THE IMPACT OF NEUROMUSCULAR WARM-UP ON MUSCLE CONTRACTILITY AND INJURY PREVENTION IN FEMALE SOCCER PLAYERS: ANALYSIS USING TENSIOMYOGRAPHY

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Abstract

As female soccer's popularity and participation rise, injury rates are expected to increase due to the sport's complexity, highlighting the importance of regular health and neuromuscular function screenings for injury prevention. The aim of the study was to determine how neuromuscular warm-up affects the contractility of the lower limb muscles and its significance in the prevention of injuries in female soccer players. The research sample consisted of 36 female soccer players, who were divided into an experimental (EG) and a control (CG) group with an average age 17.45 ± 2.63 years (EG) and 16.24 ± 1.09 years (CG). The contractility of the lower limb muscles was monitored using Tensiomyography (TMG). We evaluated bilaterally five muscles of the lower limbs for each soccer player: m. biceps femoris, m. gastrocnemius medialis, m. gluteus maximus, m. vastus lateralis, and m. vastus medialis. The experimental factor in the research, implemented during the warm-up phase of the training session, was neuromuscular warm-up over 12 weeks of EG. To assess the effect of the intervention program on changes in the muscle contractility of the soccer players, we employed the non-parametric Wilcoxon signed-rank test for dependent samples and the Mann-Whitney U test for independent samples. Results indicates that the speed of muscle contraction (Tc) and muscle stiffness (Dm) vary among different muscles and even between dominant and non-dominant limbs of soccer players. The impact of neuromuscular warm-up on contraction time and maximal displacement was negligible, except for a moderate effect in m. gluteus maximus of the non-dominant limb. Although the impact of neuromuscular warm-up on lower limb muscle contractility was not significant, more regular monitoring and inclusion of neuromuscular warm-up at a higher weekly frequency may have beneficial effects.

Keywords

women's soccer, muscular contractile properties, tensiomyography, neuromuscular warm-up, injury prevention

Introduction

Women's soccer, spanning professional, semi-professional, and community levels, is experiencing rapid global growth [1]. The International Football Association (FIFA) aims to double the number of registered female players worldwide from 30 million (in 2019) to 60 million by 2026 [2]. With the increasing popularity of women's soccer, there is also a rise in professional standards, and players at different levels may be exposed to higher training and competitive demands than before, which can have impact for their performance and health [3, 4]. In women's soccer, a high incidence of injuries is a significant and recurring reality, regardless of performance level [5–24]. Generally, athletes after severe injury are more susceptible to re-injury, experience functional deficits, reduced quality of life, and are at increased risk of obesity compared to uninjured athletes [25]. The injury itself or fear of re-injury can prematurely end a player's career [26–29], which can have negative psychological as well as socio-economic impacts on the players [30]. The inclusion of compensatory or preventive training programs is essential in women's soccer.

In youth sports, neuromuscular training (NMT) has been shown to reduce the risk of lower limb injuries by 35% [31]. Additionally, NMT training has been found

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to decrease the risk of ankle injuries by 44–86% and the risk of knee injuries by 45–83% in young athletes [32]. NMT training is particularly effective in reducing the risk of anterior cruciate ligament (ACL) injuries, which are among the most common severe sports-related injuries leading to long absences from sports and are associated with permanent knee function impairment and a high risk of early-onset osteoarthritis [25]. It is estimated that implementing NMT programs for young athletes aged 12–25 participating in high-risk sports could reduce the prevalence of ACL injuries by at least 40% [33]. In addition to their preventive effects, NMT warm-up programs have shown improvements in athletic performance, including strength, sprinting abilities, agility, leg strength, balance and stability, as well as sport-specific skills, especially in young athletes [34, 35].

A benefit of NMT warm-up is its practicality, as it does not require special equipment and can be performed indoors or outdoors. In this regard, we consider the neuromuscular warm-up developed by Hilska, Leppänen et al. [36] to be the most suitable. This neuromuscular warm-up is designed to not burden sports coaches in creating training sessions and can replace their traditional warm-up routines.

Tensiomyography (TMG) is non-invasive method of neuromuscular assessment and was developed at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia [37]. TMG measures the radial deformation of skeletal muscles and subsequently their contractile properties in response to external electrical stimulation [38]. TMG provides information on acute and chronic muscle responses to various training loads (strength, endurance, speed, flexibility). The acquired information can then be used to determine the type, intensity, and frequency of training to facilitate faster and more efficient recovery [37].

Tensiomyography (TMG) is a valuable tool in injury prevention [39], with significant potential to enhance injury prevention efforts and enable athletes to return more effectively. In soccer, TMG finds wide-ranging applications [40–52], but only one study focused on female soccer, examining national Slovenian team players at the beginning of the season [53].

Contraction time (*Tc*) depends on the percentage of fast and slow muscle fibers in the muscle [54, 55]. Lower *Tc* values are observed as the percentage of type II muscle fibers increases. Given that soccer is a sport played over a long duration (at least 90 minutes) and on a large field, it requires endurance, strength, and speed. While an excess of fast-twitch muscle fibers provides soccer players an advantage in speed and strength-based movements, an excess of slow-twitch muscle fibers offers an advantage in terms of endurance [56]. Previous findings suggest that muscles with a higher proportion of fast fibers are less prone to muscle atrophy [57].

The diagnostic device TMG can reliably be used for non-invasive estimation of prevailing muscle fiber characteristics of skeletal muscles [58], monitoring muscle fatigue [40, 59], adaptations induced by training and rehabilitation [41, 60–63], and ultimately assessing neuromuscular injury risk factors for injuries [42, 43].

The role of mechanical and contractile properties through TMG as risk factors for anterior cruciate ligament (ACL) injury in professional male soccer players was investigated, concluding that decreased fatigue resistance and muscle stiffness of the posterior thigh muscles may be risk factors for ACL injury [42].

It is documented that female soccer players have 4–6 times higher risk of ACL injury compared to male players [64, 65]. Muscle imbalance in the quadriceps and hamstring muscles, as monitored by TMG parameters, may be another risk factor for ACL injury in female players [42]. Reduction in contraction speed, fatigue resistance, and changes in muscle tone or stiffness of the *m. vastus medialis, m. vastus lateralis, m. rectus femoris, m. semitendinosus, m. biceps femoris, and m. gluteus maximus* may also contribute to ACL injury risk [47].

The aim of the study was to determine how neuromuscular warm-up affects the contractility of the lower limb muscles and its significance in the prevention of injuries in female soccer players.

Material and Methods

This study complies with the ethics committee University of Presov, Prešov, Slovakia (Approval no. ECUP032022PO).

The research sample consisted of 36 female soccer players, who were divided into an experimental (EG) and a control (CG) group based on their club affiliation. The pretest diagnostics were executed before the start of the competitive period of the 2023/2024 season (August 2023). The posttest diagnostics were executed at the end of the competitive period of the 2023/2024 season (November 2023). The EG group (n=20) consisted of players from FC Spartak Myjava (Slovakia) with an average age 17.45 ± 2.63 years, body height 168.31 ± 6.13 cm, and body weight 60.21 ± 8.87 kg. The CG group (n=16) consisted of players from 1. FC Tatran Prešov (Slovakia) with an average age 16.24 ± 1.09 years, body height 163.84 ± 5.58 cm, and body weight 55.91 ± 6.87 kg. Both research groups compete in the 1st Slovak Women's League. Before initiating the assessment of muscle contractility, measurements of basic somatic characteristics were performed as a method of closer description of the research sample. Body height was measured using a portable stadiometer SECA 217 (Seca GmbH & Co. KG, Hamburg, Germany). Body weight was determined using bioelectrical impedance analysis with the InBody 270 device (InBody Co., Ltd, Seoul, Korea). The contractility of the lower limb

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muscles was monitored using Tensiomyography (TMG-S1) (TMG-BMC Ltd., Ljubljana, Slovenia, 2011), a non-invasive method of neuromuscular assessment developed at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia [37].

Records of the Tensiomyography (TMG) displacement curve over time allow for the assessment of muscle contractile properties and the acquisition of various parameters that can provide information about muscle stiffness [55]. The main parameters of muscle contraction obtained using TMG include maximum muscle contraction amplitude (*Dm*, maximal displacement), contraction time (*Tc*), delay time (*Td*), sustain time (*Ts*), and relaxation time (*Tr*). Among these parameters, *Dm* and *Tc* are generally considered the most significant [55, 66–69]. For this reason, our research focuses on the values of *Tc* and *Dm*. We evaluated bilaterally five muscles of the lower limbs: *m. biceps femoris, m. gastrocnemius medialis, m. gluteus maximus, m. vastus lateralis, and m. vastus medialis* (Fig. 1). The selection of muscles was made after consultation with Dr. Maroš Varga, MHA, from the Sports-Arthro Center, AGEL Hospital (Košice-Šaca, Slovakia), who, based on his experience and long-term practice, identified these muscles as the most injured muscles in soccer.

Fig. 1: Diagnosed muscle by Tensiomyography.

The experimental factor in the research was neuromuscular warm-up, implemented in the warm-up phase of the training session with the aim of improving muscle contractility of female soccer players. The neuromuscular warm-up was developed by Hilska, Leppänen, et al. [36], whose goal was to investigate whether neuromuscular warm-up could reduce the risk of lower limb acute injuries in youth male and female soccer players. The components of the neuromuscular warm-up were derived from a program that had previously been implemented and tested in floorball [70].

Throughout the 2023/2024 competitive season, we integrated neuromuscular warm-up into the preparatory phase of the training sessions for the experimental group of female soccer players, with duration of 12 weeks. The frequency of warm-up was 2–3 times per week, lasting 15–20 minutes each session. This frequency was based on the findings of the authors [71], who argue that applying neuromuscular warm-up twice a week is successful in preventing injuries in soccer.

For the analysis of injury occurrences, we utilized the FIFA Reporting Injuries questionnaire six months prior to the commencement of the experimental intervention and six months after its initiation [72].

Based on the sample size of the research groups we assessed the normality of the distribution of statistical data using the Shapiro-Wilko test. Since we found a violation of normal distribution, we preferred non-parametric statistical methods for further processing. We used the median ($\tilde{x}$) as a measure of central tendency. To assess the effect of the neuromuscular warm-up on changes in the muscle contractility of the soccer players, we employed the non-parametric Wilcoxon signed-rank test for dependent samples and the Mann-Whitney U test for independent samples. The significance of differences was assessed at a significance level of $p<0.05$. For better understanding of the practical significance of the results, we provided the effect size for both tests, determined through the Rosenthal's r coefficient. We assessed the effect size according to Cohen [73]: 0.1–0.3 = small effect; 0.3–0.5 = medium effect; greater than 0.5 = large effect. Data were processed using the statistical software STATISTICA (version 13.5, StatSoft, Poland) and graphically represented using Microsoft Office Excel (Microsoft Corporation, Redmond, Washington).

Results

Half of both research groups (50%) reported a certain type of injury in the 6-month period prior to the baseline assessment, resulting in an absence from training or match play for 20 days (EG) and 23 days (CG). Lower limb injuries, particularly in the ankle and

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knee joints, and thigh muscle injuries were most common. The number of acute injuries decreased by 47% in the experimental group, while the number of injuries due to long-term excessive load increased by 47%. Conversely, in the control group, there was an increase of 12% in acute injuries and a decrease of 12% in injuries caused by long-term excessive load. In the experimental group, there was an increased incidence of muscle injuries, but a decrease in ankle and knee joint injuries. Such changes were not observed in the control group. The impact of neuromuscular warm-up did not show a statistically significant difference in injury occurrence. However, we observed a change in the injury profile, with more muscle injuries and fewer joint injuries. From the values illustrated in Fig. 2, we found that in the *m. biceps femoris*, the time of muscle contraction in the DLE during the pretest was significantly lower in the CG (p=0.004, r=0.485), indicating a faster muscle contraction compared to the EG. Female football players in the EG did not reach the reference value in the DLE, with the contraction time being slower by 28% in the pretest and 30% in the posttest. Female football players in the CG reached the reference value only in the pretest (with a difference of 1%), but in the posttest, the contraction time was 33% slower. In the *m. gastrocnemius medialis*, the reference value was not reached in the DLE, with the muscle being slower by 6% in both measurements. In the NLE, the contraction time was slower by 2% (pretest) and 4% (posttest) in EG. In the *m. gluteus maximus*, the contraction speed was higher by 16% in the EG. In the *m. vastus medialis*, a statistically significant slower contraction was recorded in the CG by 12% in the DLE and 7% in the NLE.

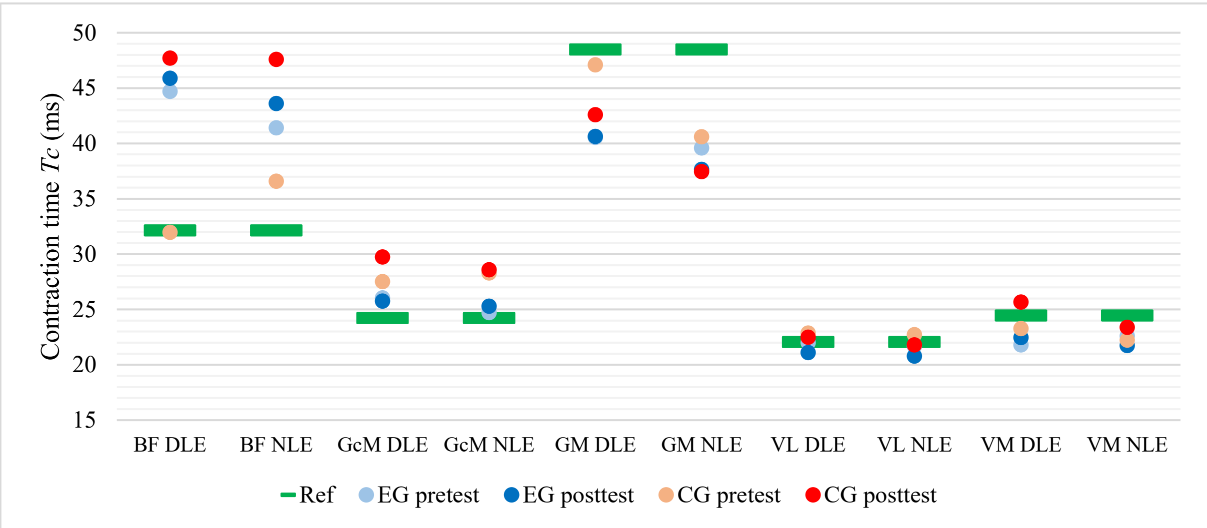

Fig. 2: The contraction time in the tested muscles. BF—biceps femoris; GcM—gastrocnemius medialis; GM—gluteus maximus, VL—vastus lateralis; VM—vastus medialis; Ref—reference value; EG—experimental group; K—control group; ms—milliseconds; DLE—dominant lower extremity; NLE—nondominant lower extremity.

Table 1: The impact of the intervention factor on the contraction time (Tc).

muscle		Experimental group					Control group				
		n	T	Z	p	r	n	T	Z	p	r
BF	DLE	20	104.000	0.037	0.970	0.006	16	26.000	2.172	0.030*	0.362
	NLE	20	98.000	0.261	0.794	0.044	16	50.000	0.931	0.352	0.155
GcM	DLE	20	84.000	0.784	0.433	0.131	16	62.000	0.310	0.756	0.052
	NLE	20	90.000	0.560	0.575	0.093	16	56.000	0.621	0.535	0.103
GM	DLE	20	81.000	0.896	0.370	0.149	16	34.000	1.758	0.079	0.293
	NLE	20	45.000	2.240	0.025*	0.373	16	42.000	1.344	0.179	0.224
VL	DLE	20	68.000	1.381	0.167	0.230	16	61.000	0.362	0.717	0.060
	NLE	20	66.000	1.456	0.145	0.243	16	58.000	0.517	0.605	0.086
VM	DLE	20	85.000	0.747	0.455	0.124	16	38.000	1.551	0.121	0.259
	NLE	20	71.000	1.269	0.204	0.212	16	48.000	1.034	0.301	0.172

BF—biceps femoris; GcM—gastrocnemius medialis; GM—gluteus maximus, VL—vastus lateralis; VM—vastus medialis; DLE—dominant lower extremity; NLE—nondominant lower extremity; n—sample size; T—value of Wilcoxn pair test; Z—value of the test criterion; p—Significance level; *—statistical significance at the level p<0.05; r—effect size.

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In Table 1, we present a comparison of the effect of neuromuscular warm-up on the *Tc* value. The table shows that statistically significant differences occur only in a few cases. The most notable differences are observed in the *m. biceps femoris* of the DLE in the CG (p=0.030) and in the *m. gluteus maximus* of the NLE in the EG (p=0.025). In other cases, the p-values suggest that the differences between the EG and CG are not statistically significant. Effect size coefficients are mostly low, indicating a weak to moderate effect size.

The CG demonstrated a 28% lower maximum amplitude in the pretest. A statistically significant difference was observed between the EG and CG in both the dominant (p=0.015, r=0.406) and non-dominant (p=0.002, r=0.512) lower extremities. In the *m. gluteus maximus* of the dominant DLE, female football players in the EG achieved a 13% lower maximum amplitude in the pretest and 21% lower in the posttest. The CG exhibited a 17% lower maximum amplitude in the pretest. A statistically significant difference was observed between the EG and CG in both the dominant (p=0.006, r=0.459) and non-dominant (p=0.037, r=0.348) lower extremities. The CG approached the reference level in the posttest. In the NLE, female football players in the EG had a lower value by 22% in the pretest and by 23% in the posttest compared to the reference value. The CG approached the reference level in both measurements (5%). A statistically significant Fig. 3 illustrates the comparison of pretest and posttest in the EG and CG across all measured muscles. It is evident that the *m. gluteus maximus* exhibits the highest maximum amplitude. In the pretest, the *m. biceps femoris* of the dominant lower limb (DLE) in the female football players of the EG recorded a 29% higher value than the reference, increasing to 36% in the posttest (a difference of 7%). The CG demonstrated a 32% lower value in the pretest compared to the reference value. In the posttest, this value was at the reference level (a difference of 9%). A statistically significant difference was observed between the EG and CG in the dominant DLE during both pretest (p=0.001, r=0.618) and posttest (p=0.004, r=0.480). In the non-dominant lower limb (NLE) of female football players in the EG, the values were 38% higher in the pretest and 30% higher in the posttest than the reference value (a difference of 8%). The CG exhibited a 32% lower value in the pretest compared to the reference. A statistically significant difference was observed between the EG and CG in the NLE during the pretest (p=0.003, r=0.491), with the difference being at the reference level in the posttest (a difference of 5%). In the *m. gastrocnemius medialis* of the dominant DLE, female football players in the EG achieved a 12% higher value in the pretest compared to the reference, but their results were at the reference level in the posttest difference was observed between the EG and CG in the NLE (p=0.001, r=0.549). No significant difference was observed in the other diagnosed muscles (*m. vastus lateralis* and *m. vastus medialis*) between the measured and reference values.

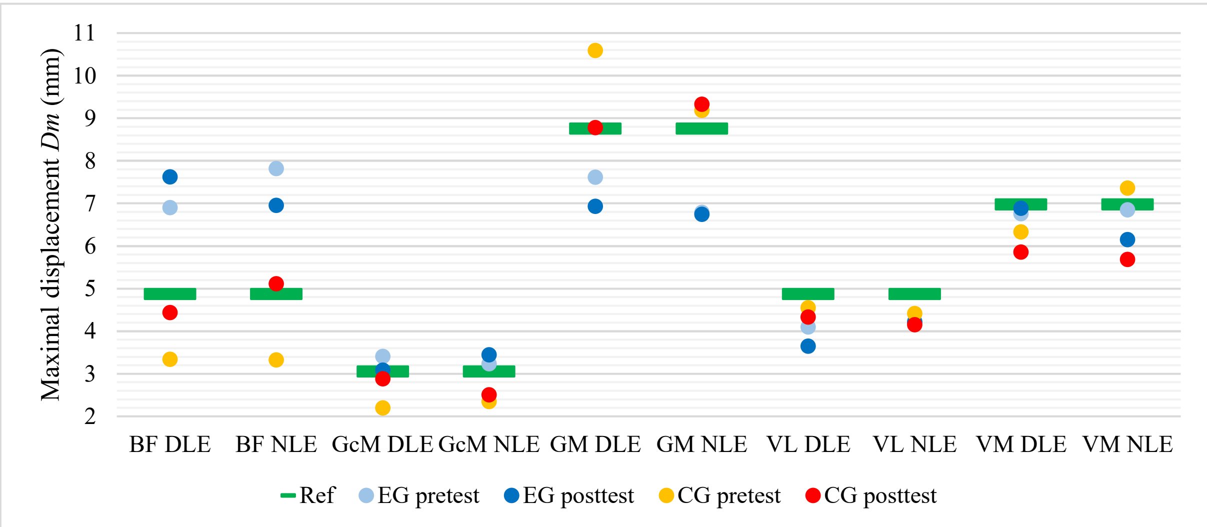

Fig. 3: The value of maximal displacement. BF—biceps femoris; GcM—gastrocnemius medialis; GM—gluteus maximus, VL—vastus lateralis; VM—vastus medialis; Ref—reference value; EG—experimental group; K—control group; mm—millimeters; DLE—dominant lower extremity; NLE—nondominant lower extremity.

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Table 2: The impact of the intervention factor on the maximal displacement Dm.

muscle		Experimental group					Control group				
		n	T	Z	p	r	n	T	Z	p	r
BF	DLE	20	103.000	0.075	0.940	0.012	16	43.000	1.293	0.196	0.215
	NLE	20	87.000	0.672	0.502	0.112	16	38.000	1.551	0.121	0.259
GcM	DLE	20	87.000	0.672	0.502	0.112	16	48.000	1.034	0.301	0.172
	NLE	20	100.000	0.187	0.852	0.031	16	56.000	0.621	0.535	0.103
GM	DLE	20	95.000	0.373	0.709	0.062	16	25.000	2.223	0.026*	0.371
	NLE	20	54.000	1.904	0.057	0.317	16	66.000	0.103	0.918	0.017
VL	DLE	20	45.000	2.240	0.025*	0.373	16	53.000	0.776	0.438	0.129
	NLE	20	96.000	0.336	0.737	0.056	16	57.000	0.569	0.569	0.095
VM	DLE	20	86.000	0.709	0.478	0.118	16	53.000	0.776	0.438	0.129
	NLE	20	50.000	2.053	0.040*	0.342	16	23.000	2.327	0.020*	0.388

BF—biceps femoris; GcM—gastrocnemius medialis; GM—gluteus maximus, VL—vastus lateralis; VM—vastus medialis; DLE—dominant lower extremity; NLE—nondominant lower extremity; n—sample size; T—value of Wilcoxn pair test; Z—value of the test criterion; p—Significance level; *—statistical significance at the level p<0.05; r—effect size.

In Table 2, we compare the effect of neuromuscular warm-up on the *Dm* value (maximal displacement). In the EG, we observed a statistically significant difference in the *m. vastus lateralis* muscle of the dominant limb (p=0.025, r=0.373) and the *m. vastus medialis* muscle of the non-dominant limb (p=0.040, r=0.342). No statistically significant changes in the *Dm* value occurred in the other muscles. In the CG, we observed a statistically significant difference in the *m. gluteus maximus* muscle of the dominant limb (p=0.026, r=0.371) and the *m. vastus medialis* muscle of the non-dominant limb (p=0.020, r=0.388).

Discussion

We incorporated neuromuscular warm-up into the preparatory phase of the training session for female soccer players in the experimental group over a period of 12 weeks during the 2023/2024 competitive season. The warm-up frequency was 2–3 times per week (lasting 15 to 20 minutes), based on the findings of authors Bizzini and Dvořák [71], who argue that applying neuromuscular warm-up twice a week is successful in injury prevention in soccer.

In our experiment, the female soccer players in the experimental group-maintained *Tc* values at the same level in both dominant and non-dominant legs in the *m. biceps femoris* through neuromuscular warm-up, but we observed higher achieved values compared to reference values. In the CG, female soccer players achieved the reference value in the pretest for the *m. biceps femoris*, but a noteworthy increase in contraction time was noted in this muscle during the posttest measurement. Our research results are inconsistent with findings of other authors [61], as the soccer players in our study achieved higher values than national team soccer players (dominant leg: 29.8 ms, non-dominant leg: 29.2 ms). However, it is noteworthy that *Tc* values decreased with increasing age. Given that the neuromuscular system is influenced by an individual's level of physical activity [74] in an exercise-dependent manner [75], it was surprising that the muscle contraction time (*Tc*) in the *m. biceps femoris* of female soccer players was similar to that of an older population scheduled for total knee arthroplasty (43.4 ms) [61], inactive adults (43.1 ms) [75], recreationally active adults (40.0 ms) [62], and endurance athletes (42.5 ms) [76] but longer compared to strength-trained athletes (14.3 ms), professional soccer players (26.3 ms) [44], soccer players before (29.1 ms) and after (24.8 ms) anterior cruciate ligament surgery [41]. The comparison of contractile properties between injured and uninjured soccer players and sprinters revealed higher *Tc* values in the injured lower limb, attributing this to the fact that injury mainly affects type II muscle fibers, indicating that higher *Tc* values activate a smaller number of type II muscle fibers in TMG diagnostics [48]. *Tc* values in the *m. gastrocnemius medialis* were the same in the experimental group as in national team soccer players (dominant leg: 22.3 ms, non-dominant leg: 22.5 ms) [53], similarly to the female soccer players in the control group. However, interestingly, the values of the control group female soccer players increased to the level of healthy non-athletic men after 35 days of rest (31.0 ms), an older population scheduled for total knee arthroplasty (31.6 ms) [61], and inactive adult men (30.0 ms) [75] in the post-test measurement. The values of the experimental group were at the level of recreational adult athletes (25.0 ms) and male soccer players (23.0 ms) [42] during both measurements.

Female soccer players in the EG achieved the same *Tc* values in both measurements in the *m. gluteus maximus* as patients before undergoing hip arthroscopy (39.64 ms). Female soccer players in the CG achieved higher values, but in the posttest diagnosis, this value decreased to the level of patients after hip arthroscopy (35.05 ms) [63]. Similar values were reported by authors who found that the *Tc* value in the injured leg in the *m. gluteus maximus* was 37 ms, while in the

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healthy leg, it was 32.9 ms [77]. These findings may predict the occurrence of femoroacetabular impingement, which primarily affects young athletes. The relationship between impairment of contractility or function of the *m. gluteus maximus* and various hip disorders has already been demonstrated [78, 79]. A decrease in *Tc* value in the *m. gluteus maximus* may indicate the presence of a certain disorder causing reduced muscle contraction speed [44, 80]. Few of the mentioned authors who addressed the issue of using TMG in soccer examined the *m. gluteus maximus*, despite its importance in knee joint control and protection [81].

In the *m. vastus lateralis*, lower contraction time results were observed in both research groups compared to soccer players (26.31 ms), whose values increased after four 4-minute immersions in cold water (4 °C) (28.69 ms). Similarly, professional soccer players [45] achieved higher contraction time values (26.1 ms) than the female soccer players in our study. Female soccer players in the study by Paravlic et al. [53] achieved the same values (dominant leg: 21.2 ms, non-dominant leg: 20.7 ms). Based on these findings, we conclude that female soccer players achieve lower contraction time values compared to male soccer players in the *m. vastus lateralis*, which may be influenced by men having significantly higher proportions of type II fibers in the *m. vastus lateralis* compared to women [82].

Both research groups of female soccer players achieved the reference value in the *m. vastus medialis* at the pretest diagnosis. Due to neuromuscular warm-up, female soccer players in the EG maintained the level of this value in the posttest diagnosis. These findings correlate with studies where female soccer players achieved similar values (dominant leg: 23.1, non-dominant leg: 23.6) [53] and with professional rugby players who achieved 23.4 ms [83]. The female soccer players in the CG showed a significant increase in *Tc* value in both lower limbs in the post-test. In the *m. vastus medialis*, similar to the *m. vastus lateralis*, we observed higher *Tc* values in healthy, non-athletic men (25.1 ms) [55], professional cyclists (dominant leg: 25.2 ms, non-dominant leg: 27.0 ms) [76] and an older population scheduled for total knee arthroplasty (29.4 ms) compared to our research group.

The *Dm* value provides information about muscle structure. An increased *Dm* value correlates well with decreased muscle stiffness [55]. Higher values indicate fatigue or the presence of pathology, such as anterior cruciate ligament injury, which may indicate that muscles are less fatigue-resistant [42]. A decrease in *Dm* value is an indicator of increased muscle stiffness [44]. Changes in *Dm* value have been shown to be the most sensitive measures of muscle fatigue [69, 84]. Maximum muscle contraction amplitude was significantly higher in the EG in the *m. biceps femoris* compared to the reference value, which may indicate a lack of muscle tone, fatigue, or the presence of various disorders. After neuromuscular warm-up, these values were at the same level and significantly higher than those of national team soccer players [53], but consistent with professional soccer players before anterior cruciate ligament surgery [41]. The CG female soccer players recorded a significant increase in *Dm* value after their training process. In the *m. gastrocnemius medialis*, we observed the same values in female soccer players in the EG in both measurements, which are at the reference value level and consistent with the values of national team soccer players (3.1 mm) [53]. The female soccer players in the CG initially showed significantly lower values, which increased in the dominant leg to the reference value level but remained at the same level in the non-dominant leg. Injured soccer players before anterior cruciate ligament surgery had higher values by 3.8 mm, but these values decreased in the healthy leg [41]. The highest *Dm* values were recorded in both research groups in the *m. gluteus maximus*. Female soccer players in the EG did not achieve the reference values in either leg in both pretest and posttest diagnoses, but these values remained at the same level. The CG female soccer players experienced a significant decrease in the dominant leg, reaching the reference value level. In the non-dominant leg, they did not achieve the reference value, but they reached the same values in both measurements, which were significantly higher than those of non-athletic men (dominant leg: 7.48, non-dominant leg: 7.32 mm) [81]. In contrast, female soccer players in both research groups had higher values than 40-year-old women and men before and after undergoing hip arthroscopy (5.50–6.32 mm) [63]. Due to neuromuscular warm-up, we found a significant decrease in *Dm* value in the EG in the *m. vastus lateralis* of the dominant leg and *m. vastus medialis* of the non-dominant leg. Female soccer players in both research groups achieved lower values in the *m. vastus lateralis* compared to national team soccer players (dominant leg: 5.3, non-dominant leg: 5.0 mm) [53]. The female soccer players in the CG achieved the same values as elite soccer players (dominant leg: 4.31, non-dominant leg: 4.12 mm) [52].

The limitation of this study included performing neuromuscular warm-up during the competitive period of the football season and conducting the warm-up only 2–3 times per week.

Conclusion

The results indicate that *Tc* (contraction time) and *Dm* (maximal displacement) are important indicators assessed using Tensiomyography (TMG). We found that neuromuscular warm-up had minimal impact on the contraction time and maximal displacement of muscles measured in this study. We can conclude that neuromuscular warm-up did not significantly affect the

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muscle contractility of the female soccer players. These findings have important clinical implications for the training and injury prevention of female soccer players.

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