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Functional assessment of muscle response in lower limbs of tumbling gymnasts through tensiomyography

Evaluación funcional de la respuesta muscular de miembros inferiores en gimnastas de tumbling mediante tensiomiografía

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| Abstract |

Introduction: Jumping capacity, a distinctive technical skill of tumbling gymnasts, is associated to a successful performance in training and competition; hence the need for an individualized, precise and localized assessment of the most demanded muscle structures.

Objective: To assess muscle response of the flexo-extension structure in the knee joint and the extension of the ankle joint in a sample of 12 high-performance male gymnasts.

Materials and methods: An acrobatic training protocol including sets of forward somersault in tumbling track was conducted. The contraction time, delay time and deformation of muscle belly were evaluated, and the muscular response speed was calculated using tensiomyography before and after the training intervention in different periods of time.

Results: Significant differences were found ($p<0.05$) according to the muscle group involved, where rectus femoris and biceps femoris presented greater enhancement and shortening of the contraction and delay time. Major differences appeared between agonist-antagonist muscles (vastus lateralis-biceps femoris) ($p<0.05$) due to a decrease in the contraction and delay speed in vastus medialis ($p<0.001$).

Conclusions: Tensiomyography allows estimating the states of activation-enhancing of the musculature responsible of jumping in tumblers, as well as planning the training based on the state of muscle fatigue.

Keywords: Gymnastics; Athletes; Athlete Performance; Muscle fatigue (MeSH).

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| Resumen |

Introducción. La capacidad de salto, gesto técnico característico en gimnastas de *tumbling*, está vinculada al desempeño exitoso en entrenamiento y competición, de ahí la necesidad de una evaluación individualizada, precisa y localizada de aquellas estructuras musculares más solicitadas.

Objetivo. Evaluar la respuesta muscular de la estructura flexo-extensora de la rodilla y extensora del tobillo en una muestra de 12 gimnastas masculinos de *tumbling* de alto rendimiento.

Materiales y métodos. Se realizó un protocolo de entrenamiento acrobático con series de saltos mortales adelante en pista de *tumbling*. Se evaluaron tiempo de contracción, tiempo de activación y deformación radial del vientre muscular y se calculó la velocidad de respuesta normalizada mediante tensiomiografía antes y después de la intervención del entrenamiento.

Resultados. Se observaron diferencias significativas ($p<0.05$) según el grupo muscular implicado, siendo el recto femoral y el bíceps femoral los que presentaron mayor potenciación al reducir el tiempo de contracción y activación. Aparecieron diferencias entre musculatura agonista-antagonista —vasto lateral-bíceps femoral— ($p<0.05$), respaldadas por una disminución de la velocidad de activación y contracción en el vasto medial ($p<0.001$).

Conclusiones. La tensiomiografía permite estimar los estados de activación-potenciación de la musculatura responsable del salto en gimnastas de *tumbling*, así como planificar el entrenamiento según el estado de fatiga muscular.

Palabras Clave: Gimnasia; Atletas; Rendimiento atlético; Fatiga muscular (DeCS).

Rojas-Barrionuevo N, Vernetta-Santana M, López-Bedoya J. [Evaluación funcional de la respuesta muscular de miembros inferiores en gimnastas de *tumbling* mediante tensiomiografía]. Rev. Fac. Med. 2016;64(3):505-12. English. doi: http://dx.doi.org/10.15446/revfacmed.v64n3.54004.

Introduction

Since its appearance as a demonstration sport during the Olympic Games of Atlanta 1996 and Sydney 2000, tumbling has increased its recognition worldwide. However, taking into account the intrinsic characteristics and the set of technical, physical and conditional factors, this gymnastic modality requires a detailed study to establish its basis in relation to injury prevention (1).

High performance gymnasts are exposed to demanding training programs, a large number of hours per session and a high volume of repetition of high intensity exercises, causing overload on certain systems and muscle groups (2). The jumping capacity of a gymnast, along with successful performance in floor and jump routines, is considered as an expression of dynamic and isoinertial force, which is essential not only in sports but also in acrobatic gymnastics (3). Reviews on this capacity in aerobic gymnastics, artistic gymnastics and rhythmic gymnastics (4,3,5) have been found, but they are rare in disciplines such as trampoline and tumbling (2,6).

The analysis of injuries related to the technical requirements and distribution of training loads was observed with attention to prevent injuries in a previous study with tumbling gymnasts. This study shows a higher percentage of lesions in lower limbs (72%), presenting the ankles (30%) and knees (10%) as the most affected areas mostly by tears or sprains of moderate severity, and related to tendinous-ligamentous (44%), muscle (32%), bone (16%) and articular (8%) issues (1). These facts demonstrate the need for an individualized, precise and localized, assessment of those muscular structures more frequently required for tumbling practice.

Tensiomyography (TMG) is a non-invasive tool to assess neuromuscular response, muscle stiffness, mechanical characteristics and contractile capabilities of muscle surface, using a bipolar electrical stimulation, and controlled and variable intensity. This tool allows to measure radial displacement of muscle belly (Dm), contraction time (Tc), activation time, latency or reactivity (Td), relaxation time (Tr), contraction holding time (Ts) (7) and, indirectly, the normalized response speed (Vrn) (8).

The purpose of this study was to evaluate neuromuscular response in male elite tumbling gymnasts through TMG and, through the analysis of the time of contraction and activation, the radial displacement of muscle belly and the normalized response rate in the musculature responsible for flexo-extension of knees (9) and extending ankles (10). Likewise, an analysis of the recovery time for each muscle group after the training intervention was attempted.

Materials and methods

Sample

This study involved 12 male tumbling gymnasts with the following characteristics: age 20.6±2.6, weight 67.2±5.5kg and height 173.4±3.2cm (mean ($\bar{x}$) ± standard deviation (σ)). Participants had more than five years of experience in training, and trained for ±3 hours/day, 4-5 times a week and competed exclusively in national events.

All participants were previously informed about the potential risk of the study and signed a written consent approved by the Ethics Committee of Universidad de Granada, following the criteria set out in the Declaration of Helsinki of the World Medical Association for medical research involving human subjects.

Measurement procedure

For evaluation through TMG, a TMG-S1 accuracy sensor (Furlan & Co., Ltd.) was used and placed perpendicularly on the point with greatest muscle diameter of the muscles responsible for flexion-extension in the knee joint and the medial gastrocnemius (MG) for the extension of the ankle (11): vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM) and biceps femoris (BF). These muscle groups were selected as they are the most relevant for capacity jump (9).

An anatomical knee flexion cushion was used at 30° for evaluations in supine position, considering 0° as the maximum joint extension and 5° as flexion with pronation (9). Measuring points were noted with a dermatologic pencil (7,12) (Figure 1).

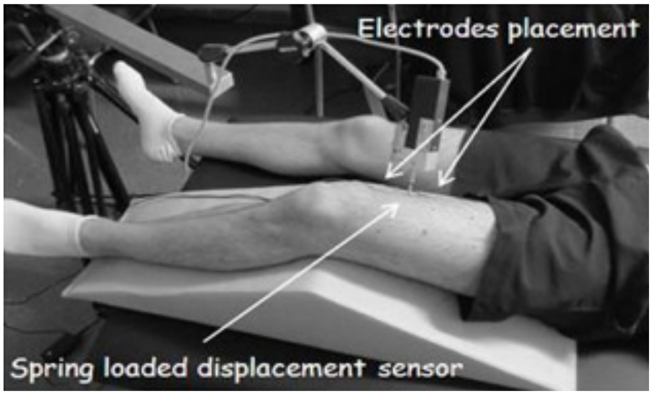

Figure 1. Placing the sensor and electrodes for measurements of the vastus medialis (VM). Source: Own elaboration based on the data obtained in the study.

To cause stimulation and consequent contraction, a bipolar electrical discharge of 100mA in one millisecond was applied with an initial plunger pressure of 1.5x10-2 N/mm-2 (8) and through two electrodes placed at the proximal and distal muscle ends, separated by 2-5cm as indicated by the sensor (13). To avoid post-tetanic activation, each stimulation was performed with sufficient pause between stimuli (8,13-15). The validity of the protocol used with TMG and the reproducibility of the method show that this is a highly accurate tool for this type of work (8).

The parameters measured were Dm, which assesses muscle stiffness; Tc, which is obtained by determining the time between 10% and 90% of the maximum radial displacement; Td, which represents the time it takes for the analyzed muscle to reach 10% of its maximum radial displacement, and Vrn, which shows the relation between the difference of displacement between 10% and 90%, exactly at 80%, and increased time of contraction for the same values in seconds (16).

Training protocol

At the beginning of the protocol, a standard warm-up and smooth running stretching was performed individually: five minutes of continuous running at 8 km/h —controlled by the Sigma Sport RC 1209® heart rate monitor— and four minutes for preset stretching exercises. The tumbling training protocol consisted of 12 sets of 6 repetitions of somersault to front landing from a raised platform with a height of 60cm through a plyometric rebound (3). Performing jumps from this height was determined following Marina (3), who pointed that the Drop Jump (DJ) from 60cm requires more stiffness from gymnasts.

An interval of two minute breaks between sets and five seconds between repetitions was established. The estimated duration of the protocol was about 1 hour and 30 minutes, which included two days off, compared to their weekly workout routine, to prevent influence of fatigue on the data. Participants were always convened at the same range of time (from 10 am to 12 m).

Three days were established to implement data collection and four subjects were individually evaluated each day; they were summoned every 40 minutes. All participants performed the same protocol under the same conditions (exercise room with a room temperature of 21-22°C).

Evaluations were performed by the same evaluator at the end of the warm-up, after the protocol and after 5, 15 and 30 minute-rest intervals as shown in Figure 2.

Statistical analysis

A Shapiro-Wilk Test was performed to verify the normality of distribution and the intraclass correlation coefficient (ICC) for TMG parameters was calculated using two measures per participant, as well as the confidence interval (CI) at 95%. As a rule, ICC below 0.5, between 0.5 and 0.7, and above 0.7 were interpreted as poor, moderate or good reliability, respectively (10). For the analysis of variance (ANOVA), repeated measures of data obtained for VM, RF, VL, BF and intra-protocol GM test were taken into account, through multiple comparison testing using the Bonferroni method and a significance level $p \leq 0.05$. The effect size (ES) (Cohen's d) was calculated through the formula: $(\mu 1- \mu 2)$/(pooled standard deviation)

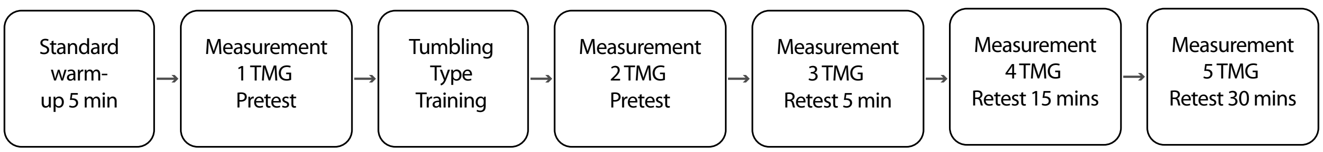

Figure 2. Tumbling measurement protocol design and rest periods between measurements. TU: tumbling; TMG: Tensiomyography. Source: Own elaboration based on the data obtained in the study.

Where $\mu 1$ and $\mu 2$ represent the mean in each condition and the pooled standard deviation was calculated using $[(\sigma 12+\sigma 22)/2]$ (17).

The effect size with values of 0.2, 0.5 and 0.8 were considered to represent small, medium or large differences, respectively (18).

Limitations of the study

The main limitations of this study are determined by a low sample size, exclusively male, so increasing the sample size and establishing the existence of sex differences is considered as useful.

When extrapolating the results the recommendation is to be cautious since these results were obtained through a specific gymnastic training protocol and a type of jump that involves only plyometrics as impulsion means. Therefore, although TMG is shown as a valid and reliable tool, it is necessary to standardize the measurement protocol to avoid possible errors when interpreting results.

Results

Descriptive statistics for each of the evaluated parameters (Tc, Td, Dm and Vrn) shown in Table 1.

Data obtained showed a good or very good reliability for 9 of the 15 values (0.74 to 0.95) and intermediate reliability the other (0.54 to 0.68), except for Td in the RF evaluation, which showed a lower ICC value (0.386) (Table 2).

To test the effects of training on muscles evaluated according to the selected parameters and the rest time, Table 3 shows the results of repeated measures ANOVA between each of the interventions of the evaluation: pretest, posttest, retest 5 minutes, retest 15 min and retest 30 min.

A greater number of significant differences ($p \leq 0.001$) was established for VM to show more variability in all parameters depending on the recovery time, followed by RF and VL ($p \leq 0.05$). By contrast, BF and GM showed less differences ($p \leq 0.05$). Comparison by pairs specifies where these significant differences are found regarding recovery time and muscle group ($p \leq 0.05$) (Table 4).

Data obtained through repeated measures ANOVA and Bonferroni post hoc adjustment for Vrn per muscle group are shown in Figure 3. The normalized response speed (Vrn) of the muscle in VL and VM are higher, followed by GM. The lowest values are found in RF and BF. Statistically significant differences ($p \leq 0.05$) are found in VL after 15 and 30 min rest, in RF at 30 min, in VM at 5, 15 and 30 min, and in BF at 15 min.

The relationship between agonist-antagonist muscle pairs was analyzed according to the time of evaluation, based on the Vrn values obtained and the consequent post hoc adjustment (Bonferroni). It should be noted that this was not a detailed and conclusive analysis of the potential existence of asymmetries or muscle instability, since determining such dysfunctionality should be done based on the muscle set in symmetry expressed as a percentage. Statistical significance between BF-VL and BF-VM ($p \leq 0.05$) muscles was obtained. No significant differences between BF-VM at 0, 5 and 30 minutes, between BF-VM at 30 minutes, nor between BF-RF were found (Table 5).

Discussion

The main findings of this study show that this training caused different tendencies to fatigue depending on the involved muscle group, being RF and BF the most enhanced muscles following the protocol based on the values obtained between pretest-posttest for Tc and Td parameters, highlighting statistical significance in RF, Tc: p=0.040, TE=0.73, td: p=0.006 and TE=0.82. On the other hand, VL, VM and GM experienced no significant changes in these parameters, but showed tendency to fatigue due to the progressive increase over time.

Thus, major differences appear between agonist (VL) and antagonist (BF) muscles, fact that is backed by a decrease in the rate of activation and contraction speed in the VM responsible for stabilizing the knee (9), muscle that causes rapid adaptation contractions to movement in small amplitudes of the knee extension (15). In parallel, the effect of a longer contact time is added during the jump causing a sustained isometric contraction that increases muscle and tendon structures stiffness, muscle volume and strength (19).

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±σ	Min-Max	x̄±σ	Min-Max	x̄± σ	Min-Max	x̄±σ	Min-Max
VL	Pr	22.94±5.15	18.14-34.00	22.11±1.90	19.04-25.95	7.38±2.34	3.86-12.68	36.31±7.18	23.52-44.08
	P0	22.89±4.35	18.12-30.76	22.29±2.57	18.80-27.90	7.19±2.17	4.14-10.77	36.04±6.37	26.00-44.13
	P1	23.79±4.53	19.16-31.53	22.88±2.34	18.75-26.24	7.04±2.13	3.94-10.47	34.67±6.11	25.36-41.74
	P2	24.95±6.51	18.00-41.22	23.30±2.32	20.92-27.23	7.22±2.10	4.16-10.60	33.72±7.18	19.40-44.44
	P3	25.27±5.66	19.84-38.67	23.37±2.55	19.58-28.47	7.12±2.51	3.41-11.19	32.87±6.06	20.68-40.32
RF	Pr	31.39±6.05	24.05-44.18	25.74±3.20	22.76-33.50	10.11±1.61	5.85-12.05	26.29±4.70	18.10-33.26
	P0	29.05±5.37	22.38-40.23	23.52±1.85	20.68-27.75	10.04±1.64	7.16-13.82	28.33±4.80	19.88-35.74
	P1	30.76±5.76	22.14-40.18	24.36±1.91	21.87-28.39	9.82±1.64	6.36-12.00	26.85±5.01	19.90-36.12
	P2	32.69±9.19	23.75-52.85	24.19±2.16	19.86-28.08	8.67±1.60	6.12-10.74	25.99±6.03	15.13-33.67
	P3	34.60±9.04	27.44-53.30	25.37±2.17	22.06-28.64	10.24±2.11	6.52-13.94	24.31±5.04	15.00-29.14
VM	Pr	22.71±2.50	19.06-27.70	21.18±1.51	18.77-23.88	9.17±1.39	7.24-11.71	35.60±3.83	28.87-41.96
	P0	23.10±3.49	19.02-27.70	20.88±1.43	18.52-23.80	10.01±1.57	8.21-14.28	35.25±4.61	25.33-42.04
	P1	25.50±4.19	20.55-34.42	21.78±1.66	19.26-24.32	8.42±1.37	6.36-11.26	32.08±4.83	23.23-38.91
VM	P2	26.63±4.79	20.42-36.28	22.36±1.75	19.72-25.86	7.98±1.97	5.68-12.53	30.84±4.96	22.04-39.17
	P3	26.29±3.85	20.15-33.45	22.66±2.31	19.97-28.35	8.63±1.85	5.87-12.39	31.00±4.44	23.91-39.17
	Pr	34.14±14.34	17.85-63.06	23.69±2.87	19.88-30.45	8.18±2.54	4.93-12.66	26.92±9.77	12.68-44.80
	P0	32.59±12.67	21.31-62.97	22.76±1.89	20.21-26.34	7.39±2.59	3.28-12.13	27.40±8.45	12.70-37.52
	P1	35.66±13.97	21.78-65.99	23.86±2.22	19.52-27.33	8.05±2.72	4.19-11.97	25.29±8.34	12.12-36.71
	P2	40.72±12.52	20.77-66.63	25.34±2.94	20.55-29.54	9.04±3.27	4.28-14.28	22.03±7.81	12.00-38.51
	P3	37.35±13.29	16.12-61.58	24.62±2.64	19.47-28.45	8.14±2.17	3.83-11.69	24.45±10.18	12.98-49.62
GM	Pr	28.43±10.64	15.74-49.80	19.89±1.65	17.57-23.03	3.95±1.12	2.09-5.63	31.27±10.75	16.06-50.81
	P0	28.43±10.26	18.47-46.60	20.69±2.33	17.85-24.38	4.35±1.02	3.31-6.21	30.98±9.53	17.14-43.29
	P1	26.86±4.84	20.94-33.03	20.95±1.49	19.04-23.27	3.85±0.92	2.49-4.94	30.64±5.65	24.21-38.19
	P2	35.57±16.67	21.86-64.94	23.11±2.96	19.55-27.99	4.75±1.79	3.25-8.25	26.16±9.47	12.31-36.59
	P3	27.67±6.16	21.07-38.43	21.71±2.15	18.23-24.15	3.83±1.01	1.75-4.52	30.07±6.20	20.81-37.95

VL: vastus lateralis; RF: rectus femoris; VM: vastus medialis; BF: biceps femoris; GM: medial gastrocnemius; Tc: contraction time; Td: activation time; Dm: radial displacement; Vrn: normalized response speed; Pr: pretest; P0: posttest 0 min; P1: posttest 5 minutes; P2: postest 15 min; P3: postest 30 min; x̄: average; σ: standard deviation; Min-Max: minimum-maximum. Source: Own elaboration based on the data obtained in the study.

Table 2. Intraclass correlation analysis in vastus lateralis, rectus femoris, vastus medialis, biceps femoris and medial gastrocnemius.

Muscle	Variables	ICC (95%)	σ	Sig
Vastus lateralis	Tc	0.818	0.366; 0.983	0.007
	Td	0.909	-0.049; 0.985	0.001
	Dm	0.952	0.848; 0.992	0.000
Femoral rectus	Tc	0.770	0.145; 0.956	0.015
	Td	0.386	0.024; 0.729	0.305
	Dm	0.945	0.911; 0.992	0.000
Vastus medialis	Tc	0.565	-0.196; 0.945	0.113
	Td	0.684	0.212; 0.939	0.042
	Dm	0.748	0.344; 0.947	0.021
Biceps femoris	Tc	0.935	0.880; 0.996	0.000
	Td	0.787	0.373; 0.993	0.012
	Dm	0.660	-0.648-0.983	0.053
Gastrocnemius muscle	Tc	0.776	-0.222; 0.971	0.014
	Td	0.575	-0.603; 0.924	0.105
	Dm	0.545	-0.242; 0.898	0.129

Tc: contraction time; Td: activation time; Dm: radial displacement; ICC: intraclass correlation coefficient; σ: standard deviation; Sig: significance ($p \leq 0.05$). Source: Own elaboration based on the data obtained in the study.

Table 3. Results of the analysis of variance for repeated measures per muscle group in Tumbling.

Muscle	Variables	F (gl) P	
VL	Tc (ms)	5.96 (1.63;17.94)	0.014
	Td (ms)	4.22 (4;44)	0.006
	Dm (mm)	0.24 (4;44)	0.911
	Vrn (mm/s)	8.38 (4;44)	0.000
RF	Tc (ms)	3.74 (2.11;23.27)	0.037
	Td (ms)	9.69 (2.01;22.14)	0.001
	Dm (mm)	3.18 (4;44)	0.022
	Vrn (mm/s)	4.62 (4;44)	0.003
VM	Tc (ms)	11.81 (4;44)	0.000
	Td (ms)	13.68 (1.83;20.22)	0.000
	Dm (mm)	9.35 (4;44)	0.000
	Vrn (mm/s)	18.41 (4;44)	0.000
BF	Tc (ms)	2.35 (1.53;16.85)	0.135
	Td (ms)	5.57 (4;44)	0.001
	Dm (mm)	2.12 (4;44)	0.094
	Vrn (mm/s)	3.20 (2.01;22.16)	0.060
GM	Tc (ms)	1.46 (1.84;11.08)	0.271
	Td (ms)	6.23 (4;44)	0.001
GM	Dm (mm)	1.43 (1.92;11.58)	0.277
	Vrn (mm/s)	1.13 (4;44)	0.365

VL: vastus lateralis; RF: rectus femoris; VM: vastus medialis; BF: biceps femoris; GM: medial gastrocnemius; Tc: contraction time; Td: activation time; Dm: radial displacement; Vrn: normalized response speed; F (gl): population variance estimate (degrees of freedom); P: significance value (p≤0.05). Source: Own elaboration based on the data obtained in the study.

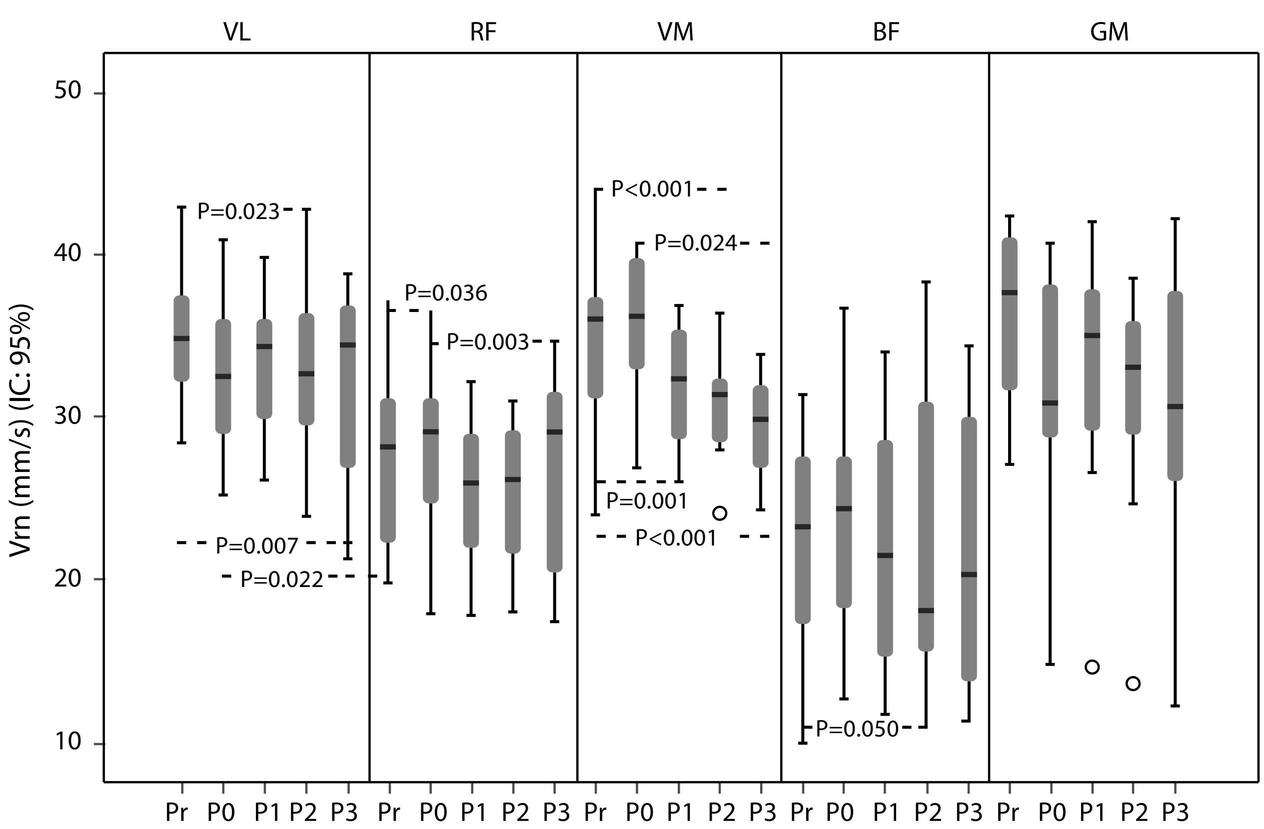

Figure 3. Box plot of normalized response speed (Vrn) in mm/s (CI:95%). VL: vastus lateralis; RF: rectus femoris; VM: vastus medialis; BF: biceps femoris; GM: medial gastrocnemius; Pr: pretest; P0: postest 0 min; P1: postest 5 min; P2: postest 15 min; P3: postest 30 min; P: significance value (p≤0.05). Source: Own elaboration based on the data obtained in the study.

Table 4. Comparison by pairs of the factorial analysis of repeated measures per muscle group in tumbling and post hoc adjustment through Bonferroni.

Muscle	Variance analysis of repeated measures				
	Variables	Comparison by pairs	t(gl) P		ES
VL	Tc (ms)	Pr-P3	-4.69(11)	0.007	0.81
	Td (ms)	Pr-P3 P0-P3	-3.73(11) -3.91(11)	0.033 0.024	0.74 0.76
	Vrn (mm/s)	Pr-P2 Pr-P3 P0-P3	3.95(11) 4.63(11) 3.95(11)	0.023 0.007 0.022	0.76 0.81 0.76
RF	Tc (ms)	Pr-P0	3.62(11)	0.040	0.73
	Td (ms)	Pr-P0 P0-P1 P0-P3 P2-P3	4.78(11) -3.96(11) -6.65(11) -3.69(11)	0.006 0.022 0.001 0.035	0.82 0.76 0.89 0.74
	Dm (mm)	P1-P2 P2-P3	4.23(11) -3.79(11)	0.014 0.030	0.78 0.75
	Vrn (mm/s)	Pr-P0 P0-P3	-3.68(11) 5.14(11)	0.036 0.003	0.74 0.84
VM	Tc (ms)	Pr-P1 Pr-P2 Pr-P3 P0-P2	-4.15(11) -4.78(11) -5.51(11) -3.93(11)	0.016 0.006 0.002 0.023	0.78 0.82 0.85 0.76
	Td (ms)	Pr-P2 P0-P1 P0-P2 P0-P3 P1-P2	-4.74(11) -4.33(11) -7.30(11) -4.26(11) -3,55(11)	0.006 0.012 0.000 0.014 0.045	0.81 0.79 0.91 0.78 0.73
	Dm (mm)	P0-P1 P0-P2 P0-P3	5.33(11) 7.01(11) 3.72(11)	0.002 0.000 0.034	0.84 0.90 0.74
	Vrn (mm/s)	Pr-P1 Pr-P2 Pr-P3 P0-P3	5.93(11) 7.21(11) 6.48(11) 3.92(11)	0.001 0.000 0.000 0.024	0.87 0.90 0.89 0.76
BF	Tc (ms) Td (ms) Vrn (mm/s) Td (ms)	Pr-P2 P0-P2 Pr-P2 P0-P2	-3.63(11) -4.47(11) 3.50(11) -4.54(11)	0.039 0.009 0.050 0.039	0.73 0.80 0.72 0.80

VL: vastus lateralis; RF: rectus femoris; VM: vastus medialis; BF: biceps femoris; GM: medial gastrocnemius; Tc: contraction time; Td: activation time; Dm: radial displacement; Pr: pretest; P0: postest 0 min; P1: postest 5 min; P2: postest 15 min; P3: postest 30 min; t (gl): t-Student (degrees of freedom); P: significance value (p≤0.05); ES: Cohen's d effect size. Source: Own elaboration based on the data obtained in the study.

Table 5. Differences between agonist and antagonist muscles through variance analysis for repeated measures and post hoc Bonferroni adjustment.

Variance analysis Functionality knee joint		VL RF VM				
		F (gl)	p	PH (p)	PH (p)	PH (p)
BF	Pretest	12.42(1.63;18.01)	0.001	0.050	1.000	0.036
	Posttest 0'	8.03(1.92;21.16)	0.003	0.041	1.000	0.090
	Posttest 5'	8.92(1.48;16.30)	0.004	0.026	1.000	0.143
	Posttest 15'	19.08(3;33)	0.000	0.001	0.453	0.006
	Posttest 30'	9.49(1.44;15.92)	0.004	0.067	1.000	0.124

VL: vastus lateralis; RF: rectus femoris; VM: vastus medialis; BF: biceps femoris; F (gl): estimate of the population variance (degrees of freedom); P: significance value (p≤0.05); PH (p): *post hoc* (significance) (p≤0.05). Source: Own elaboration based on the data obtained in the study.

As mentioned above, the protocol focused on plyometric jumping, predominant in training and competition in gymnastics (20). Marina (3) emphasizes on the high volume of plyometric jumps that gymnasts perform during their sporting life, resulting in greater stability in the implementation of vertical jumps, and suggests to perform these type of jumps preferably on elastic surfaces similar to those used in competition.

According to Rodríguez-Matoso *et al.* (23), stiffness determines motor efficiency depending on the sport; this is a quality of gymnasts for achieving high performance in plyometric jumps, and was determined through DJ from 60cm and 90cm drop (20). Since stiffness requires the first value, this is the starting height for jumps.

Contrary to experiences in VL and GM, after completing the training protocol, Td and Tc values decreased and enhancement was indicated in all muscle groups. Such decrease in Td and Tc is due to high tension and explosiveness actions (9), and workload (21).

In this regard, Šimunič *et al.* (22) emphasize that knowing the exact point where fatigue process overcomes enhancement would be crucial; this is a key aspect to plan training since a brief prolonged exercise generates fatigue as a parallel process to empowerment, first by overcoming it, and then appearing in the end. Dm seems to be affected, to a lesser extent, in the absence of significant changes, except for VM ($p<0.001$), which reaches its greatest stiffness at 15 minutes ($p<0.001$; TE=0.90) and RF ($p<0.05$), which, similarly, achieves maximum stiffness also at around 15 minutes ($p=0.014$; TE=0.78). In both cases the values decrease gradually, indicating a trend toward muscle strengthening.

It has been estimated that certain situations of fatigue or stress, as well as of enhancement, influence greatly on the parameters evaluated since, on the one hand, an enhanced muscle has low values of Dm, Ts and Tr and a decrease in Tc and, on the other, a fatigued muscle has high values of Dm, Td, Ts and Tr as well as an increasing trend towards Tc (23). However, if Dm increases excessively, this may indicate muscle weakness, high fatigue or adaptive response to resistance training according to the literature (24).

VM recovers its initial Td values after five minutes of rest ($p=0.012$; TE=0.79), while Tc indicates fatigue by progressively increasing even 30 minutes after these explosive force actions ($p=0.002$; TE=0.85) (25). Similarly, BF reestablishes these parameters within five minutes of rest ($p<0.05$), while RF needs 15 minutes for both (Tc: $p=0.039$; Td TE=0.73 and $p=0.009$; TE=0.80). VL and GM show a slight increase, but progressive, of fatigue as Td increases ($p<0.05$), while enhancement is seen through Tc, being more evident in VL ($p=0.007$; TE=0.81).

In contrast, a study on cyclical sports showed that most neural fatigue was reached during the eccentric contraction phase, with Tc recovery after 15 minutes of completion of the test (26).

Gastrocnemius, along with the soleus and plantar flexors of the foot, is one of the extensors of the foot causing significant improvement in jumping ability, as they contribute in the transmission of the lifting power to the trunk in the last 20% of the impulsion (27). In this study, low values of Dm in GM are reported, which indicates an enhanced muscle and stiffness that allows greater efficiency in the actions of an explosive nature (23).

Starting levels in the normalized response speed (Vrn) for VL, VM and GM are higher than for RF and BF, hence the significant differences found in the speed of contraction between BF-VL and BF-VM, in both cases, reaching the biggest differences within 15 minutes after completion of the protocol ($p=0.001$ and $p=0.006$, respectively). These results can be compared with those by Heredia *et al.* (28), who got a greater Vrn in the muscles of the quadriceps in the presence of a higher percentage of fast fibers, as well as higher values of VL and BF in former players. In another study with volleyball players on jumping ability, a higher Vrn was estimated for VL and VM in relation to RF and BF (16). In this manner, excessive muscle tone can generate decompensation, resulting in functional asymmetries in the flexo-extensor muscles of the knee, where these values are lower than 65% (22,23).

Upon completion of the training, VL, VM and GM values decrease gradually during the first 30 minutes, but the latter tends to restore its starting values after 15 minutes. On the contrary, a gain of Vrn for RF and BF is obtained, causing greater joint instability right before the end of the training takes place, but the initial values quickly recover after five minutes.

Several studies considered Vrn relevant as an indicator of functional instability and influence on the ability to jump (29), when estimating the loss of muscle mass and the decreased contractile elements when there is deterioration in the rate of contraction (28).

Practical applications

TMG is presented as a valuable tool for estimating the threshold at which muscle strengthening reaches levels of unwanted fatigue, so changes in training sessions designed to meet muscle deficiencies that create potential instabilities are recommended, especially in the ankle and knee joints; the latter are the main involved in the successful performance of the jump and optimal athletic performance and prevent, therefore, both lateral and functional instability. Also, implementing a longer recovery time of the muscles responsible for flexion and extension of the knee is suggested in order to prevent such instability and possible risk of injury when plyometrics are included in the same training session.

Conclusions

The major muscle groups boosted following the Tumbling track protocol (RF and BF) show greater activation and enhancement as a result of explosive actions arising from plyometric jump, even the recovery time, regarding activation and consequent contraction, is smaller and allows that fatigue does not interfere with the mentioned functional balance. Likewise, RF and BF require more time to cause neural activation and generate a stronger contraction.

Greater involvement in contraction time and contact with the surface implied an increase in the level of enhancement, which was held for the first five minutes and gradually disappeared. The decrease in the rate of contraction, as occurred between BF-VM and BF-VL, increased agonist-antagonist functional differences in the plyometric co-contraction, generating higher levels of joint instability, estimating that VL and VM are the muscle groups with the highest percentage of fast fibers and showing great involvement in this type of characteristic jump in tumbling.

Conflicts of interest

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