



Baseline Mechanical and Neuromuscular Profile of Knee Extensor and Flexor Muscles in Professional Soccer Players at the Start of the Pre-Season

by

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The aim of the study was to determine the mechanical and neuromuscular profile of knee extensor and flexor muscles in professional soccer players at the start of the pre-season, and to calculate percentages for symmetry, as well as examine differences according to the player's positional role. The vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and biceps femoris (BF) of 16 professional soccer players were evaluated by means of tensiomyography (TMG) on the first day of the pre-season. A paired-samples t test ($p < .05$) was used to compare the dominant and non-dominant lower limb. One-way ANOVA was applied, with the positional role as an independent factor. No differences were observed between the dominant and non-dominant leg. The highest degree of symmetry corresponded to the VM ($92.5 \pm 2.7\%$), and the lowest to the BF ($80.7 \pm 10.9\%$). The positional role was associated with significant differences in some of the variables for the BF, RF and VM, although only the half-relaxation time in the BF and the time to sustain force in the VM differed across all the playing positions considered. TMG was shown to be a useful way of evaluating the neuromuscular characteristics of soccer players at the start of the pre-season, and of establishing baseline values for individual players.

Key words: *tensiomyography, knee, lateral symmetry, functional symmetry, periodization.*

Introduction

The neuromuscular system of soccer players is a key factor in their competitive performance, as it is this system which determines a player's immediate force response, reactivity and running speed during matches.

The neuromuscular system has recently begun to be analysed by means of tensiomyography (TMG), a non-invasive technique that, by means of a portable device, can measure the properties of individual superficial muscles by recording the isometric muscle contraction induced externally by electrostimulation (Valenčič and Knez, 1997;

Valenčič and Djordjevič, 2001; Valenčič et al., 2001). TMG muscle properties are sensitive to changes in muscle force with different strength training protocols (de Paula et al., 2015; Zubac and Šimunić, 2016) and TMG can discriminate de "athlete-type" using indicators moderately correlated with explosive lower body performance (Loturco et al., 2015). TMG can provide important information about the type of muscle fibre (Dahmane et al., 2005, 2006; Šimunić et al., 2011), muscle tone (Pišot et al., 2008), muscle fatigue (de Paula et al., 2015; García-Manso et al., 2011), the damage caused to muscles by eccentric

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training (Hunter et al., 2012), and muscle imbalance and asymmetries (García-García et al., 2013b). In addition, some TMG variables appear to be related with potential predictors of cycling performance (García-García, 2013). The possibility of assessing isolated muscles in the field and, therefore, avoiding the influence of factors such as motivation, player fatigue and an altered training schedule, gives TMG an advantage over other commonly used methods.

Although TMG has been used to study the neuromuscular characteristics of soccer players (Alvarez-Diaz et al., 2014; García-García et al., 2014, 2016; Rey et al., 2012a, 2012b), reference data obtained during the pre-season in the complete absence of fatigue have yet to be published. Obviously, data of this kind would provide useful information about players' baseline levels prior to beginning their formal training. Mohr et al. (2005) found that fatigue occurred at three different stages of a soccer game: immediately after short-term intense periods of effort, in the initial phase of the second half and towards the end of the game. Nedelec et al. (2014) observed that this neuromuscular fatigue may last for up to 72 hours after a match, depending on the number of sprints, changes of direction, accelerations and decelerations that had been performed during the game.

These findings highlight the difficulty of establishing baseline neuromuscular data (in the absence of fatigue) during the competitive season. This is relevant because, as Turner and Stewart (2014) point out, it is necessary to conduct regular physiological monitoring of players to assess the effectiveness of training. However, monitoring of this kind requires knowledge of a player's initial status, since these reference values of physical and physiological condition are known to change as the season progresses (Caldwell and Peters, 2009). This suggests that the only point at which neuromuscular data can truly be obtained in the absence of fatigue is at the start of the pre-season, before players have begun training.

The primary aim of this study was to determine the biomechanical and neuromuscular profile of knee extensor and flexor muscles in professional soccer players at the start of the pre-season. On the basis of the data obtained we then calculated percentages for both the lateral symmetry of each muscle and the functional

symmetry of each leg, and examined the extent to which these values varied according to different positional roles.

Methods

Participants

The sample comprised 16 professional soccer players (2 goalkeepers, 3 central defenders, 4 full-backs, 4 midfielders and 3 forwards) from a team in the Spanish professional league. All these players (age 28.2 ± 4.4 years, body mass 74.5 ± 4.3 kg, body height 178.8 ± 6.0 cm) were in good health and injury-free.

Ethical Statement

All participants provided written consent subsequent to being informed about the research process and the possible risks of TMG assessment. The coaching staff and management board of the professional soccer team were also informed about the nature of the study. The research protocol followed the principles of the Declaration of Helsinki regarding biomedical research involving human subjects (18th Medical Assembly, 1964; revised 2008 in Seoul). The study was approved by the management board and coaching staff of the professional soccer team and by the Ethics Committee of the Faculty of Education and Sport Sciences, University of Vigo.

Procedures

The players were assessed on the first day of the pre-season, prior to undergoing any training. They had all had at least four weeks rest since the end of the previous season. The first step involved a medical examination, including blood samples, with players being required to attend in a fasting state and having fully rested. All the players were found to be in good health and without disturbance in fatigue biomarkers (ie. creatine kinase). They then underwent the TMG assessment. Measurements were taken on the club's premises by two experts in TMG: one was responsible for monitoring the intensity and frequency of the applied stimulus, while the other monitored the sensor placement and recorded the leg being assessed. In order to obtain repeatability coefficients for the TMG variables, two measurements were taken at random from one of the players' muscles; the sensor and electrode position used for the first measurement was marked so that they could be placed in the same location when taking the second measurement 15-

30 minutes later.

Measures

TMG was used to measure the radial muscle belly displacement of the vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) knee extensor muscles, and of the long head of the biceps femoris (BF) flexor muscle. Measurements were taken under static and relaxed conditions. Knee extensors were measured with the subject in the supine position and the knee joint fixed at an angle of 140° by means of a wedge cushion designed for that purpose. The knee flexor muscle was measured with the subject in the prone position and the knee joint fixed at an angle of 165°, once again by means of a specially designed wedge cushion.

The TMG assessments were performed once the subject had been in a relaxed supine position for 10-15 minutes. Electrical stimulation was applied with monophasic pulse duration of 1 ms and an initial current amplitude of 30 mA, which was progressively increased in 5 mA steps until reaching 110 mA (maximal stimulator output). Consecutive stimuli were separated by a rest period of 10 s (Križaj et al., 2008). Of the 17 curves recorded for each participant, only the curve with the highest maximum radial displacement was included in the analysis for each muscle assessed, following the protocol described by García-García et al. (2013a) and García-García et al. (2016).

Measures of radial muscle belly displacement were acquired by means of a digital displacement transducer (GK 30, Panoptik d.o.o., Ljubljana, Slovenia) set perpendicular to the thickest part of the muscle belly. Due to individual anatomical differences, the sensor location was determined individually for each muscle in each participant (Valenčič and Djordjevič, 2001). The thickest part of the muscle belly was determined visually and through palpation during a voluntary contraction. The self-adhesive electrodes (5x5 cm, Cefar-Compex Medical AB Co., Ltd, Malmö, Sweden) were placed symmetrically at a distance of 5 cm from the sensor (Tous et al., 2010), in accordance with the protocol suggested by Perotto et al. (2005). The positive electrode was positioned above the measurement point and proximally, while the negative electrode was placed below this point and distally. For all measurements the point of

maximum radial muscle belly displacement was determined by obtaining the time-displacement curve for each muscle, as well as on the basis of low intensity measurements (20 mA) obtained previously by placing the sensor at different points 2-3 mm apart within the area defined by the electrodes, until the exact point of maximum radial displacement was identified. The electrical stimulus was produced by a TMG-S2 (EMF-FURLAN & Co. d.o.o., Ljubljana, Slovenia) stimulator.

Each measurement involved recording the following variables of involuntary isometric contraction produced by the electrical stimulus: maximum radial muscle belly displacement (D_m) in mm; contraction time (T_c) as the time in ms from 10 to 90% of D_m ; delay time (T_d) as the time in ms from the onset to 10% of D_m ; time to sustain (T_s) as the time in ms between 50% of D_m on both the ascending and descending sides of the curve; half-relaxation time (T_r) as the time in ms between 90 and 50% of D_m on the descending curve; contraction velocity (V_c) as the rate ($\text{mm}\cdot\text{s}^{-1}$) between the radial displacement occurring during the time period of T_c (D_{m80}) and T_c [D_{m80}/T_c].

Statistical analysis

Application of the Kolmogorov-Smirnov test, in conjunction with the Lilliefors test ($p < .05$), showed that the sample distribution was normal, linear and homoscedastic. Intraclass correlation coefficients (ICCs) with a 95% confidence interval (CI) were used to assess the reliability of TMG measurements. A paired-samples t test ($p < .05$) was used to compare sides (dominant vs. non-dominant lower limb). One-way ANOVA with the Bonferroni test ($p < .01$) was applied, with the positional role as an independent factor. All data were analysed using SPSS v19.0 for Windows (SPSS Inc., Chicago, IL, USA). The lateral symmetry (LS) and functional symmetry (FS) percentages were calculated using the algorithm implemented by the TMG-BMC tensiomyography® software (Figures 1 and 2). In addition, Cohen's d effect sizes for identified statistical differences were determined. Effect sizes (ES) with values of 0.2, 0.5 and 0.8 were considered to represent small, medium and large differences, respectively (Cohen, 1988). Finally, in order to establish whether these data are reliable (G_r) and generalizable (G_g), an analysis of variance

components by the least-squares procedure and maximum likelihood (<.0001), and an analysis of generalizability ($G_r > 0.800$; $G_a > 0.800$) were performed using SAS System for Windows v. 9.1 and SAGT software v.1, respectively.

Results

The ICC values (95% CI) obtained ranged between 0.81 and 0.99: Dm, 0.99; Tc, 0.97 Ts, 0.91; Td, 0.86; and Tr, 0.81. No significant differences ($p > .05$) were observed between the dominant and non-dominant leg for any of the variables measured.

Table 1 shows the values obtained for each of the variables assessed with TMG in each muscle. These values represent the average value of both sides, as no significant differences were found between the dominant and non-dominant leg.

It can be seen in the table that the vastus medialis had the shortest Tc and Td and it had the highest Vc, the biceps femoris had the smallest Dm and Vc, and the vastus lateralis had the shortest Ts and Tr. The greatest lateral symmetry corresponded to the vastus medialis ($92.5 \pm 2.7\%$), while the lowest symmetry value was that obtained for the biceps femoris ($80.7 \pm 10.9\%$). The right leg ($80.8 \pm 12.2\%$) showed more functional symmetry than did the left leg ($75.4 \pm 10.3\%$).

Table 2 shows the differences between positional roles for each of the variables assessed in each muscle. Goalkeepers had a longer Ts in the RF and a longer Tr in the VM than forwards with a great effect size (107.2 ± 0.7 ms vs. 51.8 ± 3.3 ms, $F = 4446.7$, $p = .01$, $d = 20.3$; 50.6 ± 0.3 ms vs. 37.5 ± 13.6 ms, $F = 1074.4$, $p = .01$, $d = 1.1$, respectively).

Central defenders had a smaller Dm in the RF than goalkeepers with a great effect size (8.7 ± 0.3 mm vs. 11 ± 0.6 mm; $F = 29.872$, $p = .01$, $d = 5.8$), and they showed greater lateral symmetry in the VM in comparison with midfielders with a moderate effect size ($94.6 \pm 1.1\%$ vs. $91 \pm 1\%$; $F = 17.286$, $p = .01$, $d = 0.5$). Full backs had a much shorter Td in the BF than midfield players (23.1 ± 0.6 ms vs. 25 ± 0.5 ms; $F = 20.187$, $p = .004$, $d = 3.5$), and they showed much greater lateral symmetry in the VL compared with forwards ($91.4 \pm 3\%$ vs. $72.5 \pm 3.1\%$; $F = 33.724$, $p = .004$, $d = 6.2$). Finally, forwards had a much longer Tr in the BF (156.9 ± 0.1 ms) with a great effect size than all the other positional roles ($F = 11.095$, $p = .002$), central defenders having the shortest Tr in this muscle (56.2 ± 17.8 ms). Forward was also the positional role that had the longest Ts in the VM with a great effect size (228 ± 8.8 ms), while the lowest value corresponded to goalkeepers (190.3 ± 2.6 ms) ($F = 6.560$, $p = .009$).

In all generalizability analysis models the residual error coincides in the calculation by the least-squares procedure (VARCOMP Type I) and maximum likelihood (GLM General Linear Model), as it is confirmed that the sample distribution was normal, linear and homoscedastic (Searle et al., 1992). The precision models of the Tc ($G_r = 1.000$ $G_a = 0.945$); Dm ($G_r = 1.000$ $G_a = 0.905$), Td ($G_r = 1.000$ $G_a = 0.944$), Ts ($G_r = 1.000$ $G_a = 0.981$), Tr ($G_r = 1.000$ $G_a = 0.961$), and Vc ($G_r = 1.000$ $G_a = 0.943$) variables present a high level of reliability and generalizability ($G_r > 0.900$; $G_a > 0.900$), since 1.000 is the highest value that can take both coefficients.

$$LS = 0.1 \cdot \frac{\min(TDr TDL)}{\max(TDr TDL)} + 0.6 \cdot \frac{\min(TCr TCL)}{\max(TCr TCL)} + 0.1 \cdot \frac{\min(TSr TSl)}{\max(TSr TSl)} + 0.2 \cdot \frac{\min(DMr DML)}{\max(DMr DML)}$$

Figure 1

LS = lateral symmetry, where "r" is the right side and "l" is the left side in all parameters. min = minimum, max = maximum

$$FS = 0.1 * \min(\text{average}(Tdr1, Tdr2), \text{average}(Tdr3, Tdr4)) / \max(\text{average}(Tdr1, Tdr2), \text{average}(Tdr3, Tdr4)) + 0.8 * \min(\text{average}(Tcr1, Tcr2), \text{average}(Tcr3, Tcr4)) / \max(\text{average}(Tcr1, Tcr2), \text{average}(Tcr3, Tcr4)) + 0.1 * \min(\text{average}(Tsr1, Tsr2), \text{average}(Tsr3, Tsr4)) / \max(\text{average}(Tsr1, Tsr2), \text{average}(Tsr3, Tsr4))$$

Figure 2

FS = Functional symmetry, where "r" is the right side and "l" is the left side in all variables. min = minimum, max = maximum

Table 1

Pre-season TMG assessments in professional soccer players. Tc, Td, Ts and Tr are in milliseconds, while Dm is in millimetres and Vc is in mm·s⁻¹. Values are mean (dominant and non-dominant legs) and standard deviation. LS: lateral symmetry; FS: functional symmetry

TMG	Vastus medialis	Vastus lateralis	Rectus femoris	Biceps femoris
Tc	25.0 ± 1.4 ms	26.1 ± 3.0 ms	30.9 ± 3.3 ms	34.5 ± 6.6 ms
Dm	9.1 ± 1.3 mm	7.2 ± 2.2 mm	10.4 ± 2.3 mm	7.0 ± 1.7 mm
Td	22.3 ± 0.9 ms	24.6 ± 1.5 ms	25.2 ± 1.8 ms	23.8 ± 1.8 ms
Ts	202.7 ± 12.2 ms	73.6 ± 36.0 ms	102.0 ± 37.6 ms	241.5 ± 33.5 ms
Tr	80.7 ± 44.1 ms	44.6 ± 33.8 ms	66.0 ± 36.7 ms	68.7 ± 28.2 ms
Vc	0.29 ± 0.04 mm·s ⁻¹	0.22 ± 0.07 mm·s ⁻¹	0.27 ± 0.06 mm·s ⁻¹	0.16 ± 0.03 mm·s ⁻¹
LS	92.5 ± 2.7%	86.1 ± 7.5%	84.3 ± 9.0%	80.7 ± 10.9%
FS right	80.8 ± 12.2%			
FS left	75.4 ± 10.3%			

Table 2

One-way ANOVA with the positional role as an independent factor. ES: Cohen's *d* effect sizes. BF: biceps femoris; RF: rectus femoris; VL: vastus lateralis; VM: vastus medialis; Sym: symmetry; FS functional symmetry. Tc, Td, Ts and Tr are in milliseconds, while Dm is in millimetres. Values are mean (dominant and non-dominant legs) and standard deviation. GK: goalkeeper; CD: central defender; FB: full back; M: midfielder; F: forward. Sig. Dif.: significant difference on this parameter between the positions indicated ($p < .01$).

Variables	GK	CD	FB	M	F	Sig.	ES
Tc BF	31.4 ± 5.2	33.3 ± 2.7	34.9 ± 9.5	37.1 ± 7.6	34.7 ± 0.1		
Td BF	23.2 ± 1.1	23.9 ± 3.9	23.1 ± 0.6	25 ± 0.5	24.4 ± 0.2	FB-M	3.4
Tr BF	64.7 ± 13.2	56.2 ± 17.8		68.1 ± 8.2	156.9 ± 0.1	FB-F	8.8
			60.4 ± 14.1			CD-F	7.3
						M-F	8.7
Dm BF	6.2 ± 1.2	6.4 ± 2.6	6.8 ± 8.1	8.1 ± 2.4	8 ± 0.3		
Ts BF	217.3 ± 51.3	236.9 ± 41.1	236.7 ± 24.8	250.6 ± 22.9	284.2 ± 23.4		
Vc BF	0.15 ± 0.007	0.15 ± 0.04	0.16 ± 0.05	0.16 ± 0.02	0.18 ± 0.05		
Tc RF	31.4 ± 0.4	31.3 ± 3.6	31.1 ± 4.8	30.7 ± 3	28.6 ± 0.4		
Td RF	23.9 ± 0.8	24.8 ± 2	25.6 ± 2.3	25.9 ± 2.2	24.8 ± 0.6		
Tr RF	62.2 ± 5.6	93.4 ± 30.1	73.2 ± 35.3	45.2 ± 47.6	26 ± 11.2		
Dm RF	11 ± 0.6	8.7 ± 0.3	10.5 ± 1.6	12.1 ± 4.5	9 ± 0.2	CD-GK	5.8
Ts RF	107.2 ± 0.7	131.6 ± 26.7	107.2 ± 35.9	77.6 ± 47.3	51.8 ± 3.3	GK-F	20.3
Vc RF	0.29 ± 0.01	0.26 ± 0.08	0.25 ± 0.03	0.28 ± 0.12	0.24 ± 0.01		
Tc VL	28.6 ± 2.4	24.7 ± 1.6	25.6 ± 3.5	27.1 ± 3.8	24.2 ± 0.1		
Td VL	24.8 ± 0.2	24.9 ± 1.7	23.8 ± 1.5	25.9 ± 1.4	23.6 ± 0.1		
Tr VL	42.7 ± 40.1	40.9 ± 32.7	49.6 ± 51.9	43.6 ± 7.4	40.7 ± 4.8		
Dm VL	7.6 ± 0.7	5.3 ± 1.9	6.9 ± 1.4	9.2 ± 3.6	7.4 ± 0.5		
Ts VL	72.8 ± 41.9	72.1 ± 36.6	77.1 ± 54.6	72.9 ± 13	70.5 ± 7.7		
Vc VL	0.20 ± 0.01	0.20 ± 0.07	0.20 ± 0.06	0.23 ± 0.12	0.25 ± 0.01		
Tc VM	27.1 ± 1.6	24.5 ± 0.3	24.9 ± 1.1	24.2 ± 1.7	24.3 ± 0.1		
Td VM	21.9 ± 0.2	22 ± 1.9	22.7 ± 0.8	22.1 ± 0.2	22.4 ± 0.2		
Tr VM	50.6 ± 0.3	104.3 ± 67.6	84.5 ± 40.1	85.5 ± 45.7	37.5 ± 13.6	GK-F	1.1
Dm VM	8.9 ± 0.4	8.6 ± 1.5	9.6 ± 1.2	9.4 ± 2.1	7.3 ± 0.2		
Ts VM	190.3 ± 2.6	208.4 ± 5.5	194.3 ± 5.2	213.1 ± 12.6	228 ± 8.8	FB-CD	2.6
						FB-M	1.9
						FB-F	4.9
						CD-GK	3.6
Vc VM	0.26 ± 0.01	0.28 ± 0.04	0.31 ± 0.04	0.28 ± 0.01	0.23 ± 0.01		
Sym BF	92%	79 ± 16.5%	76.8 ± 9.6%	78 ± 8.5%	91 ± 1.4%		
Sym RF	84.5 ± 10.6%	83.3 ± 6%	83.6 ± 12.9%	84.6 ± 9%	90.4 ± 2.7%		
Sym VL	87 ± 4.2%	87 ± 6.9%	91.4 ± 3%	80.6 ± 8.7%	72.5 ± 3.1%	FB-F	6.2
Sym VM	95 ± 1.4%	94.6 ± 1.1%	92 ± 3.3%	91 ± 1%	88.5 ± 0.7%	CD-M	0.5
Knee FS Right	85.5 ± 12%	83 ± 10.3%	81.6 ± 12.7%	75 ± 19.6%	79 ± 4%		
Knee FS Left	82.5 ± 2.1%	75.6 ± 10%	73.2 ± 15.2%	76.3 ± 7.2%	68.5 ± 1.7%		

Discussion

This study reports pre-season reference values for a series of TMG variables (Tc, Dm, Td, Ts, Tr and Vc) measured in professional soccer players. While no significant differences were observed between the dominant and non-dominant leg, we did find some differences according to the players' positional role, although only the Tr in the BF and the Ts in the VM differed across all the playing positions considered.

If one considers a value below 0.8 as the cut-off for insufficient reliability (Atkinson and Nevill, 1998), then the ICCs for these pre-season data indicate good reliability for all the TMG variables; in fact, some of them (Dm, Tc and Ts) yielded high reliability coefficients. TMG measurements of the VL, VM, RF and BF had previously been reported to show good same-day reliability in both soccer players (García-García et al., 2016; Rey et al., 2012a) and other groups of subjects (Carrasco et al., 2011; Križaj et al., 2008; Tous Fajardo et al., 2010). In addition, in this study all the TMG data present a high level of reliability and generalizability.

As for the TMG values of professional soccer players, the Tc values at the start of pre-season were lower than during the season (García-García et al., 2016), using the same methodology, in knee extensors muscles (VM 25 vs 28.7-35.2 ms; VL 26.1 vs 28.5-36.9 ms; RF 30.9 vs 31.5-38.3 ms); however, knee flexor muscle BF was higher (34.5 vs 28.8-29.8 ms). Also Dm values at the start of the pre-season were lower than during the season in all muscles evaluated (9.1 vs 7.2-8.4 mm; VL 7.2 vs 5.5-5.9 mm; RF 10.4 vs 8.6-9.8 mm; BF 7.0 vs 5.3-6.6 mm). Td value was similar to those obtained during the season.

Loturco et al. (2016) observed a drop in Vc and Dm in BF and RF, along with a slower sprint speed in Brazilian professional soccer players, after eight week training that began just after the end of the state championship and ended before the start of the national championship. Our results are substantially higher in the Tc, Td, Dm and Vc values compared to values found by these authors. However, it is important to point out that in this work we used a different formula to calculate Vc. Our Tc and Dm values for RF are also substantially higher than those reported by Gil et al. (2015) in Brazilian professional soccer

players. However, the values for BF are similar to those we found at the start of the season. Unfortunately, these authors do not report at what point during the season the data were collected.

All these results support the hypothesis that the Tc, Td and Dm variables of professional players evolve throughout the soccer season, as has been suggested by García-García et al. (2016).

In their study of semi-professional soccer player during the competitive season, Rey et al. (2012a) reported Tc (29.63 ± 3.99 ms), Dm (11.34 ± 3.09 mm) and Td (25.91 ± 2.02 ms) values in the RF that are similar to those obtained here. However, their Tc (26.68 ± 4.45 ms) and Dm (5.30 ± 1.62 mm) values for the BF were much lower than those of our players at the start of the pre-season.

These findings are consistent with the reported adaptive capacity of the BF, since the Tc of sprinters has been found to be much shorter than that of sedentary people (19.5 ± 2.3 ms vs. 30.25 ± 3.5 ms) (Dahmane et al., 2006). However, caution should be exercised when making this comparison, since the data were obtained at different points of the season and the method used to obtain the TMG measures was different. The values reported by Álvarez-Díaz et al. (2014) with amateur players also differ from those obtained here in professional athletes: the Tc, Td, Ts and Dm values obtained by these authors were lower for all the muscles assessed. This difference could likewise be attributed to the different procedure used to obtain data, to the different point in the season when data were collected and/or to the different competitive level of the players involved.

The Tc and Dm values achieved by our soccer players at the start of the pre-season are, as expected, substantially different from those reported in a study that used the same methodology to assess professional road cyclists during preparatory and competitive periods of the season (García-García et al., 2013a). Specifically, Tc was shorter and Dm was greater in our soccer players than it was among cyclists. This latter difference can be explained in terms of the increased muscle tone that the cyclists would have developed as a result of training completed by the time they were assessed, since smaller Dm has been reported to be associated with increased

muscle tone (Pišot et al., 2008), improvement in jumping performance (Zagas and Šimunič, 2016) or muscular fatigue (de Paula et al., 2015).

The differences observed in the TMG variables of our players' muscles at the start of the pre-season (i.e. longer Tc in the RF and BF than in the VM and VL; greater Dm in the VM and RF than in the VL and BF, etc.) can be explained by the findings of Pincivero et al. (2000), who reported that the EMG amplitude of the VL (determined by calculating the root mean square over the same contraction period for each muscle) was greater than that of the RF and VM, and also that the EMG amplitude of the RF was greater than that of the VM. In a similar vein, Rabita et al. (2000) showed that the muscles of the quadriceps had a different capacity for adaptation, hence, the different strategies required to increase their respective strength.

We observed no differences between the dominant and non-dominant leg of our soccer players, a result that is consistent with the findings of García-García et al. (2014), Álvarez-Díaz et al. (2014), Gil et al. (2015) and García-García et al. (2016); although Álvarez-Díaz et al. (2014) did report some differences in certain variables of the VM (Tc), VL (Tc and Td), RF (Ts and Tr) and BF (Ts), they concluded that TMG measurements of soccer players were not generally influenced by leg dominance. Studies of professional volleyball players (Rodríguez-Ruiz et al., 2012) and cyclists (García-García et al., 2013b) have likewise found no differences between the dominant and non-dominant leg when using TMG as the assessment tool.

The observed lack of a leg dominance effect is also consistent with research on professional soccer players that has used the maximum force output (isometric and isokinetic) with the dominant and non-dominant leg as an indicator of lateral symmetry (Capranica et al., 1992; Draganidis et al., 2015; Masuda et al., 2003; Zakas, 2006). It should be noted, however, that some studies have reported bilateral asymmetries in the force generated during concentric and eccentric contraction of the knee flexor muscles (Arderm et al., 2015; Rahnema et al., 2005), with asymmetry being defined as a difference of more than 10% between the two sides (Rahnema et al., 2005) or a bilateral eccentric and concentric hamstring peak torque ratio <0.86 (Arderm et al.,

2015).

The percentages of lateral symmetry in our soccer players, calculated using the TMG-BMC tensiomyography® software, are similar to those obtained by García-García et al. (2014), also in professional soccer players, but they are slightly higher than the values reported by García-García et al. (2013b) with professional cyclists, where the mean value for the four muscles assessed was $82.26 \pm 9.84\%$, a degree of symmetry that remained stable across the competitive season. The latter authors suggested that lateral symmetry above 80% in each muscle and the absence of any significant differences between muscles would indicate an adequate lateral symmetry. Based on these criteria, the four muscles assessed in our soccer players could be regarded as showing adequate lateral symmetry, the lowest value corresponding to the BF ($80.7 \pm 10.9\%$). It should be noted, however, that percentages of lateral symmetry have been reported to vary across the soccer season (García-García et al., 2014), and therefore it would be necessary to monitor this aspect over the whole competitive season.

The percentages of functional symmetry in our players (also calculated using the TMG-BMC tensiomyography® software) are very similar to those obtained in professional cyclists during the preparatory period (García-García et al., 2013b), where the mean value for both legs was $77.4 \pm 9\%$; however, during the competitive period of the cycling season this value dropped to $73.2 \pm 8.8\%$, which is lower than the percentage obtained in our soccer players at the start of the pre-season. There is no consensus as to what would constitute an adequate degree of functional symmetry when using TMG, although the differences observed here between the three knee extensors and the BF (i.e. lower percentage of lateral symmetry in the BF, longer Tc) suggest the need to monitor the hamstring/quadriceps (H/Q) ratio of soccer players during the season. This ratio has traditionally been calculated by assessing maximal voluntary contraction (MVC), with a low value being considered a risk factor for knee injury (Zebis et al., 2011). One study of elite soccer players that used MVC and the rate of force development to calculate the H/Q strength ratio did indeed find low values (Zebis et al., 2011). Also the use of eccentric H/concentric Q ratio may

be a better predictor of soccer injuries (Draganidis et al., 2015). This ratio is more affected in response to a soccer match (Draganidis et al., 2015). TMG may also be a useful way of assessing the H/Q ratio, although further studies that use this technique to assess knee functional symmetry are needed in order to determine the cut-off percentages for adequate symmetry.

A number of significant differences were observed in TMG variables for the VM, RF and BF depending on the positional role usually adopted by our players. However, only the Tr in the BF and the Ts in the VM differed across all the playing positions considered. Rey et al. (2012a) also found some significant differences in the RF according to the positional role, although this was not the case for the BF. Specifically, these authors observed differences in the Tc of the RF between full-backs, midfielders and goalkeepers, in the Tr of the RF between midfielders and central defenders, and in the Ts of the RF between all positions except for goalkeepers. Of these variables, only the TS of the RF produced significant differences among our players, although we also observed differences in the Td and Tr of the BF, in the Dm and Ts of the RF, and in the Tr and Ts of the VM, as well as in the lateral symmetry percentages of the VL and VM. These results suggest that the neuromuscular characteristics of soccer players, as measured by TMG, may differ depending on the individual's positional role, a conclusion that is consistent with what has been found when using other methods of assessment (Ruas et al., 2015; Wisloff et al., 1998). It should be noted, however, that the method used by Rey et al. (2012a) to collect their data differs somewhat from our approach here, and caution should therefore be exercised when making any comparison.

TMG would appear to be a useful way of monitoring the neuromuscular system of soccer players, both during the pre-season and competitive periods, and it can indicate how players' muscles respond to different loads, whether in training or during matches (Alvarez-Díaz et al., 2014; García-García et al., 2013a, 2016; Rey et al., 2012a). More specifically, it is a portable and non-invasive approach that can provide information not only about individual responses to training (effect training), but also about neuromuscular fatigue and possible functional

and lateral asymmetries. Several questions remain to be addressed, however, including how to deal with the neuromuscular changes that may occur in elite soccer players during the season, the nature of the relationship between TMG variables, and the identification of potential predictors of performance. In addition, further investigation is required of the extent to which it is possible, using a static method based on isometric contraction, to assess the subsequent dynamic behaviour of stretch-shortening cycles, which are characteristic of the mechanical performance inherent to soccer. Further exploration is also required of the knowledge on percentages for symmetry that are established with this tool in order to determine, for example, what percentage indicates muscular asymmetry, whether lateral or functional. As mentioned above, listing more proven methods such as the H/Q ratio with percentages obtained with TMG could provide useful information in this respect. It would be advisable to monitor these percentages throughout the competitive season in order to establish how they vary according to the training and competition load, and the injuries sustained. Further work is certainly necessary, so that percentages for symmetry with TMG have greater explanatory capacity.

Finally, there is a need to identify patterns of TMG variables that differentiate between the various positional roles of professional soccer players.

Conclusions

TMG would seem to be a useful way of evaluating the neuromuscular characteristics of soccer players at the start of the pre-season, and of establishing baseline values for individual players. The latter values provide a benchmark against which to assess players' neuromuscular status over the course of a season, whether in response to different training loads or match play. Some significant differences were observed according to the positional role in variables of the BF, RF and VM, and in the lateral symmetry of the VL and VM. However, only the Tr in the BF and the Ts in the VM differed across all the playing positions considered. Nevertheless, further studies are required along the lines of the same methodology in the use of TMG in different professional teams, in order to clearly identify the

baseline neuromuscular values of professional soccer players, as well as the differences between specific playing positions.

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