Original Research

Muscle contractile properties of professional soccer players according to playing position and limb dominance

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Background and Purpose

This study aimed to characterise selected lower-limb muscle contractile properties in a sample of male professional soccer players, and to investigate if muscle contractile properties differed according to playing position or limb dominance.

Study Design

Cross-sectional study

Methods

One hundred and ninety-three male professional soccer players (mean ± SD: age=21.6yrs ± 4.4; height=181.1cm ± 10.0; body mass=77.4kg ± 8.5) had bilateral measurements of muscle contractile properties taken during the pre-season period (June-July) of the 2016-17, 2017-18 and 2018-19 seasons using Tensiomyography. The following muscles were measured: Adductor Magnus (AM), Bicep Femoris (BF), Gastrocnemius Lateralis (GL), Gastrocnemius Medialis (GM), Gluteus Maximus (GT) and Rectus Femoris (RF). Participants were sub-categorised by playing position and limb dominance. Data were analysed using Kruskal Wallis H tests or Mann-Whitney U tests.

Results

The left GM muscle produced the shortest delay time (Td) (19.5 ms ± 1.9) and contraction time (Tc) (21.3 ms ± 14.3) whilst the right BF had the longest sustain time (Ts) (196.9 ms ± 83.9). Relaxation time (Tr) was shortest in the right GL (39.3 ms ± 22.7) and the right GT the largest maximal displacement (Dm) value (10.2 mm ± 3.6). Small differences were present between the left AM Td in Forwards ($p=0.005$, $\eta^2=0.05$) and Midfielders and in the left GM Ts between Forwards and Goalkeepers ($p=0.04$, $\eta^2=0.02$). The right RF Tc measurement was lower in the right dominant participants ($p=0.04$, $\eta^2=0.35$). No other differences were detected between playing positions or limb dominance ($p>0.05$).

Conclusion

The findings from this study provide a profile of lower limb muscle contractile properties in a sample of male professional soccer players. The lack of consistent differences reported between sub-categories suggest that soccer players are homogeneous, regardless of playing position or limb dominance. The data generated from this study may be used to monitor soccer players following periods of inactivity, fixture congestion, long-term injury or acute changes in professional status.

1.0. INTRODUCTION

Male professional soccer players are subjected to routine physiological assessment before, during and after competition.[1] Information from physiological testing is used within these environments to assess the efficacy of training interventions, evaluate sport related practices or competitive situations[2] which may contribute to reducing injury risk.[3] Non-invasive techniques to examine the contractile properties of muscle are increasingly used in sporting environments. Technology such as mechanomyography (MMG)[4] and Tensiomyography (TMG)[5] were produced to provide reliable and valid methods to estimate the contractile properties of skeletal muscle. Using this technology, previous studies have estimated muscle contractile properties according to muscle composition in response to fatigue, and in response to rehabilitation following musculoskeletal injury.[4,6–8]

TMG has emerged as a portable, non-invasive method used to assess muscle contractile properties of individual, superficial skeletal muscles.[8] During TMG assessment, a single pulsed electrical twitch contraction is applied (via two surface electrodes) to a single muscle causing radial displacement of a digital transducer, which is placed perpendicular to the muscle belly.[9] The TMG software then produces a waveform detailing time and displacement of the contraction. The involuntary nature of assessment removes error associated with participant effort and motivation. Studies have reported good to excellent between day, inter-rater and intra-session reliability of measurements for selected lower limb muscles.[1,10–13] These findings have been confirmed by methodological testing in our laboratory for the rectus femoris (RF) and bicep femoris (BF).[14] Previously TMG has been used to highlight significant changes in maximal muscle displacement (Dm) and muscle contraction time (Tc) following a period of bed rest,[15,16] strength training,[17] injury[6,7] and sport-related training or match-play.[18,19] To contextualise change data in relation to the population of interest, normative values are needed.

Muscle contractile properties in soccer players may be expected to differ from other sports given the specific demands of the game.[20] Furthermore, within male professional soccer, little is known whether muscle contractile properties differ in relation to specific playing position or self-reported limb dominance. A study by Rey et al., (2012)[1] investigated TMG parameters according to playing position in a sample of 78 male soccer players competing in the Spanish first division and reported statistically significant differences in in the RF. Alvarez-Diaz et al., (2016)[21] reported no differences in TMG parameters between lower limb muscles in the dominant and non-dominant limbs of 38 elite soccer players. Whilst these studies provide some initial inferences, the relatively small sample sizes and narrow focus of particular muscle groups means further studies in this area are warranted. Furthermore, there are currently no studies reporting muscle contractile properties of any lower limb muscles amongst male professional soccer players who compete in English professional leagues. Due to the cultural differences in training and match play,[22] and the seasonal variations between English and other European countries, it would be interesting to observe muscle contractile properties differ between soccer players from different leagues across Europe.[23,24]

The aim of this study was to profile selected lower-limb muscle contractile properties in a sample of male professional soccer players using TMG. A secondary aim was to investigate if muscle contractile properties differed according to (1) playing position and/or (2) limb dominance.

2.0. MATERIALS AND METHODS

2.1. DESIGN

A cross-sectional study design was used. Measurements took place during the pre-season period (June-July) of the 2016-17, 2017-18 and 2018-19 seasons. Ethical approval was granted by School of Health Research Ethics Committee at Leeds Beckett University, UK and complied with the Declaration of Helsinki on human research and international standards.

2.2. PARTICIPANTS

One hundred and ninety-three (n=193) professional senior soccer players (mean ± SD: age=21.6yrs±4.4; height=181.1cm±10.0; body mass=77.4kg±8.5) were recruited from ten different English Football League squads competing in the Championship, league one and league two. The principal investigator was responsible for explaining the study design, procedures and outcomes to each participant before any measurements were taken. Participants were asked not to take part in the study if they were currently suffering from any trunk or lower-limb musculoskeletal injury, had sustained a lower-limb musculoskeletal injury within the last 3 months, had a pacemaker or any cardiovascular disease, currently took regular medication, had allergies to adhesive glue or had a current dermatological condition.[25] Participants agreed to refrain from caffeine consumption for 12 hours before testing, maintain their normal diet and refrain from exercise 72 hours prior to the testing time. Prior to the commencement of the study, all participants were provided with a participant information document and required to complete an informed consent document. Participants attended the study testing session for a maximum of one hour at scheduled appointment times.

2.3. ANTHROPOMETRIC MEASURES

For all measurements, participants wore t-shirts, underwear and shorts. Prior to muscle contractile properties measurements, anthropometric measures were taken. Height was measured using a stadiometer (SECA Alpha, Birmingham, UK) to the nearest 0.1 cm. Body mass was measured using electronic scales (SECAAlpha770, Birmingham, UK) to the nearest 0.1kg. Following this, each participant was marked for TMG sensor and electrode placements with a dermatological pen using standardised methods from our laboratory,[9,26] (Figure 1). Based upon the methods previously published,[26] and to ensure standardisation within and between participants, the sensor tip was placed at the midway point between the muscle origin or closet palpable bony landmark (AM, pubic symphysis; BF, ischial tuberosity; RF, greater trochanter; GT, posterior superior iliac spine) and insertion points (AM, medial femoral condyle; BF, lateral femoral condyle; RF, lateral femoral condyle; GT, ischial tuberosity). A vertical line was then marked at the midway point and resisted isometric testing revealed the borders of each individual muscle. The midway

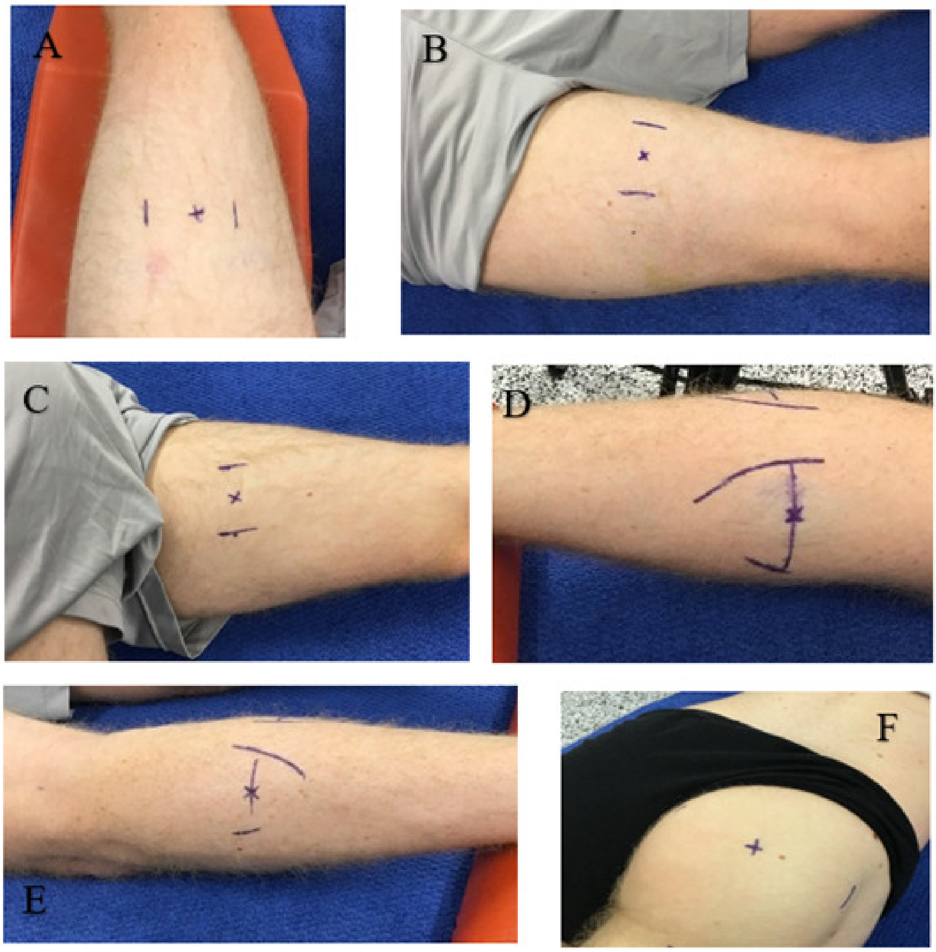

Figure 1. Probe placement locations for TMG assessment.

A: Probe placement marking for bicep femoris; B: Probe placement marking for bicep femoris; C: Probe placement marking for adductor magnus; D: Probe placement marking for gastrocnemius medialis; E: Probe placement marking for gastrocnemius lateralis; F: Probe placement marking for gluteus maximus

point was then measured to obtain the absolute mid-point of the muscle belly. For the GL and GM, the sensor tip position was selected using the widest region of the gastrocnemius muscle girth (to the naked eye) and then then a vertical line running directly to the lateral and medical popliteal crease respectively.[26]

2.4. MEASUREMENTS OF MUSCLE CONTRACTILE PROPERTIES

Each participant received one TMG (GK 40, Panoptik d.o.o., Ljubljana, Slovenia) assessment, bilaterally, on the following muscles: Adductor Magnus (AM), Bicep Femoris (BF), Gastrocnemius Lateralis (GL), Gastrocnemius Medialis (GM), Gluteus Maximus (GT) and Rectus Femoris (RF). The muscles were selected due to previous epidemiological injury data suggesting a these to be commonly reported sites of injury amongst male soccer players.[23,27] Additionally, the GT muscle was selected due to its involvement in posterior chain movements.[28] All measurements were taken by a qualified musculoskeletal practitioner who had undertaken 2 days of training from the equipment manufacturer.

Participants were tested in a sequential order, with posterior muscles (GL, GM, BF, GT) tested bilaterally first with the participant in prone, followed by the AM muscles (in side-lying left and right) and finally the RF muscles with the participant in a supine position (Figure 2). A semi-circular foam pad was placed underneath the ankle for both prone and side lying positions to allow 15 degrees of knee flexion or hip adduction during testing. When testing in supine, a larger triangular foam pad was placed under the knee crease of the tested leg, to place the limb knee in 30 degrees of knee flexion. Once the participant was in position, two self-adhesive electrodes (5x5cm, Med-Fit, Stockport, UK) were placed in the pre-marked positions, proximal and distal to the sensor position. This is with the exception of the GT, where the electrodes were placed laterally and distally due to the shape and location of the muscle belly. The spring-loaded sensor was then positioned in the marked position, perpendicular to the muscle belly. Compression of the sensor tip into the skin was placed ~50% of the total sensor length[29,30]; this was estimated by the operator. Once the probe and electrodes were in place the operator applied an initial 1ms wide square monophasic electrical pulse stimulation of 20ma as a familiarisation at the first GL muscle site. The initial amplitude was then set at 30mA (milli amps) with stimulation increasing by 5mA after an inter-stimulus time of 10-seconds.[1,11,31] This was repeated un-

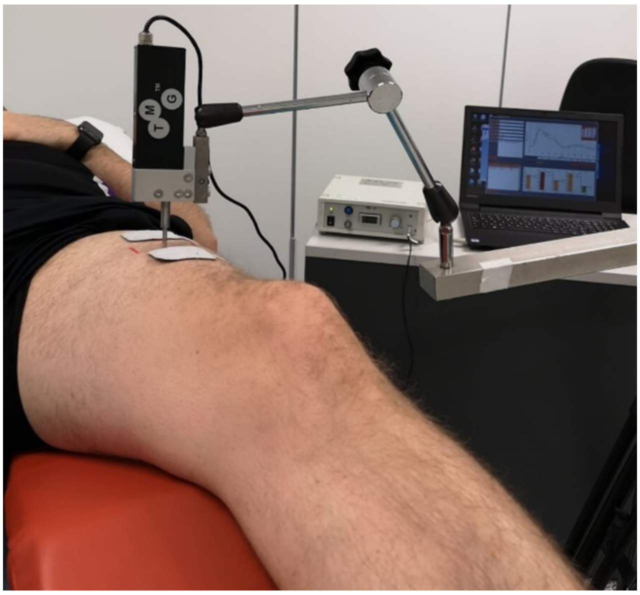

Figure 2. Equipment set up during TMG assessment of the RF muscle

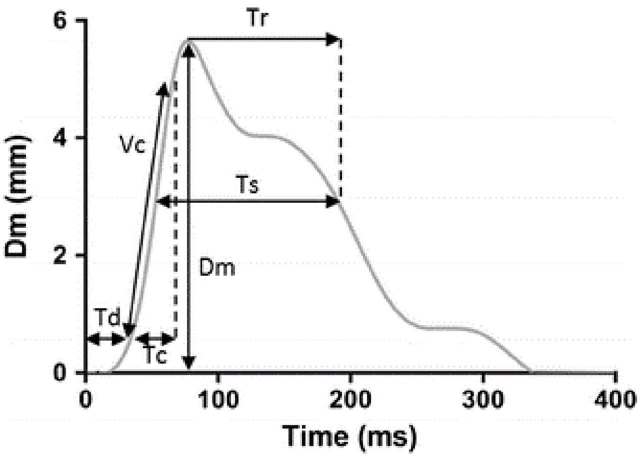

Figure 3. Typical displacement curve detailing; displacement (Dm), contraction time (Tc), delay time (Td), contraction velocity (Vc), sustain time (Ts) and half-relaxation time (Tr).

Extracted from Macgregor et al., (2018).[32]

til there was a plateau in the displacement curve, signifying absolute spatial transverse deformation had occurred within the muscle.[32] Alternatively, if maximal amplitude, (set at 100mA by the manufacturer) was achieved, the final associated curve values were recorded.

The time-displacement curve produced allowed the following contractile properties to be calculated: maximal displacement (Dm) as the trace of a full muscle contraction, delay time (Td) as the time taken from onset of muscle contraction to 10% of Dm in the ascending curve, contraction time (Tc) as the time taken from 10% to 90% of Dm, sustain time (Ts) as the time taken between 50% of Dm on both ascending and descending curves, relaxation Time (Tr) as the time taken from 90% to 50% on the descending curve[11] (Figure 3).

2.5. DATA ANALYSIS

Analysis of results were completed using SPSS for windows version 27 (SPSS Inc., Chicago, IL). The full data set was initially used to calculate descriptive statistics for the following variables: age, height, body mass, Td, Tc, Ts, Tr and Dm of the following muscles (GL, GM, BF, GT, AL, RF). All results are presented as means ± standard deviation (SD). The data set was then divided into the following sub-groups for further analysis:

1. Playing position – comparisons were made between Goalkeepers (n=15), Defenders (n=62), Midfielders (n=64) and Forwards (n=52)
2. Dominance – comparisons were made between the self-reported dominant vs non-dominant limbs (dominant right (n=144), dominant left (n=47)).[33]

Normality and equality of variance for the data set was assessed using the Shapiro-wilk test and normality plots. Data was shown to be non-parametric for the whole sample and when sub-categorised by playing position and limb dominance. To assess for differences between playing positions, a Kruskal Wallis H test was used *(H)* to assess the median ranks. A Bonferroni post-hoc correction was then applied to establish where significant differences were seen between pairs of playing positions. A Mann-Whitney U test *(U)* was used to assess for differences between the median ranks in the dominant and non-dominant limbs. All statistical significance values were set at $p<0.05$. Effect sizes (η^2) were calculated for significant results and assessed using Cohen's effect size index: *small* $(d = 0.2)$, *medium* $(d = 0.5)$, *and large* $(d \geqslant 0.8)$.[34] The Effect size following a Mann-Whitney U test was calculated using the following equation $r = z / \sqrt{n}$.

3.0. RESULTS

Participant demographics and the TMG variables for the six muscles (GL, GM, BF, GT, AL, RF) across the whole sample are detailed in Table 1. Means and standard deviation (1SD) values are presented.

3.1. PLAYING POSITION

TMG parameters according to playing position are detailed in Table 2. Means and 1SD values are presented in the table and significance values where p = <0.05 are highlighted. The left AM Td measurement was statistically significantly lower in the Forwards compared to the Midfielders, with a small effect size (1.4ms *(H(3) =11.293, p=0.005,* η^2=0.05). Forwards also recorded significantly lower values, yet a small effect size in the left GM Ts measurement compared to Goalkeepers (25.6ms *(H(3) =7.310, p=0.04,* η^2=0.02). No differences were seen between the remaining variables across the different playing positions *(p=>0.05)*.

3.2. LIMB DOMINANCE

The right RF Tc measurement was significantly lower in the right dominant participants compared to the left and

Table 1. Muscle contractile properties measurements for the whole sample (n=193)

Muscle	Limb			TMG Variables		
		Td (ms)	Tc (ms)	Ts (ms)	Tr (ms)	Dm (mm)
GL	**Left**	21.0 ± 2.0	27.5 ± 18.7	195.3 ± 44.3	42.5 ± 31.8	4.6 ± 2.3
	Right	21.1 ± 2.1	27.5 ± 19.4	195.1 ± 40.4	39.3 ± 22.7	4.2 ± 2.3
GM	**Left**	19.5 ± 1.9	21.3 ± 14.3	181.5 ± 70.2	48.9 ± 47.2	2.2 ± 1.7
	Right	20.3 ± 8.2	21.5 ± 16.4	186.3 ± 80.5	51.7 ± 63.7	2.1 ± 1.9
RF	**Left**	24.1 ± 1.9	30.5 ± 5.9	112.6 ± 51.7	65.2 ± 43.9	8.8 ± 2.9
	Right	24.2 ± 1.9	30.5 ± 6.3	111.1 ± 49.1	66.8 ± 43.2	8.6 ± 2.6
BF	**Left**	23.9 ± 2.8	35.6 ± 20.1	186.2 ± 58.6	60.1 ± 37.2	6.5 ± 3.2
	Right	23.7 ± 2.6	34.3 ± 19.8	196.9 ± 83.9	62.3 ± 49.3	6.3 ± 3.2
GT	**Left**	27.2 ± 2.5	37.3 ± 14.9	181.8 ± 48.7	83.8 ± 48.3	9.8 ± 4.0
	Right	27.1 ± 2.8	37.6 ± 14.6	181.4 ± 37.1	87.7 ± 41.4	10.2 ± 3.6
AM	**Left**	20.8 ± 2.5	22.9 ± 12.1	146.7 ± 92.2	51.2 ± 48.0	3.6 ± 2.4
	Right	21.7 ± 17.7	21.5 ± 11.8	138.1 ± 82.6	48.1 ± 45.3	3.6 ± 2.9

showed a medium effect size (*U*=29.645, *z*=4.933, *p=0.04,* r=0.35). No differences were reported in any of the remaining variables between the dominant and non-dominant limbs within this study *(p=>0.05)*. Table 2 details all values for the dominant and non-dominant limbs.

4.0. DISCUSSION

The purpose of this study was to profile lower limb muscle contractile properties in a sample of male professional soccer players competing in English professional soccer and to investigate if differences were present between playing positions and according to limb dominance. To the authors knowledge, this is the largest study to profile the muscle contractile properties in a sample of male professional soccer and the only study to obtain measurements of players competing in English soccer leagues. In this study, muscle contractile properties reference vales are reported for the AM, BF, GL, GM, GT and RF muscles. Td and Tc were shortest in the left GM whilst Ts was longest in the BF. Tr was shortest in the right GL and the largest Dm value was in the right GT. A secondary aim of the study was to investigate if muscle contractile properties differed between playing positions and according to limb dominance. Small differences were present between the left AM Td between Forwards and Midfielders and in the left GM Ts between Forwards and Goalkeepers. The right RF Tc measurement was lower in the right dominant participants. No other differences were detected between playing positions or limb dominance. These findings initially suggest that soccer players are largely comparable in lower limb muscle contractile properties, regardless of playing position and limb dominance.

4.1. PROFILING MUSCLE CONTRACTILE PROPERTIES

Measurements of Dm across the different muscles showed a degree of variance. According to previous studies, Dm is an estimation of mechanical stiffness or muscle tone.[35] It is therefore plausible to suggest that variance was present because the muscles included in this study have a variety of roles and also diverse architectural characteristics, both of which have an influence on muscle stiffness.[36] Collectively this study found little variance in the Td and Tc measurements of the GL, BF, RF and AM muscles, although the GT muscle produced longer Td and Tc measurements. This is unsurprising as the GT muscle has previously suggested to contain a higher proportion of slow twitch relative to fast twitch fibres[37] and previous studies have shown a direct relationship between Tc measurements and fibre type composition.[8,35] It would be interesting to investigate if Td and Tc measurements are still similar during in-season timepoints, as it is unknown whether congested training and match periods may create larger variance between the individual muscles. A future study could consider this, with a view of unpicking whether measurements of muscle contractile properties are sensitive enough to detect physiological fatigue and muscle injury risk.

A previous study by Rey et al (2012)[1] obtained measurements of muscle contractile properties in the RF and BF muscles from a sample of 78 male professional soccer players and reported comparable values to our findings besides the RF Tr and BF Dm values. Furthermore, recent studies[21,38] involving male professional soccer players, also competing in Spanish soccer, have reported similar values in BF, GL, GM and RF to our study. Therefore, it does appear that there is a level of consistency in measurements across the current literature when profiling the muscle contractile properties of male professional soccer players across different competitions and countries. Previous studies have found TMG to be able to detect changes in muscle contractile properties following training interventions,[39] and eccentric-induced delayed onset muscle soreness activities.[40] Therefore, data from this study and others should now be used as another measurement outcome of muscle function, following soccer players completion of training phases, acute periods of fixture congestion or as part of return to play decision making process. To further enhance the use of these reference values, future studies could attempt to

Table 2. Measurements of muscle contractile properties according to playing position and limb dominance

TMG Variables	Muscle	Playing Position								Limb Dominance			
		GK (n=15)		Def (n=62)		Mid (n=64)		Fwd (n=52)		Left Dominant (n=47)		Right Dominant (n=146)	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Td (ms)	GL	20.5 ± 2.0	21.7 ± 2.4	20.5 ± 1.7	20.5 ± 1.8	21.5 ± 2.4	21.5 ± 2.2	21.0 ± 1.8	21.2 ± 2.2	21.0 ± 1.9	21.1 ± 1.9	21.0 ± 2.1	21.1 ± 2.2
	GM	20.1 ± 1.4	19.6 ± 1.7	19.0 ± 1.9	19.6 ± 2.6	19.6 ± 2.0	19.8 ± 2.1	19.7 ± 1.9	21.7 ± 15.4	19.4 ± 1.7	22.4 ± 16.2	19.5 ± 2.0	19.5 ± 1.9
	RF	24.8 ± 1.5	25.4 ± 1.5	24.2 ± 2.0	24.2 ± 1.9	23.8 ± 1.5	24.2 ± 1.7	24.2 ± 2.3	24.1 ± 2.2	24.3 ± 1.7	24.3 ± 1.6	24.1 ± 2.0	24.2 ± 2.0
	BF	23.9 ± 2.5	24.3 ± 2.5	24.0 ± 3.1	23.7 ± 2.8	24.1 ± 2.5	23.6 ± 2.3	23.5 ± 2.7	23.6 ± 2.9	23.8 ± 2.6	24.0 ± 2.7	23.9 ± 2.8	23.6 ± 2.6
	GT	27.5 ± 2.2	27.9 ± 2.5	27.6 ± 2.1	27.3 ± 2.6	27.0 ± 2.5	26.7 ± 2.9	26.8 ± 3.0	27.1 ± 3.0	27.2 ± 2.9	27.8 ± 2.6	27.2 ± 2.4	26.8 ± 2.8
	AM	21.6 ± 2.6	20.9 ± 2.6	20.7 ± 2.8	20.6 ± 2.6	21.3 ± 2.4 [a]	24.2 ± 30.6	19.9 ± 2.1	20.1 ± 2.6	20.8 ± 2.4	20.5 ± 2.6	20.7 ± 2.5	22.1 ± 20.3
Tc (ms)	GL	24.4 ± 13.1	29.6 ± 16.1	26.7 ± 14.4	22.5 ± 8.7	31.1 ± 25.9	31.5 ± 28.3	25.0 ± 12.9	27.7 ± 14.2	28.4 ± 16.7	28.1 ± 14.8	27.3 ± 19.4	27.3 ± 20.7
	GM	20.2 ± 3.2	21.5 ± 5.3	19.6 ± 3.7	19.6 ± 3.6	23.7 ± 24.1	23.4 ± 27.4	20.6 ± 3.6	21.4 ± 6.5	19.9 ± 3.4	20.9 ± 4.7	21.7 ± 16.4	21.7 ± 18.8
	RF	33.5 ± 6.4	32.3 ± 7.4	31.0 ± 5.1	31.3 ± 6.3	28.8 ± 5.3	30.0 ± 6.3	31.0 ± 6.8	29.6 ± 6.1	31.2 ± 5.7	31.5 ± 6.3	31.2 ± 5.9[c]	30.2 ± 6.3
	BF	31.8 ± 13.8	34.7 ± 14.1	33.6 ± 15.0	31.4 ± 13.3	40.0 ± 27.4	37.2 ± 27.9	33.6 ± 15.5	34.0 ± 15.4	34.9 ± 15.8	35.6 ± 14.1	35.8 ± 21.4	33.8 ± 21.4
	GT	37.5 ± 5.9	37.9 ± 4.1	38.4 ± 10.6	37.1 ± 7.1	37.9 ± 22.8	38.0 ± 22.3	35.2 ± 7.0	37.6 ± 10.9	37.1 ± 11.8	38.8 ± 11.5	37.4 ± 15.9	37.2 ± 15.4
	AM	26.8 ± 15.0	18.6 ± 5.2	23.0 ± 12.5	21.6 ± 10.4	24.9 ± 13.5	23.3 ± 16.3	19.1 ± 6.9	20.0 ± 7.0	25.2 ± 13.9	22.7 ± 11.4	22.1 ± 11.3	21.1 ± 11.9
Ts (ms)	GL	192.1 ± 27.8	186.9 ± 50.2	192.8 ± 34.3	195.2 ± 39.6	190.1 ± 39.0	196.3 ± 40.4	205.4 ± 60.8	195.8 ± 39.1	191.5 ± 25.7	192.4 ± 26.9	196.5 ± 48.9	196.0 ± 44.0
	GM	204.1 ± 56.6[b]	178.0 ± 60.7	176.7 ± 79.6	179.4 ± 74.7	183.1 ± 69.7	196.0 ± 99.6	178.5 ± 63.0	184.8 ± 65.1	202.3 ± 44.7	186.1 ± 60.2	174.7 ± 75.6	186.4 ± 86.4
	RF	103.6 ± 51.3	118.7 ± 47.9	112.5 ± 49.8	108.4 ± 46.7	104.5 ± 52.2	106.9 ± 50.8	125.5 ± 52.4	117.1 ± 50.5	117.6 ± 50.8	109.0 ± 43.3	111.0 ± 52.1	111.7 ± 109.0
	BF	193.4 ±	198.7 ±	201.2 ±	187.2 ±	179.8 ±	211.9 ±	173.9 ±	189.7 ±	201.8 ±	188.8 ±	181.1 ±	199.6 ±

		61.5	67.5	61.0	60.3	53.5	114.2	58.3	65.9	53.2	54.4	59.3	91.4
	GT	217.1 ± 71.4	186.7 ± 22.7	185.3 ± 38.7	180.7 ± 34.1	179.0 ± 49.2	183.8 ± 41.7	170.9 ± 47.0	177.6 ± 38.5	188.2 ± 64.7	186.2 ± 36.1	179.7 ± 42.4	179.8 ± 37.4
	AM	137.8 ± 74.3	119.2 ± 91.7	138.4 ± 85.1	135.8 ± 90.2	165.5 ± 91.3	139.0 ± 78.4	136.0 ± 104.3	145.2 ± 77.0	139.1 ± 79.1	154.0 ± 82.7	149.1 ± 96.2	133.0 ± 82.3
Tr (ms)	**GL**	37.8 ± 23.9	43.0 ± 24.7	37.0 ± 16.2	33.9 ± 11.6	42.7 ± 20.6	43.6 ± 31.5	49.7 ± 51.8	39.1 ± 17.7	40.2 ± 17.7	36.0 ± 12.3	43.2 ± 35.3	40.4 ± 25.2
	GM	63.7 ± 51.6	57.5 ± 54.9	40.1 ± 46.3	48.1 ± 48.3	46.6 ± 44.0	54.6 ± 89.7	57.3 ± 49.7	50.4 ± 39.9	50.9 ± 55.9	52.2 ± 45.9	48.2 ± 44.2	51.5 ± 68.7
	RF	60.5 ± 50.1	74.3 ± 44.8	65.2 ± 42.8	63.8 ± 41.3	61.0 ± 43.8	63.9 ± 45.2	71.6 ± 43.9	71.6 ± 43.1	67.6 ± 43.4	65.2 ± 36.8	64.4 ± 44.2	67.3 ± 45.2
	BF	82.0 ± 55.9	58.6 ± 29.5	61.4 ± 36.2	59.2 ± 35.3	58.5 ± 30.1	69.8 ± 69.0	54.2 ± 38.4	58.0 ± 37.8	62.2 ± 39.3	57.3 ± 26.9	59.4 ± 36.4	64.0 ± 54.6
	GT	67.4 ± 37.2	90.2 ± 48.5	98.3 ± 51.2	90.4 ± 38.0	80.9 ± 46.6	87.9 ± 45.7	74.8 ± 38.2	83.4 ± 38.1	94.4 ± 55.2	86.4 ± 40.0	80.4 ± 42.7	88.1 ± 41.9
	AM	57.8 ± 42.1	53.2 ± 54.7	46.9 ± 43.1	44.4 ± 41.8	60.7 ± 54.9	49.8 ± 44.7	42.9 ± 45.0	49.0 ± 48.0	52.0 ± 48.9	59.2 ± 52.5	51.0 ± 47.8	44.5 ± 42.2
Dm (mm)	**GL**	3.8 ± 2.0	4.0 ± 2.0	4.6 ± 1.9	3.9 ± 1.8	5.0 ± 3.0	4.5 ± 2.9	4.2 ± 2.0	4.2 ± 1.9	4.5 ± 2.3	4.3 ± 1.7	4.6 ± 2.4	4.2 ± 2.4
	GM	2.1 ± 0.8	1.8 ± 0.7	1.9 ± 1.0	2.0 ± 0.8	2.3 ± 2.6	2.3 ± 3.2	2.2 ± 1.1	2.1 ± 0.9	2.1 ± 1.1	2.0 ± 0.7	2.2 ± 1.9	2.1 ± 2.2
	RF	8.6 ± 2.8	9.2 ± 2.8	9.0 ± 2.6	8.5 ± 2.0	9.1 ± 3.3	8.7 ± 2.7	8.1 ± 2.5	8.2 ± 2.9	8.4 ± 2.3	8.5 ± 2.5	8.9 ± 3.0	8.6 ± 2.6
	BF	5.6 ± 3.1	6.2 ± 3.0	6.5 ± 2.9	6.4 ± 3.1	7.4 ± 3.6	6.7 ± 3.2	5.6 ± 2.9	5.6 ± 3.2	6.4 ± 3.4	6.5 ± 2.4	6.5 ± 3.2	6.2 ± 3.1
	GT	8.4 ± 2.3	10.1 ± 2.8	10.5 ±4.1	10.5 ± 3.6	10.4 ± 4.2	10.3 ± 3.8	8.6 ± 3.6	9.9 ± 3.4	9.5 ± 4.1	10.2 ± 3.6	9.9 ± 4.0	10.2 ± 3.6
	AM	4.0 ± 3.1	3.1 ± 2.4	3.5 ± 2.4	3.5 ± 2.6	4.1 ± 2.4	3.8 ± 3.5	3.0 ± 2.3	3.5 ± 2.8	3.8 ± 2.4	3.8 ± 3.1	3.5 ± 2.5	3.5 ± 2.9

Values are presented as the mean ± 1SD.

a. Significant difference between midfielders and forwards following post hoc correction (p=<0.05)

b. Significant difference between goalkeepers and forwards following post hoc correction (p=<0.05)

c. Significant difference between dominant and non-dominant limbs (p=<0.05) add more primary data, with a view to then conducting a systematic review with meta-analysis. This would present a more representative sample of the adult, male soccer population and may allow for muscle contractile properties data to be integrated within future musculoskeletal injury modelling analysis. For such a study, consideration would need to be given around which time point the data was collected within the soccer season. In our study, all measurements were obtained during the pre-season period (June-July) which is immediately after a period of off-season rest. Previous studies have presented differences in muscle contractile properties during in-season soccer competition when compared to pre-season which may be partially attributed to periodised training and match cycles.[38,41,42] The aforementioned studies[1,21] do not disclose the period in the season when measurements were taken which may create some heterogeneity in the data, if pooling was to take place.

The findings from the present study show that male professional soccer players have shorter Tc values compared to a sample of the general population who had their RF rectus femoris muscle assessed using TMG.[43] This concurs with Toskic et al., (2016)[44] who reported lower Tc values in the vastus lateralis and the RF muscles of multi-sport athletes relative to aged matched in-active controls. When comparing our study findings to other sporting disciplines, professional soccer players had lower Dm and a lower Tc in the BF muscle relative to elite gymnasts[45] and male triathlon competitors.[2] It may be that the bias toward the use of the lower limbs in soccer promotes a higher level of mechanical stiffness, compared to whole-body activities such as gymnastics and triathlon. These suggestions must be interpreted cognisant of the difficulty comparing competition 'level' and quantifying relative training load between such disparate sports. However, the differences in both healthy male adults and elite athletes from a variety of sports provide a clear rationale for individualised profiling of muscle contractile properties using TMG.

4.2. PLAYING POSITION

We reported differences in the left AM Td between Forwards and Midfielders and in the left GM Ts between Forwards and Goalkeepers. However, the effect seizes reported were very small (η^2=0.02-0.05) which therefore suggests a lack of clinical meaningfulness in the findings. Coupled with this is the lack of differences seen in any other TMG parameter across all muscles. Previously Rey et al., (2012)[1] found no significant differences between the BF muscle when sub-divided into different soccer playing positions yet differences were seen in the RF Tc, with External Defenders having a longer value compared to Goalkeepers and Central Defenders. The authors speculated this may be due to the requirements for the playing position, with Goalkeepers and Central Defenders performing more thigh-dominant explosive jumping movements than External Defenders.[1] Further work by García-García et al., (2017)[38] also showed differences in the RF Dm values between Central Defenders and Goalkeepers. Although this does bring into question the sensitivity of TMG measurements for detecting position-specific difference that may be present, it is difficult to directly compare our results, as we did not further sub-categorise defenders into External and Central Defenders. Additionally, there was some variance in the methodological design between studies with specific amplitude level and probe placements not reported.[1,38] A future study could consider further exploration of role-specific requirements during match play such as distances covered, number of high-speed runs and volume of jumping activities and investigate whether TMG does have the ability to detect if differences are present. This may offer a different way of evaluating individuals within a soccer team. From the data presented in this study, it could be suggested that soccer players are a homogenous population, regardless of playing position and therefore future measurements of muscle contractile properties can be compared to the whole sample values obtained during this study. We therefore suggest that future studies attempting to profile soccer players by playing position should consider other measurements, that closely mimic position specific demands such as aerobic fitness or anaerobic power.[46,47]

4.3. LIMB DOMINANCE

The present study observed differences in only the right RF Tc measurements between the dominant and non-dominant limbs of professional soccer players. It is difficult to speculate the clinical meaningfulness of this finding as no other TMG parameters in the right RF were different between limbs, and additionally there were no other differences seen in any paired tests. The general lack of differences reported were consistent with previous findings where contralateral limb muscle function symmetry was assessed in this group of athletes.[38,41,48–50] Alvarez-Diaz et al., (2016)[21] reported differences in certain TMG variables (VM (Tc), VL (Tc and Td), RF (Ts and Tr) and BF (Ts)) although no consistent pattern of asymmetry could be established. This is perhaps unsurprising due to the high volume of bipedal running activities that take place during soccer related training and match play, relative to the unipedal soccer kicking activities. Indeed, previous studies assessing the impact that lower limb dominance has on runners report no significant difference in running kinematics between limbs.[51,52] The findings from this study, coupled with the previous evidence, suggest that the contralateral limb can be used to accurately estimate the values of Tc and Dm required following a period of inactivity and/or injury.

4.3. STUDY LIMITATIONS

The present study is not without limitations. The standardised timepoint used for measurements (pre-season) was selected in order to capture the largest number of healthy participants and also the mimic the baseline musculoskeletal testing routines that commonly take place in male professional soccer. Whilst this promoted homogeneity in the data set in relation to training and match play exposure levels, all participants had just been subjected to a period of rest (off-season). This may limit direct comparisons with muscle contractile properties measured during in-season time points. A future study could consider repeat measurements across a full soccer season to establish if fluctuations occur as a result of fixture congestion periods and in-season periodised training cycles.

Although the electrode and probe placement utilised within this study were standardised, there are currently no published reliability estimates for the protocol that was used.[26] It would therefore be of benefit to complete a future study estimating the reliability figures for this protocol, to increase confidence in the study method.

The use of portable equipment for the measurement of muscle contractile properties was important to improve the clinical relevance of the findings and to remove barriers in the recruitment of professional soccer players. However, this meant that there was a variance in the environments where measurements took place, as it was impossible to fully control the environment. This may have affected the results. To try and minimise this affect, the principal investigator attempted to control the lighting, room temperature and ensured all internal doors were closed at each of the venues.

4.4. CONCLUSIONS

This is the first study to profile lower limb muscle contractile properties in a sample of professional soccer players competing in the English professional leagues. The findings from this study suggest that soccer players are largely comparable in lower limb muscle contractile properties, regardless of playing position or limb dominance. The utility of this study is that the data may be used as a preliminary benchmark to inform rehabilitation strategies, return to play decisions and physiological readiness following periods of inactivity.

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DECLARATION OF INTEREST STATEMENT

The authorship team report no conflicts of interest.

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