Article Classification:
Original article

THE EFFECT OF SIMULATED TENNIS TOURNAMENT PLAY ON SELECTED PERFORMANCE MEASURES

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OPEN ACCESS

Submitted: 10 October 2024
Accepted: 4 March 2025
Published: 14 July 2025

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Cite this article as:
Scott, A., Wilson, M., Cabarkapa, D., Fry, A., Fry, M. (2025). The effect of simulated tennis tournament play on selected performance measure. *Journal of Applied Sports Sciences*, 9(1), pp. 49 - 64.
DOI: *10.37393/JASS.2025.09.01.5*

ABSTRACT

Tennis is a sport that requires a mix of both anaerobic and aerobic energy systems. Many studies have quantified performance metrics of tennis populations related to sprinting, jumping, aerobic endurance, and other metrics, but no studies have quantified performance and endocrine measures during live gameplay. The purpose of this study was to analyze the effects of multiple tennis matches on selected measures of performance and physiological responses in male adult tennis players. Eleven amateur male adult tennis players participated in five 70-minute (3 single and 2 doubles) matches with ~30 minutes of rest between matches. Testing included: agility, 20-yard sprint times, service speed, dominant hand grip strength, vertical jump height (VJH), peak power derived from jump height (PPj), mean power derived from jump height (MPj), and performance on a 10-sec modified Wingate test which resulted in the determination of peak power (PP) and mean power (MP). Serum concentrations of cortisol, testosterone, IgA, IgM, and IgG were also collected. Results of repeated measured ANOVA ($p < .05$) indicated that (mean ± SE) agility (13.17 ± 0.68-10.41 ± 0.24 sec), VJH (45.95 ± 2.59-44.91 ± 2.18 cm), PPj (7608.47 ± 43.90-7531.50 ± 119.79 Watts), MPj (1460.84 ± 54.42-1430.73 ± 48.75 Watts), PP (949.55 ± 30.85-783.32 ± 27.99 Watts) and MP (823.61 ± 27.77-783.32 ± 30.36 Watts) significantly decreased by the end of the simulated tournament. Results suggest that there is a significant demand for short-term aerobic power and capacity after playing multiple tennis matches. Therefore, training programs need to be adopted by amateur male adult tennis players to meet these demands.

Keywords: *tennis, anaerobic capacity, training, fatigue, biomarkers, power*

INTRODUCTION

Tennis is a world-renowned sport played by almost all ages. Tennis requires running at several different intensities, accelerations, decelerations, turns, strokes, speed, and other multidirectional movements. Those who play the sport are exposed to short bursts of high-intensity exercise intermingled with periods of low-intensity activity over a period of time that can last anywhere between 1 to 5 hours (López-Samanes et al., 2018). The duration of a rally in a match varies substantially based on a multitude of factors, such as surface, environment, strategy, and level of play. The average rally time in a match can be more than 15 seconds when players are hitting from the baseline, and less than 5 seconds during times players attack the net (serve-volley) (Bernardi et al., 2002). Similarly, most high-level matches have rally durations ranging from 3 to 15 seconds, consisting of work-to-rest ratios between 1:2 and 1:5 (Kovacs, 2006). While a point in tennis may last 4-10 seconds, players have a short recovery till the start of the next point (20 seconds) (Pluim, 2004). Since the main energy system being used is the ATP-CP system, tennis players still must have a strong aerobic energy system to allow for recovery faster when expressing anaerobic power through movements such as accelerations, decelerations, changes of direction, and groundstrokes (König et al., 2001; Bishop et al., 2011; Kilit et al., 2018). These studies suggest that the ATP-CP system may be taxed during a single point in tennis. While it is likely this system has the ability to completely recover between points, to what extent the metabolic system is depleted throughout the course of a prolonged (3-4 hour) match and/or multiple matches in one day is unknown. These periods of repeated high-intensity activity may cause anaerobic fatigue, perhaps hindering a tennis player's ability to perform.

A number of studies have focused on the physiological demands of a tennis match, investigating various factors such as heart rate (Baiget et al., 2014; Fernandez-Fernandez et al., 2009; Hornery, Farrow & Mujika, 2007), maximum oxygen uptake (Fernandez-Fernandez et al., 2009; Smekal et al., 2001), blood lactate concentration (Martin et al., 2011; Mendez-Villanueva et al., 2007; Smekal et al., 2001), and responses to match play (Fernandez-Fernandez et al., 2009; Kilit et al., 2016; Ojala & Häkkinen, 2013) in order to understand how different aspects of performance measures play a role in athletic development of tennis players at various levels. Other studies have also focused on jumping characteristics (Ayala et al., 2016; Bencke et al., 2002; Girard & Millet, 2009; Kilit & Arslan, 2018; Kraemer et al., 2003; Ulbricht et al., 2016; Yaprak, 2020). Most of these studies either focus on single bouts of tennis play that last anywhere from 1-3 hours or on simulating a tournament scenario in which games are played during consecutive days. Most amateur tennis players have the opportunity to participate in local, sectional, and national tournaments where each player has the option to enter multiple events (e.g., singles, doubles, mixed doubles, etc.). It is not uncommon for players to play multiple matches in a single day. In fact, the United States Tennis Association (USTA) regulations, which dictate the number of matches players may participate in during each day of tennis play, allow a player to theoretically play two singles matches or three doubles matches in a single day (United States Tennis Association, 2023). Some matches may last as long as 3-4 hours. It is currently unclear whether there are any acute performance decrements in amateur tennis players when participating in multiple matches lasting over five hours in duration. In the case that match play does continue for multiple hours, players must be well rested, as the timing of match play has been found to influence performance outcomes in male tennis players (Turner et al., 2023).

Speed and agility are important attributes for tennis players. As a constantly changing game where every shot the opponent hits has different velocities, spins, and can land in many different parts of the court, tennis players need to rapidly accelerate/decelerate and change direction of motion to respond to the opponent's offensive strategy appropriately. According to Galé-Ansodi, (2014), about 90% of the distance covered by tennis players comes in the form of accelerations and decelerations. Speed is also important to a tennis player due to the court size that must be covered. Whiteside & Reid (2017) found that male tennis players participating in the Australian Open tournament spent 33% of the total distance covered over a span of 4 rounds, at an intensity faster than 3 m/s. Repeat Sprinting Ability (RSA) has also been tested in tennis players in both hypoxic and non-hypoxic environments. Brechbuhl et al. (2018) found that when training in a hypoxic environment, the RSA of 20 competitive tennis players improved total time to exhaustion in a tennis-specific aerobic test while improving technical performance and ball accuracy. While speed is important to the success of tennis players, it may be negatively affected as match play continues. For example, Giovannini (2015) investigated RSA in junior tennis players. Results indicated a 10% decrease in RSA following a 90-minute match (Giovannini, 2015). Gallo-Salazar et al. (2017) examined the combination of speed and agility by utilizing a 5-0-5 agility test. The results identified 4.6% and 4.2% slower times in the dominant and non-dominant 5-0-5 agility test following two simulated tennis matches. Both studies suggest performance decrements in speed and agility after prolonged tennis play.

Another important performance aspect that tends to be overlooked is racket grip. According to Hennig (2007), vibrations and shocks are transferred to the arm whenever a tennis ball contacts the racket. In fact, Hennig (2007) suggests that racket oscillations between 80 and 200 Hz contribute to a common injury called tennis elbow. The same study concluded that vibration magnitude directly correlates to the spot where the ball hits the racket (Hennig, 2007). For example, off center ball contact with the racket results in roughly three times greater magnitudes in vibration than center ball contact (Hennig, 2007). A tight grip will prevent the racket head from straying from its intended path due to high angular speeds and torques (Behn, 1988). It has also been noted that a more vertical orientation of the racket allows for greater ball topspin angular velocity (Kwon et al., 2017). Previous research has found that a firmer grip may reduce the mechanical load applied to the upper limb during the swing without affecting ball velocity and help avoid muscle fatigue and soreness resulting from prolonged tennis play (Grabiner et al., 1983; Hennig, 2007). In addition, while the location of the applied grip force may vary, the net force during the serving motion appears to remain consistent (Lucki & Nicolay, 2007). Kramer & Knudson (1992) found that across 30 maximal grip strength trials, max grip strength stayed consistent in collegiate tennis players. However, the influence of fatigue on changes in grip strength over an extended period of time (i.e., tennis match, tournament) remains understudied.

As tennis is an intermittent activity involving a high physiological load, hormonal changes may result due to the intensity of the sport across the duration of a match play. Endocrine and immune markers may be good tools for determining how individuals acutely respond to the training loads. According to Gomez and colleagues (2011), salivary cortisol levels increased in elite tennis players after a 197-minute match. The same study also reported elevations in heart rate and perception of effort following each set, suggesting a progressive increase in stress and fatigue throughout a single match. Ojala & Hakkinen (2013) found similar findings when examining serum cortisol sampled over a three-day tennis tournament, alongside notable elevations in serum testosterone concentrations. Interestingly, the outcome of the tennis match could not be predicted based on analyzing testosterone, cortisol, and their ratio (Ojala & Hakkinen, 2013). Moreover, an increase in immunoglobulin A (IgA) has been associated with the onset of fatigue (Trochimiak & Hübner-Woźniak, 2012).

Other indicators of fatigue and metabolic stress can include blood lactate and immunoglobulin A (IgA) levels. Research focusing on blood lactate levels (Gomes et al., 2011) have noted that concentrations are influenced by the playing situation or characteristics of the match (i.e., service or return game and rally duration). For example, Mendez-Villanueva et al. (2007) reported that blood lactate levels were higher in serving individuals than those receiving (4.4–4.6 mmol $\bullet L^{-1}$ and 3.0–3.2 mmol $\bullet L^{-1}$), respectively. Contrary to this, no significant differences were found between serve and return games for blood lactate concentrations during a match (Fernandez-Fernandez et al., 2007; Fernandez-Fernandez et al., 2008; Smekal et al., 2001). Other studies (Fenter et al., 2017; Kovacs, 2006) have reported relatively small to no elevation in lactate concentration after a match but have attributed this to a sufficient recovery period between points to buffer the lactate. While there is very limited research on serum IgA, it is well-known that intensive and repetitive bouts of exercise can cause a decrease in salivary IgA levels (Trochimiak & Hubner-Wozniak, 2012). Therefore, with tennis being an intermittent sport in which players are required to perform repetitive bouts of high-intensity exercise, it is possible that IgA levels would decrease, negatively influencing recovery from multiple matches within a single day.

Although much research has focused on the game of tennis, most studies have examined narrow aspects of single-match play. Several studies have simulated tournament play with matches played over three or four consecutive days. However, there is limited research on the impact of playing multiple matches in a single day on performance variables such as speed, agility, power, grip strength, and endocrine and immune markers (Colomar et al., 2022). It is not unusual for tennis players to participate in 2-3 matches in a day in local or regional tournament play. With that understanding, quantifying the aforementioned performance variables' response to multiple matches in a single day can help us understand how those variables change throughout a one-day tournament and how training can help meet those demands. Therefore, the purpose of this study was to determine the impact that 3 singles and 2 doubles matches in a single day of simulated tournament play have on performance variables and hormonal and immune responses in adult tennis players. To investigate this purpose, a simulated tennis tournament was performed with ongoing performance measures being collected on players prior to, during, and after the completion of the match. The design of this study was a quasi-experimental time series design. There was no randomization, as there was no control group, with the aim of looking at the game intervention between each test. The aim was to analyze the effects of various performance effects during a simulated tennis tournament. As a result, additional insight can be provided concerning the training and conditioning requirements necessary to prepare for tournament play involving multiple matches in a single day.

METHODS

Subjects

Twelve healthy, recreationally active male tennis players volunteered to participate in the present study. All players had a 3.5-4.0 skill rating on the universal tennis scale, had prior tournament experience, and participated on average in six hours of weekly tennis play. One subject had to withdraw due to a non-study-related injury, and a stand-by player was used as his replacement, but data was not collected on that individual. Complete data were collected on eleven remaining participants ($\bar{x} \pm SD$; age = 27.6 ± 4.1 years, weight= 81.7 ± 6.9 kg). All testing procedures performed in this study were previously approved by the University's Institutional Review Board, and all subjects signed an informed consent form.

Procedures

All players were separated into groups of four and asked to report on an assigned test day. On each day, a simulated round-robin tennis tournament consisting of five 75-minute matches (3 singles and 2 doubles) was held on an indoor playing surface for the three or four players assigned to that day. All matches started at 0800 hours and were limited to 75 minutes in duration with 90-second changeovers. A 30-minute break was allowed between each match. Subjects were allowed to drink and eat ad libitum during the testing day. Performance and physiological testing were conducted at six different time points throughout the simulated tournament play. The first testing trial was administered before the onset of the tournament (i.e., Baseline), followed by one testing trial after each match played during that day (i.e., Match 1-5). Environmental conditions (e.g., temperature, relative humidity) were recorded twice daily and remained consistent across all testing procedures. Subjects were asked to approach their tournament day as if it were a real tournament and to play as hard as possible throughout each match. To help stimulate competitive play, monetary compensation was awarded based on the number of games won instead of the traditional method of scoring sets. Play was modified so that the total number of games won and lost were recorded. This allowed for an accumulation of games won/lost throughout the course of the day so that a winning percentage could be calculated for each player.

Performance Variables

One week prior to the subjects' tournament date, players were tested in the laboratory for body weight, skinfold measurements via 7-site skinfolds (Jackson and Pollock 1978) and a sub-maximal cycle ergometer test (Kenney et al., 1995). A familiarization session was performed for all performance tests, except for the tennis serve. The order of the test battery was chosen based on the *American College of Sports Medicine* guidelines for exercise testing and prescription, starting with less and progressing to more fatiguing anaerobic tests (Liguori, 2020). Also, the procedures and their order remained consistent across each of the upcoming six testing trials (i.e., Baseline – Match 5) See Figure 1. The tests performed included the following:

1. *Serve Velocity:* Serve velocity was measured at baseline by a radar gun (Country Technology Inc., Gays Mills, WI, USA). Radar accuracy was verified with a certified tuning fork. The radar gun was placed on the baseline mid-way between the center mark and the singles sideline and was set on constant mode. The service speed was clocked as the ball crossed the net. Subjects were asked to serve first serves only with maximal velocity toward the radar gun. The average of the first three in-bounds serves were recorded.
2. *Dominant Hand Grip Strength:* Grip strength was assessed using a hand grip dynamometer (Country Technology Inc., Gays Mills, WI, USA), and the players were instructed to use their dominant hand. Calibration of the dynamometer was performed and verified by the manufacturer. The instructions for the grip strength assessment were given based on the standardized protocol established by Montoye and Lamphiear (1977).
3. *Vertical Jump:* This test involved three trials in which each subject started from a standing position and was allowed to use a countermovement motion. While standing in a stationary position, the subject was instructed to jump vertically as high as possible using a full arm swing for propulsion. Jump height was obtained using a Vertec (Sports Imports, Columbus, OH, USA) vertical jump tester. Self-paced rest intervals were allowed between each jump trial.
4. *Hexagon Agility:* This test was used to assess the ability of a player to change direction while maintaining sound balance. A Hexagon shape was made on the floor by using tape to mark each side 24" long side (60.5 cm). The test measured the time it

took a player to complete three full revolutions by jumping in and out of the six-sided shape, being sure to jump over each of the six sides for each revolution. To ensure consistency of the measurements, the same research assistant recorded all times to the nearest second (0.01) using a digital stopwatch.

5. *20-Yard Sprint:* This test was used to evaluate the speed and ability of a player to accelerate over a 20-yard (18.3m) distance starting from a stationary position. The subject started in a sprinter's "ready" position (i.e., both hands on the starting line, hip raised to a position slightly higher than shoulders, front knee bent to approximately 90 degrees, and back knee bent to approximately 120 degrees). When the subject moved his hand, the stopwatch was started and then stopped again once the subject crossed the pre-determined line. To ensure consistency of the measurements, the same research assistant recorded all sprint times to the nearest second (0.01) using a digital stopwatch.
6. *Modified Wingate Anaerobic Test:* An all-out sprint on an electronically braked cycle ergometer (Monark 928 G3, Vansbro, Sweden) for 10 seconds was used to test for anaerobic power. This test was a modified version of the original Wingate anaerobic test (Bar-Or, 1987), and the 10-second cycling interval was deliberately chosen to correspond to a typical duration of a point in a regular tennis match (Kovacs, 2006). Resistance was set at 5.2 J/rev/kg of the subject's body weight, and all calibration checks were carried out according to the manufacturer's specifications.

Endocrine and Immune Measures

Upon arriving at the tennis facility, before performing any performance testing, each subject sat quietly for 10 minutes prior to venipuncture blood sampling from an antecubital vein. Samples were collected in a vacutainer following universal precautions and were processed for later analysis. Samples were also collected 5 minutes after each match ended and prior to performance testing protocols, for a total of six samples for each subject (i.e., Baseline – Match 5). Samples were stored on dry ice until placed in a -80° C freezer at the end of the day. Subsequent analyses were performed via ELISA for total Testosterone (T) and Cortisol (C). (Diagnostic Labs, Webster, TX, USA), and via spectrophotometry for IgA, IgM, and IgG (Sigma Diagnostics, Saint Louis, MO, USA). All samples were analyzed in duplicate and all samples for a subject were analyzed in the same assay. Intra-assay and inter-assay variances for the hormones were CV $\leq$ 2.9% and 4.4%, for T and C, respectively. Intra-assay variances for the immunoglobulins were all CV $\leq$ 3.1%. Standard curves for all assays exhibited $r^2 \geq 0.98$.

Simulated Tennis Tournament

On the tournament day, subjects arrived at the testing facility at 0700 hrs for baseline measures on the test battery. A 10-minute dynamic warm-up followed shortly after testing, with staggered starting times for each match. Matches were timed to 70 minutes in length with 90-second changeovers. Approximately 30 minutes were allowed between matches. Subjects were allowed to drink and eat ad libitum during the testing day. Figure 1 depicts the time course of events each subject underwent, including the order of tests in each test battery. The order of test administration was chosen based on recommendations of testing order for strength and conditioning (Kenney et al., 1995) to minimize the effect of fatigue. Familiarization tests were administered 1 week prior to the participants assigned to the tournament day. A baseline test was administered at the start of the day, followed by 5 trials, one following each of the 5 matches played that day.

Statistical Analysis

Descriptive statistics means, and standard errors ($\bar{x}$ ± SE) were calculated for each dependent variable. A repeated measures analysis of variance (ANOVA) with Tukey post-hoc adjustments was used to compare significant differences for each dependent variable across multiple testing trials (i.e., Baseline – Match 5). Statistical significance was set *a priori* to $p < .05$. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

RESULTS

Baseline trials were measured in the morning on the day of tennis play. Trials 1, 2, and 3 followed the first three singles matches, while trials 4 and 5 followed the two doubles matches. Tables 1 and 2 represent the changes throughout the day for the measured performance variables. A significant difference was found in the modified-Wingate variables, in which peak power decreased after the second doubles match (Trial 5) and mean power decreased at the end of the first doubles match (Trial 4) from baseline. No significant changes in performance scores were noted for the 20-yard sprint, service velocity, grip strength, and body weight (Table 1). Although service velocity did decrease 6% from the end of the first singles match (Trial 1) until the end of the three singles matches (Trial 3), statistical significance did not occur. Significant improvements in Hexagon Agility performance were observed between Baseline and Match 1-5 and between Match 1 and Match 2-5 (Table 1). Compared to Baseline, jump height, jump mean, peak power, and cycle mean, and peak power experienced a significant decrease after Matches 4 and 5 (Table 2). Peak power and mean power, measured through the vertical jump test, decreased significantly by the end of the first doubles match and the end of the third singles match, respectively. Jump height decreased after the first singles match (Trial 1) and was found to be significantly lower than baseline following the two doubles matches (Trials 4 and 5).

Table 3 reports the endocrine and immune variables analyzed. Although serum testosterone and cortisol concentrations seemed to decrease progressively throughout the six trials, they did not reach statistical significance. The T/C ratio also indicated no significant difference following each trial. Immune serum concentrations (IgA, IgM, and IgG) also showed no significant differences.

Table 1. *Testing scores ($\bar{x}$ ± SE) over six testing trials for hexagon agility, 20-yard (18.3m) sprint, service velocity, grip strength, and body weight.*

	Hexagon Agility (sec)	20-yard Sprint (sec)	Service Velocity (m/s)	Grip Strength (kg)	Body Weight (kg)
Baseline	13.17 ± 0.68	3.29 ± 0.06	N/A	52. 64 ± 1.89	72.27 ± 2.09
Trial 1	11.55 ± 0.45*	3.21 ± 0.06	30.76 ± 1.17	52.09 ± 1.56	72.50 ± 2.11
Trial 2	10.77 ± 0.36*†	3.27 ± 0.07	29.87 ± 1.41	52.09 ± 2.09	72.27 ± 2.16
Trial 3	10.63 ± 0.34*†	3.27 ± 0.06	29.00 ± 1.20	50.45 ± 2.38	71.25 ± 2.13
Trial 4	10.70 ± 0.36*†	3.31 ± 0.09	29.42 ± 1.35	51.36 ± 2.34	71.59 ± 2.14
Trial 5	10.41 ± 0.24*†	3.35 ± 0.06	29.80 ± 1.15	51.27 ± 2.26	71.93 ± 2.11

** significant difference from baseline ($p < .05$)*

† significant difference from Trial 1 Singles ($p < .05$)

Table 2. *Testing scores ($\bar{x}$ ± SE) over six trials for jump height, jump peak power (Harman formula), jump average power (Lewis formula), cyclic mean power, and cyclic peak power.*

	Jump Height (cm)	Jump Mean Power (W)	Jump Peak Power (W)	Cycle Mean Power (W)	Cycle Peak Power (W)
Base	45.95 ± 2.59	1460.8 ± 54.4	7608.5 ± 143.2	949.6 ± 30.9	823.6 ± 27.8
Trial 1	46.86 ± 2.38	1476.1 ± 53.1	7658.9 ± 134.0	965.8 ± 35.6	838.9 ± 30.6*
Trial 2	46.08 ± 2.51	1457.8 ± 57.7	7607.1 ± 145.5	966.0 ± 31.9	826.4 ± 33.3
Trial 3	45.72 ± 2.86	1445.5 ± 54.6	7577.8 ± 133.4	940.5 ± 31.8	802.2 ± 31.2
Trial 4	45.26 ± 2.21†	1439.0 ± 52.1*†	7554.4 ± 125.9*†	840.7 ± 31.8*†	792.5 ± 29.6*†
Trial 5	44.91 ± 2.18 †	1430.7 ± 48.8*†	7531.5 ± 119.8*†	825.5 ± 27.9*†	783.3 ± 30.4*†

** significant difference from baseline ($p < .05$)*

† significant difference from Trial 1 Singles ($p < .05$)

Table 3. *Testosterone (T; nmol·L^{-1}), Cortisol (C; nmol·L^{-1}), Testosterone-to-Cortisol Ratio (T/C), Immunoglobulin A (IgA; g·L^{-1}), Immunoglobulin M (IgA; g·L^{-1}), and Immunoglobulin G (IgA; g·L^{-1}) over six testing trials ($\bar{x}$ ± SE). No Significant differences were found for any variable across time.*

	T	C	T/C
Baseline	18.6 ± 1.6	799 ± 76	0.028 ± 0.005
Trial 1	17.6 ± 2.0	787 ± 161	0.029 ± 0.005
Trial 2	15.8 ± 2.6	566 ± 124	0.035 ± 0.008
Trial 3	17.3 ± 4.0	733 ± 147	0.031 ± 0.007
Trial 4	16.4 ± 4.8	670 ± 108	0.024 ± 0.008
Trial 5	11.6 ± 2.3	581 ± 88	0.024 ± 0.004
	IgA	**IgM**	**IgG**
Baseline	1.715 ± 0.368	0.586 ± 0.201	17.54 ± 6.46
Trial 1	1.757 ± 0.338	0.659 ± 0.202	19.21 ± 7.14
Trial 2	2.366 ± 0.745	0.728 ± 0.187	12.82 ± 4.36
Trial 3	2.584 ± 0.732	0.788 ± 0.157	22.51 ± 13.08
Trial 4	1.674 ± 0.243	1.034 ± 0.202	8.85 ± 1.20
Trial 5	3.131 ± 0.768	0.882 ± 0.109	9.85 ± 2.17

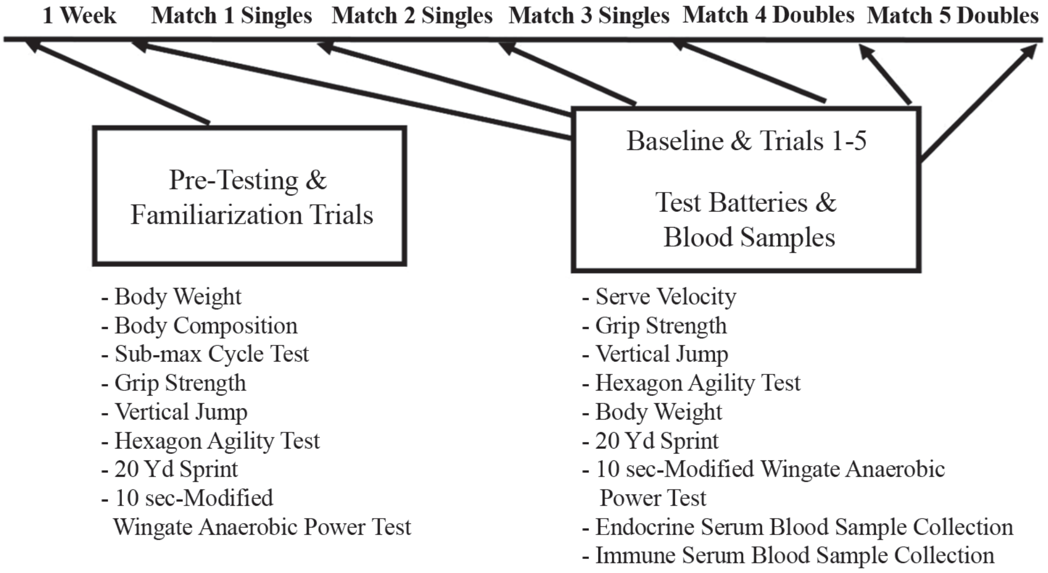

Figure 1. *Study Timeline. Depiction of the time course of events each subject underwent, including the order of tests in the test battery.*

DISCUSSION

The purpose of this study was to investigate the impact of playing three singles, and two doubles simulated tennis matches on performance and physiological responses in adult male tennis players. To the best of our knowledge, this study is the first to examine the impact of playing consecutive matches in a single day, which is frequently experienced in many tournaments for amateur tennis players. The main findings of this study indicated a progressive decrease in performance measures such as vertical jump height, peak power, and mean power from the first match to the last match. While those performance variables decreased, data indicated that agility amongst the participants gradually improved after each match. Grip strength, sprint time, and service velocity did not change from match to match. Physiological responses, such as endocrine and immune responses, remained relatively stable from match to match, suggesting that there was no significant difference in acute concentrations of endocrine and immune markers after playing consecutive matches.

In this study, the Wingate test was modified to last 10 seconds in order to best simulate the average rally duration in a tennis match. (Bar-Or, 1987). This test provided the most revealing results in the present study. Participants exhibited a significant decrease in peak power generated during the 10-second sprint after 3 hours and 30 minutes of play (after the third singles match). Peak power consequently continued to decrease after the next 2 hours and 20 minutes of doubles play. A significant decrease in mean power was also observed in a similar trend, suggesting a decrease in anaerobic capacity. A comparable decrease in power was observed when vertical jump performance was converted to peak power via the Harman formula (Beiget et al., 2014). A recent study found that upper extremity Maximum Voluntary Isometric Contractions (MVC) along with Peak Rate of Force Development (PRFD), RFD at different time intervals via an Isometric Mid-Thigh Pull (IMTP), and serve velocity were unaltered after an 80-minute simulated match in youth tennis players (Colomar et al., 2022). Despite the study not obtaining isometric strength values, understanding these variables' relation to force production and how they may alter after match play is important for understanding how training and competition affect an athlete's ability to produce force. In sports that require quick bursts of speed, like tennis, success comes from leg power and anaerobic capacity. If two players have similar skills and technical abilities, the player who can generate more power during extended play will outperform the other (Zupan et al., 2009). Therefore, a loss of peak power generated or a decrease in lower body mean power may affect efficient shot production, which could be the difference between losing a point, game, set, or match. Results suggest that training & conditioning programs utilized by adult amateur tennis players should emphasize maximal power and power-endurance training (Fernandez-Fernandez, Ulbricht, and Ferrauti, 2014).

A surprising performance parameter that changed significantly throughout the day was the hexagon agility test. Data revealed that players performed better as the day progressed. This was in contrast with the findings of Gallo-Salazar et al. (2017) and Giovannini (2015) who found a significant decrease in agility times following simulated tennis matches. The hexagon agility test was initially used by the UTSA as a screening tool for junior tennis players (Roetert et al., 1992). It was apparent that even though multiple familiarizations were administered on this test in this study, subjects may still have been experiencing improved motor ability related to the learning effect. While the hexagon agility test may be a good predictor of agility and tennis ability, it may not necessarily be a good test for determining changes in agility unless players are thoroughly familiarized.

In various studies focusing on the physical profiles of tennis players, sprint tests are commonly used to evaluate possible fatigue and recovery efficiency following a match. Giovanni (2015), for example, found a decrease in repeated sprint performance following a tennis match. Similar results were reported by Reid & Duffield (2014) as well. Contrary to these reports, the participants in this study did not show a significant change in sprint time from match to match but remained relatively consistent throughout the day. For future research, electronic timing gates should offer a higher degree of reliability and accuracy than recording time via a stopwatch. Split times should also be considered in which 5- and 10-meter times should be recorded, as well as the use of technology to assess first step speed. According to Fernandez-Fernandez et al. (2014), the first 5 meters is the best way to measure first-step quickness, an essential attribute to the success of tennis players, whereas the remaining 10 to 15 meters is best utilized to measure acceleration ability. It is possible that measuring the split times may provide a more accurate reading of fatigue following a match.

Grip strength is extremely important during tennis play to ensure solid contact with the ball in flight (Kwon et al., 2017). Greater grip strength has also been important in preventing possible injuries associated with tennis elbow (Hennig, 2007). As the subjects in this study continued throughout five consecutive matches consisting of over five hours of play, dominant hand grip strength did not change. This supports the Kramer & Knudson (1992) study that suggested tennis players seem to be resilient to grip fatigue that is often seen with untrained subjects.

Serve velocity did decrease by 6%, though not statistically significant throughout the singles matches (3 hours of 30 minutes of play). However, as these subjects progressed through doubles play, serve velocity did “recuperate” somewhat. This recuperation can most likely be attributed to the number of times per match each player was forced to serve, which is approximately half as many serves during doubles play as during singles play.

Previous studies have indicated that stress via training can modulate the secretion of stress hormones. Therefore, it would be expected that an increase in hormonal concentrations, such as cortisol and testosterone, would follow that trend. Gomes et al. (2011) reported a 25% increase in salivary cortisol concentrations after a 197-minute tennis match. However, the cortisol concentrations in this study did not increase similarly but instead seemed to decrease as each match went on. Hill et al. (2008) suggested that low-intensity exercise, 40% of maximal oxygen uptake, does not increase cortisol levels but reduces the levels, whereas moderate to high-intensity exercise provokes a rise in cortisol levels. It is possible that the intensity of the matches in this study was performed at a lower intensity compared to the match played in Gomes et al. (2011). Similarly, there was no significant difference in testosterone concentrations between matches in this study. These results differed from those of Ojala & Häkkinen (2013), who reported higher serum testosterone concentrations following a prolonged 3-hour tennis match compared to baseline concentrations.

It is widely accepted that strenuous bouts of exercise are associated with tissue damage, in which an innate immune and inflammatory response occurs. However, the exact effect of a single bout of exercise on immune competency and regulation remains controversial (Campbell and Turner, 2018). Some studies have suggested that prolonged intense exercise decreases immunoglobulin concentrations, ultimately weakening the immune system (Hejazi & Hosseini, 2012; Onuegbu et al., 2015), whereas shorter bouts of moderate to low-intensity exercise increase the levels, thus enhancing the immune system (Nieman & Wentz, 2019). Since this study involved prolonged exercise with bouts of high-intensity movements, one might expect to see immunoglobulin levels decrease. However, similarly to the endocrine response, the immune response regarding IgA, IgM, and IgG did not significantly change after each match in this study but was somewhat sporadic. While various studies look at the influence of exercise intensity and volume on immunoglobulin responses, there is limited data on this response following a tennis match. Therefore, future research should continue to focus on the immune responses after participating in a tennis match.

No changes were observed in body weight in the first three matches. Subsequent minor non-statistically significant increases in body weight can be attributed to food intake after singles play. Maintaining body weight is likely linked to adequate fluid consumption and a relatively comfortable playing environment (Ambient temperature = 16.7°C, relative humidity = 44%). However, during long matches, caution should be followed when tennis occurs in warmer conditions. In hot environmental conditions, players have recorded high sweat rates (1.0-2.5 $L \cdot h^{-1}$), resulting in a 1-2% decrease in body weight (Périard & Racinais, 2019). Therefore, steps should be taken to ensure proper fluid replacement is managed to minimize the thermal strain felt by the players when conditions are hot and humid.

Another observation made from the data was the slight improvement, although not significant, in physical performance scores following the first singles match, such as agility, vertical jump, and power. Stewart & Sleivert (1998) reported a warm-up routine consisting of exercises performed at higher intensities (60-70% of maximal oxygen uptake), in which case the range of motion significantly improved, enhancing the participants' anaerobic performance. This suggests a possible benefit of adding higher-intensity exercises in the warmup instead of the routine utilized in this study, which consisted of light stretching and jogging.

Much of the existing literature has focused on bouts of tennis play that are only portions of match play. Even fewer studies have marked changes in performance variables during successive matches of considerable length. This study was designed to determine the response of certain performance parameters and physiological responses elicited following prolonged tennis play. In this study, adult male amateur players showed significant decreases in lower body mean and peak power production. This could impact the players' "explosive first step," subsequently affecting powerful shot production. Other variables seemed to be unaffected by multiple matches in relatively neutral environmental playing conditions. However, it is necessary to note that there are many factors responsible for determining the outcomes of tennis play that were not addressed in this study, such as experience, tactical prowess, and playing surface, all of which can influence performance. As the timing of testing for the participants in this study began at 0700 hours and continued after each match, the variable of "serve velocity" decreased throughout the matches played. Previous research has shown that serve velocity is faster in the evenings than in the mornings (Atkinson & Speirs, 1998). As this study did not record faster velocities in the evening, the results of the serve velocity decreasing over the course of the day are believed to be a result of the accumulated stresses of the continued match. From this study, the scoring system of the simulated tournament was a delimitation as this scoring was chosen to equate the duration of the matches. The time of each match was set to 70 minutes. With the standard scoring system in tennis, this could potentially change the duration of some matches, which could have either lasted longer or shorter. The researchers do not have comparable data. However, this is believed by the researchers to have minimal effects.

Practical Application: There is a considerable amount of research revolving around the game of tennis as a result of the amount of fine motor and gross motor skills that must be linked together in order to breed success in the sport. However, there are still more avenues to explore.

In this study, lower body power, which was represented through peak and mean power in both vertical jump and modified Wingate tests, was negatively affected after 5 hours and 50 minutes of tennis play. Results suggest that the duration of tennis matches (both singles and doubles) can tax a player's anaerobic capacity and related power-type movements (e.g., service). Hansen et al. (2024) found that after a 3-hour long match, lower extremity muscles decreased muscle activation despite the ability to maintain consistent max ball velocities and vertical forces. As the results of this study found decreases in tennis serve velocity, this warrants the potential for compensatory mechanisms, as seen by Hansen et al. (2024). By improving lower extremity strength through appropriate and tailored resistance training programs, serve velocity may be maintained or increased due to a more forceful leg drive, thus an increased ball-racket contact height (Brito et al., 2023). Tennis is a power activity that may benefit from training that emphasizes power or explosive-type moves, such as plyometric training. Adult amateur tennis players may also benefit from training that repeatedly stresses both the ATP-CP and anaerobic glycolytic energy systems in order to improve system efficiency and capacity. As a result, peak and mean power can be sustained for longer durations. Sports coaches and strength and conditioning coaches alike must understand the needs of the tennis athletes they are training by dosing them with sufficient training to meet or exceed game demands, thus preparing them for game-like situations ranging from the energy systems required of the sport of tennis.

The role of adequate warmup in adult amateur male tennis players should also be focused on before competitive play for optimal performance. In this study, certain performance variables, such as agility, vertical jump, and power, improved after the first 70 minutes of play, indicating that the warmup undertaken by these players may have been inadequate as a pre-competition warm-up.

Further research needs to be conducted pertaining to the demands of tennis matches at all levels of play, as well as the conditioning programs that may enhance performance variables. Further exploration can also be conducted on the immune responses elicited following a prolonged tennis match. From there, proper recovery regimens can be created, ultimately improving performance.

CONCLUSION

In conclusion, the findings of this study show that performance measures decreased, and physiological measures remained stable throughout three singles matches and two doubles matches. All performance metrics, except for the hexagon agility test, were not significantly different compared to baseline and trial 1. This showed an overall decrease in each performance metric from the start of the first trial or match and after trial 1 to the end of the 5th overall trial. Players performing the hexagon agility test performed better as the day progressed. For all Endocrine measurements (Testosterone, Cortisol, and Testosterone-to-Cortisol Ratio) and Immunological measurements (IgA, IgM, IgG), there were no significant differences from baseline or Trial 1. This indicated stability in these physiological responses throughout the matches. As there was a slight improvement in physical performance scores, specifically in agility, power, and vertical jump height, following the first singles match, performance coaches working with tennis athletes are encouraged to use dynamic exercises at high intensities to help better prepare the athletes for the energy demands of the match. As this study is the first to collect the discussed performance and physiological measurements in a simulated tennis tournament, much more research regarding other performance and physiological measures across multiple matches is needed to help build upon the growing body of literature to provide insights into how tennis athletes are responding to the multi-energy system demands required in competition.

Acknowledgements:

The authors extend their appreciation to Kaycie L. Young and Chloe A. Myers for their contribution to the preparation of this manuscript. This project was supported by a grant from the U.S. Tennis Association. We also acknowledge the support of this work by the Wu Tsai Human Performance Alliance and the Joe and Clara Tsai Foundation.

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