborough Intermittent Tennis Test
DISCUSSION

The present study has shown that both On-INT and Off-INT training are effective in improving aerobic fitness in young tennis players. However, the percentage of groundstroke accuracy and time to volitional fatigue increased only in the On-INT group. Therefore, these findings suggest that On-court interval training has more beneficial effects in terms of improving skilled tennis performance and tolerance to fatigue in young tennis players.

Interval training is a time efficient strategy to stimulate a number of skeletal muscle adaptations that are comparable to traditional endurance training (14). It has been demonstrated that interval-training is more effective than continuous training in improving VO₂ max (8,16,23). The data from the present study indicate that both interval training groups significantly increased VO₂ max post-training (On-INT group = 10.6% and Off-INT group = 6.6%) compared to baseline. Based on the VO₂ max data, it makes sense that interval training should be recommended for tennis players to improve their aerobic capacity. These findings are consistent with previous investigations that studied the effects of interval training on aerobic fitness in cross-country skiers (3.5%) (28), football players (5.8%) (12), and in well-trained cyclists (5.4%) (21).

While cardiovascular changes in elite tennis players are less pronounced than in endurance trained athletes (24) in response to training, VO₂ max has been shown to be markedly increased in world class tennis players compared with untrained individuals or recreational tennis players (24). High aerobic capacity is an important requirement in order to meet the high demands of athletes on the professional tennis circuit (18). The improvements in aerobic capacity following interval training may occur through increases in both oxygen delivery (i.e., increase in stroke volume) and/or oxygen utilization by active muscles (i.e., increases in capillarization and mitochondrial density) (2). Interval training has also been shown to increase the capacity of muscle to produce energy via oxidative metabolism (14).

The Loughborough Intermittent Tennis Test (LITT) has been shown to be effective in producing fatigue after tennis-specific maximal hitting (6,22,32). It has been shown that tennis performance deteriorates near or at volitional exhaustion (7). The findings from the present study demonstrate that tennis performance during the LITT test was improved in both On-INT and Off-INT groups. However, groundstroke accuracy performance was significantly improved in the On-INT group only, which is important since previous investigations have shown correlations between stroke quality and success in match play (13). Moreover, it has been reported that the number of errors made by a player during a tennis match is a good predictor of tennis performance (29). The improvements in groundstroke accuracy in the On-INT group, compared to the Off-INT group, may be due to the increase in time to volitional fatigue (on both the LITT test and treadmill test).

A possible reason as to why there was a reduction in the time to fatigue in the On-INT group only may be due to a higher energy expenditure (i.e., higher muscle activation during sliding movements and higher ground reaction forces with a higher rate of acceleration movement in On court interval training) (9). Another possible explanation may be attributed to neural adaptations and learning effects induced by the On-court interval training program (19). The On-INT group used a number of muscle groups during the acceleration and deceleration movements (e.g., biceps femoris, rectus femoris, hip adductors, iliopsoas) during training, which may have led to an enhanced coordination and agility for the tennis-specific maximal hitting during the LITT test (4-5,11). Therefore, our data suggest that the On-court interval training protocol, that included both technical and tactical tasks as part of a specific conditioning program, is appropriate to optimize cardiorespiratory fitness, skilled tennis performance, and tolerance to fatigue in competitive young tennis players.
CONCLUSIONS

While both the On-INT and Off-INT groups experienced beneficial effects on aerobic capacity, skilled tennis performance (groundstroke accuracy score and time to fatigue during the LITT test) was improved only in the On-INT group. Based on the data from the present study, we propose that On-INT is an effective training regimen for tennis players as shown by an improvement in aerobic fitness and skilled tennis performance. Therefore, tennis players should use On-court interval training as an additional conditioning program to achieve a high level of tennis performance during match play.

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