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Quantitative Analysis of the Contractile Properties of the Thigh Muscles in the Top U18 Football Players of Serbia Measured by the TMG Method

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Abstract

The primary aim of this study was to define the quantitative values of the contractile properties of knee flexor and extensor muscles in highly trained youth football players (U18), measured using tensiomyography (TMG). The examined muscle groups included the biceps femoris (BF), rectus femoris (RF), and vastus lateralis (VL). A secondary aim was to establish descriptive normative dataset of the investigated variables for this age category of football players. The research sample consisted of 25 U18 football players from the top clubs in the Republic of Serbia. TMG variables were measured during the pre-competition phase of the season. The mean values of the measured variables for the BF muscle were: contraction time (Tc) – 25.78 ± 7.71 ms, delay time (Td) – 21.85 ± 3.98 ms, maximal radial displacement (Dm) – 5.92 ± 2.49 mm, contraction velocity (Vc) – 0.124 ± 0.212 mm/ms; for the RF muscle: Tc – 27.70 ± 4.22 ms, Td – 23.50 ± 2.75 ms, Dm – 10.54 ± 2.29 mm, Vc – 0.206 ± 0.329 mm/ms; and for the VL muscle: Tc – 22.30 ± 3.04 ms, Td – 21.30 ± 1.53 ms, Dm – 5.42 ± 1.54 mm, Vc – 0.124 ± 0.336 mm/ms. Based on a comparison between U18 players and senior players, it can be concluded that, with respect to the parameters Dm and Vc, which may be associated with training level and muscle tone, senior players demonstrate superior results. Conversely, regarding Tc and Td, which may be related to a higher proportion of fast-twitch fibers and greater muscle contraction speed, youth players achieved better outcomes.

Keywords: tensiomyography, contraction velocity, quadriceps muscles, hamstring

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Introduction

Tensiomyography (TMG) represents an important non-invasive technique for the assessment of contractile functions and properties of skeletal muscles (Šimunič et al., 2011). This method measures the radial displacement of a muscle in response to an electrical stimulus, providing insight into functional properties such as contraction time (Tc), relaxation time (Tr), delay time (Td), and maximal radial displacement (Dm) (Kot et al., 2012). This type of measurement has demonstrated high reliability and sensitivity in detecting various changes in muscle responses (Rey et al., 2012b). TMG can provide valuable information on muscle fiber composition, muscle tone, fatigue, and muscular imbalances or asymmetries (Macgregor et al., 2018). In recent years, there has been a progressive increase in research utilizing TMG across different athletic populations (García-García et al., 2017; Gil et al., 2015; Rey et al., 2012a). More recent studies have examined the application of TMG in football, with a particular focus on the activation and contractile properties of lower-limb muscles. In football, several studies have investigated the use of TMG for analyzing the effects of different training methods on muscle contractile properties (Loturco et al., 2016; Zubac & Šimunič, 2017), recovery strategies (Rey et al., 2012b), and training loads during competitive microcycles in professional players. Within the football context, understanding the functioning and characteristics of key lower-limb muscles—such as the rectus femoris (RF), biceps femoris (BF), and vastus lateralis (VL) can provide valuable insights into player performance, injury risk, and rehabilitation processes.

Football is a team sport that requires well-developed speed, agility, balance, all types of energy capacities, and strength in order to be played at the elite level (Dellal et al., 2011). In the context of football, the assessment of contractile properties of key thigh muscles, such as the biceps femoris, rectus femoris, and vastus lateralis, can be particularly informative, as these muscles play a crucial role in specific movements, including sprinting, jumping, and changes of direction. Research indicates that during a single football match, players spend approximately 96% of their time on the field engaged in movement without the ball (walking, running, jumping, etc.) (Wallace & Norton, 2014). Analyses further show that football players cover between 9 and 12 km per match, of which 8–12% consists of high-intensity running or sprinting (Haugen et al., 2014). To meet the demands of modern football, today's players must possess not only physical preparedness, but also tactical, technical, and psychological readiness.

In football activities, the quadriceps muscles play a key role during jumping and kicking, while the hamstring muscles control and stabilize the knee during changes of direction (Fried & Lloyd, 1992). Numerous studies on passing and kicking techniques in football have emphasized the importance of maximal lower-limb strength and the coordination between agonist and antagonist muscles, such as the RF and BF, during ball striking (Dorge et al., 1999; Lees & Nolan, 1998; Manolopoulos et al., 2006). Moreover, the RF and BF are also among the muscles most frequently injured during both the pre-season and competition periods (Woods et al., 2002; Woods et al., 2004).

Understanding the growth and development of young players is one of the key factors for their further progress in football. Therefore, it is essential during this period to monitor and control the training status of youth players. Like all sports, youth football is organized into categories based on chronological age, however, during this developmental phase, biological age can also have a significant impact (Vaeyens et al., 2006). Differences between biological and chronological age may negatively influence testing outcomes (Beunen et al., 1981), and consequently affect talent identification and long-term development. Furthermore, monitoring changes in training status during the developmental stages of youth football players, particularly in relation to the adaptation of organ systems and the muscular system, provides the basis for evaluating training effectiveness and identifying individual adaptability. For this reason, regular testing using standardized procedures represents a fundamental method within applied metrological approaches (Rodríguez-Matoso et al., 2012).

Taking the above into consideration, the primary aim of this study was to conduct a quantitative analysis of the contractile properties of the thigh muscles in elite youth football players from Serbia using the tensiomyography (TMG) method. In line with this primary aim, a secondary objective was to establish preliminary reference values for the examined variables, for the purpose of their metrological application in monitoring the state of training adaptation of the studied muscle groups. This would serve as a basis for developing quantitative norms within a system for monitoring the developmental progression of young football players. The findings of this study may be used for further comparisons, given the current deficiency of research in this area, which underscores the relevance of this work and its potential for practical implementation.

Methods

Participants

The study involved a sample of 25 youth football players, selected as the top performers from three clubs (FC Red Star, FC Grafičar, and FC Partizan). The sample consisted of 25 football players, including 9 defenders, 4 centers, and 12 forwards. Participants had the following descriptive characteristics: age 17.7 ± 1.1 years; height 178.9 ± 6.8 cm; weight 71.9 ± 7.5 kg; BMI 22.6 ± 1.6 kg/m^2. At the time of testing, none of the participants reported any muscle injuries. All participants were fully informed about the testing protocol, including potential risks and benefits, and provided written voluntary consent. In the case of minor players, consent was additionally obtained from their parents, and coaches were also informed and approved participation.

Measurements and Procedures

The study targeted the following muscle groups: the knee extensors and flexors, specifically the rectus femoris (RF), vastus lateralis (VL), and biceps femoris (BF) of both the left and right legs. Involuntary contractile properties of these muscles were evaluated using Tensiomyography (TMG100, TMG-BMC d.o.o., Ljubljana, Slovenia), which records muscle responses to an electrically induced stimulus delivered via two self-adhesive electrodes (Fernández-Baeza et al., 2024). RF and VL muscles were measured first in a standardized supine position, with a foam pad placed under the knee, followed by BF measurements in a standardized prone position, with a foam pad positioned above the ankle (Fabok et al., 2019). The testing procedure followed the protocol described by Rey et al. (2012a), in which a sensor (GK40, Panoptik, Ljubljana, Slovenia) positioned between the electrodes detects changes in the muscle caused by electrical stimulation, providing data on involuntary muscle contractile properties (Toskić et al., 2019). Monophasic electrical stimulation was applied, beginning at an initial intensity of 30 mA and progressively increased to 50 mA, 70 mA, and finally 100 mA. A 10-second rest interval was included between each stimulus to allow muscle relaxation and prevent potentiation effects.

Participant testing was carried out at the “Advance Fitness”, training and diagnostic center in Belgrade. All participants were among the top youth football players in Serbia. Two days prior to testing, the players engaged in light training sessions, whereas on the testing day, they abstained from any training or physical activity before the assessments. All procedures were conducted by two experienced researchers. The testing protocol included anthropometric measurements, followed by Tensiomyography (TMG) assessments. From a methodological perspective, this study is classified as a cross-sectional study, while in terms of the applied technique, it represents a laboratory-based measurement approach. The study was approved by the Ethics Committee of the Faculty of Sport and Physical Education at the University of Belgrade (Ref. No. 02/484–2) and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki for research involving human participants (Christie, 2000).

Variables

The study assessed the following variables:

1. **Dm** – the maximal radial displacement of the muscle during contraction, reflecting muscle flexibility and tone, expressed in millimetres (mm);
2. **Td** – delay time, defined as the interval between the delivery of the electrical stimulus and the onset of muscle contraction (10% of Dm), expressed in milliseconds (ms);
3. **Tc** – contraction time, defined as the duration between 10% and 90% of Dm, expressed in milliseconds (ms);
4. **Contraction velocity (Vc)** – an index of the speed of radial muscle displacement, calculated as the ratio of Dm to the sum of Tc and Td, expressed in mm/ms (Loturco et al., 2016).

For comparability with previously published reference meta-studies, all variable values are presented as the mean of the dominant and non-dominant leg (Paravlić, 2025).

Statistical analyses

The data collected in this study were analyzed using basic descriptive statistics, including Mean, SD, CV%, Min, Max. The arithmetic mean (Mean) was used to represent central tendency, while variability was described using standard deviation (SD), coefficient of variation (CV%), and minimum (Min) and maximum (Max) values (Hair et al., 2006). Normative standardization of the assessed variables was conducted through percentile calculations, applying percentile distribution in accordance with standardized sport-metric procedures (Andraos & El Mdawar, 2024; Lockie, 2025). The analysis was limited to a descriptive comparison with both international and national senior standards (Fabok et al., 2019; Paravlić, 2025; Pajović et al., 2025).

Results

The descriptive statistics for the youth football players are summarized in Table 1. This table presents the descriptive statistics of TMG parameters for the biceps femoris (BF), rectus femoris (RF), and vastus lateralis (VL) muscles. The RF muscle exhibited the highest values of contraction time (TC), delay time (TD), muscle displacement (DM), and contraction velocity (VC). In contrast, the VL muscle generally showed the lowest TC and TD values. Variability was low to moderate for TC and TD, while DM demonstrated greater variability, particularly in the BF muscle.

Table 1. Descriptive characteristics of the muscles assessed in youth football players

		TC			TD			DM			VC		
		BF R+L	RF R+L	VL R+L	BF R+L	RF R+L	VL R+L	BF R+L	RF R+L	VL R+L	BF R+L	RF R+L	VL R+L
	Mean	25.78	27.70	22.30	21.85	23.50	21.30	5.92	10.54	5.42	0.122	0.206	0.124
	SD	7.71	4.22	3.04	3.98	2.75	1.53	2.49	2.29	1.54	0.039	0.044	0.034
	CV%	29.92	15.25	13.66	18.22	11.72	7.19	42.00	21.75	28.35	0.002	0.002	0.001
	MIN	12.89	18.84	15.24	15.78	19.93	16.37	1.26	5.86	1.55	0.029	0.140	0.041
	MAX	42.73	38.26	28.19	38.75	37.41	24.33	12.67	15.60	8.37	0.205	0.344	0.206
CL 95%	**Upper**	27.98	28.90	23.16	22.98	24.29	21.74	6.62	11.19	5.86	0.133	0.219	0.133
	Lower	23.59	26.50	21.43	20.72	22.72	20.87	5.21	9.89	4.99	0.111	0.194	0.114

Note: BF (Biceps femoris); RF (Rectus femoris); VL (Vastus lateralis); TC (Contraction time); TD (Delay time); DM (Maximal radial displacement); VC (Contraction velocity)

The percentile standards of the assessed variables are summarized in Table 2.

Table 2. Percentile values for each of the assessed variables

		2.5%	**5%**	**10%**	**20%**	**50%**	**70%**	**90%**	**95%**	**97.5%**
BF R+L	TC (ms)	15.52	16.00	17.55	18.35	23.24	31.57	35.94	38.59	39.28
	TD (ms)	17.72	17.81	18.31	18.79	21.21	22.36	25.43	26.42	33.06
	DM (mm)	1.76	2.50	3.12	3.66	5.56	7.15	9.10	9.50	10.18
	VC (mm/ms)	0.051	0.062	0.078	0.093	0.119	0.142	0.176	0.184	0.199
RF R+L	TC (ms)	18.94	20.40	22.60	24.58	28.28	30.27	31.97	33.38	36.27
	TD (ms)	20.22	20.85	21.20	21.82	23.20	23.94	25.67	26.12	30.09
	DM (mm)	7.22	7.42	8.11	8.67	10.32	11.49	13.96	14.47	15.21
	VC (mm/ms)	0.144	0.150	0.151	0.172	0.200	0.227	0.262	0.282	0.292
VL R+L	TC (ms)	15.43	16.92	19.06	20.05	22.10	24.01	26.30	27.29	27.53
	TD (ms)	18.61	19.01	19.31	20.24	21.31	22.12	23.08	23.46	23.85
	DM (mm)	2.12	2.46	3.65	4.18	5.64	6.21	6.90	8.06	8.35
	VC (mm/ms)	0.058	0.067	0.087	0.092	0.128	0.139	0.161	0.181	0.190

Since the results of the tested muscle groups in U18 players from the Republic of Serbia are being reported to the scientific community for the first time, they were compared, for metrological validation, with both international and national senior standards (Fabok et al., 2019; Paravlić, 2025; Pajović et al., 2025), as shown in Figures 1–4.

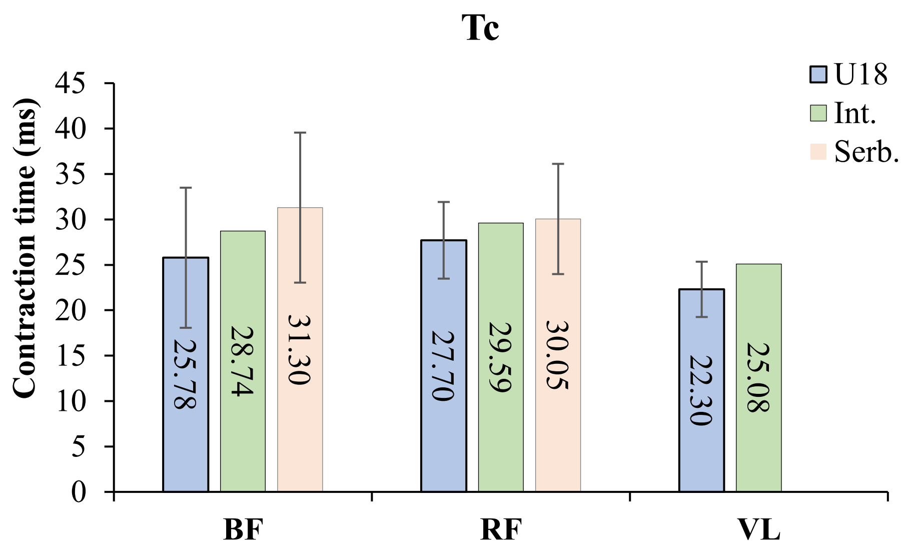

Figure 1. Descriptive statistics comparison of the TMG variable Tc between U18 and senior football players

The graph shows that contraction time (Tc) is consistently higher in the Serbian group compared to both U18 and the international group across all muscles (BF, RF, and VL). The largest differences are observed in the biceps femoris (BF) and rectus femoris (RF), while the vastus lateralis (VL) shows smaller variation between groups. Overall, this may suggest slower muscle contractile response in the Serbian group.

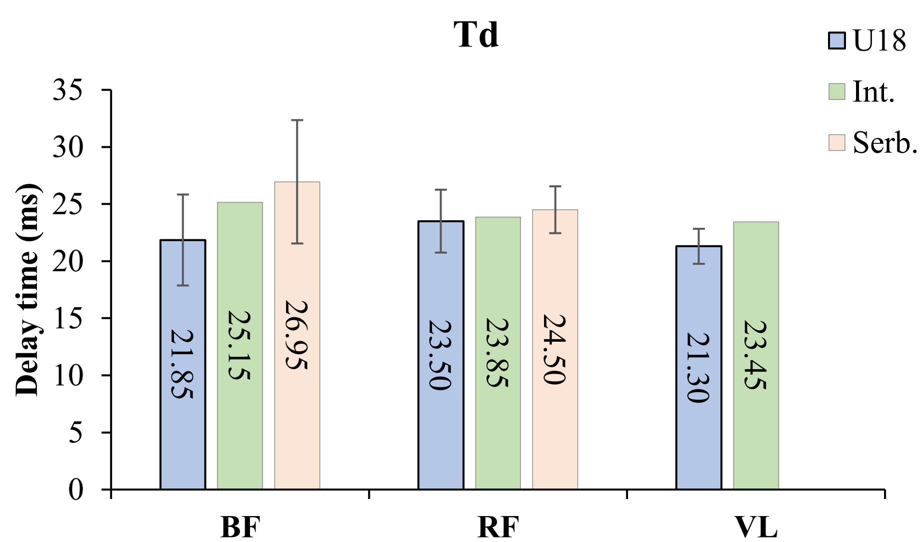

Figure 2. Descriptive statistics comparison of the TMG variable Td between U18 and senior football players

The graph indicates that delay time (Td) is generally highest in the Serbian group, particularly in the biceps femoris (BF), where the difference is most pronounced. The international group shows intermediate values, while the U18 group tends to have the lowest Td across most muscles. Differences between groups are smaller in the rectus femoris (RF) and vastus lateralis (VL), suggesting more similar neuromuscular response in these muscles.

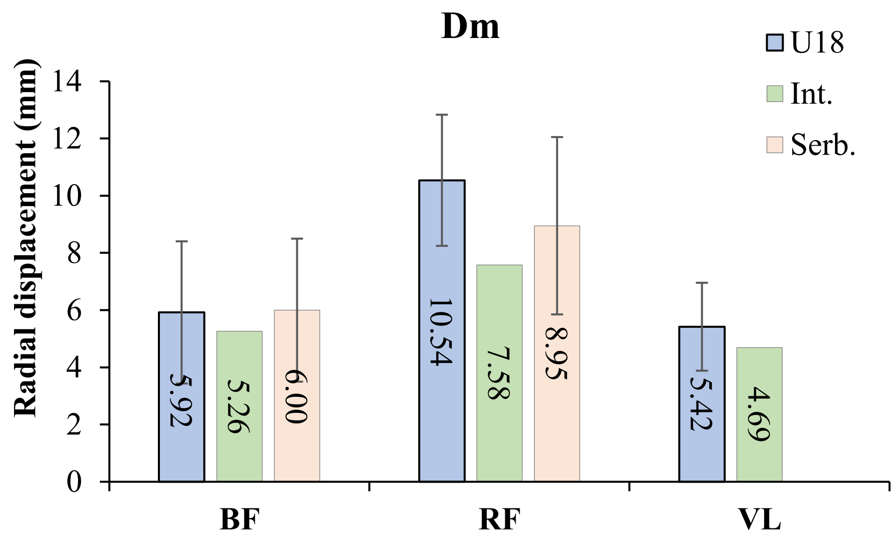

Figure 3. Descriptive statistics comparison of the TMG variable Dm between U18 and senior football players

The graph shows that muscle displacement (Dm) is highest in the U18 group, especially in the rectus femoris (RF), indicating greater muscle compliance or lower stiffness. In contrast, the international and Serbian groups generally present lower Dm values, suggesting increased muscle stiffness. Differences are less pronounced in the biceps femoris (BF) and vastus lateralis (VL), where values are more similar across groups.

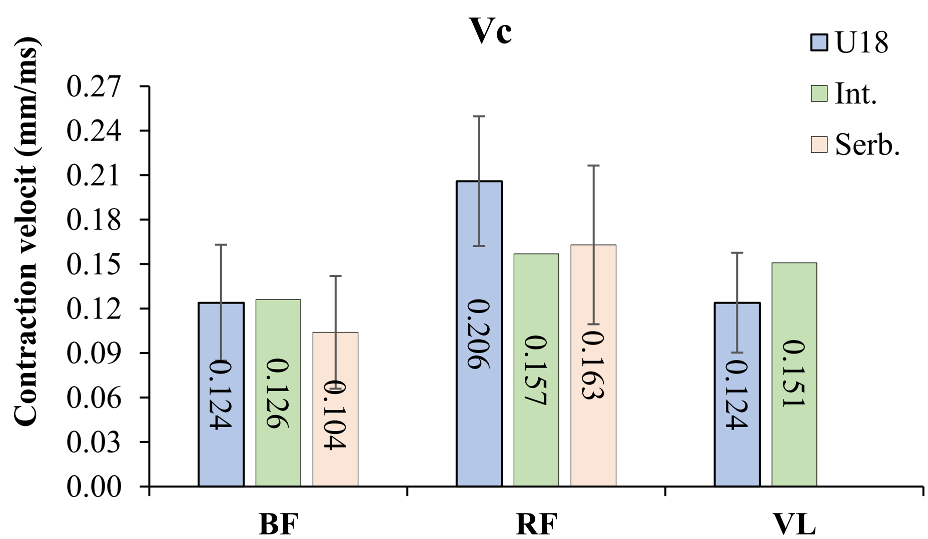

Figure 4. Descriptive statistics comparison of the TMG variable Vc between U18 and senior football players

The graph shows that contraction velocity (Vc) is highest in the U18 group, particularly in the rectus femoris (RF), indicating faster muscle contraction. The international and Serbian groups generally display lower Vc values, with the Serbian group having the lowest values in the biceps femoris (BF). Differences between groups are smaller in the vastus lateralis (VL), suggesting more comparable contraction speed in this muscle.

Discussion

The present study aimed to provide a descriptive overview of contractile properties (Tc, Td, Dm, Vc) of selected thigh muscles in elite U18 football players using tensiomyography (TMG). The main findings of this study should be interpreted as preliminary reference values specific to this population rather than definitive normative standards.

The results indicated that, for the BF muscle, the mean values of the measured variables were (Table 1): contraction time (Tc) – 25.78 ± 7.71 ms; delay time (Td) – 21.85 ± 3.98 ms; muscle belly displacement (Dm) – 5.92 ± 2.49 mm; and contraction velocity (Vc) – 0.124 ± 0.212 mm/ms. For the RF muscle, the corresponding values were Tc – 27.70 ± 4.22 ms, Td – 23.50 ± 2.75 ms, Dm – 10.54 ± 2.29 mm, and Vc – 0.206 ± 0.329 mm/ms. For the VL muscle, Tc – 22.30 ± 3.04 ms, Td – 21.30 ± 1.53 ms, Dm – 5.42 ± 1.54 mm, and Vc – 0.124 ± 0.336 mm/ms. Coefficients of variation (CV%), used to assess data homogeneity, were generally within acceptable limits (<30%) for all variables, except for the hamstring stiffness (BF, Dm CV% = 42.0). It was determined that the variation among the tested players, as systematically trained individuals, was at the level of individual differences of 42% (Table 1). In other words, the only muscle group and the only functional muscle characteristic in which the tested players differed significantly was the stiffness of the knee flexors, i.e., the stiffness of the hamstring – the biceps femoris.

In the study conducted by Kusumoto et al. (2023), it is reported that a negative correlation between lower limb muscle mass and Dm may indicate that players with greater lower limb muscle mass have lower Dm values, i.e., higher muscle stiffness. This relationship may help explain how different playing positions, with their specific on-field demands, influence lower-limb muscle composition. Furthermore, variations in training programs can modulate hamstring stiffness, potentially affecting running mechanics. Muscles with optimal Dm values can achieve a greater range of motion and enhanced energy absorption during sprints and jumps, which may reduce the risk of repetitive strain injuries (Fernández-Baeza et al., 2024). Graphical analysis of Figures 1–4, which display the measured variables across the examined muscle groups, shows that all mean values fall within the range of shared standard deviations. This observation supports the external validity of the current study. In other words, the results are consistent with previously published data for both international and national elite football players (Fabok et al., 2019; Paravlić, 2025; Pajović et al., 2025).

When comparing TMG-derived results for the BF, RF, and VL muscles between U18 and senior players, it is demonstrated that U18 players showed nominally superior values in Tc and Td parameters, regardless of the muscle group. Variables Dm and Vc, were very similar to those observed in senior players. Contraction time (Tc), measured in milliseconds via TMG, reflects the functional capacity for rapid muscle activation and excitability. Muscles with shorter contraction times indicate a high functional potential for explosive movements, whereas muscles with longer contraction times reflect slower functional characteristics (Rodríguez-Matoso et al., 2012). Tc values could be associated with the proportion of fast-twitch versus slow-twitch fibers within the measured muscle. Specifically, an inverse relationship exists between Tc and the percentage of fast-twitch fibers; as the proportion of fibers increases, Tc decreases (García-Manso et al., 2011). One potential explanation for the shorter contraction times observed in younger players is age-related differences compared to international senior players. This observation aligns with Fernández-Baeza et al. (2024), who reported that age significantly affects TMG-derived parameters. Meta-regression analyses indicated that contraction time (Tc) in quadriceps muscles tends to increase with age, particularly in the rectus femoris (RF) and vastus lateralis (VL). The reason for this phenomenon is the functionally slower muscle response with increasing age, which most likely occurs due to the decline in the contractile properties of type II (fast-twitch) muscle fibers and the reduction in muscle elasticity that take place with aging. Furthermore, the parameters of Tc and Td are also associated with muscle fiber fatigue, while a decrease in the rate of force generation indicate a low level of contraction velocity caused by possible fatigue or by the dominance of slow-twitch muscle fibers (Tous-Fajardo et al., 2010).

Muscle displacement (Dm), measured using the TMG method, is a parameter that is associated with muscle tone and stiffness. When the stimulated muscle shows a large displacement, this indicates a lack of muscle tone, whereas a small displacement may reflect increased muscle stiffness. In cases where muscle displacement is adequate, it reflects good muscle tone (García-Manso et al., 2011). When comparing U18 players with senior players reported in previous studies, U18 players exhibited the highest Dm values, which may suggest lower muscle tone, which is expected given their age and level of training in comparison with senior players. Lower Dm values in the lower limb muscles are associated with early fatigue and limited range of motion (Fernández-Baeza et al., 2024). Regarding contraction velocity (Vc; Figure 4), which integrates muscle displacement, contraction time, and delay time, U18 players showed slightly lower values across all measured muscles compared to senior players. The study conducted by Paravlić (2025) found that Vc values were higher in elite players compared to highly trained players for the BF muscle. This finding is consistent with the observed differences between senior and U18 players, reflecting age and training status. These results also suggest that Vc is a sensitive parameter for monitoring training-induced adaptations in muscle function and may serve as a valuable metric for identification, distinguishing functional-contractile potential across age groups and performance levels in football (Paravlić, 2025).

Due to the limited number of relevant studies on this topic, particularly regarding TMG assessments of youth players and their comparison with senior athletes, further research is needed to evaluate and validate the findings of the current study. One of the main limitations of this study is the absence of direct performance-related measures such as sprint, change of direction ability, strength, or injury history. Without these variables, the practical implications of the findings remain limited, and any assumptions regarding performance or training adaptations are necessarily speculative (Bishop et al., 2018).

The interpretation of TMG-derived variables requires particular caution. For example, Tc has often been associated with muscle fiber-type composition; however, this relationship is indirect and influenced by multiple physiological and mechanical factors (Macgregor et al., 2018). Similarly, maximal displacement (Dm) has been linked to muscle stiffness, although it should not be interpreted as a direct measure of this property (Šimunič, 2012). Therefore, these variables should be interpreted as indicators of contractile behaviour rather than definitive markers of specific muscle qualities.

Although comparisons with senior players were explored, it is important to emphasize that these observations are descriptive in nature and were not supported by inferential statistical analysis. Consequently, any apparent differences should be interpreted with caution and should not be considered conclusive evidence of superior or inferior neuromuscular characteristics.

Additionally, the relatively small sample size (n = 25), inclusion of players from only a limited number of clubs, and the lack of biological maturity analysis restrict the generalizability of the results. Given the known influence of maturation on neuromuscular characteristics in youth athletes, future research should incorporate maturity status to improve interpretability (Lloyd et al., 2015).

Overall, this study contributes descriptive data to the field of football science, but further research with larger samples, inferential statistics, and integrated performance measures is necessary to establish stronger applied relevance.

Conclusion

This study provides preliminary descriptive reference values for contractile properties of selected thigh muscles in elite U18 football players tensiomyography. The findings contribute to the existing literature by offering population-specific data; however, they should not be interpreted as definitive normative standards.

Due to the descriptive nature of the analysis and the absence of inferential statistics, comparisons with other populations, including senior players, remain limited. Furthermore, the lack of performance-related variables restricts the ability to draw conclusions regarding functional or competitive relevance. While TMG parameters such as Tc, Dm, and Vc may offer useful insights into neuromuscular characteristics, their interpretation should be approached with caution, as their relationship with muscle structure and performance outcomes is not fully established. Future studies should aim to include larger and more diverse samples, incorporate inferential statistical approaches, and integrate performance and maturation-related variables in order to enhance both scientific validity and practical applicability. In its current form, this study should be viewed as a descriptive contribution that may serve as a foundation for further research and applied monitoring in youth football populations. This study provides a descriptive contribution to the understanding of contractile properties in elite youth football players, but further research incorporating inferential statistics, larger samples, and performance-related measures is required to establish stronger scientific and practical relevance.

***Conflict of interests*:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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