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Original Research

An investigation into the between-day reliability of muscle contractile properties measured using Tensiomyography.

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Background and Purpose

Tensiomyography (TMG) is reported to measure muscle contractile properties of superficial skeletal muscle. Between day reliability has not been reported for all of the major lower limb muscles in a mixed gender sample of healthy adults. Therefore, the aim of this study was to examine the between-day reliability of muscle contractile properties associated with involuntary contractions of the rectus femoris (RF) and bicep femoris (BF), as measured by TMG.

Study Design

Within-subject repeated measures study (3 consecutive days)

Methods

Twenty-four healthy participants (twelve males; twelve females) were recruited to take part in the study over 3 consecutive days. Measurements of muscle contractile properties were obtained on the bicep femoris (BF) and rectus femoris (RF) muscles in the dominant limb. All data were checked for normality using the Shapiro-Wilk test. Pooled intra-class correlation coefficient (ICC), coefficient of variance (CV) and standard error of measurement (SEM) values were generated for the BF and RF for delay time (Td), sustain time (Ts), relaxation time (Tr), contraction time (Tc) maximal displacement (Dm). Additionally, a Bland-Altman analysis was performed for paired data points (day 1 vs 2, 2 vs 3 and 3 vs 1). Identical analyses were then performed on gender sub-groups.

Results

Good to excellent ICC values (0.68-0.93) were reported for delay time (Td), contraction time (Tc), and maximal displacement (Dm) in BF and RF muscles. Conversely, relaxation time (Tr) and sustain time (Ts) reported low ICC values (-0.10-0.56). Levels of agreement were not significantly different in most pairs of data points across the whole sample and also across males and females (p=>0.05). However, significant differences were detected in the whole sample: day 3 vs day 1 in the Td (p=0.03) and Dm RF (p=0.009); males: BF Td day 1 vs 2 (p=0.04); females: BF day 2 vs 2 (p=0.01), RF Td day 1 vs 2 (p=0.03), RF Ts day 3 vs 1 (p=0.04).

Conclusion

The Td, Tc, and Dm variables obtained during TMG measurements demonstrate acceptable reliability across 3 consecutive days. The Tr and Ts variables cannot be measured reliably between days using TMG.

INTRODUCTION

Tensiomyography (TMG) is a non-invasive method used to estimate spatial and temporal contractile properties of skeletal muscle in response to an evoked stimulation.[1–4] The TMG technique uses a (1μm) spring-loaded sensor to estimate the radial displacement of a single superficial skeletal muscle.[5] A single twitch stimulus (1ms duration) evokes a contraction to a single muscle through two self-adhesive electrodes which are placed proximally and distally from the sensor tip, over the muscle belly, generating an isometric contraction.[6,7] The radial enlargement of the muscle belly is measured with the displacement sensor which generates results presented as time/displacement curves.[8] From the results, information can be obtained re-

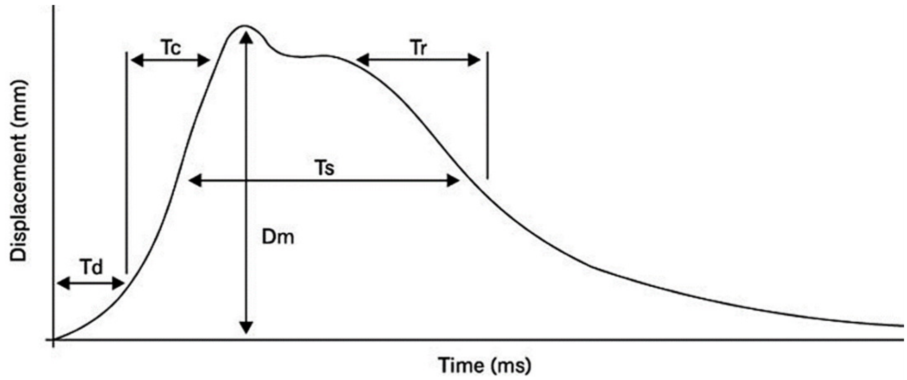

Figure 1. Time/displacement curve displaying the contractile properties measured using TMG.[10]

garding maximal radial displacement (Dm), delay time (Td), contraction time (Tc), sustain time (Ts), and relaxation time (Tr) (Figure. 1).[6] However, due to their functional relevance (stiffness and speed of contraction), the Dm and Tc parameters are the most frequently examined contractile properties using the TMG.[9]

Previously, TMG has been used to report muscular imbalance[11] and changes in muscle function due to training[12] or rehabilitation following injury[13] amongst elite male football players. Furthermore, measurements of muscle contractile properties have been characterised in sports such as volleyball,[14] ultra-endurance triathlon events,[15] surfing[16] and masters power and endurance athletes.[17] In addition to studies involving athletic participants, TMG has also been used to assess the effects of interventions such as bed rest in non-athletic populations.[18,19]

The ability of a measurement tool to report meaningful differences between individuals and over time, depends on the reliability of the measure. This is especially important when assessing whether small physiological differences between individuals or changes as a result of disuse or if interventions are of clinical or functional significance. The use of TMG in the estimation of muscle function is a relatively new phenomenon[20] compared to more established methods such as isokinetic dynamometry (IKD),[21] electromyography (EMG)[22] and perhaps most comparably mechanomyography (MMG).[23] As such validity and reliability of the technique are less well established and limited to specific populations.

Martín-Rodríguez et al., (2017)[24] identified ten studies examining the reliability of TMG, including between-day and within-day reliability,[25–27] as well as the inter-rater and intra-rater reliability.[28] Reliability studies have consistently used ICC descriptive statistics to record the variability between a set of measurements,[29] the CV to assess the stability of each variable across time points[30] and the SEM to highlight the precision of a score.[31] Some studies have also used the Bland-Altman method to assess for levels of agreement (LoA) between testing points.[26,28] Certain parameters obtained through TMG assessment have been shown to have good to excellent reliability when measuring muscle contractile properties (Dm, Td, Tc, Ts, and Tr) for the lower extremity muscles (vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and biceps femoris (BF)).[10,26,32] These data are useful because the RF and BF are the most frequently assessed muscles due to their involvement in lower limb activities and their propensity to injure.[11,32–36] However, to our knowledge, there is only one study available that estimates the between day reliability in the RF[27] and one for the BF.[26] Šimunič (2012)[26] examined the between-day reliability of TMG measuring the muscle contractile properties of the VL, BF, and VM muscles. Ten healthy male participants had measurements taken on three muscles over three consecutive days, by a single rater. The study reported excellent ICC values (>0.94) for Tc, Ts, and Dm in all three muscles, whereas Td reported excellent values for VM (0.94) and BF (0.98) but slightly lower values in VL (0.89). Tr displayed the lowest ICC values for VM (0.88), VL (0.89), and BF (0.89). All parameters except Tr had CV scores (<5%), SEM values were consistently low (<1.0) for Td, Tc, and Dm, but higher for Ts and Tr (1.70-5.46). More recently, de Paula Simola et al (2015)[27] recorded good to excellent values ranging between 0.85-0.92 for all TMG parameters between two consecutive testing days in a group of twenty male sprinters. Whilst these studies provide an initial between day reliability estimate of TMG parameters, the homogeneity of participant demographics, imbalance of gender numbers and the overall study sample size highlight some limitations which require further investigation. Males have previously shown to possess higher volumes of muscle mass and lower levels of fat, compared to females.[37,38] These physiological differences may lead to variance in outcome measurements that require an evoked stimulation to induce a muscle contraction.[39,40] Investigations of between-day reliability which include a robust sample of both males and females will highlight if the TMG measurement tool is still able to maintain reliability of measurements when these factors are accounted for.

Therefore, the aim of the present study was to examine the between-day reliability of the RF and BF muscle contractile properties measurements using TMG in an equally mixed gender sample of participants across three consecutive testing days.

METHODS AND MATERIALS

This study received approval from the School of Clinical and Applied Sciences, Research Ethics Committee of Leeds Beckett University and complied with the Declaration of Helsinki on human research and international standards. The principal investigator carried out all measurements having undertaken a period of training with a member of the research team who was experienced and competent at using the TMG equipment. During the first training session, the principal investigator was familiarised with the TMG equipment set up and also the software used to calculate the time/displacement curve. The second training session was used as a practice session, where the principal investigator set up the equipment and conducted a full TMG assessment on the BF and RF muscles from one healthy male volunteer.

RESEARCH DESIGN

A within-subject repeated measures study design was used, in which the five dependent variables (TMG contractile properties: Td, Tc, Ts, Tr, and Dm) were measured against three independent variables (day: 1, 2, and 3). Measurements were taken on the dominant BF and RF muscles. All TMG assessments were completed in the same lab, at the same time (+/- 2 hours) on three consecutive days.

PARTICIPANT RECRUITMENT AND SCREENING

A sample of 24 healthy, adult participants (mean ± SD, age: 22.5 ± 2.9yrs, height: 173.73 ± 11.55cm, weight: 76.19 ± 14.98kg, body mass index (BMI): 25.13 ± 3.64) were recruited for this study, comprising of 12 males (age: 23.84 ± 3.43yrs, height: 183.46 ± 7.65cm, weight: 84.07 ± 13.51kg, BMI: 24.88 ± 2.76) and 12 females (age: 21.15 ± 1.72yrs, height: 164.00 ± 3.76cm, weight: 68.30 ± 12.27kg, BMI: 25.39 ± 4.46).

All participants were recruited on a voluntary, unpaid basis using social media and posters, with the majority being students. Once recruited, participants were briefed on the study process by the principal investigator and invited to provide both written and verbal informed consent. Participants were then screened using a set of eligibility criteria and were given the right to withdraw at any time during the study. Participants were required to be free of musculoskeletal injury and have no history of neuromuscular disorder or muscular disease. Participants were also ineligible to take part if they were currently seeking medical care, pregnant, or fitted with an implanted medical device (i.e., a pacemaker). In line with previous studies,[5,9] those who were eligible were asked to refrain from consuming caffeine within 12 hours prior to each laboratory visit and to avoid any vigorous activity or intake of energy supplements in the 48 hours prior to each testing session.

EXPERIMENTAL PROCEDURES

Participants had their height measured using a stadiometer (SECA Alpha, Birmingham, UK) to the nearest millimetre (mm) and body mass was measured using calibrated electronic scales (SECA Alpha 770, Birmingham, UK) to the nearest gram (g). During TMG assessment on day 1, the intended transducer probe position and electrode positions were marked up on both the BF and RF muscles by only the principal investigator. The standardised method for this was previously developed in our laboratory[9,41] as there is currently large variance in the standard operating procedures during TMG assessment. Briefly, the sensor probe was positioned at the intersect where the mid-way points of the muscle length and the centre of the width of the muscle belly cross. The muscle length was identified by measuring the distance between two palpable anatomical landmarks in the proximal and distal regions of the thigh (BF (long head), ischial tuberosity; RF, greater trochanter) and the insertion (BF, lateral femoral condyle; RF, lateral femoral condyle). The width was measured by palpating the medial and lateral borders of each muscle and marking the middle point. Following this, the electrode placements were marked at a 5cm inter-electrode distance with the sensor probe point half-way between, in line with previous studies.[9,41]

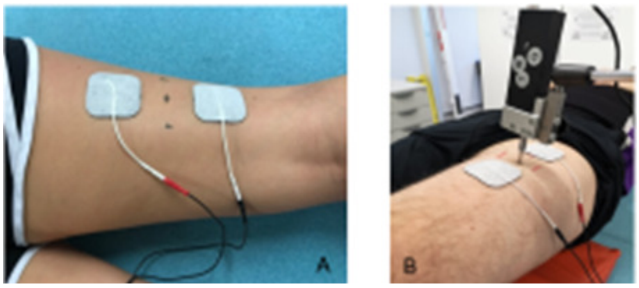

Figure 2. Marking protocol and Tensiomyography set up. A: Sensor probe and electrodes placement for the BF muscle, B: TMG sensor probe position for assessment of the RF muscle.

A familiarisation protocol was completed on the non-dominant bicep femoris (BF) of each participant on day one of testing, prior to testing on their dominant leg. The non-dominant limb was selected to minimise interference in the participants dominant limb. Electrode and sensor probe placements were not measured for familiarisation testing. Once positioned, a single monophasic stimulation was applied at 30 milliamps (mA) and increased at 10 second intervals until the simulation level reached 55mA.

Following the familiarisation protocol and consent, testing on the dominant BF and RF took place. The BF was measured with the participants in a prone position with a semicircle foam pad placed underneath the ankle joints and the RF was measured with the participants in a supine position with a triangular foam pad placed under the knee joint. The purpose of this was to ensure a knee joint angle of 15-20 degrees. The procedure for electrical stimulation began with an initial current amplitude of 30mA which gradually increased by 5mA until either there was a decrease in the maximal displacement on the time/displacement curve or the stimulation output reached 100mA (maximum available).[28] Between each measurement, a 10-second interstimulus time period was adhered to in order to minimise

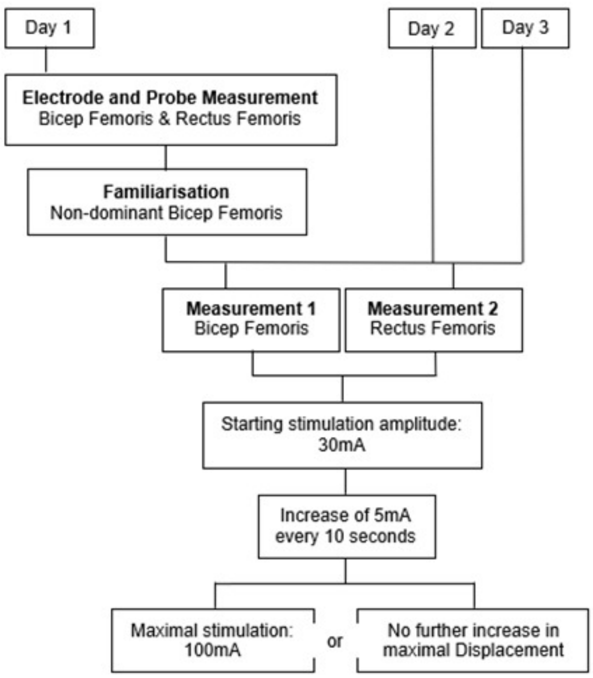

Figure 3. Testing protocol; repeat measures of the Tc, Td, Tr, Ts and Dm measurements produced during TMG assessment.

the effects of fatigue.[10,42] A stopwatch was used to ensure consistency of this time period. Testing for day 2 and day 3 remained the same. As a dermatological pen was used to draw the markings for the electrode and sensor probe placement, the markings stayed on throughout the 3 days which reduced systematic measurement error. Familiarisation testing was only included during the day 1 testing session. Figure 3 illustrates the testing protocol on each of the testing days.

DATA AND STATISTICAL ANALYSIS

Results from the TMG were exported as Microsoft Excel spreadsheets. Treatment of the data took place in Microsoft Excel where the measurements producing the highest Dm values were extracted for each testing time point and muscle. The data was then imported to IBM SPSS (Statistical Package for the Social Sciences version 25, (Chicago, IL)) for statistical analysis. Each variable (Tc, Td, Tr, Ts, Dm) was assessed for normality using a Shaprio-Wilk test. Following this, the pooled ICC was used to assess for relationships in the mean values for Td, Tc, Tr, Ts, and Dm in the RF and BF muscles on the three consecutive days (1, 2, 3) and 95% confidence interval (95% CI) were calculated. For the purpose of this analysis, ICC values were interpreted using the following guidelines: "values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability".[29] A Bland-Altman method was used to analyse the LoA between testing days (day 1 vs 2, 2 vs 3 and 3 vs 1).[43] Additionally, the CV and SEM were also estimated for each variable across the 3 days. The SEM was calculated using the following equation: SEM= pooled SD x $\sqrt{(1\text{-ICC})}$, where the pooled SD is the sum of all standard deviation squared, divided by the number of participants (Σ= $(SD_1, SD_2, SD_3...)^2$ /24).[44] The aforementioned analyses were completed on the whole sample and also according to gender (male and female). The statistical significance level was set at $p<0.05$. Descriptive statistics are presented as the mean with included standard deviation.

RESULTS

REPEATED MEASURES ANOVA AND RELIABILITY ANALYSIS

Table 1 reports descriptive data (mean ± SD) for all 3-days, and also the ICC, CV and SEM reliability estimates for each variable in the BF and RF muscles. Good to excellent ICC values (0.80-0.99) were reported for Td (0.93), Tc (0.91), and Dm (0.85) in the BF, and Tc (0.88) and Dm (0.86) in the RF. The ICC values for Ts and Tr in the BF were 0.25 and 0.46 respectively. In the RF, the ICC values for Ts and Tr were 0.77 and 0.58, repectively. CV scores <10 were reported for Td in the BF and Td and Tc in the RF. SEM values were higher in all paramters when comparing the BF and RF besides Tr which was 499.2ms higher in the RF.

Table 2 shows the Bland-Altman results for LoA's between each pair of testing days in each TMG variable in both the BF and RF muscles. Day 3 vs day 1 in the Td and Dm RF measurements were significantly different (p=0.03; p=0.009), suggesting a low level of agreement between testing points. However, all other paired analysis revealed no significant differences between testing points (p=>0.05).

Table 3 displays the desctiptive data of the males and female sub-groups and also reliability analysis. The values presented in table 3 highlight females had lower ICC scores in all TMG parameters in the RF besides Dm which was identical at 0.86, which accounted for lower overall ICC scores when gender was not considered. Good to excellent ICC values were reported for Td (0.88), Tc (0.95), Dm (0.84) in the BF and Td (0.91), Tc (0.89), Ts (0.89), and Dm (0.86) in the RF for the 12 male participants. Low ICC values were still reported for Ts and Tr in the BF for the males, and Td, Tr, and Ts in the RF for the females. Following Bland-Altman analysis, significant differences were detected between the paired data points in the males: BF Td day 1 vs 2 (p=0.04) and females: BF day 2 vs 2 (p=0.01), RF Td day 1 vs 2 (p=0.03), RF Ts day 3 vs 1 (p=0.04). All other paired data points had non-significant differences (p=>0.05). The tables including individual p-values and lower and upper level of agreement values can be found in the supplementary appendix 1.

DISCUSSION

This study aimed to examine the between-day reliability of muscle contractile properties of the BF and RF muscles as measured by TMG in a mixed gender sample of partic-

Table 1. Reliability analysis for Bicep Femoris (BF) and Rectus Femoris (RF) muscles. Values are presented as the mean ± standard deviation

N=24	Day 1	Day 2	Day 3	Total Mean	SEM	CV	ICC [95% CI]
BF							
Td (ms)	24.63 (4.00)	25.10 (3.14)	24.93 (3.86)	24.89 (1.21)	0.69	4.77	0.93 [0.86-0.97]
Tc (ms)	36.33 (12.10)	33.32 (11.65)	34.71 (13.20)	34.79 (4.71)	10.49	13.32	0.91 [0.82-0.96]
Ts (ms)	175.65 (38.66)	153.84 (56.00)	173.53 (61.28)	167.67 (33.55)	1625.84	20.01	0.46 [-0.04-0.75]
Tr (ms)	51.22 (17.92)	46.49 (23.68)	60.72 (43.82)	52.81 (18.14)	743.11	34.35	0.25 [-0.46-0.65]
Dm (mm)	6.07 (3.03)	5.73 (2.71)	5.43 (2.76)	5.74 (1.31)	1.05	22.82	0.85 [0.72-0.93]
RF							
Td (ms)	24.34 (1.64)	24.81 (2.03)	25.38 (2.77)	24.84 (1.08)	1.66	4.35	0.68 [0.38-0.85]
Tc (ms)	30.73 (7.80)	31.44 (6.84)	30.96 (6.50)	31.04 (2.83)	4.92	9.12	0.88 [0.77-0.95]
Ts (ms)	110.12 (58.74)	123.21 (66.97)	129.12 (66.45)	120.82 (33.66)	938.05	27.86	0.77 [0.55-0.89]
Tr (ms)	62.00 (52.88)	67.51 (49.55)	72.75 (57.17)	67.42 (33.82)	1242.30	50.16	0.58 [0.16-0.80]
Dm (mm)	6.11 (2.45)	6.54 (2.24)	7.09 (2.58)	6.58 (1.23)	0.76	18.69	0.86 [0.72-0.93]

Td – delay time; Tc – contraction time; Ts – sustain time; Tr – relaxation time; Dm – maximal displacement; SEM – standard error of measurement; CV – coefficient of variation; ICC – intra-class correlation coefficient; CI – confidence interval.

ipants. For the whole sample, the ICC values for Dm were 0.85 and 0.86 for BF and RF respectively. For Tc, values were recorded at 0.91 for the BF and 0.88 for the RF. The only other parameter which recorded good to excellent reliability was Td of the BF muscle (0.93). All remaining parameters (Tr, Ts) could not be assessed reliably, with recorded ICC values of between 0.25-0.56. LoA's were demonstrated between all paired testing days besides the RF Td and Dm measurements between day 1 and 3. When sub-categorised by gender, comparable reliability results were reported for the BF Td and Dm measurements and the RF Tc, Tr and Dm measurements. Males had higher ICC values in the BF Tc measurements and RF Td and Ts measurements. Females had higher ICC values in the BF Ts and Tr measurements. High LoA were demonstrated between most pairs of data points when sub-classified by gender.

Previously, the only study to assess between day reliability of muscle contractile properties in the BF across 3 consecutive days showed good-to-excellent ICC values (0.88-0.99) and low CV values (<10%) for all five parameters.[26] However, Tr and Ts reported the highest CV (3%-9.50%), RE (4.50-8.64), and SEM (3ms-5.46ms), and Tr reported the lowest ICC (0.88). The results from this study are in agreement with findings in the current study which report that Td, Tc and Dm are all parameters with high levels of reliability. However, the previous study also indicates that Ts is considered a reliable measure due to its excellent ICC value (0.92) which is in contrast to the present study findings where the ICC for Ts was 0.46 for the BF muscle. Furthermore, the measurements of bias (LoA's) were also lower in the present study between day 3 and 1 in the Td and Dm of the RF muscle which is again in contrast to findings by Šimunič (2012).[24] The differences between the present study and previous study findings may be attributed to methodological variances. Firstly, the electrical stimulation amplitude was not specified in the study by Šimunič (2012)[24] compared to the present study where repeated stimulations were used until maximal displacement was recorded. Therefore, the participants in the present study may have experienced a higher number of stimulations which may have induced some low-level fatigue, as all TMG parameters have been found to be highly sensitive to repetitive stimulations.[25]

Other studies which have looked at the reliability of TMG derived parameters on alternative skeletal muscles appear to show the Dm parameter to demonstrate the most stability across time.[27,42] For example, Ditroilo et al, (2013)[45] assessed the long-term stability of mechanical and contractile properties of the gastrocnemius medialis (GM) in rested, exercised, and fatigued conditions. The study reported moderate ICC values for Tc and Td (0.62 and 0.60), and good ICC values for Ts, Tr, and Dm (0.78, 0.79, 0.86). A further investigation by de Paula Simola et al. (2015)[27] examined the inter-day reliability of TMG to measure the mechanical properties of the BF, RF, and gastrocnemius lateralis (GL) over two consecutive days. The study findings reported that Td, Tc, and Dm presented good to excellent ICC (>0.8) and poor CV values (<10%), whereas Ts and Tr produced lower ICC (0.70) and higher CV values (>20%). These results are comparable to the current study which re-

Table 2. Bland-Altman analysis for Bicep Femoris (BF) and Rectus Femoris (RF) muscles. Values are presented as the mean ± standard deviation

N=24	Testing Day	Difference Mean	P-value	Lower LOA	Upper LOA
BF					
Td (ms)	1 to 2	-0.47 (2.28)	0.32	-4.94	4.00
	2 to 3	0.16 (2.16)	0.71	-4.07	4.40
	3 to 1	0.30 (2.45)	0.54	-4.51	5.12
Tc (ms)	1 to 2	3.01 (8.39)	0.09	-13.43	19.46
	2 to 3	-1.39 (8.84)	0.44	-18.73	15.94
	3 to 1	-1.61 (7.48)	0.30	-16.29	13.05
Ts (ms)	1 to 2	21.80 (73.91)	0.16	-123.07	166.68
	2 to 3	-19.68 (60.31)	0.12	-137.89	98.52
	3 to 1	-2.12 (62.01)	0.86	-123.67	119.42
Tr (ms)	1 to 2	4.72 (19.66)	0.25	-33.82	43.27
	2 to 3	-14.23 (52.25)	0.19	-116.64	88.17
	3 to 1	9.50 (43.88)	0.29	-76.50	95.52
Dm (mm)	1 to 2	0.33 (2.26)	0.48	-4.10	4.76
	2 to 3	0.30 (2.30)	0.52	-4.21	4.83
	3 to 1	-0.63 (2.43)	0.21	-5.40	4.12
RF					
Td (ms)	1 to 2	-0.47 (1.65)	0.17	-3.72	2.78
	2 to 3	-0.57 (2.96)	0.35	-6.38	5.23
	3 to 1	-1.04 (2.24)	0.03*	-5.45	3.36
Tc (ms)	1 to 2	-0.70 (5.94)	0.56	-12.36	10.95
	2 to 3	0.47 (4.07)	0.57	-7.51	8.46
	3 to 1	0.22 (6.01)	0.85	-11.55	12.01
Ts (ms)	1 to 2	-13.09 (60.74)	0.30	-132.14	105.96
	2 to 3	-5.91 (67.74)	0.67	-137.34	125.52
	3 to 1	19.00 (58.88)	0.12	-96.40	134.41
Tr (ms)	1 to 2	-5.51 (59.81)	0.65	-122.74	111.71
	2 to 3	-5.23 (65.16)	0.69	-132.95	122.49
	3 to 1	10.74 (63.21)	0.41	-113.16	134.65
Dm (mm)	1 to 2	-0.43 (1.88)	0.26	-4.12	3.25
	2 to 3	-0.54 (2.18)	0.23	-4.83	3.74
	3 to 1	0.98 (1.68)	0.009*	-2.31	4.27

Td – delay time; Tc – contraction time; Ts – sustain time; Tr – relaxation time; Dm – maximal displacement; P-value – t test probability value; Lower LOA – lower level of agreement; Upper LOA – upper lower level of agreement; BF – bicep femoris; RF – rectus femoris.
*P value < 0.05.

ported good to excellent ICC values (0.83-0.91) and low CV (<10%) for Td, Tc, and Dm, and lower ICC and high CV values for Tr and Ts. The method of measurement for identifying the most appropriate probe placement position was not detailed in the study by de Paula Simola et al. (2015).[27] However, once the position was identified, both the probe and electrode placement points were permanently marked, like in the present study. This ensured the same area of muscle was reassessed on each of the testing days, thus increasing the consistency of measurement. Whilst consistency in probe position ensured best practice for repeat measurements, the comparable findings between studies with different methodologies implies that the Dm parameter is a reliable parameter to use, regardless of the methodological processes.

To the authors knowledge, there are no other studies which have looked at the between-day reliability of TMG. Other studies looking to investigate the reliability of TMG measurements have used repeat measure designs within the same day. A study by Križaj et al., (2008)[25] reported ICC values ranging from 0.86-0.98 in the bicep brachii muscle on 13 male volunteers. In this study, Dm obtained the highest value (0.98) and Tr the lowest (0.86) in a method whereby 30 twitch contractions were elicited at 10 second intervals. Further work by Tous-Fajardo et al., (2010)[28] investigated the within day repeatability of the vastus medialis muscle. The ICC values ranged from 0.77-0.97, with

Table 3. Reliability analysis for Bicep Femoris and Rectus Femoris for males and females. Values are presented as the mean ± standard deviation

	Day 1	Day 2	Day 3	Total Mean	SEM	CV	ICC [95% CI]
Males (N=12)							
BF							
Td (ms)	22.71 (2.62)	24.22 (3.09)	23.62 (2.87)	23.52 (1.27)	0.88	5.40	0.88 [0.68-0.96]
Tc (ms)	33.25 (13.48)	30.21 (13.20)	29.88 (13.13)	31.11 (3.95)	5.30	12.70	0.95 [0.87-0.99]
Ts (ms)	178.87 (45.15)	143.07 (67.72)	175.61 (79.83)	165.85 (48.72)	3445.13	29.38	0.27 [-0.86-0.77]
Tr (ms)	44.02 (13.85)	40.78 (24.05)	63.19 (58.56)	49.33 (24.77)	1371.81	50.21	-0.15 [-1.97-0.64]
Dm (mm)	4.96 (3.33)	5.29 (3.08)	4.54 (2.87)	4.93 (1.40)	1.35	28.40	0.84 [0.59-0.95]
RF							
Td (ms)	23.91 (1.60)	24.96 (2.37)	24.59 (2.21)	24.49 (0.90)	0.31	3.67	0.91 [0.75-0.97]
Tc (ms)	34.24 (8.85)	34.22 (8.16)	33.22 (7.10)	33.90 (3.35)	5.81	9.88	0.89 [0.70-0.97]
Ts (ms)	108.75 (58.60)	121.33 (77.23)	138.36 (61.10)	122.81 (25.32)	413.19	20.62	0.89 [0.71-0.96]
Tr (ms)	46.42 (38.46)	56.26 (39.60)	70.79 (48.33)	57.82 (26.09)	676.46	45.12	0.65 [0.12-0.89]
Dm (mm)	5.91 (2.50)	6.52 (2.14)	6.68 (2.28)	6.37 (1.13)	0.65	17.74	0.86 [0.64-0.96]
Females (N=12)							
BF							
Td (ms)	26.54 (4.32)	25.97 (3.07)	26.25 (4.37)	26.25 (1.14)	0.64	4.34	0.94 [0.83-0.98]
Tc (ms)	39.42 (10.18)	36.43 (9.41)	39.55 (11.86)	38.46 (5.47)	20.15	14.22	0.81 [0.49-0.94]
Ts (ms)	172.43 (32.62)	164.61 (41.45)	171.45 (38.33)	169.50 (18.39)	203.91	10.85	0.84 [0.57-0.95]
Tr (ms)	58.41 (19.15)	52.20 (22.86)	58.26 (23.93)	56.29 (11.52)	109.43	20.47	0.77 [0.39-0.93]
Dm (mm)	7.18 (2.32)	6.17 (2.35)	6.31 (2.44)	6.55 (1.22)	0.81	18.63	0.84 [0.60-0.95]
RF							
Td (ms)	24.76 (1.64)	24.65 (1.72)	26.17 (3.14)	25.19 (1.25)	3.98	4.96	0.31 [-0.67-0.77]
Tc (ms)	27.22 (4.69)	28.65 (3.77)	28.70 (5.18)	28.19 (2.31)	5.66	8.19	0.73 [0.30-0.92]
Ts (ms)	111.49 (61.45)	125.09 (58.35)	119.88 (72.88)	118.82 (42.00)	1686.18	35.35	0.60 [-0.12-0.88]
Tr (ms)	77.58 (61.96)	78.76 (57.35)	74.70 (67.00)	77.02 (41.54)	1883.26	53.93	0.51 [-0.39-0.85]
Dm (mm)	6.31 (2.50)	6.56 (2.43)	7.50 (2.89)	6.79 (1.34)	0.85	19.73	0.86 [0.64-0.96]

Td – delay time; Tc – contraction time; Ts – sustain time; Tr – relaxation time;
Dm – maximal displacement; SEM – standard error of measurement; CV – coefficient of variation;
ICC – intra-class correlation coefficient; CI – confidence interval.

the probe repositioned between measurements. The results from our study also confirm that Tr had the lowest ICC values (BF 0.25, RF 0.58), highlighting that this parameter should be interpreted with a degree of caution when looking at differences between repeat measurements.

Collectively, the results between the present and previous studies suggest that Dm, Tc and Td parameters demonstrate reliability between testing time points, whether that be on the same or between consecutive days. Therefore, future studies that evaluate these parameters as part of repeat measures designs may do so, with a level of confidence. Conversely, the consistent trend suggesting lower ICC values and high SEM values for Tr and Ts suggests that future studies reporting differences in these values over differing timepoints should be interpreted with a degree of caution

GENDER DIFFERENCES

The only study examining reliability of TMG measurement which included females recruited a sample of 16 participants, consisting of 14 males and 2 females.[46] No comparisons between gender were made. In contrast, the present study used an equal sample of males and females (n=12) which allowed for gender related comparisons to be drawn. The present study showed males were older (+2.46 years), taller (+19.34cm), and heavier (+15kg) than their female counterparts. Sub-analysis of reliability measurements according to gender revealed 5 parameters (BF Td, Dm; RF Tc, Tr and Dm) were comparable between genders, if the 95% CI values were considered as opposed to mean values. Additionally, high LoA's were present between most pairs of data points in the males or females. In 5 parameters, the male participants had higher ICC values in BF Tc and RF Td and Ts measurements, whilst the females had higher ICC values in BF Ts and Tr measurements. Additionally, the mean values were generally higher in the measurements taken from the male participants, suggesting that when assessed as a whole sample, the female participants lowered many of the overall ICC values. It is plausible to suggest that this may be partially due to females having a higher proportion of sub-cutaneous fat in the thigh region, compared to males.[47,48] This may create difficulty when identifying muscle location for probe placement purposes and also during the delivery of an electrical stimulation that is required during TMG assessment.[49] However, this theory is currently speculation as no previous studies have investigated if sub-cutaneous fat quantity has any effect on TMG measurements. Nevertheless, previous studies investigating transcutaneous electrical stimulation have shown increased volumes of sub-cutaneous fat require larger amplitudes or larger electrode pads to achieve comparable muscle contractions.[40] A future study could look to investigate if this is also a consideration during TMG assessment.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

During data collection, testing was all performed in the same laboratory to standardise the environmental conditions. However, there were two routes when entering the building (stairs and lift) which could have varied the participants pre-activity exercise levels. The addition of a pretest rest (or washout period) would eliminate any ill effects from this in future studies. Additionally, participants were not blinded to the testing procedure. However, this is not perceived to be a significant limitation as testing is involuntary and free of voluntary effort of motivation.

CONCLUSIONS

To the authors knowledge this is the first study to examine the between-day reliability of both the RF and BF muscle contractile properties on an equally mixed gender sample over three consecutive days. The results from this study highlight good to excellent levels of relative reliability (ICC values >0.70) are assumed for Td, Tc, and Dm in the BF and RF, whereas Ts and Tr reported low levels of reliability (ICC values -0.10-0.56). Absolute reliability was reported using the CV values which were low (<10%) for Td in the BF and Td and Tc in the RF. Males and females were included as participants for this study to investigate if gender differences exist in both the measurement and reliability of repeat TMG assessments. Female participants had consistently lower ICC scores than males, particularly in the RF muscle. High LoA between days were mostly reported in the whole sample and also when gender was accounted for. The findings of the current study and the results from previous studies have contributed to the increasing knowledge that surrounds the reliability of using TMG to measure muscle contractile properties. Across the literature, results support the proposed suggestion that Dm, Tc and Td have relative reliability. However, Tr measurements produced poor reliability scores and therefore future repeat measurement study designs that report Tr differences should be interpreted cognisant of this.

Summary Box

The findings from this study suggest that practitioners using the TMG measurement tool in the between-day assessment of muscle contractile properties should focus on the Dm, Tc and Td variables. The measurement error values reported in this study will assist practitioners when they are assessing for the presence of meaningful change in measurement outcomes, across periods of time in performance settings.

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SUPPLEMENTARY MATERIALS

Supplementary Appendix Tables

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