Acute effects of training load on contractile properties during a competitive microcycle in elite soccer players

AUTHORS: **Ezequiel Rey[1], Francisco J. Corredoira[1], Pablo B. Costa[2], Alexandra Pérez-Ferreirós[1], María A. Fernández-Villarino[1]**

[1] Faculty of Education and Sport Sciences, University of Vigo, Pontevedra, Spain
[2] Human Performance Laboratory, Center for Sport Performance, Department of Kinesiology, California State University, Fullerton, CA, USA

Corresponding author:
Ezequiel Rey
Faculty of Education and Sports Sciences, University of Vigo
Campus A Xunqueira s/n,
Pontevedra 36005, Spain.
E-mail: zequirey@uvigo.es

ABSTRACT: The aim of this study was to examine changes in muscle contractile properties across a microcycle of training in professional soccer players during the in-season period. Nineteen professional soccer players were assessed with tensiomyography (TMG) on the biceps femoris and rectus femoris before and after 5 training sessions of an in-season microcycle. Training load was quantified during each training session. Significant differences were observed in training load variables across different training sessions, with the last training session prior to match day showing the lowest values for all training load variables. Significant pre- to post-session increases were observed in muscle stiffness of the rectus femoris and biceps femoris during the first four training sessions (effect size range, 0.5 to 0.9). However, no significant differences were observed in muscle contraction time and contraction velocity from pre- to post-session. In addition, repeated measures correlation analysis revealed significant relationships between absolute change in muscle stiffness of the rectus femoris and training duration, high-speed distance covered during training, and training average distance. The current study shows that players are physically taxed on their muscular stiffness by the training load. Post-session muscular stiffness assessment should be recommended to determine neuromuscular status and readiness in professional soccer players during the competitive season.

CITATION: Rey E, Corredoira EJ, Costa PB et al. Acute effects of training load on contractile properties during a competitive microcycle in elite soccer players. Biol Sport. 2020:37(2):157-163.

Received: 2019-08-08; Reviewed: 2019-11-27; Re-submitted: 2019-12-28; Accepted: 2020-02-17; Published: 2020-03-30.

Key words:
Fatigue
Stiffness
Tensiomyography
Periodization
GPS

INTRODUCTION

Due to the complexity of team sports performance, technical staff in soccer should prescribe daily training load fluctuations during a microcycle that may help to increase or maintain performance throughout the competitive in-season period, while avoiding maladaptive responses, injury, overtraining, and accumulated fatigue on match days [1].

To achieve these goals and facilitate coach decision-making, monitoring the impact of the sessions on players has been recognized as an important step towards being successful in the training process [2]. The scientific literature has reported a number of approaches to quantify the athlete's training response and fatigue status in team sports [3]. These include haematological markers, heart rate variability, self-report perceptual measures, and evaluations of the neuromuscular function [3]. In relation to neuromuscular function, jump test protocols, including squat jump and countermovement jump (CMJ), are most widely used. However, such measures often lack sensitivity to detect contractile property changes in team sports [3]. Specifically, Malone *et al.* [4] evaluated the change in CMJ performance across a microcycle of training in elite youth soccer players during the in-season period. The results revealed that the use of jump height as an indicator of neuromuscular status might lack the sensitivity to detect changes in training load [3,4]. This highlights the need for future research that investigates alternative methods to track neuromuscular function in soccer players. In response to these conflicting findings, previous authors have revealed that using muscular stiffness measurements to assess the neuromuscular function may provide a more sensitive measure to identify the athletic status [5]. In this regard, earlier investigations have shown that weekly training demands may alter muscular stiffness and that elevated stiffness levels before training session are a discriminatory factor for injury incidence [6,7].

Tensiomyography (TMG) has been identified as a potential tool for assessing post-exercise stiffness and neuromuscular status [8,9] without producing additional fatigue and without depending on voluntary motivation [10]. Several investigations have highlighted the usefulness and sensitivity of TMG variables in detecting muscular mechanical properties changes following various kinds of exercise, such as strength-training protocols [11,12], ultra-endurance triathlon [13], and eccentric exercise [14]. Generally, decreases in contractile properties have been observed in the form of increased muscle contraction time and muscle tone, as well as decreased muscle contraction velocity [11–14], demonstrating that TMG could provide useful insights when assessing athletes' status [8].

Given the apparent daily fluctuations of training load in soccer [1], muscle contractile properties may vary accordingly, and hence external training load could also be adjusted to account for the goals of that particular day. However, we were unable to find any studies that have investigated changes in muscle contractile properties as a consequence of soccer training loads. Therefore, the purpose of this study was to examine the change in TMG variables across a microcycle of training in professional soccer players during the in-season period. In addition, training load variables across the microcycle were quantified and examined in relation to the change in TMG variables. We hypothesized that there would be significant increases in TMG parameters from pre-session to post-session. We also hypothesized that the individual changes in TMG parameters from pre-session to post-session would be related to the training load magnitude.

MATERIALS AND METHODS

Design

A repeated-measures design was used to evaluate the changes in muscular contractile properties assessed with TMG across one training microcycle during the in-season competitive phase in professional soccer players. The entire study covered a period of six days comprising five training sessions classified in relation to the number of days before the next competitive match [4]: M-6 (6 days before match), M-4 (4 days before match), M-3 (3 days before match), M-2 (2 days before match), and M-1 (1 day before match). The TMG variables were measured on the biceps femoris (BF) and rectus femoris (RF) before and immediately after each training session (Figure 1). Training load was quantified by training duration, rating of perceived exertion (RPE), heart rate (HR), and global positioning system (GPS). All training and testing were performed at the club's training facilities.

Subjects

A total of 19 Spanish male professional soccer players were assessed (mean±*SD*: age, 26.0±4.1 years; body mass, 77.5±3.5 kg; height, 180.2±4.2 cm). All subjects had a minimum of four and a maximum of ten years of professional soccer experience. Typical player training consisted of 5–6 full team practices for a total training load of approximately 7–9 h per week and 45–70 min per session. The team also regularly competed in one official match per week. Because the physical load and specific training of goalkeepers differ from that of field players, they were not included in this study. Only players who participated in full training throughout the microcycle were considered for inclusion. Coaches and players were informed of the purpose, benefits, and risks of the study and gave their written informed consent. The local Investigational Review Committee approved the study.

Methodology

TMG measurement protocol

During TMG assessment, a displacement-measuring sensor recorded the geometric changes (radial displacement) that occurred in the muscle belly when a contraction was produced in response to an external electrical stimulus [15,16]. The assessment was made on the RF and BF of the dominant leg. These muscles were selected because of their specific role in specific soccer kinematics [17]. Measurements were performed under static and relaxed conditions

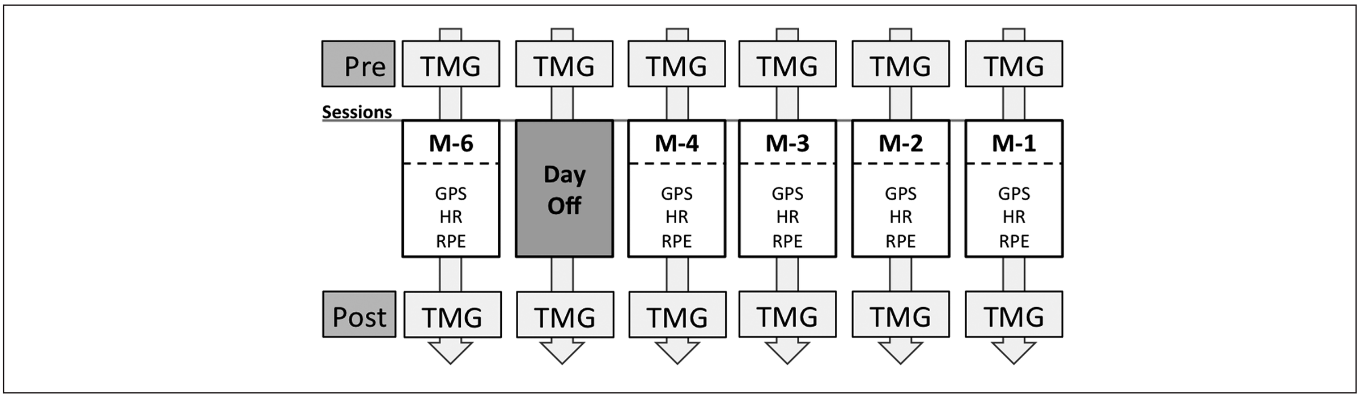

FIG. 1. Schematic representation of experimental design. TMG=tensiomyography; GPS=global positioning system; HR=heart rate; RPE=rating of perceived exertion.

with the subject in the supine and prone position to measure the RF and BF, respectively. With the subject in the supine position, the knee joint was fixed at a 120° angle (180° corresponding to full extension of the knee). The measured limb was positioned on a triangular wedge foam cushion to maintain a fixed knee angle.

A Trans-Tek DC-DC digital displacement transducer (GK 40, Panoptik d.o.o., Ljubljana, Slovenia), which incorporates a spring of 0.17 $N \cdot m^{-1}$, was set perpendicular to the muscle belly to acquire RF and BF radial displacement. The measurement point for each muscle was anatomically established as the point of maximal muscle belly displacement detected by palpation during a voluntary contraction [18]. The location of the sensor and the electrodes was marked with a semi-permanent marker pen in order to ensure reliability on subsequent measurements [14]. Both electrodes (5×5 cm) were placed symmetrically to the sensor; the positive electrode (anode) was placed proximally and the negative electrode (cathode) distally, 5 cm from the measurement point. Electrodes were self-adhesive (Compex Medical SA, Ecublens, Switzerland). The stimulation pulse was 1ms, while the signal amplitude started at 30 mA. The electrical stimulation was applied with a TMG-S1 electrostimulator (Furlan Co. & Ltd., Ljubljana, Slovenia). For each pulse, current amplitude was increased by 10mA, until the maximal displacement of the muscle belly was reached [8]. To avoid fatigue or post-tetanic potentiation effects, a 15-s resting period was allowed between electrical stimuli [12]. Of the total curves recorded for each player (range 4–7), only the curve with the highest maximum radial displacement was included in the analysis both for RF and BF. The same evaluator, who was experienced in taking these assessments, took all measurements. Maximal radial muscle-belly displacement (Dm) and contraction time between 10 and 90 % Dm (Tc) of the RF and BF were measured using TMG. TMG-derived contraction velocity (Vc) was also calculated by dividing Dm by the sum of Tc and Td [19].

Training load quantification

To quantify external training load during each session, each player wore a portable local positional system (WIMU PRO; Realtrack Systems SL, Almeria, Spain) fitted to the upper back using adjustable harnesses. Sampling frequency for 3-axis accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer and 10 Hz for the positional system. Previous studies have shown that WIMU PRO position-tracking technology is a valid and reliable system for time-motion analysis in soccer [20]. Data were analysed using the system-specific software (WIMU Software; Realtrack Systems SL, Almeria, Spain). Similarly to previous studies in soccer [21], the following variables were calculated during each training session: total distance, high-speed running distance (> 21 $km \cdot h^{-1}$), sprint distance (> 24 $km \cdot h^{-1}$), average distance (distance covered divided by training duration, expressed as $m \cdot min^{-1}$), number of accelerations (> 2 $m \cdot s^{-2}$), and the number of decelerations (< -2 $m \cdot s^{-2}$).

Heart rate responses were monitored during all training sessions to provide the percentage of maximal HR (%HR_{max}). Heart rate was recorded at 1-second intervals (rate to rate) during all training sessions using the Polar T2 system using R-R technology (Polar Electro Oy, Kempele, Finland). To assess the internal load and the exercise intensity players were asked to report their RPE using Foster's 0–10 scale [21]. Players were shown the scale 30 min after each training session and asked: "How was your workout?" [22]. All players were familiar with this scale, as part of normal training monitoring.

Statistical analysis

A two-way (time [pre vs. post-session] × day [M-6 vs. M-4 vs. M-3 vs. M-2 vs. M-1]) repeated-measures analysis of variance (ANOVA) was used to analyse pre- to post-session changes and microcycle changes in the TMG variables. To examine any differences for each training load variable across the five training sessions (M-6 vs. M-4 vs. M-3 vs. M-2 vs. M-1) a one-way repeated-measures ANOVA was used. In the event of a significant effect occurring, Bonferroni-adjusted post-hoc tests were used to identify differences between microcycle days. Additionally, Cohen's d effect sizes (ES) were calculated for all comparisons. ES with values of 0.2, 0.5, and 0.8 were considered to represent small, medium, and large differences, respectively [23]. Repeated measures correlations between training-load variables and change in TMG variables were assessed using the R package labelled "*rmcorr*" [23]. The rmcorr coefficient (r_{rm}) is bounded by -1 to 1 and represents the strength of the linear association between two variables [24]. Magnitude of effect for the correlations was based on the following scale: < 0.10, trivial; 0.10 to 0.29, small; 0.30 to 0.49, moderate; 0.50 to 0.69, large; 0.70 to 0.89, very large; and > 0.90, nearly perfect [25]. All variables were normally distributed (Shapiro-Wilk test). Data are presented as means with standard deviations (SD). Statistical significance was set at $P < 0.05$.

RESULTS

Table 1 displays the means and standard deviations (SD) as well significant differences observed for training duration, RPE, total distance covered, average distance, high-speed distance, sprint distance, accelerations, decelerations, and %HR_{max} during a weekly microcycle.

Repeated-measures ANOVA detected a significant main effect for microcycle day in the training duration variable. Bonferroni-adjusted post hoc tests showed higher training duration for M-4 and M-3 compared with M-6 (ES=1.9 and 1.3; $p < 0.001$ and $p=0.001$) and M-1 (ES=4.8 and 2.7; $p < 0.001$ and $p=0.009$). Regarding RPE, there was a significant main effect for microcycle day. Differences were observed between M-4 compared with M-6 (ES=1.1 and 1.0; $p=0.005$ and $p=0.007$) and M-1 (ES=5.2 and 4.7; $p < 0.001$), as well as between M-3 compared with M-6 (ES=1.0; $p=0.007$) and M-1 (ES=4.7; $p < 0.001$). For total distance covered, there was a significant main effect for microcycle day. Differences were observed for total distance on M-4 and M-3 compared with M-6 (ES=2.6 and 2.1; $p < 0.001$) and M-1 (ES=6.2 and 5.5, $p < 0.001$), and on M-6 compared with M-1 (ES=2.1, $p < 0.001$).

TABLE 1. Training load during the 6-day testing period.*

Training Load	M-6	M-4	M-3	M-2	M-1
Duration (min)	50±13†	68±3$^{\#}$	63±6$^{\#}$	53±10	48±5
RPE	4.9±2.1§	6.6±0.7$^{\#}$	6.5±0.8$^{\#}$	4.5±1.1	2.7±0.8
Total distance (m)	4417±821§	6283±558	5901±546	4307±726	2936±520$^{\infty}$
High-speed distance (m)	34±45	76±44	114±62¶	40±35	31±38
Sprinting distance (m)	7±11	19±16	36±32¶	10±12	7±12
Average distance ($m\cdot min^{-1}$)	89±14	92±10	90±9	81±7	60±11^{+}
Accelerations	854±306	959±211	942±222	708±136	608±130^{+}
Deccelerations	854±313	946±194	934±212	709±147	615±135^{+}
HRmax (%)	69±10	73±5$^{\partial}$	69±8	70±6	61±8

*Data are presented in relation to training seasions prior to the next competitive match. RPE=rating of perceived exertion. †Significantly different than M-4 and M-3. $^{\#}$Significantly different than M-2 and M-1. §Significantly different than M-4, M-3, and M-1. $^{\infty}$Significantly different than M-4, M-3, and M-2. ¶Significantly different than M-6, M-2, and M-1. $^{+}$Significantly different than M-6, M-4, and M-3. $^{\partial}$Significantly different than M-1.

In terms of average distance, the repeated-measured ANOVA indicated a significant main effect for microcycle day. Lower values were found for average distance on M-1 compared with M-6 (ES=2.3, $p < 0.001$), M-4 (ES=3.0, $p < 0.001$), and M-3 (ES=2.9, $p < 0.001$). For high-speed and sprint distances, there was a significant main effect for microcycle day. Higher values were observed for high-speed and sprint distances on M-3 compared with M-6 (ES=1.4 and 1.2; $p < 0.001$), M-2 (ES=1.5 and 1.1, $p < 0.001$), and M-1 (ES=1.6 and 1.2, $p < 0.001$). Regarding the number of accelerations and decelerations, there was a significant main effect for microcycle day. Lower values were found for accelerations and decelerations for M-1 compared with M-6 (ES=1.0 and 0.9; $p=0.010$ and $p=0.013$), M-4 (ES=2.0 and 1.9; $p < 0.001$), and M-3 (ES=1.8 and 1.8; $p < 0.001$). Finally, there was a significant main effect for microcycle day in $\%HR_{max}$. Higher values were observed for %HRmax on M-4 compared with M-1 (ES=1.8; $p=0.001$).

For the Dm of the RF, there was no two-way interaction for time × day interaction ($p=0.845$). There was no main effect for day ($p=0.938$). However, repeated-measures ANOVA detected a significant main effect for time. Decreases from pre- to post-session Dm values for the RF on M-6 ($p=0.08$; ES=0.8), M-4 ($p=0.025$; ES=0.8), M-3 ($p=0.030$; ES=0.6), and M-2 ($p=0.025$; ES=0.5) were observed (Figure 2).

For the Dm of the BF, there was no two-way interaction for time × day interaction ($p=0.772$) and no main effect for day ($p=0.946$). However, there was a significant main effect for time. Decreases from pre- to post-session Dm values of BF on M-6 ($p=0.05$; ES=0.9), M-4 ($p=0.016$; ES=0.7), M-3 ($p=0.003$; ES=0.9), and M-2 ($p=0.016$; ES=0.6) were observed.

For the Tc of the RF, there was no two-way interaction for time × day interaction ($p=0.947$). In addition, there were no main effects for time ($p=0.054$) or day ($p=0.660$). For the Tc of the BF, there was no two-way interaction for time × day ($p=0.999$). In addition, there were no main effects for time ($p=0.112$) or day ($p=0.849$).

For the Vc of the RF, there was no two-way interaction for time × day interaction ($p=0.610$). In addition, there were no main effects for time ($p=0.196$) or day ($p=0.311$). For the Vc of the BF, there was no two-way interaction for time × day ($p=0.829$). In addition, there were no main effects for time ($p=0.169$) or day ($p=0.541$).

There were significant correlations between relative change in Dm of RF and training duration ($r_{rm}=0.709$; $p < 0.01$; large), high-speed distance covered ($r_{rm}=0.685$; $p < 0.05$; moderate), and training average distance ($r_{rm}=0.674$; $p < 0.05$; moderate). No significant correlations were found between relative change in Tc and Vc of RF and BF and any of the training load variables.

DISCUSSION

The main findings of this study are that: a) significant differences were observed in training load variables across different training sessions, with M-4 showing the highest values for training duration, RPE, total distance, average distance, accelerations, decelerations, and HR_{max}, M-3 showing the highest values of high-speed and sprint distance, and M-1 showing the lowest values for all training load variables, b) significant pre- to post-session differences were observed in Dm of RF and BF during M-6, M-4, M-3, and M-2, c) no pre- to post-session differences were observed in Tc of RF and BF, d) no significant differences were observed in TMG variables across training sessions during the microcycle, and e) significant relationships were found between absolute change in Dm of RF and training duration, high-speed distance, and average distance.

The training load of the present study was similar to those observed previously in the English Premier League [26,27], showing a similar

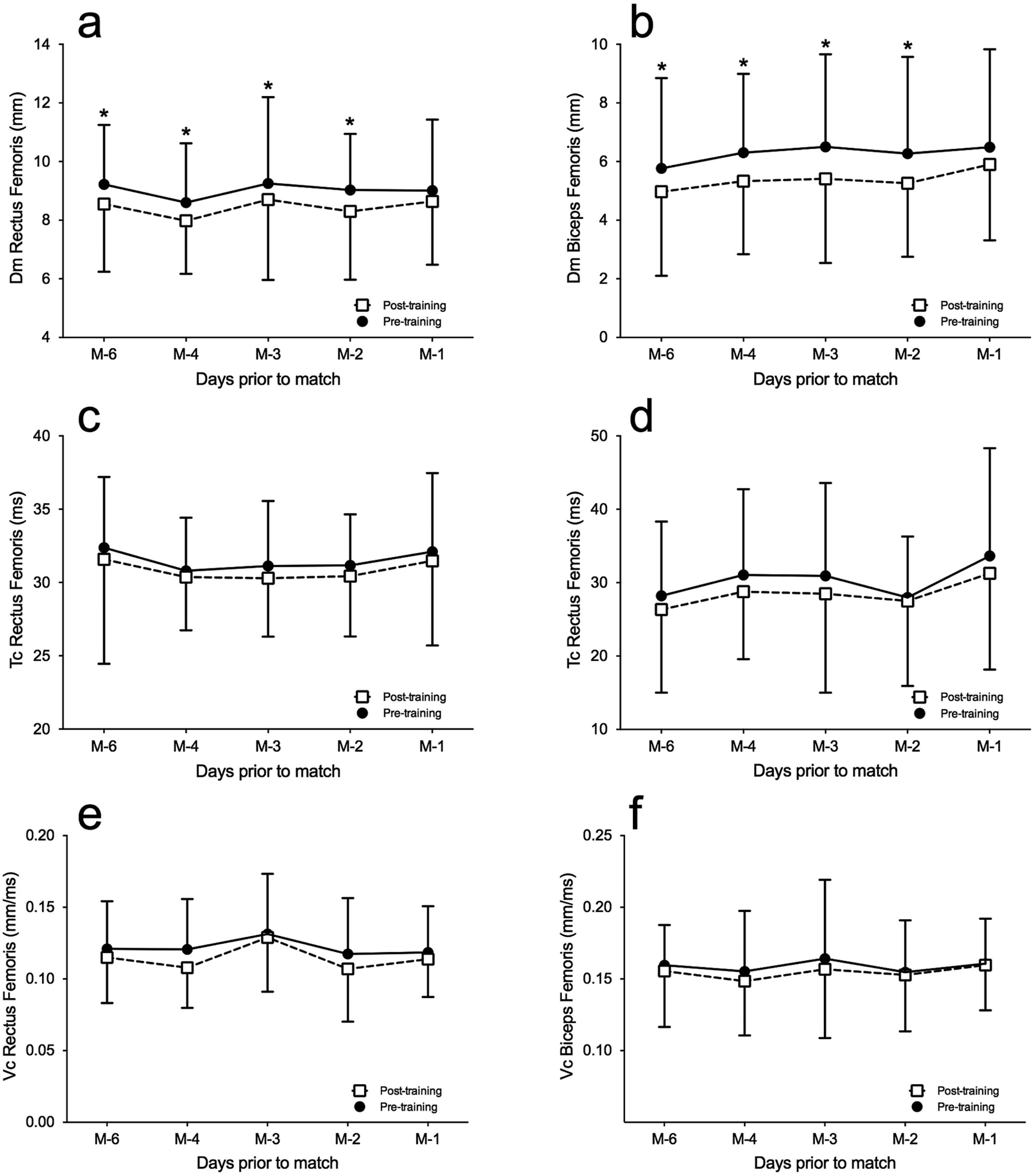

FIG. 2. Differences in tensiomyography parameters during a microcycle. *Significant differences between pre-session and post-session values. (A) Maximal radial displacement (Dm) of rectus femoris; (B) Dm of biceps femoris; (C) contraction time (Tc) of rectus femoris; (D) Tc of biceps femoris; (E) contraction velocity (Vc) of rectus femoris; (F) Vc of biceps femoris.

trend for microcycle structure characterized by an increase in daily training loads during earlier training sessions and a decrease in training load as a competitive match approaches [28]. In the present study, the largest absolute loads were observed on M-4 and M-3 (mid days of microcycle), whilst the lightest load on M-1 (last training session) reflects an attempt to facilitate the full recovery and players' readiness prior to the next match.

In soccer practice, the quadriceps muscle group plays an important role in sprinting, jumping and ball kicking, whereas the hamstring controls the running activities and stabilizes the knee during turns or tackles [17]. Furthermore, quadriceps and hamstrings are the most frequently strained muscles during the preseason and competitive season, respectively [29]. However, the question of how soccer-training load may influence the stiffness status of these muscles in professional players is still unanswered. Our results demonstrated that soccer training caused a significant increase in muscle radial stiffness (lower values of Dm) of the RF (>7%) and BF (>12%) from pre-session to post-session on those days of higher training load (M-6, M-4, M-3, and M-2) (Figure 2). Interestingly, these changes were not observed on M-1 (one day before the match), perhaps due to the prescription of reduced training loads to ensure full recovery before the match [4] (Table 1). Thus, the different acute effects of soccer sessions on knee flexor and extensor muscles' stiffness can be partially explained by the magnitude of training load. This conclusion is partially supported by the significant associations observed between post-session changes in Dm of RF and training duration, high-speed distance, and average distance. These findings may have important practical implications, as previous evidence suggests significant effects of muscle stiffness on symptoms of muscle damage and injury risk [6,7]. Therefore, the assessment of stiffness may constitute an important component of players' screening during the microcycle.

Previous evidence demonstrated that stiffness might be highly dependent on the type of muscle contractions primarily involved in the sport [10]. Thus, comparisons with previous studies are difficult due to strongly contrasting forms of induced fatigue. However, the increase in muscle stiffness observed in our study is partially in agreement with previous investigations [14,30,31]. In this regard, some researchers have indicated that impaired muscle function may be partially explained by reduced efficiency of the excitation-contraction coupling, impaired membrane conduction properties, and destruction of cellular structures (i.e., peripheral fatigue) [8,11]. Based on the present findings, it appears that soccer players are neuromuscularly taxed as a result of the training load. In this context, Dm seems to be sensitive enough to detect these changes after a soccer session. However, more research is needed to examine the effects of different training activities and training periods on muscle stiffness through the season.

Contrary to Dm and to almost all the previous evidence [11,13,32], Tc remained unaffected after the soccer training sessions. Our results are in contrast to previous studies showing an increase in Tc immediately after eccentric training [13,14,32], but are in agreement with more recent research [14]. In addition, no correlation was found between absolute changes in Tc and training load variables. Moreover, Vc remained unaffected after each training session. Therefore, based on the present results, the speed-time component of the TMG should not be recommended for assessment of neuromuscular status in response to soccer training during an in-season microcycle [30].

Previous research has demonstrated that weekly training demands may alter muscular stiffness [7]. However, to the best of our knowledge, no studies have examined the progression of muscle stiffness across a microcycle in professional soccer players. Interestingly, there were no changes in Dm, Tc, and Vc of the RF and BF across the microcycle training sessions. Considering pre- to post-session increases observed in RF and BF stiffness, it appears that soccer players participating in the present study had the possibility to recover their neuromuscular status between training sessions across the microcycle. During the in-season microcycles, conditioning coaches need to be able to prescribe weekly training loads to achieve the maintenance of fitness levels and to ensure players' full recovery before competitive matches [4]. Thus, one possible explanation for the lack of variation in Dm, Tc, and Vc between training sessions would be the attempt by coaches to unload the players during in-season microcycles.

CONCLUSIONS

Current study demonstrated that soccer players are physically taxed on their muscular stiffness immediately after session as a result of training load. However, they were able to recover their mechanical muscle functions for the subsequent training session. Considering these findings, strength and conditioning professionals as well as medical staff, working with professional soccer teams, are encouraged to assess acute muscle stiffness responses to training load, as an indicator of players' neuromuscular status, in order to adjust the training plan. In addition, due to the portability of equipment and the low physical demands of testing, this study supports the use of TMG to determine stiffness status and neuromuscular readiness in professional players during the competitive season. To further substantiate the results of the present study, it is necessary that future investigations be carried out with a larger cohort of soccer players to provide an overall representation of stiffness variations during microcycles. In addition, further research is needed into the relationship between variations in muscle stiffness and the occurrence of injuries in soccer players.

Acknowledgments

E.R. was supported by the program "José Castillejo" from the Spanish Ministry of Science, Innovation, and Universities.

Conflict of interest

The authors declared no conflict of interest.

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