Tennis singles match play induces inspiratory muscle fatigue in female tennis players

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Abstract Inspiratory muscle fatigue (IMF) may limit exercise performance. It has been reported that IMF occurs after various exercises; however, it remains unclear whether IMF occurs after tennis singles match play. The purpose of this study was to test whether tennis singles match play induced IMF. Nine female college tennis players participated in this study. The players were paired in accordance with their skill level, and then played a singles match for an effective playing time (EPT) of 20 minutes. A portable autospirometer was used to measure the maximal inspiratory pressure (MIP) before and immediately after the match as an index of IMF. Heart rate and perceptual measurements were recorded after every 2.5 minutes of effective playing time. The total match duration in this study was 96 ± 8 minutes. Post-match MIP was significantly lower than pre-match MIP (103 ± 21 cmH₂O vs. 92 ± 22 cmH₂O, $p < 0.05$, effect size = 0.47), and the magnitude of the decrease in MIP was $10.0 \pm 9.7\%$. The present results show that IMF occurs after tennis singles match play in females.

Keywords : respiratory muscle, diaphragm, maximal inspiratory pressure, tennis

Introduction

Inspiratory muscle fatigue (IMF) occurs after various exercises such as marathon running¹⁾, triathlon participation²⁾, rowing³⁾, and swimming⁴⁾. It is considered that IMF may limit exercise performance^{5,6)}. Earlier research shows that the maximal inspiratory pressure (MIP) was significantly decreased immediately after 44.2 km of treadmill running ($77.4 \pm 1.8\%$ maximal oxygen uptake [$\dot{V}O_{2max}$]; mean time 208 ± 22 min) compared to the MIP before exercise⁷⁾, and was also decreased by 18% after the completion of a marathon race (42.2 km) compared to the pre-race MIP¹⁾. Furthermore, diaphragmatic fatigue was induced by cycling exercise to exhaustion at 95% $\dot{V}O_{2max}$ (mean time 14 ± 3 min) and 80% $\dot{V}O_{2max}$ (mean time 31 ± 8 min)⁸⁾. These previous studies suggest that IMF occurs after short-term high-intensity exercise (approximately 30 min) at $\geq 80\%$ $\dot{V}O_{2max}$ ⁸⁾ and after prolonged submaximal exercise (approximately 200 min) at 75–80% $\dot{V}O_{2max}$ ⁷⁾.

Tennis match play is characterized by intermittent exercise that alternates short bouts of high-intensity exercise and short recovery bouts, interrupted by several resting periods of longer duration⁹⁾. The typical length of a three-set tennis match is 90 minutes¹⁰⁾, and the effective playing time (EPT) (the proportion of match time spent in play) is 10–30%¹¹⁾. During a tennis match, the average oxygen uptake is 50% $\dot{V}O_{2max}$, and the average heart rate is 140–160

beats/minute¹¹⁾. However, the oxygen uptake and heart rate increase to approximately 80% $\dot{V}O_{2max}$ and 190–200 beats/minute, respectively, during phases of high activity such as long and fast rallies¹²⁾. Thus, a tennis match can be considered to be comprised of high-intensity, intermittent exercise for a prolonged duration.

Only a few studies have investigated the effects of intermittent exercise on IMF. One study found that IMF was not incurred after 16×6 -second intermittent cycling sprints¹³⁾. Furthermore, the MIP was not reduced by intermittent cycling sprint exercise at 90% $\dot{V}O_{2max}$ (seven $\times$ 1-minute sessions with 2-minute recovery intervals)¹⁴⁾. These previous findings suggest that intermittent sprint exercise provides sufficient time for the respiratory muscles to remove fatigue-inducing metabolites and recover oxygen debt¹³⁾. However, the entire duration of intermittent sprint exercise^{13,14)} is shorter than the typical length of a three-set tennis match. Thus, tennis match play is actually characterized as prolonged exercise, and may therefore induce IMF, as is observed after a marathon race¹⁾. In addition, as limb motion increases diaphragmatic activity¹⁵⁾ and intra-abdominal pressure¹⁶⁾, tennis-specific motions such as ground strokes and service may contribute to the occurrence of IMF. However, to the best of our knowledge, no study has investigated whether or not IMF is induced by intermittent sprint exercise for a prolonged duration, such as tennis match play.

The present study examined the MIP of females before and after a tennis singles match. We hypothesized that

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tennis would induce IMF in female players due to the tennis-specific physiological demands and tennis-specific motions. To test this hypothesis, we defined 20 minutes of EPT as the duration of a tennis match. This length of match time is equivalent to a typical three-set tennis match¹⁷⁾.

Materials and Methods

Participants. Nine female college tennis players participated in the study. The mean ($\pm$ standard deviation [SD]) participant characteristics were: age 20 ± 1 year, height 158 ± 4 cm, body weight 55 ± 4 kg, weekly training volume 25 ± 15 hours/week, and length of athletic career 12 ± 3 years. The participants had all played in an inter-scholastic and/or intercollegiate tennis tournament in the previous year. None of the participants had any history or clinical signs of cardiovascular or pulmonary disease. The participants were informed of the study purpose, requirements, and risks before providing written informed consent. The study was approved by the Human Subjects Committee of Chukyo University, Japan (approval number 2019-028), and all participants provided written informed consent prior to study commencement.

Experimental design. Participants played a singles tennis match on an outdoor hardcourt surface. All matches were played during autumn, with a mean wet bulb globe temperature of $22.7 \pm 4.4^\circ\text{C}$. Participants were paired in accordance with their skill level. On arrival at the tennis court, participants performed self-paced jogging and stretching as a warm-up for 20 minutes. After the warm-up, the pre-match body weight and MIP were measured. Participants then performed 10 minutes of tennis-specific warm-up, including rallies and serves. After the tennis-specific warm-up, the participants played a singles match for 20 minutes of EPT, as determined using the method of Périard et al.¹⁸⁾. To calculate the EPT, a stopwatch was used to measure the duration of each point, starting with the ball toss of the serve and ending when the ball had bounced twice or passed the opposing player. In case of a double fault, the start time for the point was recorded from the beginning of the second serve. Aces and double faults were recorded and normalized to the number of points¹⁸⁾. Participants had the opportunity to rest for 20 seconds between points, 90 seconds between change-overs, and 120 seconds between sets in accordance with the International Tennis Federation rules. Participants were permitted to ingest cold sports drinks (Pocari Sweat; Otsuka Pharmaceutical, Tokyo, Japan) ad libitum during the match. After the match, the post-match body weight and MIP were measured.

Maximal inspiratory pressure. The MIP was measured before the start of the match and immediately after the match using a handheld mouth pressure meter (AAM377;

Minato Medical Science, Osaka, Japan) connected to a portable autospirometer (AS-507; Minato Medical Science). Participants sat with their nose occluded during all MIP measurements. Participants were instructed to breathe out to residual volume and then inhale as hard and as quickly as possible to total lung capacity and sustain this inspiration for at least 1 second¹⁹⁾. More than five trials were completed for all measurements, and the average of the highest three measurements with less than 10% variability was used as the MIP value. The percentage pre- to post-match decrease in MIP was considered an index of the IMF¹⁹⁾.

Physiological and perceptual measurements. Heart rate was recorded every 5 seconds with a heart rate monitor (A300; Polar Electro, Kempele, Finland) and reported as the average per 2.5 minutes of EPT. The total sweat loss was calculated as: (pre-match body weight – post-match body weight) + the amount of drink ingested. The whole-body and dyspneic rating of perceived exertion (RPE)²⁰⁾ were recorded per 2.5 minutes of EPT; the RPE was subjectively graded by the participants, and ranged from 6 (“no exertion”) to 20 (“maximal exertion”).

Statistical analyses. Results are presented as mean $\pm$ standard deviation (SD). All statistical analyses were performed using SPSS version 23.0 software (IBM Corp., Armonk, NY). Paired t-tests were used to analyze the pre- and post-match MIP and body weight. Effect size (ES) was calculated based on Cohen’s d as small (0.2–0.5), moderate (0.5–0.8), or large (> 0.8)²¹⁾. Statistical significance was accepted at $p < 0.05$.

Results

Maximal inspiratory pressure. Fig. 1 shows the individual and pre- and post-match MIP values. The post-match MIP was significantly lower than the pre-match MIP (103 ± 21 cmH₂O vs. 92 ± 22 cmH₂O, $p < 0.05$, ES = 0.47: small). The magnitude of the decrease in MIP was $10.0 \pm 9.7\%$.

Body weight, fluid ingestion, total sweat loss. The pre- and post-match body weights did not significantly differ (55.6 ± 4.2 kg vs. 55.7 ± 3.9 kg). The volume of fluid ingested during the match was $1,003 \pm 278$ g, and the total sweat loss was $1,000 \pm 537$ g.

Heart rate, rating of perceived exertion. The changes in heart rate and RPE (whole-body and dyspneic) during the match (from 0 to 20 minutes of EPT) are presented in Table 1. The heart rate during the match was 153 ± 5 beats/minute. The whole-body and dyspneic RPE were 14 ± 1 and 14 ± 1 , respectively.

Discussion

The present study investigated whether 20 minutes of EPT in tennis singles match play induced IMF in female college tennis players. We hypothesized that IMF would be induced by singles tennis match play due to the tennis-specific physiological demands of intermittent sprint exercise for a prolonged duration, and tennis-specific motions such as ground strokes and service. The present results demonstrated that IMF did occur after tennis singles match play, and the magnitude of the decrease in MIP was $10.0 \pm 9.7\%$.

The MIP was significantly lower after the tennis match than before the tennis match (Fig. 1). According to earlier

Fig. 1 Maximal inspiratory pressure pre- and post-match (● = individual, ○ = mean $\pm$ SD, $n = 9$). *Significant difference vs. pre-match ($p < 0.05$).

research, the MIP was significantly decreased by 15.3% immediately after 44.2 km of treadmill running⁷⁾ and by 18% after the completion of a marathon race¹⁾. However, these previous studies focused on IMF after running exercise of prolonged duration (≥ 200 minutes), while the total match duration in the present study was only 96 ± 8 minutes. Thus, the decrease in IMF seen in the present study (10.0%) was less than that reported in the previous studies that evaluated the change in MIP after running exercise of prolonged duration.

The induction of IMF has not previously been reported after a short duration of intermittent sprint exercise, as the provision of rest time during intermittent exercise provides sufficient time for the respiratory muscles to remove fatigue-inducing metabolites and recover oxygen debt¹³⁾, and the diaphragm has a significantly greater ability to recover from fatigue compared to other muscle groups²²⁾. The present study attempted to recreate the typical intensity and duration of tennis match-play, as the mean heart rate (153 ± 5 beats/minute), RPE (14 ± 1), and total match duration (96 ± 8 minutes) are similar to values reported in a previous study^{11,12)}. Thus, the tennis-specific physiological demands of prolonged moderate-intensity exercise may have resulted in the development of IMF in the present study.

The diaphragm is the main muscle responsible for inspiration, but the diaphragm and intercostal muscles also contribute to the control and stabilization of posture in humans^{23,24)}. Electromyographic activity in the diaphragm occurs about 20 milliseconds before the onset of electromyographic activity in the deltoids during rapid flexion of the shoulder, and the increase in mean transdiaphragmatic pressure associated with rapid arm flexion is 13.5 cmH₂O¹⁵⁾. Furthermore, running increases the vertical load on the body, which induces increased intra-abdominal pressure¹⁶⁾. Therefore, the increased diaphragmatic activity due to tennis-specific motions (e.g., ground strokes and service) may explain the development of IMF after tennis match play, even though the EPT was only 20 minutes in the present study. In addition, the accessory muscles used in breathing are also likely to be heavily engaged during tennis-specific motions, which may contribute to the development of IMF.

All participants in the present study were female college tennis players. Females have smaller airways for a given lung volume than men, and higher progesterone levels,

Table 1. The changes in the heart rate and RPE during the match ($n = 9$).

	0 min	2.5 min	5 min	7.5 min	10 min	12.5 min	15 min	17.5 min	20 min
heart rate (beats/min)	108 $\pm$ 9	147 $\pm$ 14	157 $\pm$ 12	154 $\pm$ 13	144 $\pm$ 12	155 $\pm$ 8	154 $\pm$ 11	149 $\pm$ 15	161 $\pm$ 10
RPE whole-body		13 $\pm$ 1	13 $\pm$ 1	13 $\pm$ 1	13 $\pm$ 1	14 $\pm$ 1	14 $\pm$ 1	14 $\pm$ 1	15 $\pm$ 2
RPE dyspneic		13 $\pm$ 2	13 $\pm$ 1	13 $\pm$ 1	13 $\pm$ 1	14 $\pm$ 1	14 $\pm$ 1	14 $\pm$ 1	14 $\pm$ 2

Data are presented as mean $\pm$ SD. RPE = rating of perceived exertion.

that may contribute to mechanical flow limitations and greater ventilatory effort during intensive exercise²⁵⁻²⁷). Therefore, it is possible that women experience greater IMF after tennis match-play than men. However, although there are gender differences in pulmonary function during exercise, the diaphragm is more resistant to fatigue in women than men²⁸), as women use a smaller fraction of their maximal exercise ventilatory capacity during exercise than men²⁸). Further research is needed to compare the effects of gender differences on IMF in tennis.

Tennis-specific endurance evaluated using the Hit and Turn Tennis Test²⁹) is strongly correlated with tennis performance (ranking) in female players, and significantly differs between national and regional selected players³⁰). Thus, tennis-specific endurance is an important factor in being a successful tennis player. Tennis-specific endurance reportedly improves after 6 weeks of intermittent sprint training³¹). Therefore, it has been recommended that tennis players perform intermittent sprint training as a time-efficient stimulus for enhancing tennis-specific aerobic fitness, enabling the players to spend more time doing on-court practice³¹). Previous studies have also shown that 6 weeks of inspiratory muscle training improves high-intensity, intermittent running performance in repetitive sprints athletes³²). Although it is difficult to recommend a single type of training that will improve all of the factors responsible for performance in tennis, these previous studies suggest that repeated sprint training combined with inspiratory muscle training may more substantially improve tennis-specific endurance compared to repeated sprint training alone. The present study found the occurrence of IMF after the tennis match, which suggests that tennis players may benefit from inspiratory muscle training. Further research is needed to clarify the effects of inspiratory muscle training on tennis-specific endurance.

The present study had several limitations. First, the increased progesterone levels during the luteal phase of the menstrual cycle are reportedly associated with increased ventilatory drive²⁵). However, the effects of the menstrual cycle on IMF are unclear, as the menstrual stage was not reported in the present study. Second, the present study was implemented in autumn, while major tennis tournaments such as the US Open and Australian Open are held in summer. Further study is needed to clarify the effect of environmental temperature, as IMF is more likely to occur when the environmental temperature is higher compared to a thermo-neutral environmental temperature³³). Regarding this study, the fluid intake and total sweat loss suggest that the fluid intake was adequate during the match, and so the hydration status likely had no influence on the IMF.

Conclusion

The present study showed that IMF occurs in female tennis players after 20 minutes of EPT in tennis singles

match play.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Author Contributions

Experiment conception and design: JO and JK. Experiment implementation: JO, JK and RI. Data analysis: JO and JK. Paper composition: TO, TM and YU. Analyzing and writing advisory: JO and TO. All authors approved the final version of the manuscript.

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