

Research article

Effects of the Tennis Tournament on Players' Physical Performance, Hormonal Responses, Muscle Damage and Recovery

Tuomo Ojala ✉ and Keijo Häkkinen

Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland

Abstract

The purpose of this study was to examine changes in selected physiological and performance variables of male tennis players ($n=8$) during a 3-day tennis tournament and the following 2-day recovery period. Each player played three two-hour tennis matches. The following measurements were taken: blood samples for serum testosterone T, cortisol C, creatinekinase CK, performance tests of maximal isometric leg press MVC and maximal rate of force development RFD, 5m run 5m, 5-leap 5l, counter movement jump CMJ and serve velocity S and DOMS questionnaire. During the games at 40 and 80 minutes the following tests were made: blood sample, MVC, 5m, CMJ and S. Both MVC and RFD were before the 2nd and 3rd match significantly lower than before the 1st match ($p < 0.02$) and remained reduced after 1 to 2 days of recovery. Serum C was significantly higher than the baseline value before each match ($p < 0.05$) and after 40 minutes of playing ($p < 0.03$). Serum T elevated from the baseline during every match at T40 ($p < 0.02$). CK elevated during the whole tournament peaking after the 3rd match. After one rest day CK was still significantly higher than the baseline value. Upper and lower body DOMS were elevated significantly but remained above the baseline after one rest day. The tennis tournament leads to reduced MVC and RFD, increased muscle damage and soreness and reduced recovery. It seems that a tennis tournament causes such a heavy speed strength load for the legs in addition to muscle damage that the recovery of explosive attributes of leg extensor muscles is impaired after two days of rest after the tournament. Serum cortisol and testosterone concentration elevated before and during the tennis match, but the outcome of the tennis match is difficult to predict using C or/and T levels before, during or after the match.

Key words: Tennis, maximal voluntary contraction, rate of force development, creatinekinase, fatigue.

Introduction

The demands of a tennis tournament are high both mentally and physiologically. Many studies have examined the effects of one tennis match (Bergeron et al., 1991; Fernandez-Fernandez, 2007; Filaire et al., 2009; Girard et al., 2006; 2008; Hornery et al., 2007). However, tennis is a tournament sport, and it is important to study what changes take place in player's performance and physiological variables in a tournament environment when several games are played.

Tennis is an anaerobic sport with aerobic breaks between the rallies (Fernandez et al., 2006). A tennis match lasts normally 1.5-2 hours but it can last even over 4 hours. Typically one point lasts 5-10 seconds and between the points there is a 20s break and during the changeovers the break varies from 60 to 120s. During the

match players run an average of 3 meters per shot and during the best of three set match players perform 300-500 high intensity efforts. The exercise intensity during the game is about 50-60% of maximal oxygen uptake or 60-80% of maximal heart rate (Fernandez et al., 2006.) Average blood lactate concentration level ranges from 1.7 to 3.8 $\text{mmol}\cdot\text{l}^{-1}$ (Mendez-Villanueva, 2007; Murias et al., 2007), but during long and intense rallies lactate levels can go up to 8.6 $\text{mmol}\cdot\text{l}^{-1}$. The rate of perceived exertion (RPE, range 6-20) is around 10-17 during a tennis match (Mendez-Villanueva et al., 2007)

Tennis movement is a combination of eccentric and concentric muscle action, called as stretch-shortening cycle. All the movements are rapid and explosive including acceleration, deceleration, stretches, jumps and stroke making from various body positions. It has been previously shown that stroke velocity, running speed and maximum force (MVC) decreases during a tennis match (Ferrauti et al., 2001b; Girard et al., 2006; 2008; 2011). Muscle damage has been suggested one factor behind fatigue (Girard et al., 2006; Mendez-Villanueva et al., 2007). Eccentric muscle action is related to exercise induced muscle damage (EIMD) (Piitulainen et al., 2011). EIMD causes muscle soreness, muscle swelling and inflammation, increased plasma levels of muscle protein and serum creatinekinase (CK) and impairment of muscle function reducing MVC and RFD (Byrne et al., 2004; Morgan and Allen, 1999). Muscle soreness (Girard et al., 2006) and serum CK activity (Hornery et al., 2007), which is a marker for muscle damage, has been reported to elevate during a tennis match. Previously, there is no published data of muscle soreness and CK from a tennis tournament environment.

A tennis match like any other high intensity sport competition causes acute hormonal responses (Filaire, 2009; Salvador et al., 2003). Serum hormones of cortisol and testosterone concentration during a tennis match have been studied before (Bergeron et al., 1991; Booth et al., 1989; Ferrauti et al., 2001a; Filaire et al., 2009). Serum cortisol elevates at rest before the match in tennis (Booth et al., 1989; Filaire et al., 2009) and in other sports (Filaire et al., 2001; Kivlighan et al., 2005; Salvador et al., 2003; Suay et al., 1999). During the tennis match serum cortisol concentration elevates (Booth et al., 1989; Filaire et al., 2009), if the intensity is above 60-70% of maximum VO_2 (Kraemer et al., 1989; Wittert et al., 1991). Serum testosterone concentration elevates significantly before the exercise (Bergeron et al. 1991; Booth et al., 1989; Salvador et al., 2003; Suay et al. 1999) or remains at a control level (Filaire et al., 2001; Gonzalez-Bono et

al., 1999). Testosterone concentration elevates during the tennis match (Bergeron et al., 1991; Booth et al., 1989) and in other sports (Kivlighan et al., 2005; Suay et al., 1999) or remains at a control level (Filaire et al., 2001; Gonzalez-Bono et al., 1999; Salvador et al., 2003). Serum testosterone concentration will not elevate if the player does not feel the match is important, if he knows he is going to win or lose, if the opponent is at a different level (Booth et al., 1989; Gonzales-Bono et al., 1999).

The relationship between the outcome of the match and serum hormone levels have been studied, but the results are somewhat conflicting. Winner's serum cortisol concentration has been significantly lower compared to the losers in tennis (Filaire et al., 2009), but in wrestling (Elias, 1981) and in judo (Suay et al., 1999) winners have showed higher cortisol concentration. Serum testosterone concentration does not seem to relate to outcome of the match (Booth et al., 1989; Filaire et al., 2001; Suay et al., 1999).

The purpose of this study was to examine how player's physical performance is compromised during a 3-day tournament and what kind of effects the matches have on player's hormonal responses. In addition this study attempted to examine the level of muscle damage that takes place during a match and during the whole tournament. Based on previous studies, we hypothesized that during a 3-day tennis tournament player's maximal leg strength and rate of force development would be impaired (Girard et al., 2006; 2008; 2011), muscle soreness increased throughout the tournament (Girard et al., 2006; Hornery et al., 2007) and that winners might have lower serum cortisol concentrations than losers (Filaire et al., 2009).

Methods

Participants

Eight male tennis players of age 23.0 ± 3.8 years, height 1.85 ± 0.07 m, weight 77.4 ± 8.7 kg volunteered to participate in this study. They were informed in detail about the nature of the experiment and its possible risks involved. All subjects provided written informed consent and they had a change to withdraw from the study at any stage of the study. All players had over 10 years of playing background, and they were all national level top tennis players. Six out of eight players had or had had professional

ranking during their career. During a normal training week players practiced 8.5 ± 2.5 hours for tennis and 4.0 ± 1.5 times for physical fitness. The study was performed after 6-week training period and it was the first tournament of the season for all players. All players were informed to lighten their training 3 days before the tournament.

Experimental set up

All measurements of the present study were performed during five days (Figure 1). The first three days players played an invitational singles tennis tournament and the last two days was the recovery phase. During the tournament the measurements were performed before, during (after 40 and 80 minutes) and after the match (T0, T40, T80, T120). The measurements were performed every day at the same time of the day and in the same order. The players were divided into two four-player groups using their national ranking. One group played every day in the morning and the other in the afternoon. The players played one match per day. After the tournament players had recovery tests at 24 and 48 hours after the last match. Matches were played at the indoor hard court (GreenSet® comfort) using the normal ITF (International Tennis Federation) rules except the playing time was standardized to 120 minutes. The matches were played using 4 new Wilson Tour balls. The air temperature was 22 °C. Before, during and after the tournament players were informed to use their normal food and fluid intake. In addition, they were instructed to use their normal social and sleep rhythm that they use during a normal tennis tournament.

Measurements

Maximum strength tests

Maximum voluntary force (MVC) of the lower extremities was measured using isometric bilateral leg press (Häkkinen et al. 1998). Isometric leg press was performed using 107° knee angle. In addition to maximal peak force (N) the maximal rate of force development was analysed ($N \cdot s^{-1}$). Players had 3 trials before and after the match, and during the match only two. The best and technically acceptable trial was taken into the final analysis.

Speed strength tests

Speed strength was measured using a standing 5-jump,

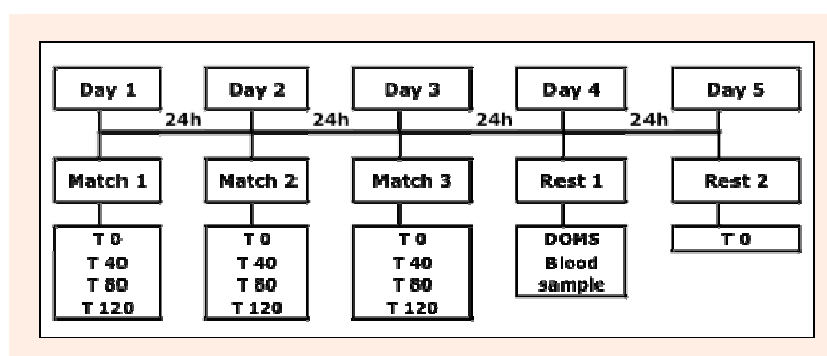


Figure 1. Experimental set up. Measurements performed at T0 and T120 were: Blood sample, DOMS, all maximum strength and speed strength tests. At T40 and T80 following measurements were performed: Blood sample, serve speed, isometric leg press, countermovement jump and 5m run.

countermovement jump (CMJ), 5m run (5m) and serve velocity test. The standing 5-jump was performed at the tennis court. The maximal standing 5-jump was used to measure explosiveness of leg extensor muscles in to the horizontal direction (Mero et al., 1981). Maximal vertical jumping ability was measured using a counter movement jump (CMJ) on a contact mat with a clock (Komi and Bosco, 1978). Acceleration running speed was measured with a standing start over 5 m. The subject was standing 0.5 m from the first photocell gate and then accelerated maximally over 5 m to the second photocell gate (accuracy of 0.01s). In all tests the best performance of three trials (recovery from 2 to 5 minutes between the trials) was selected for the final analysis. The service velocity test was performed to measure explosiveness of the whole body in the actual tennis performance. In the service test each player served 10 serves to deuce court; only the serves that went in to the service box were accepted. Serve velocity was measured using radar gun (Stalker Pro, Stalker Radar, USA).

Blood sampling

Blood samples were taken from an antecubital vein in a sitting position. During the match day samples were taken before (T0), during (T40 and T80) and after the match (T120). Recovery samples on day 4 and 5 were taken at the same time of day as before the match sample. The control sample was taken within two weeks from the tournament on a normal rest day.

Four milliliters blood from a vein was centrifuged (10min, 3500rpm). Serum samples were frozen until the analyzing process. The following analyses were performed: hormonal and creatinekinase concentrations were analysed with a kemiluminometric measurement using Immunilite 1000 machine (Diagnostic Products Co, LA, USA). Cortisol intra-assay coefficient of variation was 4.6%, testosterone 5.7% and creatinekinase 0.8%. The sensitivity for cortisol was 5.5 nmol·l⁻¹, testosterone 0.5 nmol·l⁻¹ and creatinekinase 7 U·l⁻¹. Blood lactate and glucose was measured before (T0), during (T40 and T80) and after the match (T120) from fingertip blood sample (EKF Biosen C_Line Sport, Magdeburg, Germany). The measurement range for B-lact was 0.5-40 mmol·l⁻¹ and the intra-assay CV was 1.5% and B-gluc range 0.5-50 mmol·l⁻¹ and CV 1.5%.

DOMS

Before every test day players filled the DOMS questionnaire in which they gave their subjective feeling (1-10, 10 is a lot of pain) how much DOMS they felt in the upper and lower body and core. They also marked the feeling they had for playing tennis (1-10, 10 is the best feeling).

RPE and heart rate

During every changeover players marked their RPE feeling using the Borg scale 6-20. Heart rate was measured during the matches (Suunto smartbelt, Finland).

Match video

The matches were videotaped for the match. From the video the following variables were measured: break be-

tween points, point length, stroke count/point, work/rest -ratio, winners, unforced errors, aces, double faults and first serve percentage.

Statistical analyses

Conventional statistical methods were used to obtain means, standard deviations and correlation coefficients. Holm-Bonferroni post hoc test was used to assess statistical differences between the matches and different time points during the tournament. Winners and losers were compared using the relative values. Correlations between the matches and recovery days were analyzed using Pearson correlation matrix. The morning and afternoon groups' changes were compared using covariance analysis. $P \leq 0.05$ was regarded as statistically significant. The statistical analyses were carried out using the software program Microsoft Excel 2008 for mac 12.2.1 -version and spss 18.0 -program.

Results

MVC and RFD

MVC of leg extensors was significantly lower after the third match compared to the start of the tournament ($p < 0.05$) (Figure 2). MVC was significantly lower before the second and the third match compared to MVC before first match. During the first match MVC reduced significantly ($p < 0.05$). RFD reduced significantly after the second and the third match compared to RFD before the tournament (Figure 2). RFD was also reduced significantly before the second and the third match ($p < 0.05$) and remained reduced on the second day ($p < 0.05$) compared to RFD before the first match. RFD reduced significantly during the first match ($p < 0.001$). No significant differences were observed between the winners and losers in MVC or RFD.

There were no significant changes between the matches in CMJ, 5m and 5-jump (Table 1). After the second match 5m was significantly lower than before the match. 5-jump reduced significantly during the first match. Serve velocity was significantly slower before the third match compared to the first match. During the first match serve velocity reduced significantly (T0 vs T40 and T80).

No significant differences between the winners and losers were observed in CMJ, 5m, 5-jump or serve velocity. The losers reduced significantly their 5m during the match but no changes occurred among the winners.

Serum hormones

Serum cortisol concentration was significantly higher before every match ($p < 0.05$) and T40 ($p < 0.05$) compared to the control (Figure 3). Cortisol concentration of the winners raised significantly compared to the control value in all time points T0 ($p < 0.01$), T40 ($p < 0.001$), T80 ($p < 0.05$), T120 ($p < 0.05$). The losers had the same response only at T0 ($p < 0.05$) and T40 ($p < 0.05$). The covariance between the morning and afternoon group was significant ($p < 0.05$).

Serum testosterone concentration increased significantly during every match at T40 ($p = 0.02$, $p = 0.02$, $p =$

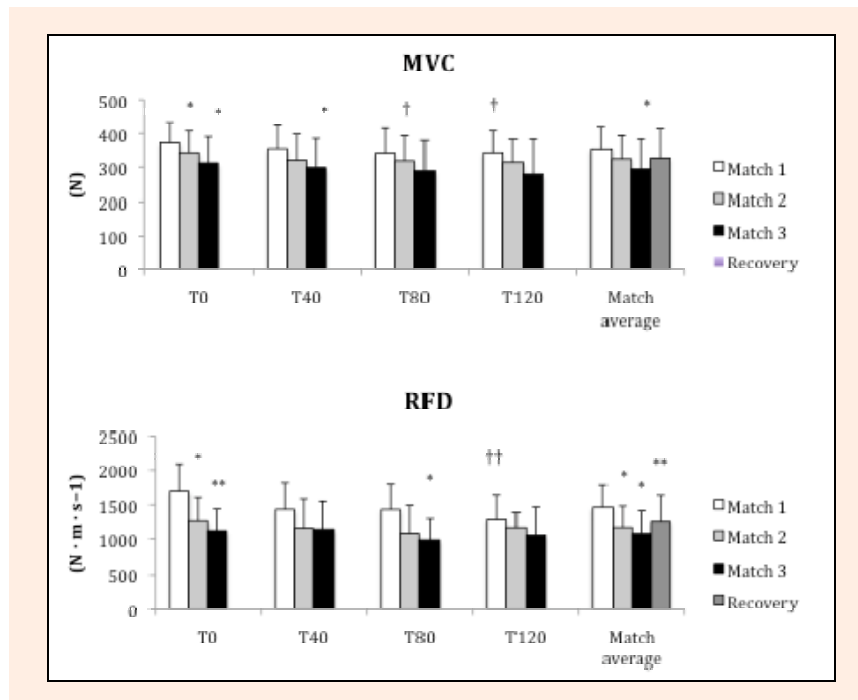


Figure 2. Maximal voluntary force (MVC) and RFD of leg extensor muscles. Recovery 48h after the last match. * $p < 0.05$ compared with Match 1, † $p < 0.05$ compared with T0, $n = 8$.

0.015) compared to the control value and to the first match at T80 ($p = 0.027$) (Figure 4). There were no significant differences between the winners and losers between or during the matches. The covariance between the morning and afternoon group was significant ($p = 0.026$).

Creatinekinase and DOMS

CK increased significantly throughout the whole tournament (Figure 5). Between the matches CK was significantly different between the first and second and the first and third match ($p < 0.005$). Between the second and third match the difference was significant at T80 and T120 ($p = 0.003$). There were no differences between the winners and losers.

DOMS of the legs and upper body increased significantly during the second and third match compared to the start of the tournament as well as for the legs between the second and third match ($p < 0.02$) (Figure 6). Legs DOMS remained significantly higher during both rest days compared to the start of the tournament ($p = 0.002$; $p = 0.038$). Upper body DOMS remained significantly higher during a first rest day compared to the start of the tournament ($p = 0.012$). There were no differences between the winners and losers in DOMS.

Match characteristics

Mean blood lactate during the match was 3.4; 4.1; 3.9 $\text{nmol}\cdot\text{l}^{-1}$ (Table 2). During the matches mean heart rate was 149 ± 12 ; 142 ± 16 ; 150 ± 11 . Mean duration of the points was 6.0 ± 1.0 ; 5.8 ± 0.8 ; 5.6 ± 0.4 , mean work/rest-ratio 0.25 ± 0.05 ; 0.24 ± 0.05 ; 0.23 ± 0.03 and mean RPE was 13.2; 12.8; and 14.4, respectively.

Discussion

The present tennis tournament led to significant changes in player's physical performance, considerable hormonal responses and increases in variables indicating muscle soreness. Maximal and explosive isometric force of lower extremities reduced significantly during the tournament. Serum cortisol increased significantly already before the match and testosterone during the first 40-80 minutes of the match and players CK and DOMS increased significantly throughout the whole tournament. One day of rest day after the tournament was not sufficient to reduce CK concentration and DOMS and to recover force production the leg extensor muscles to the level observed before the tournament.

Table 1. CMJ, 5m run, 5-jump and serve velocity during the tournament. Recovery 48h after the last match. Data are means (\pm SD).

	Time	CMJ (cm)	5m (s)	5-jump (m)	Serve ($\text{km}\cdot\text{h}^{-1}$)
Match 1	T0	35.0 (5.7)	1.04 (.05)	12.67 (.79)	187.5 (9.3)
	T120	34.6 (5.0)	1.08 (.06)	12.48 (.86) *	182.5 (14.5)
Match 2	T0	33.6 (6.5)	1.04 (.05)	12.49 (.94)	183.6 (10.0)
	T120	34.5 (5.7)	1.09 (.07) *	12.48 (.98)	182.4 (11.1)
Match 3	T0	34.3 (5.5)	1.06 (.07)	12.53 (.95)	182.4 (9.6) †††
	T120	33.9 (5.9)	1.08 (.03)	12.50 (1.18)	185.3 (11.6)
	Recovery	34.5 (5.4)	1.06 (.09)	12.69 (.92)	187.6 (11.4) §

* $p < 0.05$ compared with T0, ††† $p < 0.001$ compared with Match 1, § $p < 0.05$ compared with T0 Match 3.

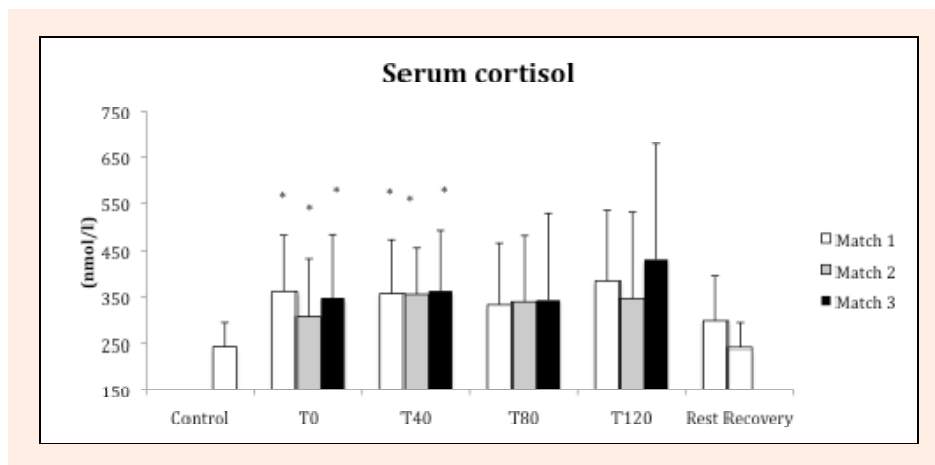


Figure 3. Serum cortisol concentration during the tournament. * $p < 0.05$ compared to control, $n = 8$. Rest 24h after the last match and recovery 48h after the last match.

The present tournament led to the reductions in players MVC by 26% and RFD by 38% from the start of the tournament. During the matches MVC decreased constantly in all matches, but the decrease was significant only in the first match at T80 and T120 compared to T0. Girard et al. (2006; 2008) reported that the decrease in the lower extremities MVC became significant 150 minutes after the beginning of the tennis match in a prolonged 3-hour tennis match. After the first match MVC in the present study did not recover between the matches remaining significantly lower before the 2nd (8%) and before the 3rd (16%) match than that recorded before the tournament.

Neuromuscular impairment during a prolonged tennis match may be due to the failure of central activation and alterations in excitation-contraction coupling process (Girard et al., 2008), which is linked to EIMD (Warren et al., 1999). An increase in serum CK has been previously reported during a tennis match (Hornery et al. 2007) and accompanied by a progressive reduction in maximal force and an increase in muscle soreness (Girard et al., 2006; 2008). Type II muscle fibers are fast and strong muscle fibers that are recruited during explosive and forceful actions (Karatzafiri et al., 2001). It has been suggested that the damaged type II muscle fibers might impair the tennis performance by reducing player's abilities to move between the points and perform the strokes properly (Mendez-Villanueva, 2007). Singh et al. (2011)

reported that elevated muscle soreness was related to impaired 10m running speed and vertical jump 48-hours after the rugby performance. In the present study player's physical performance 48-hours after the tournament was still reduced from the start of the tournament. It seems that muscle damage is one of the important factors behind the impairment of the physical performance during a tennis match and during a 3-day tennis tournament.

The impairment of legs RFD has been previously reported in a sport competition (Thornlund et al., 2008; 2009). Interestingly, in this present study the counter-movement jump (CMJ) did not reduce during the matches although MVC and RFD reduced. Actually during the 2nd match CMJ increased during a match. Girard et al. (2006) reported similar kinds of results where CMJ increased since the beginning of the match and MVC reduced. This kind of improving has been explained by insufficient warm-up before the match and by an increase in muscle temperature through various mechanisms such as increased transmission rate of nerve impulses, decreased viscous resistance, and/or increased glycogenolysis, glycolysis, and high energy phosphate degradation (Bishop et al., 2003; Girard et al., 2006). Thornlund et al. (2009) observed similar results after the football match where leg extensors RFD reduced but CMJ remained at the same level before and after match. It could be that the muscles elastic component of muscles can function throughout the

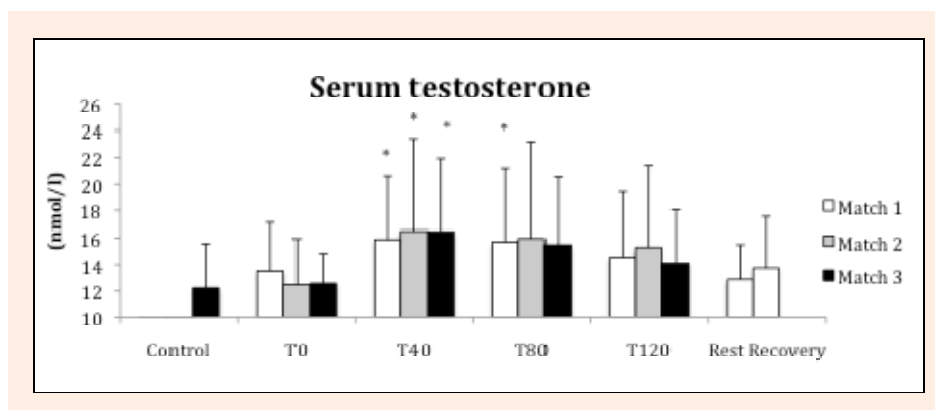


Figure 4. Serum testosterone concentration during the tournament. * $p < 0.05$ compared to control, $n = 8$. Rest 24h after the last match, recovery 48h after the last match.

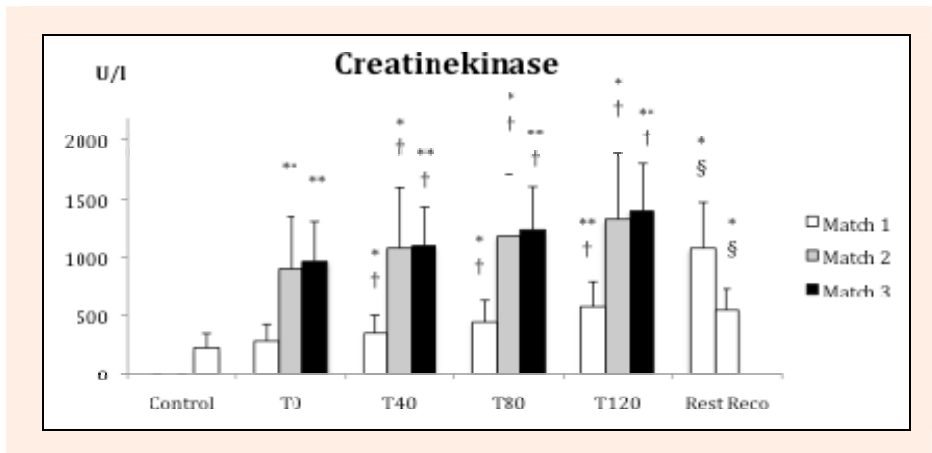


Figure 5. Creatinekinase during the tournament. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ compared to control, ††† $p < 0.001$ compared to T0, § $p < 0.05$ compared to match 3 T120, $n = 8$. Rest 24h after the last match, reco 48h after the last match.

tennis tournament and maintain the performance in CMJ, 5m run and in 5-jump. RFD was measured in an isometric leg press with no stretch-shortening cycle action. Previously, it has been shown that muscle fascia and tendons may allow tendons to absorb energy rapidly even if the contractile elements' maximum capacity for energy absorption is limited (Roberts and Azizi, 2010). It has been suggested that the use of elastic elements may be effective although the force generating elements are damaged (Byrne and Eston, 2002).

The serve speed decreased before the 2nd and 3rd match compared to the beginning of the tournament. Reid et al. (2008) showed that service velocity correlated with greater muscle force during the loading stage of serve. After the last match players were able to increase service speed, although the increase was not significant. That result was probably followed by the information that the test was last of the tournament and they did not have any match left so the players might felt they can give everything they had left. It must be taken into consideration that during this tournament the physical load during a match was little bit heavier than during a normal match because of the multiple measurements.

The present match analysis indicated that high intensity on-court movement has led to the reduced physical performance, hormonal responses and muscle soreness. The average match lactate concentration (3.4-4.1 mmol·l⁻¹)

was a little above reported in previous studies (Fernandez-Fernandez et al., 2007; Mendez-Villanueva et al., 2007). The work/rest -ratio and the significant increase in RPE throughout every match were in line with previous studies (Fernandez-Fernandez et al., 2007; Girard et al., 2006; Kovacs, 2006; Mendez-Villanueva et al., 2007). The duration of the point and the work/rest -ratio increased during a match, because the balls became softer and maybe because players tried to avoid unforced errors hitting easier shots when they got tired (Ferrauti et al., 2001b).

Serum cortisol concentrations elevated significantly at rest already before and serum testosterone during the match. Increased cortisol (Booth et al., 1989; Filaire et al., 2009) and testosterone (Bergeron et al., 1991; Booth et al., 1989) concentration before, and during and after the match has been reported in earlier tennis studies. The elevated cortisol concentration before the match is related to preparation for the upcoming bout. The tennis match like any other intensive physical and mental exercise causes the stress reaction in the player's body, which brings on the release of cortisol. The increase in serum cortisol may influence in multiple ways causing actions to the immune system, stimulating glucose metabolism, and altering mood, memory, and behavioral response to threatening circumstances (Ericson et al., 2003). The high levels of serum cortisol and testosterone concentration

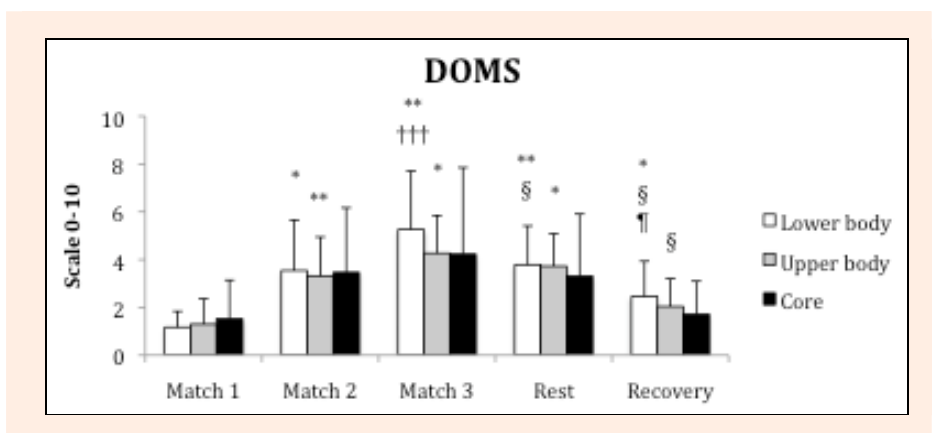


Figure 6. Leg, upper body and core DOMS. * $p < 0.05$; ** $p < 0.01$; compared with Match 1, ††† $p < 0.001$ compared with Match 2, § $p < 0.05$ compared with Match 3, ¶ $p < 0.05$ compared with rest, $n = 8$. Rest 24h after the last match, recovery 48h after the last match.

Table 2. Lactate, RPE, heart rate, work-rest –ratio. Data are means (\pm SD).

	Time (min)	Lactate (nmol \cdot l $^{-1}$)	RPE	Heart rate	Point duration (s)	Work/rest - ratio
Match 1	0	2.1 (.2)				
	0-40	3.0 (1.0)	11.8 (1.5)	147 (13)	5.7 (.7)	.23 (.04)
	40-80	4.3 (1.9) †	13.3 (.6) †	151 (12) †	6.3 (1.1)	.26 (.05)
	80-120	4.2 (2.9) †††	14.4 (1.3) †§	149 (13)	6.2 (1.5)	.26 (.07)
	Match	3.4 (1.2)	13.2 (.8) ¶	149 (12)	6.0 (1.0)	.25 (.05)
Match 2	0	1.8 (.6)				
	0-40	4.8 (2.8)	11.0 (2.1) &	142 (13)	5.6 (.4)	.23 (.02)
	40-80	4.6 (2.0) †	12.8 (2.5)	142 (19)	5.8 (1.0)	.24 (.06)
	80-120	5.3 (2.0) ††	14.6 (2.0) †§	143 (16)	6.0 (1.0)	.26 (.06) †††
	Match	4.1 (1.1) *	12.8 (1.7) ¶	142 (16) **	5.8 (.8)	.24 (.05)
Match 3	0	2.0 (.5)				
	0-40	4.9 (2.3)	13.2 (1.5)	148 (11)	5.1 (.4)	.21 (.03)
	40-80	4.1 (1.0) ††	14.3 (1.8) †	148 (12)	5.5 (.4) *	.22 (.03) ¶
	80-120	4.6 (1.7)	15.7 (1.4) †§§	152 (13)	6.4 (.7) *†	.25 (.03) ***
	Match	3.9 (.6)	14.4 (1.5)	150 (11)	5.6 (.4)	.23 (.03)

*, ** and *** denote $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively compared with Match 1.

†, †† and ††† denote $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively compared with before match and 0-40.

§ and §§ denote $p < 0.05$ and $p < 0.01$ respectively compared with 40-80.

¶ $p < 0.05$ compared with Match 3.

during the matches are related to high intensity of the action (Ahtiainen et al., 2003; Häkkinen and Pakarinen, 1995; Kraemer et al., 1989; Wittert et al., 1991). The relationship between serum hormone concentrations and outcome of the match could not be observed in the present study. Traditionally low serum cortisol concentration and high testosterone concentration has been related to positive outcome of the bout (Mazur, 1985; Mazur and Booth, 1998). Comparing the winners and losers in a game like tennis the background of the players and previous encounters should be taken into consideration. According to the cognitive activation theory of stress, the previous experiences from the match situations have effect on the player's reactions and hormonal responses. Previous success promotes changes to succeed and a lack of success is related to elevated change to failure (Ursin and Eriksen, 2004.) Also the individuals who do not try to be dominant can experience the winning more stressful than the losing. When taking into consideration previous studies and the present study, it may be reasonable to suggest that winning or losing the match does not have impact on hormonal responses, but the player reacts to match by using his own natural coping mechanisms and the way that suits best to himself (Salvador et al., 2005).

Practical applications for the coaches

During a tennis tournament player's physical performance is impaired and the recovery is compromised. Impaired strength levels need to be taken into consideration while planning match preparation and recovery before, during and after the tournament. It is recommended that a after physically tough tournament players need over 24 h rest for the full physical recovery. Player's physical training must be designed to prepare player's whole body to cope under heavy speed strength load throughout the match and the tournament. Interval training using normal tennis match work/rest –ratio 1/4, 1/3, 1/2 is recommended.

Conclusion

The tennis tournament impairs player's MVC and RFD,

increases muscle damage and soreness and reduces recovery. It seems that muscle damage is one factor behind the impairment of the physical performance during a tennis match and tournament. Serum cortisol and testosterone concentration elevated before and during the tennis match, but it seems that the result of the tennis match is difficult to predict using cortisol or/and testosterone levels before, during or after the match. After the tournament the levels of serum hormones and physical performance recovered except the RFD. It seems that a tennis tournament causes such a heavy speed strength load for the legs in addition to muscle damage that one day of rest after the tournament is insufficient to recover explosive attributes of leg extensor muscles.

References

- Ahtiainen, J.P., Pakarinen, A., Kraemer, W.J. and Häkkinen, K. (2003) Acute hormonal and neuromuscular responses and recovery to forced vs. maximum repetitions multiple resistance exercises. *International Journal of Sport Medicine* **24**(6), 410-418.
- Bergeron, M.F., Maresh, C.M., Kraemer, W.J., Abraham, A., Conroy, B. and Gabaree, C. (1991) Tennis: A physiological profile during match play. *International Journal of Sports Medicine* **12**(5), 474-479.
- Bishop, D. (2003) Warm up II. Performance changes following active warm up and how to structure the warm up. *Sports Medicine* **33**(7), 483-498.
- Booth, A., Shelley, G., Mazur, A., Tharp, G. and Kittok R. (1989) Testosterone, and winning and losing in human competition. *Hormonal Behaviour* **23**, 556-571.
- Byrne, C. and Eston, R.G. (2002) The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. *Journal of Sports Sciences* **20**(5), 417-425.
- Byrne, C., Twist, C. and Eston, R.G. (2004) Neuromuscular function following exercise-induced muscle damage: theoretical and applied implications. *Sports Medicine* **34**, 49-69.
- Elias, M. (1981) Serum cortisol, testosterone, and testosterone-binding globulin responses to competitive fighting in human males. *Aggressive Behavior* **7**(3), 215-224.
- Erickson, K., Drevets, W. and Schulkin, J., (2003) Glucocorticoid regulation of diverse cognitive functions in normal and pathological emotional states. *Neuroscience and Biobehavioral Reviews* **27**, 233-246.
- Ferrauti, A., Neumann, G., Weber, K. and Keul, J. (2001a) Urine cate-

- choline concentrations and psychophysical stress in elite tennis under practice and tournament conditions. *Journal of Sports Medicine and Physical Fitness* **41**, 269-274.
- Ferrauti, A., Babette, M., Pluim B.M. and Weber, K. (2001b) The effect of recovery duration on running speed and stroke quality during intermittent training drills in elite tennis players. *Journal of Sports Sciences* **19**(4), 235-242.
- Filaire, E., Sagnol, M., Ferrand, C. and Lac, G. (2001) Psychophysiological stress in judo athletes during competitions. *Journal of Sports Medicine and Physical Fitness* **41**, 263-268.
- Filaire, E., Alix, D., Ferrand, C. and Verger, M. (2009) Psychophysiological stress in tennis players during the first single match of a tournament. *Psychoneuroendocrinology* **34**, 150-157.
- Fernandez, J., Mendez-Villanueva, A. and Pluim, B. (2006) Intensity of tennis match play *British Journal of Sports Medicine* **40**, 387-439.
- Fernandez-Fernandez, J., Mendez-Villanueva, A., Fernandez-Garcia, B. and Terrados, N. (2007) Match activity and physiological responses during a junior female singles tennis tournament. *British Journal of Sports Medicine* **41**, 711-716.
- Girard, O., Lattier, G., Micallef, J.P. and Millet, G.P. (2006) Changes in exercise characteristics, maximal voluntary contraction and explosive strength during prolonged tennis playing. *British Journal of Sports Medicine* **40**, 521-526.
- Girard, O., Lattier, G., Maffiuletti, N.A., Micallef, J.P. and Millet, G.P. (2008) Neuromuscular fatigue during a prolonged intermittent exercise: Application to tennis. *Journal of Clinical Endocrinology and Metabolism* **18**(6), 1038-1046.
- Girard, O., Racinais, S., Micallef, J-P. and Millet, G.P. (2011) Spinal modulations accompany peripheral fatigue during prolonged tennis playing. *Scandinavian Journal of Medicine Science in Sports* **21**, 455-464
- Gonzalez-Bono, E., Salvador, A., Serrano, M.A. and Ricarte, J. (1999). Testosterone, cortisol, and mood in a sports team competition. *Hormonal Behaviour* **35**, 55-62.
- Hornery, D.J., Farrow, D., Mujika, I. and Young, W. (2007) Caffeine, carbohydrate, and cooling use during prolonged simulated tennis. *International Journal of Sports Physiology and Performance* **2**, 423-438.
- Häkkinen K. and Pakarinen A. (1995). Acute hormonal responses to heavy resistance exercise in men and women at different ages. *International Journal of Sports Medicine* **16**(8), 507-513.
- Häkkinen K., Kallinen M., Izquierdo M., Jokelainen, K., Lassila, H., Mätkiä, E., Kraemer, W.J., Newton, R.U. and Alen, M. (1998) Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *Journal of Applied Physiology* **84**(4), 1341-1349.
- Karatzaféri, C., de Haan, A., van Mechelen, W. and Sargeant, A.J. (2001) Metabolism changes in single human fibres during brief maximal exercise. *Experimental Physiology* **86**, 411-415.
- Kivlighan, K.T., Granger, D.A. and Booth, A. (2005) Gender differences in testosterone and cortisol response to competition. *Psychoneuroendocrinology* **30**, 58-71.
- Komi, P.V. and Bosco, C. (1978) Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine Science Sports* **10**, 261-265.
- Kovacs, M. (2006) Applied physiology of tennis performance. *British Journal of Sports Medicine* **40**, 381-386.
- Kraemer, W.J., Patton, J.F., Knuttgen, H.G., Marchitelli, J.L., Cruthirds, C., Damokosh, A., Harman, E., Frykman, P. and Dziados, J.E. (1989) Hypothalamic-pituitary-adrenal responses to short-duration high-intensity cycle exercise. *Journal of Applied Physiology* **66**(1), 161-166.
- Mazur, A. (1985) A biosocial model of status in face-to-face primate groups. *Social Forces* **64**, 377-402.
- Mazur, A. and Booth, A. (1998) Testosterone and dominance in men. *Behavioral Brain Science* **21**, 353-397.
- Mendez-Villanueva, A., Fernandez-Fernandez, J., Bishop, D., Fernandez-Garcia, B. and Terrados, N. (2007) Activity patterns, blood lactate concentrations and ratings of perceived exertion during a professional singles tennis tournament. *British Journal of Sports Medicine* **41**, 296-300.
- Mero, A., Luhtanen, P., Viitasalo, T. and Komi, P.V. (1981) Relation between the maximal running velocity, muscle fiber characteristics, force production and force relaxation of sprinters. *Scandinavian Journal of Sport Sciences* **3**, 16-22.
- Millet, G.Y and Lepers, R. (2004) Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. *Sports Medicine* **34**(2), 105-116.
- Morgan, D.L. and Allen, D.G. (1999) Early events in stretch-induced muscle damage. *Journal of Applied Physiol* **87**, 2007-2015.
- Murias, J.M., Lanatta, D., Arcuri, C.R. and Lain, F.A. (2007) Metabolic and functional responses playing tennis on different surfaces. *Journal of Strength and Condition Research* **21**(1), 112-117.
- Piitulainen, H., Botter, A., Merletti, R. and Avela, J. (2011) Muscle fiber conduction velocity is more affected after eccentric than concentric exercise. *European Journal of Applied Physiology* **111**, 261-273.
- Ratel, S., Lazaar, N., Williams, C.A., Bedu, M. and Duche, P. (2003) Age differences in human skeletal muscle fatigue during high-intensity intermittent exercise. *Acta Paediatrica* **92**(11), 1248-54.
- Reid M., Elliott, B. and Alderson, J. (2008) Lower-Limb Coordination and Shoulder Joint Mechanics in the Tennis Serve. *Medicine and Science in Sports and Exercise* **40**(2), 308-315.
- Roberts, T.J. and Azizi E. (2010) The series-elastic shock absorber: tendons attenuate muscle power during eccentric actions. *Journal of Applied Physiology* **109**, 396-404.
- Salvador, A., Suay, F., Gonzalez-Bono, E. and Serrano, M.A., (2003) Anticipatory cortisol, testosterone and psychological responses to judo competition in young men. *Psychoneuroendocrinology* **28**, 364-375.
- Salvador, A. (2005). Coping with competitive situations in humans. *Neuroscience and Biobehavioral Reviews* **29**, 195-205.
- Singh, T.K.R., Guelfi, K.J., Landers, G., Dawson, B. and Bishop, D. (2011) A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity circuit. *Journal of Science and Medicine in Sport* **14**, 441-446.
- Suay, F., Salvador, A., Gonzalez-Bono, E., Sanchis, C., Martinez, M., Martinez-Sanchis, S., Simon, V.M. and Montoro, J.B. (1999) Effects on competition and its outcome on serum testosterone, cortisol, and prolactin. *Psychoneuroendocrinology* **24**, 551-566.
- Thornlund, J.B., Michalsik, L.B., Madsen, K. and Aagaard, P. (2008) Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. *Scandinavian Journal of Medicine Science in Sports* **18**, 462-472.
- Thornlund, J.B., Madsen, K. and Aagaard, P. (2009) Rapid muscle force capacity changes after soccer match play. *International Journal of Sport Medicine* **30**, 273-278.
- Ursin, H. and Eriksen, H.R. (2004) The cognitive activation theory of stress. *Psychoneuroendocrinology* **29**, 567-592.
- Warren, G.L., Ingalls, C.P., Shah, S.J. and Armstrong, R.B. (1999) Uncoupling of in vivo torque production from EMG in mouse muscles injured by eccentric contractions. *Journal of Physiology* **515**(2), 609-619.
- Wittert, G.A., Stewart, D.E., Graves, M.P., Ellis, M.J., Wells, J.E., Donald, R.A. and Espiner, E.A. (1991). Plasma corticotropin releasing factor and vasopressin responses to exercise in normal man. *Clinical Endocrinology (Oxf)*, **35**(4), 311-317.

Key points

- The tennis tournament impairs player's MVC and RFD, increases muscle damage and soreness and reduces recovery.
- One day of rest after the tennis tournament is insufficient to recover explosive attributes of leg extensor muscles.
- Serum cortisol and testosterone concentration elevated before and during tennis match.
- The result of the tennis match is difficult to predict using cortisol or/and testosterone levels before, during or after the match.

AUTHORS BIOGRAPHY

**Tuomo OJALA****Employment**

Department of Biology of Physical Activity,
University of Jyväskylä.

Degree

MSc

Research interests

Tennis physiology.

E-mail: Ojala.tuomo@gmail.com

**Keijo HÄKKINEN****Employment**

Professor & head in the Department of Biol-
ogy of Physical Activity, University of Jy-
väskylä, Finland.

Degree

PhD

Research interests

Neuromuscular performance, fatigue &
recovery, and neuromuscular and hormonal
adaptations during resistance training.

E-mail: Keijo.hakkinen@jyu.fi

✉ Tuomo Ojala

Department of Biology of Physical Activity, University of
Jyväskylä, Jyväskylä, Finland