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APPLICATION OF TENSIOMYOGRAPHY TO ASSESS THE MUSCLE RESPONSE IN THE LOWER LIMBS OF ACROBATIC GYMNASTS

Mercedes Vernetta-Santana; Nicolás Rojas; Isabel Montosa; Jesús López-Bedoya

Physical Education and Sports Department. Faculty of Sport Sciences. University of Granada, Spain.

ABSTRACT

Aim: The purpose of this study was to use tensiomyography to assess the muscle response in flexion-extension of the knee joint and extension of the ankle joint in gymnasts. Methods:Eleven high-performance male acrobatic gymnasts (mean ± SD: age 20.8±3.2 years; body mass 67.0±6.8 kg, height 172.7±5.7 cm) participated in this study. The contraction time, activation time and deformation of the muscle belly were evaluated and speed of muscular response was calculated, before and after training at different intervals. An acrobatic training protocol with sets of forward tucked somersaults on a 12 x 12 m gymnastic floor was performed.Results: The results showed different states of muscle enhancement after finalizing the training protocol, with vastusmedialis, rectus femoris and biceps femoris being the most affected. Notably, vastusmedialis and gastrocnemius medialis experienced fatigue at different stages of the assessment with vastusmedialis showing a greater number of statistical significant variances in terms of loss of normalized response speed as recovery time was increased ($p \leq 0.05$; ES>0.50). Conclusion: the fatigability profile obtained in those muscle groups may help in identifying optimal recovery periods, as well as planning the training of acrobatic gymnasts according to the enhancement levels.

Key words: tensiomyography, acrobatic gymnastics, jumping capacity, plyometrics, muscle response

APLICACIÓN DE LA TENSIOMIOGRAFÍA PARA EVALUAR LA RESPUESTA MUSCULAR EN LAS EXTREMIDADES INFERIORES EN GIMNASTAS DE ACROBÁTICA

RESUMEN

El objetivo de este estudio fue utilizar la tensiomiografía para evaluar la respuesta muscular en la flexión-extensión de la articulación de la rodilla y la extensión de la articulación del tobillo en gimnastas. Métodos: Once gimnastas de acrobática masculinos de alto rendimiento (media ± DE: edad 20,8 ± 3,2 años, masa corporal 67,0 ± 6,8 kg, altura 172,7 ± 5,7 cm) participaron en este estudio. Se evaluó el tiempo de contracción, el tiempo de activación, la deformación del vientre muscular y se calculó la velocidad de la respuesta muscular, antes y después del entrenamiento a diferentes intervalos. Se realizó un protocolo de entrenamiento acrobático con series de saltos mortales hacia adelante en un practicable gimnástico homologado de 12 x 12 m. Los resultados mostraron diferentes estados de potenciación muscular después de finalizar el protocolo de entrenamiento, siendo el vasto medial, recto femoral y bíceps femoral los más afectados. Fundamentalmente, el vasto medial y gastrocnemius medial experimentaron fatiga en diferentes etapas de la evaluación mostrando el vasto medial un mayor número de varianzas estadísticamente significativas en términos de pérdida de velocidad de respuesta normalizada a medida que aumentaba el tiempo de recuperación ($p \leq 0.05$, TE> 0.50). El perfil de fatiga obtenido en esos grupos musculares puede ayudar a identificar los períodos de recuperación óptimos, así como a planificar el entrenamiento de los gimnastas de acrobática de acuerdo con los niveles de mejora.

Palabras clave: tensiomiografía, gimnasia acrobática, capacidad de salto, pliometría, respuesta muscular

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Correspondence: Isabel Montosa Mirón isabelmontosa@gmail.com
Physical Education and Sports Department. Faculty of Sport Sciences. University of Granada.
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INTRODUCTION

Jumping capacity is essential in all gymnastic sports with an acrobatic component: tumbling, trampoline, double-minitrampoline, men and women's artistic gymnastics, acrobatic gymnastics, among others. All of these are gymnastic disciplines characterized by explosive lower limb muscle contractions (Gómez-Landero, Vernetta, & López-Bedoya, 2011).

In acrobatic gymnastics, this ability is linked to successful performance in training and competition, hence the necessity for individualized and precise assessment for the principle muscle groups required Acrobatic gymnastics (AG) was included in the International Federation of Sports Acrobatics in 1973 and was recognized by the International Gymnastics Federation in 1999.

AG requires the collaboration of between two to four acrobats who perform a routine involving jumping, summersaults and human pyramids within a designated space (12 x 12 m gymnastic floor) (Floría, Gómez-Landero, & Harrison 2015). The gymnastic exercise involves combining individual and group elements synchronized to music, which is the essence of this discipline (Taboada, Vernetta & Gutiérrez-Sánchez, 2017). In competition, they can collaborate in pairs or in groups of three or four members. During group acrobatic elements there are two main roles: the base gymnasts who support others, and top gymnasts who perform flexibility, balance and combination routines on top of the base or, are propelled by their colleagues in order to perform large acrobatic jumps.

High-performance gymnasts have to undertake demanding training programs, with many hours per session and a large volume of repetitions of high intensity exercises which provoke a significant overload of certain systems and muscle groups (Grapton, Lion, Gauchard, Barrault, & Perrin, 2013; Purnell, Shirley, Nicholson, & Adams, 2010).

Gymnasts' jumping ability is often linked to successful performance (especially in floor routines and vault in artistic gymnastics) and is sometimes considered as an overall indicator of gymnastics proficiency (Mkaouer, Jemni, Amara, Chaabène & Tabka, 2013).

Studies of jumping capacity in gymnasts have been focused on the three more traditional Olympic gymnastic disciplines: men and women's artistic gymnastics and rhythmic gymnastics (Batista, Lebre & Ávila, 2016; Dalas, Zacharogiannis & Paradisis, 2013; Langer, Williford, & Olson, 2006; Marina & Jemi, 2014; Sands, McNeal, & Stone, 2009), limited in trampoline and tumbling, (Gómez-Landero et al., 2011; Grapton et al., 2013; Rojas, Vernetta & López-Bedoya, 2016) with no studies relating to AG.Considering this lack of information further study of the muscle structures specific to AG is required.

For the purpose of this study Tensiomyography was employed (TMG), a non-invasive tool which allows neuromuscular response, stiffness and mechanical characteristics to be evaluated, as well as the contractile capabilities of the superficial musculature when it is activated by a bipolar electrical stimulation of varied and controlled intensity. Among the possible parameters to assess are the radial displacement of the muscle belly (Dm), contraction time (Tc), delay time (Td), relaxation time (Tr), sustain time (Ts) (Tous-Fajardo et al., 2010), and indirectly normalised response speed (Vrn) (Rodríguez-Ruíz, et al., 2013).

Therefore, the aim of this study was to assess through TMG the neuromuscular response in high-performance male acrobatic gymnasts, analyzing the variability in contraction and delay time, radial displacement of the muscle belly and the normalised response speed responsible for flexion-extension of the knee joint and extension of the ankle joint (Rodríguez-Ruíz, et al., 2014). Moreover, to analyse the influence of the recovery time in each muscle group after the training protocol.

METHOD

Participants

Eleven male subjects who acted as the 'base' in AG participated in this study: (mean ± SD: age 20.8±3.2 years; body mass 67.0±6.8 kg, height 172.7±5.7 cm). All the gymnasts had been training for over 5 years, for an average of 3 h per day, 4-5 times per week. All of them had competed at the national and international level. None of the participants had any injury relating to the musculature of the knee or ankle joints and were free of any type of muscle or joint pain which might have prevented them performing the training protocol or affected the consequent measurements taken during the study.

All participants were fully informed of the procedures and risks involved beforehand and written consent was obtained. The study was performed according to the Declaration of Helsinki and was approved by the University of Granada ethics committee.

Procedure of measurement

For the electrical stimulation through TMG a precision sensor *TMG–S1 (Furlan& Co., Ltd.*)™, was utilized and placed perpendicular to the skin overlying the greater diameter of the muscle belly: vastuslateralis (VL), rectus femoris (RF), vastusmedialis (VM) and biceps femoris (BF), responsible for flexo-extension of the knee joint, and gastrocnemius medialis (GM), for the extension of the ankle joint. These muscle groups were selected because they are the most representative jumping capacity, as is shown with volleyball players (Rodríguez-Ruíz et al., 2014). For measurements in the supine position we used an anatomical cushion with 30º knee flexion, assuming 0º maximum joint extension, and 5º for assessment in the prone position (Rodríguez-Ruíz et al., 2014). The area was marked with a waterproof pen (Tous-Fajardo et al., 2010).

The stimulation was achieved after applying a bipolar electrical pulse with a 100 mA predefined intensity for a duration of one millisecond, with an initial pressure of the sensor displacement of 1.5 x 10^{-2} N · mm^{-2}. (Ditroilo, Smith, Fairweather, & Hunter, 2013; Rodríguez-Ruíz et al., 2013). Both electrodes were set at the proximal and distal ends of the muscle and spaced at between approximately 2 and 5 cm depending on the muscle and avoiding the tendons (García-García, Cancela-Carral, Martínez-Trigo & Serrano-Gómez, 2013). In order to prevent fatigue and post-tetanic activation in the two consecutive measurements, they were implemented with a 10 s pause between them (Rodríguez-Ruíz et al., 2013; Travnik, Djordjevic, Rozman, Hribernik, &Dahmane 2013).

TMG has proved its validity and reliability in the data collection protocol as well as in reproducibility and is considered to be a high precision tool for this type of study (Ditroilo et al., 2013; Rodríguez-Ruíz et al., 2013).

The parameters evaluated were Dm, Tc, Td and Vrn. The maximum radial deformation (Dm) evaluates the muscle stiffness, the contraction time (Tc) is obtained by determining the time between 10% to 90% of maximum radial deformation, the delay time (Td) represents the time it takes for the analysed muscle to reach 10% of its maximum radial deformation, the normalised response speed shows the relationship between the difference of the deformation between 10% to 90%, at exactly 80%, and the increase of the contraction time for those values in seconds (Rodríguez-Ruíz et al., 2012).

Training protocol

Each participant was monitored individually, with a standard warm-up of continuous running and stretching similar for all participants: 5 min of continuous running at 8 km · h^{-1} (measured by heart rate monitor Sigma Running RC 1209™), and 4 min for the predefined stretching exercises. The training protocol for floor gymnastics consisted of 12 sets of 6 repetitions of forward tucked somersaults – to standing from a raised platform at 60 cm, from a plyometric rebound. Rojas et al. (2016), established that a Drop Jump (DJ) from 60 cm produces optimal plyometric performance, due to the fact that it requires a higher degree of stiffness.

A rest period of 2 min between sets and 5 s between repetitions was implemented. The duration of the protocol was estimated to take approximately 1 h 30 min and to avoid any order effects they were performed with a week of rest between them, enough time to recover properly from this type of training, as well as two rest days after their weekly training routine.

Participants always performed the protocol in the same order and schedule (from 10 to 12 h in the morning).

The data were collected over three different days, and up to four gymnasts per day were assessed. Each subject was asked to perform the protocol every 40 min, always in the same order and at the same time, the ambient temperature was controlled between 21-22ºC.

They were evaluated by the same assessor, just at the end of the warm-up, immediately after the protocol and after rest intervals of 5, 15 and 30 min.

Statistical analyses

With the object of verifying the normality of distribution the Shapiro-Wilk test was used. An intra-class correlation coefficient (ICC) of TMG parameters was assessed using two measures for each participant, 95% confidence intervals (CIs). ICC lower than 0.5, between 0.51-0.70 and higher than 0.71 was interpreted to reflect mediocre, moderate or good reliability respectively. An analysis of repeated measures ANOVA was conducted for the data obtained from VL, RF, VM, BF and GM intra protocol, with post hoc tests using Bonferroni corrections, statistical significance was set at $p \leq 0.05$. Effect sizes (ES) (Cohen's d effect) were obtained by the formula: (μ1 − μ2) / pooled standard deviations, where μ1 and μ2 represent the mean in each condition, and the pooled standard deviations were calculated using [(SD12 + SD22)/2] (Hopkins, 2004). Cohen's d effect sizes for statistical differences were determined and pooled standard deviations were applied due to the absence of a control group. Effect sizes (ES) with values of 0.2, 0.5, and 0.8 were considered to represent small, medium, and large differences respectively. The significance level used was $p<0.05$.

RESULTS

The reliability analyses for the contractile parameters between the two preliminary measurements was good to very good for 9 of the values (0.74-0.96), moderate in 5 (0.54-0.69), and lower for Td in RF with a ICC (0.415).

Table 1 shows the descriptive values for each assessed parameter (Tc, Td, Dm, Vrn), in addition to the evaluation moments.

TABLE 1
Results of the descriptive statistics of each parameter according to muscle group and assessment time.

Muscle	Measure	Tc (ms)		Td (ms)		Dm (mm)		Vrn (mm/s)	
		x̄±SD	Min-Max	x̄±SD	Min-Max	x̄±SD	Min-Max	x̄±SD	Min-Max
VL	Pr	23.34±3.01	18.67-28.17	23.40±2.60	20.61-26.97	8.43±2.21	4.76-11.58	34.80±4.52	28.39-42.84
	P0	24.44±3.71	19.53-31.71	22.52±2.28	20.01-26.21	7.17±2.43	3.66-11.76	33.39±4.92	25.22-40.95
	R1	24.54±3.77	20.12-30.98	22.67±2.06	19.81-26.02	6.97±2.27	2.20-10.60	33.25±4.76	25.81-39.75
	R2	24.89±4.45	18.77-33.49	22.69±2.08	19.98-25.92	7.23±2.16	3.06-10.67	33.03±5.62	23.88-42.61
	R3	25.23±4.19	20.63-31.36	34.39±2.02	20.48-26.09	7.47±2.17	4.29-11.26	32.46±5.13	25.50-38.76
RF	Pr	30.25±6.73	21.53-40.30	25.12±1.68	22.71-27.64	10.00±3.17	5.44-17.14	27.58±5.70	19.84-37.15
	P0	28.69±6.53	21.91-44.25	23.08±2.00	20.30-27.56	10.08±2.21	5.26-13.84	28.95±5.30	18.07-36.50
	R1	32.15±6.33	24.86-44.98	24.26±1.86	21.96-28.73	10.05±2.39	6.05-14.83	25.68±4.57	17.78-32.17
	R2	24.53±1.37	21.75-27.14	24.53±1.37	21.75-27.14	9.64±2.95	4.82-15.41	26.08±4.22	18.24-30.56
	R3	31.97±7.52	25.44-45.89	24.47±1.56	21.61-26.60	10.44±3.20	3.82-15.31	26.16±5.37	17.42-31.43
VM	Pr	24.09±4.53	18.24-33.37	21.81±2.17	19.34-27.27	8.55±1.39	6.10-11.08	34.22±6.05	23.97-43.84
	P0	22.75±3.51	19.79-29.82	20.79±1.51	18.96-24.28	9.65±2.24	5.41-13.44	35.82±4.85	26.82-40.42
	R1	24.67±3.17	21.48-30.67	21.45±1.34	19.77-23.80	8.61±1.65	5.99-11.49	32.88±3.96	26.08-37.22
	R2	25.60±3.29	22.03-33.14	21.76±1.09	20.66-23.96	8.27±1.70	5.06-10.42	31.68±3.75	24.13-36.31
	R3	26.21±3.45	22.05-32.80	21.74±2.19	16.92-25.41	8.19±1.36	5.63-10.64	30.97±3.87	24.38-36.27
BF	Pr	36.38±12.50	25.52-66.93	23.30±1.38	21.38-25.98	9.30±2.01	6.55-12.03	23.85±6.21	11.95-31.33
	P0	34.65±12.29	21.89-63.24	22.75±1.84	20.72-25.89	8.25±1.76	5.59-10.78	25.22±6.96	12.65-36.54
	R1	36.05±13.93	23.55-68.32	23.13±2.16	21.44-26.99	8.36±2.89	5.12-15.36	24.65±7.37	11.70-33.96
	R2	37.34±14.43	20.90-62.99	23.39±2.44	20.15-28.17	8.07±2.47	5.33-13.00	24.48±9.00	12.69-38.25
	R3	33.51±9.87	23.18-52.75	23.48±2.11	20.25-27.11	8.08±2.39	5.32-13.22	25.57±6.49	15.16-34.49
GM	Pr	22.51±3.45	18.88-29.30	19.29±1.57	16.48-22.14	3.74±1.28	1.98-6.58	36.24±5.18	27.29-42.37
	P0	26.06±9.64	19.63-53.57	20.49±1.22	18.20-21.97	4.22±1.43	2.42-7.01	33.09±7.50	14.93-40.73
	R1	23.57±3.63	19.04-30.08	20.49±2.25	17.86-25.11	3.67±1.23	2.37-6.61	34.63±5.08	26.59-42.01
	R2	25.21±3.73	20.74-32.48	21.02±1.13	18.98-22.97	4.14±1.37	2.03-6.82	32.32±4.42	24.62-38.57
	R3	25.71±5.14	18.98-34.56	21.14±2.56	17.78-26.42	3.83±1.19	2.36-6.52	32.19±6.11	23.14-42.13

VL: Vastuslateralis; RF: Rectus femoris; VM: Vastusmedialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: activation time; Dm: radial displacement; Vrn: normalized response speed; Pr: pretest; P0: postest 0 min; R1: retest 5 min; R2: retest 15 min; R3: retest 30 min; x̄: average; SD: standard deviation; Mín-Max: minimun-maximun.

The comparative analysis of repeated measurements (ANOVA) prior to the detailed adjustment and relating to incremental recovery times, showed statistical significance in: VL-Dm ($F_{(4;40)=}$ 5.85; p<0.01), RF-Td ($F_{(4;40)=}$ 4.84; p<0.01), VM-Tc ($F_{(1.95;19.56)=}$ 6.12; p<0.01), VM-Dm ($F_{(4;40)=}$ 4.22; p<0.01), VM-Vrn ($F_{(1.91:19.17)=}$ 7.32; p<0.01), GM-Td ($F_{(4;40)=}$ 2.60; p≤0.05) (Table 2).

TABLE 2
Results of repeated measurements ANOVA per muscle group.

Analysis of variance for repeated measures			
Muscle	*Variables*	*F (df)*	*p*
VL	Tc (ms)	1.20 (4;40)	0.323
	Td (ms)	2.45 (1.51;15.13)	0.129
	Dm (mm)	5.85 (4;40)	0.001
	Vrn (mm/s)	0.96 (4;40)	0.436
RF	Tc (ms)	1.53 (2.0;20.0)	0.240
	Td (ms)	4.84 (4;40)	0.003
	Dm (mm)	0.57 (4;40)	0.680
	Vrn (mm/s)	2.16 (4;40)	0.090
VM	Tc (ms)	6.12 (1.95;19.56)	0.009
	Td (ms)	1.78 (4;40)	0.150
	Dm (mm)	4.22 (4;40)	0.006
	Vrn (mm/s)	7.32 (1.91:19.17)	0.005
BF	Tc (ms)	0.51 (1.57;15.76)	0.567
	Td (ms)	0.92 (4;40)	0.460
	Dm (mm)	2.46 (4;40)	0.060
	Vrn (mm/s)	0.33 (1.67;16.73)	0.680
GM	Tc (ms)	0.94 (1.64;16.41)	0.392
	Td (ms)	2.60 (4;40)	0.050
	Dm (mm)	1.50 (2.55;25.53)	0.239
	Vrn (mm/s)	1.55 (2.17;21.73)	0.234

VL: Vastuslateralis; RF: Rectus femoris; VM: Vastusmedialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: activation time; Dm: radial displacement; Vrn: normalized response speed; F (df): ratio of population variance (degrees of freedom); p: signification (p≤.05).

The post hoc adjustment showed a greater number of differences, statistical significance was found in Td for VL and VM (p<0.05). Moreover, patterns of increasing and decreasing means were noticed according to the recovery times, as evidenced in VM, significant increases in mean values and effect size (p<0.05; ES>0.50) for Tc, followed by the opposite pattern in Vrn (p<0,05; ES>0.50) (Table 3).

TABLE 3
Comparison by pairs of the factorial analysis of repeated measures per muscle group and post hoc adjustment throughBonferroni.

Analysis of variance for repeated measures					
Muscle	*Variables*	Comparison per pairs	t(df)	*p*	*ES*
VL	Tc (ms)	NS			
	Td (ms)	R2 – R3	-3.745 (10)	0.038	0.34
	Dm (mm)	NS			
	Vrn (mm/s)	NS			
RF	Tc (ms)	NS			
	Td (ms)	P0 – R1	-4.620 (10)	0.010	0.60
		P0 – R2	-3.901 (10)	0.030	0.84
	Dm (mm)	NS			
	Vrn (mm/s)	NS			
VM	Tc (ms)	P0 – R1	-4.698 (10)	0.008	0.57
		P0 – R2	-4.119 (10)	0.021	0.83
		P0 – R3	-6.009 (10)	0.001	0.99
	Td (ms)	P0 – R2	-3.996 (10)	0.025	0.73
	Dm (mm)	P0 – R3	3.967 (10)	0.027	0.78
	Vrn (mm/s)	P0 – R1	4.484 (10)	0.012	0.66
		P0 – R2	4.577 (10)	0.010	0.95
		P0 – R3	6.121 (10)	0.001	1.10
BF	Tc (ms)	NS			
	Td (ms)	NS			
	Dm (mm)	NS			
	Vrn (mm/s)	NS			
GM	Tc (ms)	NS			
	Td (ms)	Pr – R2	-4.122 (10)	0.021	1.26
	Dm (mm)	NS			
	Vrn (mm/s)	NS			

VL: Vastuslateralis; RF: Rectus femoris; VM: Vastusmedialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: activation time; Dm: radial displacement; Vrn: normalized response speed; F (df): ratio of population variance (degrees of freedom); p: signification (p≤.05).

Normalized response speed (Vrn) presented higher levels in VL, VM and GM with regard to BF and RF, both at the beginning of the assessment and in every retest, with the most pronounced disparities in VM. Comparison in the latter revealed significant differences between posttest (P0) and consecutive retests (R1, R2, R3), (p=0.012; ES=0.66), (p=0.010; ES=0.95) and (p=0.001; ES=1.10), respectively. In VM and GM a mean decrease was observed as the recovery times increased, being greater when the recovery was longer; whereas the remaining muscle groups showed a greater variability, but not lineal nor significant (Figure 1).

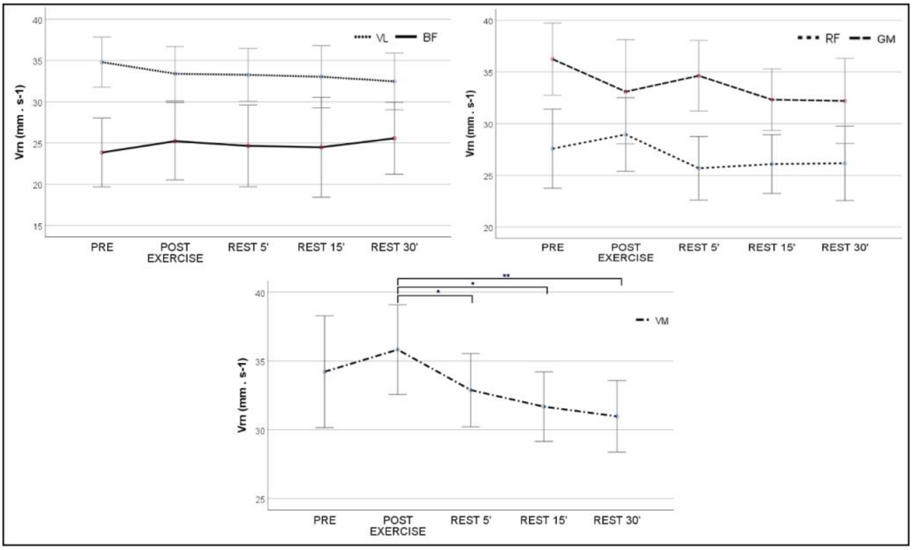

FIGURE 1: *Box-Plot of normalizad response speed (Vrn) measured in mm · s*$^{-1}$ *(Whiskers 95% of the confidence interval). VL: vastus lateralis; BF: biceps femoris; RF: rectus femoris; GM: gastrocnemius medialis; VM: vastus medialis; *: signification (p≤0.05); **: signification (p≤0.01).*

DISCUSSION AND CONCLUSIONS

The main findings of this study showed that the principal muscle groups activated just after training protocol were VM, RF and BF. No significant values were obtained in terms of the decrease between pretest-posttest for Tc and Td parameters. However, VL experienced a decrease in Td, indicating an enhancement of (23.40±2.60 to 22.52±2.28 ms), at the same time Tc increased (23.34±3.01 to 24.44±24.44 ms) indicating fatigue. Furthermore, GM showed an increase in both parameters, the only muscle group which showed initial tendency to fatigue after training.

Rodríguez-Matoso et al. (2012), pointed out that when a muscle becomes enhanced it shows lower values in Dm, Ts, Tr and a decrease in Tc; whereas a fatigued muscle (or muscle showing a deficit of mass or tone) presents higher values in Dm, Td, Ts, Tr and an increase in Tc. In other research, it was highlighted that a decrease in Td and Tc is related to actions of high tension and explosiveness (Rodríguez-Ruíz et al., 2014).

When comparing our results with other sports lower values for Tc in VL (21.06-23.35 ms) are found in soccer players when compared to the normal value of 33±4 ms and for Dm (4.92-6.57 mm), where normal values are approximately 8 mm, and normal 29 ms for Td (Rusu, et al., 2009). In a study of elite volleyball players whose jumping ability was evaluated by analysis of VL, VM, RF and BF, mean values for Dm in BF were higher than the rest, probably due to the explosive nature of the jumps (Rodríguez-Ruíz et al., 2012). Having analyzed VL, BF, VM, RF and semitendinous in high level sportsmen Rodríguez-Matoso et al., (2012), clarified that the intense and systematic practice of any sport activity is likely to produce changes in the mechanical response of the muscles subjected to the greatest workload, be it as an acute response to a competition (specific fatigue) or an inherent result of the activity itself.

With respect to the maximum radial deformation (Dm), VM, RF y GM revealed a slight increase in posttest, reestablishing the initial values after 5 min of recovery (retest 5 min). Statistical significance was found only in VM between posttest and third retest (30 min) (9.65±2.24 to 8.19±1.36 mm; p=0.027; ES=0.78). It seemed to indicate that the possible tendency to fatigue provoked by the training did not extend further than the first 5 min of recovery for these muscle groups.

In contrast, VL and BF decreased their mean values in posttest in response to actions of high tension and explosiveness and plyometrics (Rojas et al., 2016).The consecutive measurements at 5, 15 and 30 min did not reflected significant differences between them. Similarly, this parameter becomes useful when estimating the muscle fatigue states, as occurs with Tc and Td, however, if Dm increased excessively this could be a relevant indicator of muscle weakness, high level of fatigue, or an adaptive response to counter-resistance training in accordance with the literature (Rodríguez-Ruiz et al., 2012). With regard to gymnastics, stiffness plays an important role in achieving high performance for plyometric jumps (Rodríguez-Matoso et al., 2012), as can be shown through the Drop Jump (DJ) from 60 cm drop, a value that requires a higher degree of stiffness (Rojas et al., 2016).

As was mentioned at the beginning of the study, this protocol focused on the plyometric jump, predominant action in gymnastic modalities and its emphasis in training, (ideally on surfaces similar to those used in competition) results in greater stability during the execution of vertical jumps (Marina & Jemni 2014).

In consideration of the progressive rest intervals, VL, VM, BF and GM presented an increase in Tc and Td in accordance with the increased recovery time. Of particular significance were the differences found in VL-Td between retests at 15 and 30 min (22.69±2.08 to 34.39±2.02 ms; p=0.038; ES=0.34). This sudden increment could be caused by the recovery time, and it can be considered detrimental to achieving optimal jumping capacity (Pincivero, Salfetnikov, Campy, & Coelho, 2004), if recovery time is exceeded. In the case of VM, Tc was increased between posttests and each of the three retests (p<0.05; ES>0.50). GM and RF did not follow a specific pattern over the course of time with respect to Tc, even though Td increased significantly after the protocol for RF in the retests at 5 and 15 min ($p<0.05$; ES>0.50).

In this regard, one of the most interesting utilities was pointed out by Rodríguez Ruiz et al (2013), who mentioned the potential use of TMG in detecting the exact point where the fatigue process overcomes enhancement, a key point when planning training, due to the fact that short but repeated bouts of exercise generates fatigue as a parallel process to enhancement.

Generally, GM maintained low values in Dm, minor modifications after protocol, without an increase or a decrease pattern in the consecutive retests. The gastrocnemius is a distinctive muscle for jumping, considered one of the foot extensors that provokes a significant improvement in jumping capacity, because of its contribution to lifting the trunk in the last 20% of the take-off Rodríguez-Matoso et al. (2012), mentioned the relevance of determining the similarities and differences that stiffness has on the radial and longitudinal deformations of muscle, once it has been activated, because the contractile and elastic components condition the muscle stiffness and have a direct influence on the type of contraction.

Having obtained the normalized response speed (Vrn), the values in the pretest for VL, VM and GM were higher than those for RF and BF. The posttest showed an increase in the first three muscles, confirming that the training provoked a slight tendency to fatigue whereas a decrease was observed in the latter two muscles, in response to enhancement, (although not considered significant). Consecutive retests highlighted a significant decrease for VM at 5, 15 and 30 min ($p<0.05$; ES>0.50), in respect to posttest, with the greatest values recorded in the last retest (35.82±4.85 to 30.97±3.87 mm · s^{-1}; $p=0.001$; ES=1.10), which indicated the strong and causal connection between a long recovery period and the decline in the contraction capacity over time. At this point, it is worth highlighting that VM is responsible for knee joint stability (Rodríguez-Ruíz et al., 2014), which provokes rapid contractions of motion adjustment in small amplitudes in knee extension (Travnik et al., 2013). Moreover, it was emphasized that a major involvement during the jump of increased contact time and sustained isometric contraction increases the stiffness of the muscle and tendon structures, as well as muscle volume and strength (Kubo, Kanehisa, Ito, Fukunaga 2001).

In several assessments of jumping capacity with volleyball players, higher values of Vrn for VL and VM were observed in comparison to RF and BF (Rodríguez-Ruíz et al., 2012). Other studies have considered Vrn to be a relevant indicator of functional instability and to have an influence on jumping capacity, it is also related to the loss of muscle mass, the decrease in contractile elements or even a decrease in the level of muscular activity (Rodríguez-Ruíz et al., 2014).

Limitations

Caution is recommended when applying these results to different populations due to the specificity of the assessment protocol and gymnastic training. However, with the help of elite gymnasts, the current research has provided us with the initial results which serve as basis for further studies in this area, using a greater sample, different levels of performance and female population.

Tensiomyography is presented as a tool with high potential for determining the contractile capabilities of the superficial musculature, and it allows assessment of the exact point where the fatigue process overcomes enhancement, a key point when planning training.

On the basis of the results obtained, the primary muscle groups that were enhanced after the training protocol, VM, RF and BF, showed a greater activation as a consequence of the explosive actions derived from plyometric jumps. The VL was the first in experiencing signs of fatigue, as a parallel process to enhancement, where GM reached the highest levels.

With regard to radial deformation, VM, RF and GM showed a slight increase in posttest as asignal of fatigue, however, they recovered their initial values (pretest) after 5 min recovery, indicating that the tendency to fatigue in response to training did not extend beyond the first 5 min of rest. A progressive tendency of enhancement was observed in VL and BF.

The information provided by the consequent retests indicates that the training generated a progressive process of fatigue as indicated by the increase in recovery time of VL, VM, BF and GM. Nonetheless, with the exception of VL, no significant differences in recovery periods were found. This fact suggests that excessive recovery periods after training may be considered detrimental toefficient knee extension during the jump (Pincivero, et al., 2004).

Taking into account these results, as well as the type of population assessed, it is recommended to include this training at the end of the session, or if performed in the middle of a session not to exceed a recovery interval longer than 5 to 15 min between the plyometrics and the rest of exercises.

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