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ORIGINAL SCIENTIFIC PAPER

The Effect of Neuromuscular Warm-up on Muscle Contractility of Elite Female Football Players

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Abstract

Neuromuscular warm-up positively affects motor abilities and muscle performance. The purpose of the study was to extend the knowledge about the effect of neuromuscular warm-up on the level of muscle contractility in female football players. The research sample consisted of experimental (EG, n=20) and control (CG, n=16) groups of female football players. The intervention lasted 12 weeks. The neuromuscular warm-up was implemented in the experimental group, while the control group performed a standard warm-up. Muscle contractility was assessed in dominant (DLE) and non-dominant (NDL) legs using Tensiomyograph (TMG-S2) (TMG-BMC Ltd., Ljubljana, Slovenia, 2011) with emphasis on m.biceps femoris, m.gastrocnemius medialis, m.gluteus maximus, m.vastus lateralis, and m.vastus medialis. Muscle contractility was assessed with an emphasis on contraction velocity (Vc). Wilcoxon test was used to determine significant differences. After the intervention, there was a significant improvement in the contraction velocity of m. vastus lateralis DLE (p=0.040, r=0.342) and m. vastus medialis NDL (p=0.048, r=0.330). In contrast to these findings, when the standard warm-up was applied, a significant improvement was observed in the contraction velocity of m. vastus medialis NDL (p=0.011, r=0.422). Additionally, there was a decrease in the contraction velocity of m. biceps femoris, m. gastrocnemius medialis, and m. vastus lateralis in both dominant and non-dominant legs, though the decrease was not significant. Based on the results, it is concluded that NMT warm-up significantly improved the contraction velocity in specific muscles (m. vastus lateralis DLE and m. vastus medialis NDL) in the experimental group. However, the effects on other muscles were not as pronounced, and the standard warm-up showed different results. Therefore, NMT warm-up has an impact on muscle contraction velocity, but the extent and consistency of this effect vary.

Keywords: *tensiomyography, musculoskeletal system, women´s football, contraction velocity*

Introduction

Football performance is a complex of high-level physical performance variables that depend on an individual´s health status, anthropometric and physiological properties and training (Di Salvo et al., 2007). Modern football is characterized by dynamic movements such as impulsive reactions, short and long sprints, and quick changes of direction (Dos'Santos et al., 2021). Neuromuscular abilities play a determinant role in supporting the increasingly high demands of football matches (Loturco et al., 2016).

There is a paradox in the fact that standard football preparation negatively influences a player´s neuromuscular development due to the interference effect between strength and endurance training (Loturco, Pereira, et al., 2015; Noon et al., 2015). Deficiencies in neuromuscular performance heighten the risk of injury (Lehr et al., 2017). Neuromuscular performance factors such as muscle strength in the thigh, trunk, and hip, as well as postural stability, are removable risk factors for lower limb injuries (Read et al., 2016). Injury of the anterior cruciate ligament (ACL) is the most common injury

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in football players and very often causes loss from competition. Commonly purported risk factors of ACL injury include muscular fatigue, decreased core strength, decreased relative hamstring strength, and change in muscle contraction of the hamstrings and quadriceps (Alentorn-Geli et al., 2009; Dai et al., 2012). Hamstring imbalance suggests that players have strength deficiencies that affect their performance and increase ACL injury risk (Ardern et al., 2015).

Repetitive activity consisting of high-velocity contraction movements such as sprints with changes in direction in conjunction with appropriate training methods can lead to positive neuromuscular adaptation (Rusu et al., 2013). Therefore, neuromuscular warm-up appears to be an appropriate means of injury prevention. Reduced technical-tactical training volume and appropriate neuromuscular stimuli can have a positive impact on strength abilities (Loturco, Nakamura et al., 2015; Ramírez-Campillo et al., 2016). Many studies have examined the impact of neuromuscular training on physical fitness (Dhawale, Yeole, & Kargutkar, 2020; Kowalczyk, Tomaszewski, Bartoszek, & Popieluch, 2019; Nunes, Cattuzzo, Faigenbaum, & Mortatti, 2021). The results showed that neuromuscular training positively affects balance, agility, speed, muscular strength, and muscular endurance, essential for a player´s performance (Akbar et al., 2022). Results from several studies have confirmed the efficacy of neuromuscular training to reduce the risk of lower limb injury in football players (Emery & Meeuwisse, 2010; Gilchrist et al., 2008).

However, it is unclear what is the effect of neuromuscular training on muscle contractility. There is also a lack of knowledge about muscle performance and muscle contractility properties in football players that could help prevent injuries related to asymmetry or muscle fatigue. Tensiomyography provides information about muscle stiffness, contraction velocity, and muscle fatigue and assesses the presence of peripheral and central fatigue without requiring additional voluntary effort (García-Manso et al., 2011; Rey et al., 2012). Therefore, we aimed to determine the effect of neuromuscular warm-up on the muscle contractility of lower limbs in elite female football players.

Methods

Participants

The research sample consisted of control (CG, n=16) and experimental (EG, n=20) groups. Twenty female football players from two clubs FC Spartak Myjava and ŠK Slovan Bratislava were assigned to an experimental group and sixteen female football players from 1. FC Tatran Prešov were assigned to a control group. The participation of female football players in the research was voluntary. All participants were informed beforehand about the aim of the study and the procedures to be undertaken and provided written informed consent. The somatic parameters of female football players are presented in Table 1.

Table 1. Description of the research sample

	n	Age (years)	Height (cm)	Weight (kg)	BMI (kg.m-2)	PBF (%)	FFM (kg)
EG	20	17.45±2.63	168.31±6.13	60.21±8.87	21.25±2.73	18.17±5.94	49.04±6.21
CG	16	16.24±1.09	163.84±5.58	55.91±6.87	20.80±2.10	21.89±5.30	43.48±4.63

Note. EG: experimental group; CG: control group; n: sample size; BMI: body mass index; PBF: percent body fat; FFM: fat-free mass; cm: centimeter; kg: kilogram. Data are Arithmetic mean ± Standard deviation.

All the above-mentioned football clubs play in the same league (Slovak Women's First League) comprising 10 teams. The training program was conducted during the season period and comprised 8 hours of training load and 2 hours of match load per week for both groups. The research was conducted in accordance with the Helsinki Declaration and approved by the University Ethics Committee, complying with the Ethics Committee of the University of Prešov, Prešov, Slovakia (Approval no. ECUP032022PO).

Procedures and measurement

Initial testing was carried out at the beginning of the in-season period. Body height was measured using a digital stadiometer SECA 217 (Seca GmbH & Co. KG, Hamburg, Germany). Body weight and body composition were determined by bioelectrical impedance analysis using InBody 270 (InBody Co., Ltd, Seoul, Korea).

The players´ contractile muscle properties were measured using a TMG-S2 (TMG-BMC Ltd., Ljubljana, Slovenia, 2011). Tensiomyography (TMG) is used to assess the mechanical and contractile parameters of skeletal muscles in response to electrical stimuli (Rusu et al., 2013). Various parameters can be obtained from the TMG such as contraction time (Tc), delay time (Td), and maximal radial displacement (Dm). Tc is associated with the speed of force generation, Td relates

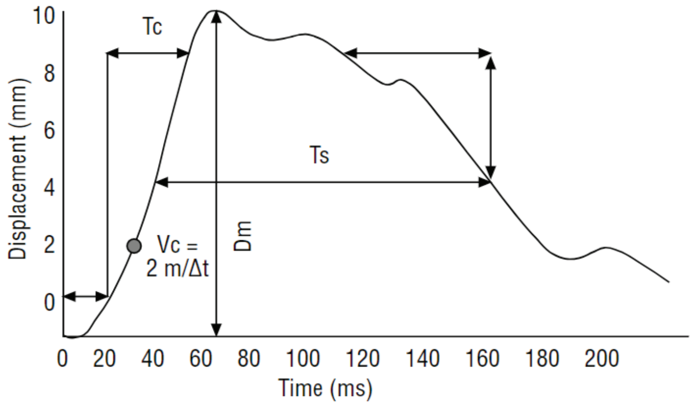

FIGURE 1. TMG parameters (Rodríguez-Matoso et al. 2012)

to the muscle fiber conduction velocity, and Dm reflects the stiffness of the muscle belly (Simunic et al., 2011). The TMG-derived measurements reveal contractile properties of individual muscles, but implementing the TMG outcomes in training sessions is difficult. A possible solution how to make the outcomes useful is to combine individual variables into a single index. In this regard, contraction velocity (Vc) can be determined by dividing maximal radial displacement by the sum of delay time and contraction time: Vc=Dm/(Td+Tc). This index provides a practical means of assessing muscle mechanical functionality. Contraction velocity can be useful for monitoring adverse effects of specific football training that could negatively impact maximum speed (Loturco et al., 2016).

Muscle contractility was assessed in dominant (DLE) and non-dominant (NDL) lower limbs with emphasis on m. biceps femoris, m. gastrocnemius medialis, m. gluteus maximus, m. vastus lateralis, and m. vastus medialis. The above-mentioned assessment procedure was repeated in the research sample after the application of a 12-week intervention program.

Intervention program

Neuromuscular warm-up (NMT warm-up) refers to a training program that includes both fundamental and sport-specific movements. The program includes a variety of activities such as resistance training, dynamic stability exercises, balance work, core strengthening, plyometrics, and agility drills (Davis et al., 2021). NMT warm-up was implemented in the experimental group for 12 weeks, twice a week (15 min each training session), from September 2023 to December 2023. The design of the intervention program was based on research by Hilska et al. (2021) who conducted research on the effectiveness of NMT warm-up intervention in the prevention of non-contact lower limb injuries.

Data analyses

The Shapiro-Wilk test was used to assess the normality of data distribution. Nonparametric methods were used because the data distribution assumptions of parametric tests were not met. Median (ME) as a measure of central tendency, and quartile deviation (QD) as a measure of variation were used. The Wilcoxon test for dependent samples was used to determine significant differences between groups with p<0.05 considered statistically significant. The “effect size” was used to assess the significance of the statistically tested differences, with effect sizes classified as small (0.1), medium (0.3), and large (0.5). Data analyses were conducted using STATISTICA software, version 13.5.0.17 (TIBCO Software Inc., Frankfurt am Main, Germany).

Results

A comprehensive description of the research sample, including descriptive statistics and the Vc values for both research groups, is presented in Table 2.

Table 2. Descriptive results of Vc value

		EG		CG	
M		Pretest	Posttest	Pretest	Posttest
BF	DLE	0.087±0.020	0.095±0.015	0.045±0.025	0.064±0.033
	NDL	0.094±0.018	0.091±0.015	0.049±0.023	0.073±0.026
GcM	DLE	0.067±0.011	0.062±0.011	0.048±0.012	0.057±0.016
	NDL	0.074±0.016	0.073±0.012	0.037±0.007	0.058±0.019
GM	DLE	0.106±0.024	0.097±0.021	0.132±0.018	0.118±0.038
	NDL	0.095±0.025	0.095±0.015	0.118±0.025	0.133±0.019
VL	DLE	0.097±0.014	0.086±0.018	0.095±0020	0.096±0.012
	NDL	0.103±0.019	0.103±0.010	0088±0.021	0.098±0.020
VM	DLE	0.153±0.027	0.149±0.018	0.144±0.015	0.124±0.021
	NDL	0.154±0.015	0.134±0.022	0.164±0.029	0.135±0.021

Note. m – muscle; BF – m.biceps femoris; GcM – m.gastrocnemius medialis; GM – m.gluteus maximus, VL – m.vastus lateralis; VM – m.vastus medialis; EG – experimental group; CG – control group; DLE – dominant lower limb; NDL – non-dominant lower limb. Data are Arithmetic mean ± Standard deviation.

The differences in contraction velocity between the control and experimental groups are presented in Table 3. After completion of the 12-week intervention, significant improvements were found in contraction velocity of m. vastus lateralis DLE (p=0.040, r=0.342) and m. vastus medialis NDL (p=0.048, r=0.330) in the experimental group. Contrary to these findings, applying the standard warm-up resulted in statistically significant improvements in contraction velocity of m. vastus medialis NDL (p=0.011, r=0.422) and a decrease in contraction velocity of m. gastrocnemius medialis, m. biceps femoris and m. vastus lateralis of dominant and non-dominant legs, although the decrease was not significant.

Table 4 presents differences between dominant and non-dominant lower limbs of participants. In experimental group, a statistically significant difference between dominant and non-dominant legs was observed in m. vastus medialis (p=0.001; r=0.647). After the intervention based on NMT warm-up, a significant difference was found between dominant and non-dominant legs in m. vastus medialis (p=0.005; r=0.467).

In control group, the initial results showed that there was a statistically significant difference between dominant and non-dominant legs in m. gastrocnemius medialis (p=0.044; r=0.336). After 12 weeks of standard warm-up, the difference between dominant and non-dominant legs in m. gastrocnemius medialis was also significant (p=0.034; r=0.353) (see Table 4).

Table 3. Result of comparison between input and output measurements

	EG					CG				
M	n	T	Z	p	r	n	T	Z	p	r
BF DLE	20	104.000	0.037	0.970	0.006	16	58.000	0.517	0.605	0.086
BF NDL	20	105.000	0.000	1.000	0.000	16	38.000	1.551	0.121	0.259
GcM DLE	20	99.000	0.224	0.823	0.037	16	43.000	1.293	0.196	0.215
GcM NDL	20	98.000	0.261	0.794	0.044	16	47.000	1.086	0.278	0.181
GM DLE	20	97.000	0.299	0.765	0.050	16	44.000	1.241	0.215	0.207
GM NDL	20	102.000	0.112	0.911	0.019	16	65.000	0.155	0.877	0.026
VL DLE	20	50.000	2.053	0.040*	0.342	16	51.000	0.879	0.379	0.147
VL NDL	20	101.000	0.149	0.881	0.025	16	65.000	0.155	0.877	0.026
VM DLE	20	81.000	0.896	0.370	0.149	16	42.000	1.344	0.179	0.224
VM NDL	20	52.000	1.979	0.048*	0.330	16	19.000	2.534	0.011*	0.422

Note. m – muscle; BF – m.biceps femoris; GcM – m.gastrocnemius medialis; GM – m.gluteus maximus, VL – m.vastus lateralis; VM – m.vastus medialis; EG – experimental group; CG – control group; DLE – dominant lower limb; NDL – non-dominant lower limb; n – sample size; T – value of Wilcoxon test; Z – standardized test statistic value; p – significance level; * - significance of p<0.05; r – effect size. Data are Arithmetic mean ± Standard deviation.

Table 4. Differences between dominant and non-dominant lower limbs

		EG					CG				
m		n	T	Z	p	r	n	T	Z	p	r
BF	Pr	20	86.000	0.709	0.478	0.118	16	66.000	0.103	0.918	0.017
	Po	20	102.000	0.112	0.911	0.019	16	40.000	1.448	0.148	0.241
GcM	Pr	20	88.000	0.635	0.526	0.106	16	29.000	2.017	0.044*	0.336
	Po	20	82.000	0.859	0.391	0.143	16	27.000	2.120	0.034*	0.353
GM	Pr	20	70.000	1.307	0.191	0.218	16	66.000	0.103	0.918	0.017
	Po	20	65.000	1.493	0.135	0,249	16	37.000	1.603	0.109	0.267
VL	Pr	20	94.000	0.411	0.681	0.068	16	60.000	0.414	0.679	0.069
	Po	20	40.000	2.427	0.015*	0.404	16	63.000	0.259	0.796	0.043
VM	Pr	20	1.000	3.883	0.001*	0.647	16	42.000	1.344	0.179	0.224
	Po	20	30.000	2.800	0.005*	0.467	16	62.000	0.310	0.756	0.052

Note. m – muscle; BF – m.biceps femoris; GcM – m.gastrocnemius medialis; GM – m.gluteus maximus, VL – m.vastus lateralis; VM – m.vastus medialis; EG – experimental group; CG – control group; DLE – dominant lower limb; NDL – non-dominant lower limb; Pr – pretest; Po – posttest; n – sample size; T – value of Wilcoxon test; Z – standardized test statistic value; p – significance level; * - significance of p<0.05; r – effect size. Data are Arithmetic mean ± Standard deviation.

Discussion

Our study revealed a decrease in muscle contraction velocity in both the dominant and non-dominant legs of female football players, which contrasts with previous studies that found no significant effect of limb laterality on muscle contraction (Gil et al., 2015; Loturco et al., 2016). This finding may suggest that lateral asymmetry can influence muscle contraction under specific conditions or in particular populations, warranting further investigation. Football players often prefer their dominant limb for activities during matches (Daneshjoo et al., 2013), which might lead to visible asymmetry in muscle contraction measurements. Our study supports the theory that bilateral asymmetry may predict injury in football players (Croisier et al., 2008) and that differences in neural responses may affect the loading of the musculoskeletal system (Brophy et al., 2010; Pedersen, Aksdal, & Stalsberg, 2019). This implies that asymmetry could have practical implications for performance and injury prevention.

Our results are at odds with the findings of Loturco et al. (2016), who reported that increases in contraction velocity (Vc) could be influenced by the type of training. De Paula Simola et al. (2016) observed an increase in Vc due to strength training, while Škof and Strojnik (2006) found that higher intensity in warm-ups enhances muscle contraction velocity. Our study indicates that there were no significant improvements in contraction velocity following the application of neuromuscular training (NMT) warm-ups, possibly due to the effects of endurance training on the training outcome.

The NMT warm-up was conducted during the competitive period of the football season, which may have influenced the athletes' performance and recovery due to the high demands and variability of competitive play. Additionally, the warm-up was performed only 2-3 times per week, which may not have been sufficient to fully capture the potential long-term effects of a more frequent or intensive NMT warm-up regimen. These factors could have impacted the effectiveness of the intervention and limited the ability to generalize the findings to different contexts or training schedules. Future studies should consider implementing a more consistent and frequent warm-up protocol and examining its effects in both pre-season and in-season phases to provide a more comprehensive understanding of its benefits and limitations.

Conclusion

The study found that a 12-week neuromuscular warm-up significantly improved contraction velocity in the m. vastus lateralis DLE and m. vastus medialis NDL in the experimental group, indicating enhanced muscle performance. In contrast, the standard warm-up in the control group improved m. vastus medialis NDL but also caused a non-significant decrease in contraction velocity in other muscles. Analysis revealed significant differences in m. vastus medialis between dominant and non-dominant limbs in the experimental group throughout the intervention, while significant differences in m. gastrocnemius medialis were observed in the control group. Based on the results, we conclude that NMT warm-up significantly improved the contraction velocity in specific muscles (m. vastus lateralis DLE and m. vastus medialis NDL) in the experimental group. However, the effects on other muscles were not as pronounced, and the standard warm-up showed different results. Therefore, NMT warm-up does have an impact on muscle contraction velocity, but the extent and consistency of this effect vary.

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Conflict of Interest

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

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