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Research article

Force-Time Curve Variable Outcomes Following a Simulated Tennis Match in Junior Players

Joshua Colomar [1,2,3]✉, Francisco Corbi [4] and Ernest Baiget [1]
[1] National Institute of Physical Education of Catalonia (INEFC), University of Barcelona (UB), Barcelona, Spain; [2] Sport and Physical Activity Studies Centre (CEEAF), University of Vic - Central University of Catalonia, Vic, Spain; [3] Sport Performance Analysis Research Group (SPARG), University of Vic - Central University of Catalonia, Barcelona, Spain; [4] National Institute of Physical Education of Catalonia (INEFC), University of Lleida (UdL), Lleida, Spain

Abstract
This study examined the alterations induced by a simulated tennis competition on maximal isometric voluntary contraction (MVC), peak rate of force development (PRFD) and rate of force development (RFD) at different stages of contraction. Twenty junior tennis players performed an 80-minute simulated tennis match and two (pre and post) muscular performance tests. Variables tested included MVC, PRFD and RFD at 50, 100, 150 and 200 ms while performing a 90º shoulder internal rotation (IR90), 90º shoulder external rotation (ER90), shoulder horizontal adduction (ADD), shoulder horizontal abduction (ABD) and isometric mid-thigh pull (IMTP). Serve velocity (SV) was also registered. No significant changes were found regarding MVC, PRFD or SV. Non-significant moderate effect size (ES) towards a decrease in the IR90 RFD at 50 ms could be observed (16%; ES = 0.5) alongside an increase in the ADD and IMTP RFD at 150 ms (-15.8%, -8.2%; ES = -0.53, -0.54) and IMTP RFD at 200 ms (-13%; ES = -0.54). Results indicate that MVC, PRFD, RFD at different time intervals and SV are unaltered following an 80-minute simulated match, possibly due to insufficient alterations triggered on key factors affecting the tested variables.

Key words: Power, serve, fatigue, effects, strength.

Introduction

Tennis has evolved into a fast-paced sport in which the ability to generate explosive actions and movements such as strokes, sprints and changes of direction is essential towards a greater performance (Kovacs, 2006). These actions rely, among other qualities, on certain fitness traits that are considered determinant for the sport and can be observed in higher ranked players. These include an enhanced level of speed over short distances, upper and lower body strength and power alongside a greater serve velocity (SV) (Ulbricht et al., 2016). Research has related force-time characteristics around the shoulder complex (Cools et al., 2014; Baiget et al., 2016; Baiget et al., 2021; Hayes et al., 2021) and upper body power levels (Ulbricht et al., 2016), to SV. Positive correlations have also been found between lower body isometric strength measurements and sprint and serve performance (Ulbricht et al., 2016; Hayes et al., 2021). These main actions normally involve one or more stretch-shortening cycles (SSC) throughout the kinetic chain (Kibler et al., 2007), and force production is to happen in a short period of time. For instance, the acceleration phase of tennis serve is due to happen in intervals as short as 80 ms approximately (Kibler et al., 2007), and other repetitive burst of fast movements such as jumping or 0-5 m accelerations and changes of direction require contraction times around 50-250 ms. (Aagaard et al., 2002). This reaffirms force production in determinant tennis actions would typically appear in what is considered as the early phase of explosive contraction (Maffiuletti, 2016; Baiget et al., 2021). This highlights the importance of generating high forces in brief or rapid intervals (i.e., rate of force development (RFD)) during the duration of a match or in consecutive days of play for an enhanced tennis performance (Girard et al., 2014; Baiget et al., 2021; Hayes et al., 2021). Therefore, how these aspects are affected by competition seems essential towards effective recovery and training organization.

Prior investigations have stated significant impairments following match-play or competitive events, including the previously mentioned strength and power qualities. These changes derived from competition include increased muscle soreness (DOMS) (Gescheit et al., 2015), reductions in maximal isometric voluntary contraction (MVC) (Girard, 2006; Girard et al., 2008, 2011, 2014), decreased range of motion (ROM) (Martin et al., 2016a; Gallo-Salazar et al., 2017; Moreno-Pérez et al., 2019) and SV (Gescheit et al., 2015). The appearance of fatigue due to muscle damage following inflammation, serum creatinkinase (CK) concentration and muscle function impairment would result in a reduction in performance in the mentioned variables (Girard, 2006; Mendez-Villanueva et al., 2007). Nevertheless, few studies to our knowledge have explored how competition-induced fatigue affects MVC and RFD at different time intervals in young tennis players. Previous works (Girard, 2006; Girard et al., 2008, 2011, 2014; Ojala and Häkkinen, 2013; Gescheit et al., 2015) have observed negative changes in these variables following prolonged tennis playing or simulated competitions, although testing typically included few selected leg or shoulder muscles or were performed including male professional or highly competitive participants.

Young players can perform an average of 10 to 21 competitive events and 65 matches year-round (Kovalchik and Reid, 2017; Johansson et al., 2022). Added to this, they also perform an accumulated 15 hours per week of tennis or fitness training. How physical qualities vary from pre to post playing conditions seems of great importance for junior competitors towards effective recovery strategies and load management. Moreover, as stated previously and

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given the importance of developing force rapidly in tennis and the significance of MVC and RFD in determinant actions, knowledge around RFD within different phases of contraction could provide insights on how mechanisms underpinning explosive force production are affected by match-play. Thus, the goal of this study was to investigate the alterations induced by tennis match-play on MVC and RFD at different stages of contraction (i.e., <250 ms), in specific joint positions observed in tennis actions and in junior competitors. Based on previous literature (Girard, 2006; Girard et al., 2008, 2011, 2014), we hypothesized that upper and lower body measures of MVC, PRFD and RFD at different time intervals would be negatively affected by fatigue. Accordingly, SV reductions would be observed.

Methods

Participants

G-Power statistical software (version 3.1.9.5; University of Dusseldorf, Dusseldorf, Germany) was used to determine that a minimum sample size of $n = 19$ was required for statistical power ≥0.8 at an alpha level of $p \leq 0.05$. Twenty (12 male and 8 female) junior tennis players (mean ± SD; age, 16.9 ± 1.7 years; height, 1.76 ± 0.07 m; body mass, 64.4 ± 7.9 kg; BMI 20.7 ± 1.8 kg/m^2) with an International Tennis Number (ITN) between 2 and 4 (advanced level) and a tennis training experience of 8.4 ± 1.9 years participated in this study. ITN was established by the consensus of two coaches accredited with RPT (Professional Tennis Registry) level 3, following the ITN Description of Standards (www.internationaltennisnumber.com). Participants had a weekly training volume of 20 h·week^{-1} consisting of 3h of technical and tactical on-court tennis training and 1h of fitness training per day from Monday to Friday. Seventeen participants (85% of total) performed a two-handed backhand, while the remaining 15% executed a one-handed fashion. One subject (5% of total) was left-handed while all other participants had a dominant right extremity. Inclusion criteria required each participant to have at least 1-year of participation in a structured physical training program and 5-years of tennis training and competition. Participants were excluded from the study if they had any back, upper or lower extremity pain or undergone surgery or rehabilitation in the past 3 months. All participants were informed in advance about the characteristics of the study and voluntarily signed an informed consent. In the case of being underage, their legal tutors signed the consent. The study was conducted following the ethical principles for biomedical research with human beings, established in the Declaration of Helsinki of the AMM (2013) and approved by an accredited Ethics Committee (15/CEICGC/2020).

Design

The experimental design was conducted as summarized in Figure 1. A cross-sectional repeated measures experimental design was performed on two testing sessions in a static order. Each player participated in two sessions (pre- and post-simulated match) separated approximately by 120 minutes under similar atmospheric, experimental conditions (wind < 2 m·s^1) and by the same researcher. Between trials, participants played an 80-minute simulated tennis match on an outdoor standard hard court following the International Tennis Federation (ITF) rules and using new tennis balls (Head ATP Pro, Spain). Matches were undertaken by participants playing an opponent with a similar ITN level. In a 15-minute window after the match, participants performed the post-competition testing session. The use of recovery strategies (e.g., self-myofascial release, massage, stretching, etc.) was not allowed in order to avoid interferences with the results. Players were allowed to consume water *ad libitum*. Energetic drinks were not allowed during the trials.

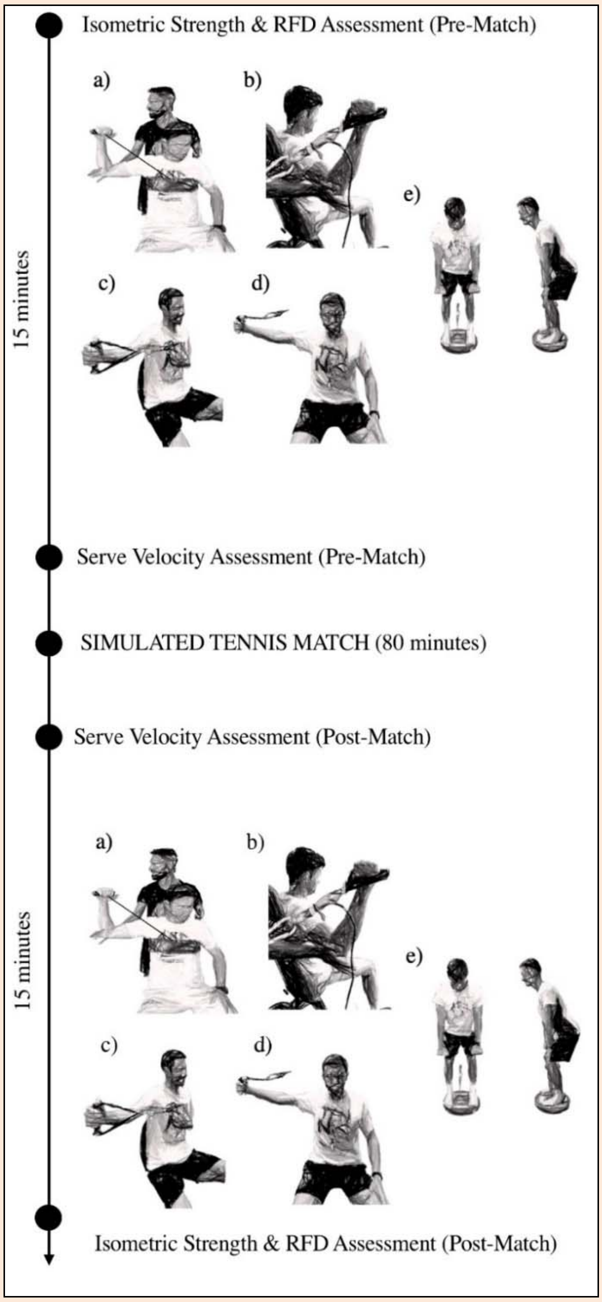

Figure 1. Experimental design. a) external shoulder rotation with the elbow and shoulder flexed 90º (ER90); b) internal shoulder rotation with the elbow and shoulder flexed 90º (IR90); c) horizontal shoulder adduction (ADD); d) horizontal shoulder abduction (ABD); e) isometric mid-thigh pull (IMTP).

Procedures

Participants did not exercise for at least 18h before the protocol took place and they were encouraged to maintain their habitual lifestyle, to avoid excitatory substances (i.e., coffee or tea) and strenuous exercise during the previous day to the test. All measurements were registered in the morning, approximately from 7:30 am to 10 am. Testing sessions were performed in May and June during competition period.

Maximum isometric voluntary contraction (MVC) and rate of force development (RFD)

Participants were asked to perform five maximum isometric tests. The different positions assessed were (a) external shoulder rotation with the elbow and shoulder flexed 90º (ER90), (b) internal shoulder rotation with the elbow and shoulder flexed 90º (IR90), (c) horizontal shoulder adduction (ADD), (d) horizontal shoulder abduction (ABD) and (e) mid-thigh pull (IMTP) as summarized in Figure 1. As a warm up and prior to testing, participants performed five minutes of dynamic mobility exercises and two submaximal trials of 3 seconds of all tested positions at approximately 50% and 75% maximal effort, separated by 60 seconds each (Comfort et al., 2019). Tests concerning upper body were performed in a similar manner as Baiget et al., (2016), sitting on an Ercolina machine (Technogym Company, Cesena, Italy). The participants sat in a position with a 90º hip flexion and the back resting on a bench. Participants were then fastened with a harness on the chest to avoid additional movement of other body segments. Only the dominant extremity was registered. For lower body assessment, tests were performed using a portable alternative to a force plate using a strength gauge (Chronojump, Boscosystem, Barcelona, Spain) attached to a heavy metal base or plate in a very similar fashion to that offered by James et al., (2017). Participants stood over the plate and the mid-thigh position was determined for each participant before testing by marking the midpoint distance between the knee and hip joints. This mid-point was established halfway between the iliac crest and the patella, as it seems athletes adopt their preferred hip and knee angles for the test (Comfort et al., 2015). The height of the bar was adjusted up or down to make sure it was in contact with the mid-thigh. Participants were allowed to use either overhand or hook grip. For all tests, participants were instructed to perform 1 second of quiet standing followed by a maximal effort for 5 seconds (as fast and hard as possible) (Comfort et al., 2019). The force-time curve for each trial was recorded using a strain gauge sampling at 80 Hz and the subsequent analysis software (Chronojump, Boscosystem, Barcelona, Spain). MVC and PRFD were defined as the highest value achieved during the 5 seconds. Additionally, force outputs at 50, 100, 150 and 200 ms from the initiation of the pull were determined for each trial (Comfort et al., 2015). RFD was then calculated as the segment between time points and following the equation: RFD = ΔForce / ΔTime (Baiget et al., 2021). Precision and reproducibility were addressed using a test-retest design for which participants performed two trials spaced by 2 min rest between attempts. To avoid that the order of the evaluations could influence fatigue, tests were randomized. The measurements showed (Table 1) acceptable levels of reliability and good-to-excellent intraclass correlation coefficients (ICC ≥ 0.823) in all variables. Although coefficients of variation (CV) lower than 10% have previously been considered an acceptable range by researchers, the variable tested should be taken into account (Atkinson and Neville, 1998). When analyzing neuromuscular measurements, CV values seem to show a certain degree of variability, especially in early phases of contraction (Buckthorpe et al., 2012), when analyzing not as experienced populations and using customized instruments (James et al., 2017). Nevertheless, CV's here were comparable (≤ 20%) to similar investigations examining force-time curve variables and using similar equipment (Baiget et al., 2021).

Table 1. Reliability of test measurements (n = 20).

	ICC (95% CI)	CV (%)
SV	0.970 (0.946 - 0.986)	4.0
MVC IR90º	0.897 (0.618 – 0.972)	11.1
MVC ER90º	0.990 (0.958 – 0.997)	6.0
MVC ADD	0.981 (0.937 – 0.994)	6.0
MVC ABD	0.923 (0.747 – 0.976)	16.6
MVC IMTP	0.982 (0.950 – 0.993)	6.7
PRFD IR90º	0.933 (0.666 – 0.987)	19.3
PRFD ER90º	0.953 (0.728 – 0.992)	15.3
PRFD ADD	0.969 (0.884 – 0.992)	19.1
PRFD ABD	0.937 (0.720 – 0.986)	20.8
PRFD IMTP	0.844 (0.307 – 0.965)	16.4
IR 90º 50 ms	0.932 (0.764 – 0.980)	19.2
IR90º 100 ms	0.965 (0.885 – 0.989)	12.1
IR90º 150 ms	0.973 (0.911 – 0.992)	13.6
IR90º 200 ms	0.920 (0.646 – 0.982)	14.9
ER 90º 50 ms	0.904 (0.615 – 0.976)	18.3
ER90º 100 ms	0.957 (0.849 – 0.987)	14.1
ER90º 150 ms	0.907 (0.677 – 0.973)	12.4
ER90º 200 ms	0.872 (0.486 – 0.968)	11.8
ADD 50 ms	0.960 (0.862 – 0.989)	14.4
ADD 100 ms	0.987 (0.959 – 0.996)	7.8
ADD 150 ms	0.860 (0.514 – 0.960)	14.0
ADD 200 ms	0.910 (0.689 – 0.974)	16.8
ABD 50 ms	0.984 (0.941 – 0.996)	11.3
ABD 100 ms	0.959 (0.848 – 0.989)	13.3
ABD 150 ms	0.890 (0.558 – 0.973)	14.8
ABD 200 ms	0.880 (0.399 – 0.976)	16.3
IMTP 50 ms	0.910 (0.622 – 0.980)	7.2
IMTP 100 ms	0.915 (0.623 – 0.981)	5.3
IMTP 150 ms	0.823 (0.286 – 0.956)	14.7
IMTP 200 ms	0.879 (0.548 – 0.967)	9.1

CV = coefficient of variation; ICC = intraclass correlation coefficient; SV = serve velocity; MVC = maximal voluntary contraction; PRFD = peak rate of force development; IR = shoulder internal rotation; ER = shoulder external rotation; ADD = horizontal shoulder adduction; ABD = horizontal shoulder abduction; IMTP = isometric mid-thigh pull.

Serve speed

Data collection was executed on a standard tennis hard court with stable wind conditions (< 2 $m \cdot s^{-1}$) using new tennis balls (Head ATP Pro, Spain). Before the measurements, participants performed a standardized warm-up that included mobility exercises, 5 minutes of free rallies and 10 progressive serves. Each subject executed 8 serves (2 sets of 4 serves on each side of the court) with 2 minutes of rest between sets and 10 seconds between serves) before and after the simulated tennis match. Only the serves that landed in the serve box were registered. Maximum SV was determined using a hand-held radar gun (Stalker ATS II,

Table 2. Match load characteristics (n = 20).

Variables	Mean ± SD
Games per match	15.7 ± 2.72
Total distance (m)	3184.6 ± 601.2
Distance at 0 to > 1 $m \cdot s^{-1}$ (m)	1260.3 ± 203.5
Distance at 1 to > 2 $m \cdot s^{-1}$ (m)	1532.0 ± 386.2
Distance at 2 to > 3 $m \cdot s^{-1}$ (m)	267.8 ± 95.5
Distance at 3 to > 4 $m \cdot s^{-1}$ (m)	88.8 ± 48.7
Distance at ≥ 4 $m \cdot s^{-1}$ (m)	35.6 ± 29.0
Peak velocity ($m \cdot s^{-1}$)	5.37 ± 0.73
Mean velocity ($m \cdot s^{-1}$)	0.96 ± 0.07
High intensity accelerations (≥ 3 $m \cdot s^{-1}$; n)	19.7 ± 10.2
High intensity decelerations (≥ -3 $m \cdot s^{-1}$; n)	34.1 ± 19.3
High intensity accelerations (≥ 3 $m \cdot s^{-1}$; $n \cdot min^{-1}$)	0.29 ± 0.15
High intensity decelerations (≥ -3 $m \cdot s^{-1}$; $n \cdot min^{-1}$)	0.49 ± 0.25
HRmax ($beats \cdot min^{-1}$)	172.1 ± 19.2
Mean HR ($beats \cdot min^{-1}$)	135.0 ± 18.8
Time spent at <70% HRmax (%)	45.8 ± 32.9
Time spent at 70-85% HRmax (%)	29.6 ± 16.8
Time spent at >85% HRmax (%)	20.2 ± 19.9
RPE	12.4 ± 1.2

HRmax = match peak heart rate; RPE = rate of perceived exertion.

USA, frequency: 34.7 GHz [Ka-Band] ± 50 MHz). The radar was positioned in the center of the baseline, 2 m behind the line and at an approximate height of 2 m following the trajectory of the ball. Players were asked to hit as hard as possible to the T and immediate feedback was provided to the participants to encourage maximum effort.

Tennis match load

Match load was recorded using a GPS unit (WimuPro®, Realtrack Systems, Almería, Spain). Both players involved in the simulated match wore an adjusted vest with the attached device and diverse data was recorded for posterior descriptive information on match load (Table 2). Registered data included variables previously used in similar participants (Hoppe et al., 2014; Galé-Ansodi et al., 2017; Perri et al., 2018) such as total distance, number of accelerations, decelerations, distance at different running speeds, mean and peak velocity. Added to this, three heart rate (HR) zones were used for analysis. Using a HR monitor (Garmin HRM Dual Basic, Garmin, USA) and based on peak HR of the match (HR_{max}), zone 1 was determined as low- (<70% HR_{max}), zone 2, moderate- (70-85% HR_{max}) and zone 3, high-intensity- (>85% HR_{max}). Time spent in different HR zones included play and changeover intervals. The same warm-up performed before the SV assessment was considered appropriate for the simulated match. Matches were played for 80 minutes regardless the score on a standard tennis hard court under stable wind conditions (<2 $m \cdot s^{-1}$). Posterior to competition, fatigue perception was measured following the 6 to 20 Borg Scale Test (RPE).

Statistical Analysis

Data are reported as mean ± standard deviation (SD). Normality of distributions and homogeneity of variances were assessed with the Shapiro-Wilk test. The reliabilities of test measurements were assessed using intraclass correlation coefficients (ICCs) and the coefficient of variation (CV) (Table 2). Parametric and non-parametric statistics were used when appropriate. Paired *t*-test were used to discern any significant differences between the mean values of pre- and post-measurements. Because some variables did not have a Gaussian distribution (all excluding SV, ER90º 200 ms, ABD 100 ms and ABD 150 ms) Wilcoxon paired test was used. Mean differences in absolute and percent values were also used. The magnitude of the differences in mean was quantified as effect size (ES) and interpreted according to the criteria used by (Cohen, 1988) <0.2 = trivial, 0.2-0.4 = small, 0.5- 0.7 = moderate, >0.7 = large. Thirty-one preplanned comparisons were considered for this study. Accordingly, correction for multiple comparisons was undertaken using the Bonferroni method with a resulting operational alpha level of 0.0016 (p = 0.05/31). All statistical analyses were performed using SPSS 23.0 software (SPSS Inc., Chicago, IL, USA).

Results

Match-load characteristics are expressed in Table 1. Pre- and post-match SV, MVC and PRFD differences are summarized in Table 3, while data concerning RFD at different times is plotted in Figure 2. No significant differences were found between pre- and post-match measurements in any of the tested conditions. Moderate effect sizes (ES) towards a decreased IR90 RFD at 50 ms and an increased RFD in the IMTP at 150 ms and 200 ms in post-match conditions could be observed (-16%, 8.2% and 13%; ES = 0.5, -0.54 and -0.54), respectively. Also, a moderate increase in the post-match measurements in ADD RFD at 150 ms was noted (15.8%; ES = -0.53). No statistically significant differences could be observed concerning MVC values, PRFD or SV.

Discussion

The main finding of this investigation was that MVC, PRFD, RFD at different time intervals and SV remain unaltered following an 80-minute simulated tennis match in young players. Yet, after following this specific load, RFD at different time points while performing a MVC in certain

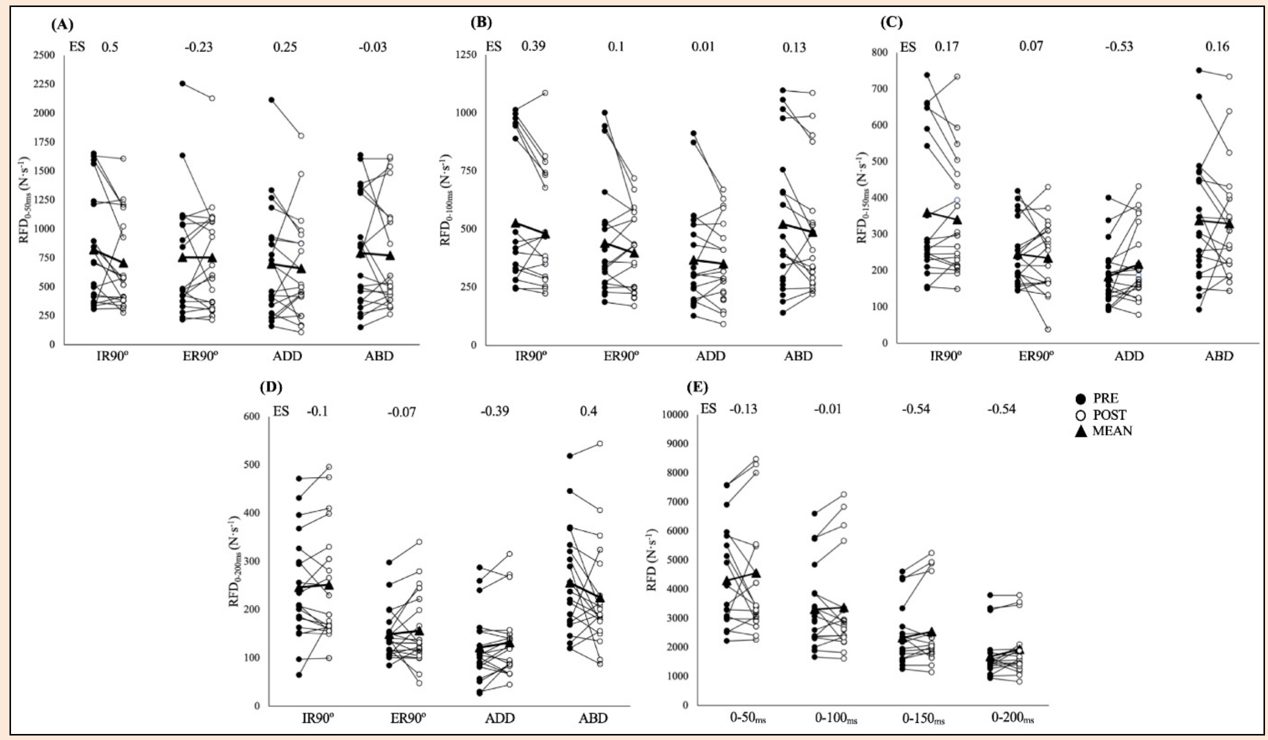

Figure 2. Pre- and post-match rate of force development (RFD) at (A) 50 ms, (B) 100 ms, (C) 150 ms, (D) 200 ms and (E) during the isometric mid-thigh pull test (IMTP) at all stages of contraction (50 ms, 100 ms, 150ms and 200 ms). Data are mean ± SD. ES = Cohen's effect size; IR90º = shoulder internal rotation; ER90º = shoulder external rotation; ADD = horizontal shoulder adduction; ABD = horizontal shoulder abduction; IMTP = isometric mid-thigh pull.

Table 3. Pre- and post-match serve velocity (SV), maximal isometric voluntary.

Variable	PRE	POST	ES	Change (%)	p
SV (km·h-1)	140.4 ± 11.8	141.1 ± 12.4	-0.14	0.4	.543
MVC IR90º (N)	125.8 ± 49.2	125.4 ± 54.7	0.19	- 0.3	.475
MVC ER90º (N)	95.4 ± 35.5	93.4 ± 38.5	0.09	- 2.1	.756
MVC ADD (N)	85.2 ± 36.7	83.6 ± 31.4	0.23	- 1.9	.388
MVC ABD (N)	115.4 ± 51.4	114.1 ± 49.6	0.24	- 1.1	.368
MVC IMTP (N)	938.8 ± 365.8	967.9 ± 402.2	-0.25	3.0	.41
PRFD IR90º (N·s-1)	954.3 ± 555.6	794.5 ± 391.4	0.33	- 20.1	.202
PRFD ER90º (N·s-1)	992.4 ± 799.2	1202.5 ± 800.3	0.04	17.5	.898
PRFD ADD (N·s-1)	935.7 ± 892.9	940.3 ± 683.5	0.07	0.5	.812
PRFD ABD (N·s-1)	969.9 ± 619.3	976.7 ± 709.8	0.1	0.7	.729
PRFD IMTP (N·s-1)	5768.6 ± 2222.1	5059.9 ± 2715.8	0.47	- 14.0	.27

ES = Cohen's effect size; SV = serve velocity; MVC = maximal isometric voluntary contraction; PRFD = peak rate of force development; IR = shoulder internal rotation; ER = shoulder external rotation; ADD = horizontal shoulder adduction; ABD = horizontal shoulder abduction; IMTP = isometric mid-thigh pull.

joint positions (i.e., IR90, ADD and IMTP) seemed moderately affected.

Previous works have established alterations in certain physical aspects following tennis match-play, involving reductions in shoulder internal rotation ROM (Martin et al., 2016b; Gallo-Salazar et al., 2017; Moreno-Pérez et al., 2019), DOMS and increased CK values (Gescheit et al., 2015). More specifically related to strength measurements, results here differ from those present in other investigations. MVC resulted in reductions in the majority of previous studies following tennis competitions or match-play (Girard, 2006; Girard et al., 2008, 2011, 2014; Gescheit et al., 2015; Gallo-Salazar et al., 2017; Moreno-Pérez et al., 2019). Nevertheless, significant reductions in this variable are noted only after performing a considerably greater competitive load compared to the one proposed here, especially regarding match-duration. In Girard et al., (2006, 2008), MVC of knee extensors suffered progressive reductions starting as soon as 30 minutes into match-play, but only being significant ($p < 0.05$) compared to pre-match conditions at 150 minutes of play, while plantar flexor and leg extensor muscles accounted similar decreases following 120 minutes of competition in further works (Girard et al., 2011, 2014; Ojala and Häkkinen, 2013), indicating that match duration could be an essential aspect inducing MVC reductions. More recent studies have also registered decreases in MVC around the shoulder joint in internal and external rotation gestures. Moreno-Pérez et al., (2019) observed significant changes towards lower strength levels in the shoulder external rotation motion following 80 minutes of match-play. As match duration is similar to that performed in this study, differences may be explained by the population analyzed or match-load differences. Reductions in MVC following a tennis match can be determined by fatigue induced in response to high and repetitive loads performed during serves, groundstrokes, short sprints and changes of direction (Mendez-Villanueva et al., 2007). Nevertheless, external match loads concerning number of strokes, running distance and high-intensity bouts may be considerably different when comparing adolescents, professional players and male or female participants (Hoppe et al., 2014; Kovalchik and Reid, 2017; Perri et al., 2018). Analyzed population differences could be one of the reasons of dissimilar results, as participants in Moreno-Pérez et al. (2019) represent professional male players of greater age and level that could achieve a higher number of strokes and high intensity bouts during competition, although performing similar match durations (Hoppe et al., 2014; Kovalchik and Reid, 2017; Perri et al., 2018). In investigations focusing on populations with a similar age (Gallo-Salazar et al., 2017), reductions in MVC have been observed in shoulder internal and external rotation values following two consecutive matches of approximately 80 minutes in one day, which in absolute numbers accounted for roughly two-times the competition duration than that performed in this study. This reinforces the idea that duration here might be of an insufficient magnitude to evoke changes, especially in players with a significantly high volume of training ($20h \cdot week^{-1}$). Added, although match duration responded to typical matches of youth populations, internal load indicators such as mean and maximal HR slightly differ from those seen in similar studies (Hoppe et al., 2014). In short, reductions in MVC in lower and upper body values seem to appear following tennis match-play of longer duration, especially in male players of greater level, while results here indicate that 80 minutes of competition seems an insufficient load to negatively affect these values in junior players.

In the same way, no decreases in PRFD of the analysed motions were noted. Gescheit et al., (2015) observed how consecutive days of prolonged tennis match-play negatively affected this variable in the IMTP test. However, in a similar way to data concerning MVC discussed previously, RFD values diminished only after day two of competition, when accumulated volume of play was at least of two matches of 240 minutes. Similarly, Ojala and Hakkinen (2013) observed a decrease in RFD in a bilateral leg press following the first match (i.e., 120 minutes duration and 13.2 RPE values) of a three-day tennis tournament while Girard et al., (2014) found similar reductions in knee extensors after a 120-minute match in hot temperature conditions (-22 ± 10.9%). Added to this, participants analysed in the aforementioned studies highly differed in age (23 ± 3.8 vs. 16.9 ± 1.7) and level (elite vs. competitive) (Ojala and Häkkinen, 2013; Girard et al., 2014) from players present in this investigation, restating that differences regarding match load and volume alongside age and level of play are important factors affecting MVC and PRFD outcomes following competition.

RFD at different stages of contraction was unaffected by 80 minutes of match-play. Investigations in other sports such as handball reported reductions in RFD as early as 50 ms in knee extensors and at 200 ms in both knee extensors and flexors (Thorlund et al., 2007). Specifically in tennis, Girard et al., (2014) observed significant decreases following 120 minutes of competition in knee extensors at 200 ms of contraction in experimented players. Unaffected variables here are surprising as tennis match-play characteristics certainly seem to have the potential to affect rates of muscle force production due to repetitive accelerations, decelerations, changes of direction and high velocity strokes (Mendez-Villanueva et al., 2007). Nevertheless, results should be analysed with caution and generally unaltered values could have a various number of reasons. First, comparing studies becomes challenging as methods to detect force production at different time intervals during a MVC bout are not fully agreed on (Thompson, 2012). Additionally, within-participant variability (see Figure 2), especially during initial phases of contraction (<50ms) could reduce the capacity of detecting changes, requiring larger sample sizes to do so (Buckthorpe et al., 2012). More specifically regarding strength values observed here, RFD would seem unaffected as MVC remained unchanged following the simulated tennis match. As literature points out, diverse mechanisms affect explosive force production and maximal strength seems increasingly dependent on MVC, especially in intervals later than 90 ms (Maffiuletti, 2016). Following this idea, inexistent reductions in MVC would result in similar RFD outcomes in the tested contraction times. Moreover, other key factors identified as mechanisms affecting earlier and later phases of RFD such as motor unit discharge rate, fibre type composition, stiffness of the muscle-tendon unit and shifts in muscle length and torque production produced by eccentric damage (Maffiuletti, 2016) may have been unaffected due to insufficient competitive load. In the same way as mentioned regarding MVC and PRFD, 80-minutes of simulated competition may have been insufficient to elicit the fatigue mechanisms that would progressively affect explosive force production, at any stage of contraction whatsoever. Although this study reproduced typical match durations and loads regarding junior tennis competition (Galé-Ansodi et al., 2017; Perri et al., 2018), the fact that the intervention consisted of a simulated tennis match with lower demands than competitive bouts (Murphy et al., 2016) and participants typically performing high training volumes throughout their program ($20h \cdot week^{-1}$) could reinforce the idea that the load was not as demanding for participants. This added to age and sex differences may result in such different results. In any case, this is speculative, and changes remained generally unaffected in all variables, including on-court functional performance measurements such as SV.

This study had some limitations. Participants were slightly heterogenous regarding age, although not in training experience and level. Added, sample size and the fact that mixed male and female participants were included in the study may have affected results to some extent. Also, the strain gauge used sampled at 200 Hz which might be a low frequency for early contraction time measurements such as the 50 ms. These issues may have affected in some way the data, and although reliability measurements were considered acceptable and comparable to similar studies (Baiget et al., 2021), results should be interpreted with caution. Furthermore, as a recommendation for future investigations, ensuring interventions of longer duration and in competitive conditions could seem essentiall to observe changes in the analysed variables.

Tennis is a sport characterized by high training volume that are sometimes distorted in several training sessions that take place on the same day with strength and conditioning programs following on-court drills and competition or vice versa. This study shows that key physical factors such as MVC, PRFD or SV do not seem to be negatively affected by relatively low loads of match-play, specifically in simulated conditions in junior players with a high training volume background. Various significant aspects affecting tennis performance rely on the aforementioned tested variables, making knowledge around how training and competition influence their outcome of high importance. Therefore, including programs that incorporate exercises focused on speed, power and velocity production following simulated matches, far from being counterproductive, could be a valid option towards effective use of training time. On the other hand, performing these interventions after matches of longer duration in competitive contexts and especially of greater match-load, may not be recommended and coaches should address training in consequence.

Conclusion

In conclusion, MVC, PRFD, RFD at different time intervals and SV are unaltered following an 80-minute simulated match in young tennis competitors, possibly due to an insufficient load and subsequent alterations of key factors and mechanisms affecting the variables tested. However, RFD values while performing a MVC in the IR90, ADD and IMTP positions seem to moderately change following an intervention of these characteristics, suggesting that performing a load of greater duration, magnitude or with more experimented players with a greater level could result in significant changes.

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Key points

- Force-time curve variables remain generally unaltered following an 80-minute simulated tennis match in young competitors.
- 80-minutes of simulated competition with moderate match load may be insufficient to negatively affect key factors of neuromuscular performance.
- Performing matches of longer duration or with older and more experienced population may derive in greater loads and negatively affect force-time curve variables.

AUTHOR BIOGRAPHY

Joshua COLOMAR
Employment
Head strength and conditioning coach; Emilio Sánchez Academy, Barcelona. Professor Universitat de Vic - Universitat Central de Catalunya (Associate)
Degree
MSc. Sports Performance.
Research interests
Performance, training and testing in intermittent sports.
E-mail: joshuacolomar@gmail.com

Ernest BAIGET
Employment
Professor. National Institute of Physical Education of Catalonia (INEFC). University of Baercelona, Spain.
Degree
Ph.D.
Research interests
Strength and conditioning, performance in intermittent sports, field-based performance testing, tennis physiology.
E-mail: ebaiget@gencat.cat

Francisco CORBI
Employment
Professor. National Institute of Physical Education of Catalonia (INEFC). University of Lleida, Spain. Human Movement Research Group. University of Lleida.
Degree
Ph.D.
Research interests
Exercise biomechanics, injury prevention, hypoxia, high performance
E-mail: f@corbi.neoma.org

✉ **Joshua Colomar**
Avinguda de l'Estadi 14, 08038, Barcelona, Spain.