Original Article

Acute effect of acrobatic jumps on different elastic platforms in the muscle response evaluated through tensiomyography

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ABSTRACT

The aim of the study was to determine the changes in the muscle mechanics for the flexo-extension of the knee joint and extension of the ankle joint from a sample of 14 high-performance male gymnasts (mean ± SD: age 20.71±3.12 years; body mass 67.59±6.10 kg, height 1.73±0.05 cm). An acrobatic training protocol in three different elastic platforms: gymnastics floor, tumbling track, and trampolining, and its recovery times were compared. The contraction time, delay time, deformation of the muscle belly were evaluated and muscular response speed was calculated by Tensiomyography. The results showed different types of propensity to fatigue according to the muscle group involved ($p<0.05$). The greater the stiffness of the surface, the greater the muscle enhancement and the shorter post-effort recovery time. In trampolining fatigue level was higher in all muscle groups ($p<0.05$) and they needed more time to retrieve the baseline. The decrease of the delay and contraction time in vastus medialis ($p<0.001$) reflected the instability experienced in performing jumps when the training surface was changed from high to low elasticity in a short period of time. Tensiomyography allowed us to estimate the different levels of activation-enhancement at which the muscle reaches levels of fatigue, which enables training on different drive surfaces to be adapted and to evaluate the optimal recovery time for preventing joint instability. **Key words:** GYMNASTIC JUMPS, JUMPING CAPACITY, OVERTRAINING, MUSCLE FATIGUE.

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INTRODUCTION

High-performance gymnasts have to undertake demanding training programs, with a high number of hours per session and a large volume of repetitions of high intensity exercises which provoke a significant overload of certain systems and muscle groups. A gymnast successful performance is linked to jumping capacity, especially in floor and jumping routines. Marina, Jemni and Rodríguez (2013) consider it to be a general indicator of gymnastic ability.

In acrobatic floor exercises with the aim of improving and refining the technique, gymnasts use platforms with different elastic responses, driving and landing times, as well as a different impact on joint systems and muscle groups involved in these motor actions. In this sense, some authors have shown the connection between the floor and muscle stiffness, the kind of technical gesture performed as well as the contact time, where the mechanical work and the total mechanical power are based on both the behaviour of the sprung surface and the subject (Arampatzis, Bruggemann & Klapsing 2001; Arampatzis, Stafilidis, Morey-Klapsing & Brüggemann, 2004).

Jumping capacity as an expression of dynamic and isoinertial force results are essential in numerous gymnastic and acrobatic sports and it is common to find evaluations of this capacity in these sports specialties (López-Bedoya, Vernetta and De la Cruz, 1999; León, 2006; Polishchuk & Mosakowska, 2007; Gómez-Landero, Vernetta and López-Bedoya, 2011; Marina et al., 2013).

Tensiomyography (TMG) allows the noninvasive 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. This enables measurement to be made of the radial displacement of the muscle belly (Dm), contraction time (Tc), delay time (Td), relaxation time (Tr), sustain time (Ts), and indirectly normalised response speed (Vrn) (Burger, Valencic, Marincek & Kogovsek, 1996; Dahmane, Valencic, Knez & Erzen, 2000; Rodríguez-Matoso et al., 2010; Tous-Fajardo et al., 2010; Valencic & Knez, 1997).

Among factors influencing the muscle response are the muscle fatigue and potentiation (Krizaj, Šimunič and Zagar, 2008), as well as the recovery process, which provide the coaches with a more accurate idea about the muscle condition (Rey, Lago-Peñas and Lago-Ballesteros, 2012). Nevertheless, it should be mentioned in terms which clarify the restrictions of this method that TMG assess acute or chronic local fatigue, but it depends on the specific place where the sensor is located, and therefore, the muscular response obtained (Koren, Šimunič, Rejc, Lazzer and Pišot, 2015).

We hypothesized that the elasticity of the different training surfaces could lead to a diverse muscle response, generating different states of fatigue on the main muscle groups involved in jumping capacity. These findings may be beneficial for trampolining gymnasts, who usually have to change the training surface in a short period of time.

Therefore, the aim of this study was to assess the neuromuscular response through TMG, analyzing the contraction and delay time, radial displacement of the muscle belly and the normalised response speed responsible for flexo-extension of the knee joint (Rodríguez-Ruíz, et al., 2012a) and extension of the ankle joint (Benítez, Fernández, Montero and Romacho, 2013) and show which parameters suffered more changes depending on the contact surface: gymnastics floor, tumbling track and trampoline. The influence of recovery time was also evaluated after each jump protocol was undertaken.

METHODS

Participants

Fourteen high-performance male gymnasts participated in this study: (mean ± SD: age 20.7±3.1 years; body mass 67.5±6.1 kg; height 173±3.2 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 have competed at national level.

All participants were fully informed of the procedures and risks involved before 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

The assessment using TMG was executed using electrical stimulation with a precision sensor *TMG–S1 (Furlan & Co., Ltd.)*™, placed perpendicularly to the skin overlying the greater diameter of the muscle belly: vastus lateralis (VL), rectus femoris (RF), vastus medialis (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 in jumping capacity, as is shown with volleyball players (Rodríguez-Ruíz et al., 2014) or as a general capacity to the vertical jump (Bobbert and Van Soest, 2001). For measurements in the supine position we used an anatomical cushion with 30º knee flexion (assuming 0º maximum joint extension), and 5º for pronation assessment (Pisot et al., 2008; Rodríguez-Ruíz et al., 2014). The area was marked with a waterproof pen (García-García, Cancela-Carral, Martínez-Trigo and Serrano-Gómez, 2013; Tous-Fajardo et al., 2010) (Figure 1).

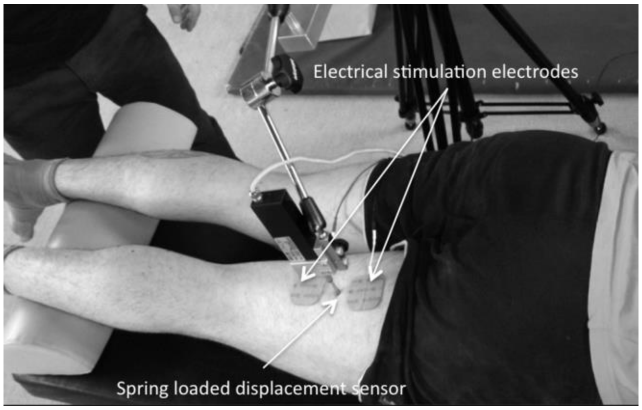

Figure 1. Sensor and electrodes placement for measurements of biceps femoris (BF). The position of the sensor tip perpendicular to the muscle belly.

To provoke the contraction, a bipolar electrical pulse with a 100mA intensity was applied for a duration of one millisecond (Heredia et al., 2011), with an initial pressure of the sensor displacement of 1.5×10^{-2} N · mm^{-2} (Dahmane, Djordjevic, Šimunič and Valencic, 2005; Ditroilo, Smith, Fairweather and Hunter, 2013), via two electrodes located at the proximal and distal ends of the muscle spaced between approximately 2 and 5 cm, depending on the muscle, half way from the sensor (not on the tendons) (García-García et al., 2013). Two consecutive measurements were implemented with 10s as the rest period between each one to avoid fatigue and post-tetanic activation (Ditroilo et al., 2013; García-García et al., 2013; Rodríguez-Ruíz et al., 2014; Travnik, Djordjevic, Rozman, Hribernik and Dahmane, 2013).

The reproducibility of this method and the validity of the TMG have been assessed in several studies (García-Manso et al., 2010; Rodríguez-Matoso et al., 2010; Rodríguez-Matoso et al., 2012), with high rates of reliability and intraclass correlation coefficient (ICC) between measurements for all variables provided by TMG (Krizaj et al., 2008; Šimunič, 2012; Benítez et al., 2013; Tous-Fajardo et al., 2010; Ditroilo 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% and the increase of the contraction time for those values (Rodríguez-Matoso et al., 2012; Rodríguez-Ruíz et al., 2012b). When a muscle becomes enhanced it shows lower values in Dm, Ts, Tr and a decrease in Tc; whereas a fatigued muscle (or due to a deficit of mass or muscle tone) presents higher values in Dm, Td, Ts, Tr and an increase in Tc (Rodríguez-Matoso et al., 2012). This approach allows estimating muscle fatigue and it can be determined when comparing the variability of these parameters between muscles and protocols.

Training Protocol

The type of training protocol was designed and repeated on the three training surfaces, whose stiffness varies from higher to lower: gymnastics floor (GF), tumbling track (TU) and the trampoline (TRA). Previously, there was a standard and individualized warm-up, similar for all participants, with 5 min of continuous running at 8 $km \cdot h^{-1}$ (measured by heart rate monitor Sigma Running RC 1209^{TM}). The training protocol consisted of 12 sets of 6 repetitions of forward tucked somersaults – to standing from a raised platform at 60 cm (Marina, 2003; Rojas, Vernetta & López-Bedoya, 2016), from a plyometric rebound, with a rest period of 2 min between sets and 5 s between repetitions. The height at which to perform all jumps was determined due to the fact that a Drop Jump (DJ) from 60 cm requires a higher degree of stiffness, such as it was indicated by (Rodríguez-Ruíz et al., 2014).

Experimental design

The design scheme is shown in Figure 2.

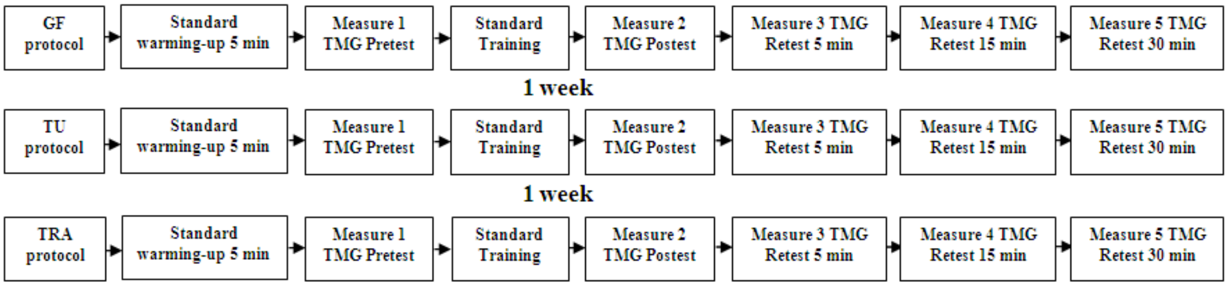

Figure 2. Design of training protocols in each surface and recovery times between measurements. GF: gymnastics floor; TU: tumbling; TRA: trampoline; TMG: Tensiomyography.

The data was collected over three different days for each participant. Similarly, the assessment was individualized to four gymnasts per day, who were called upon to perform every 40 min. Each protocol took about 1 h 30 min, and with the aim of avoiding any order effects they were administered with a week of rest between them, enough time to recover properly from this type of training, as well as two rest days off after their weekly training routine. All participants always performed the protocols in the same order, at the same time and the ambient temperature was controlled between 21-22ºC. All the participants were carefully familiarized with testing procedure before the assessment. 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

The Shapiro-Wilk test was used to verify the normality distribution. Intra-class correlation coefficient (ICC) of TMG parameters was assessed using two measures for each participant. The 95% confidence intervals (CIs) were also calculated. As a general rule, ICC lower than 0.5, between 0.5-0.7 and higher than 0.7 was interpreted to reflect poor, moderate or good reliability respectively (Benítez et al., 2013). An ANOVA of repeated measures was conducted for the data obtained from VL, RF, VM, BF and GM intra protocol, with post hoc using Bonferroni corrections, statistical significance at $p \leq 0.05$. 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 (Cohen, 1988).

RESULTS

The data obtained showed a good to very good reliability for 9 of the 15 values (0.72-0.96), and intermediate for the rest (0.54-0.69), except for the Td in RF which showed a lower value of ICC (0.415).

Table 1 shows the results of the repeated measures ANOVA, with the purpose of checking the effect of training on the parameters evaluated and establishing the differences within each protocol, based on the recovery time and the influence of the drive surface on the muscles involved.

Table 1. Results of repeated measurements ANOVA per muscle group and Protocol.

		Analysis of variance for repeated measures					
	Variables	*Gymnastics Floor*		*Tumbling*		*Trampoline*	
		F (df)	*p*	*F (df)*	*p*	*F (df)*	*p*
VL	Tc (ms)	1.42(4;52)	0.241	7.02 (1.7;22)	0.006	5.25(4;52)	0.001
	Td (ms)	2.13(2.16;28.1)	0.134	5.17 (4;52)	0.001	8.58(4;52)	0.000
	Dm (mm)	6.55(4;52)	0.000	0.39 (4;52)	0.815	1.81(4;52)	0.141
	Vrn (mm/s)	1.17(4;52)	0.335	9.06 (4;52)	0.000	5.35(4;52)	0.001
RF	Tc (ms)	1.52(2.15;27.96)	0.235	3.89 (2.12;27.60)	0.030	5.48(4;52)	0.001
	Td (ms)	5.67(2.64;34.35)	0.004	10.06 (2.27;29.60)	0.000	3.50(4;52)	0.013
	Dm (mm)	0.228(4;52)	0.922	2.79 (4;52)	0.035	1.03(4;52)	0.396
	Vrn (mm/s)	2.07(2.44;31.78)	0.134	4.53 (4;52)	0.003	4.82(2.03;26.45)	0.002
VM	Tc (ms)	10.94(4;52)	0.000	13.40 (2.58;33.53)	0.000	14.49(2.06;26.77)	0.000
	Td (ms)	2.70(4;52)	0.040	13.59 (1.98;25.76)	0.000	9.53(4;52)	0.000
	Dm (mm)	4.38(4;52)	0.004	9.18 (4;52)	0.000	4.17(4;52)	0.005
	Vrn (mm/s)	13.02(2.22;28.86)	0.000	19.96 (4;52)	0.000	21.51(2.38;30.97)	0.000
BF	Tc (ms)	0.88(2.37;30.90)	0.440	2.25 (1.75;22.72)	0.133	0.86(2.49;32.4)	0.451
	Td (ms)	1.51(4;52)	0.212	6.26 (4;52)	0.000	2.56(2.15;27.96)	0.092
	Dm (mm)	0.32(2.71;35.20)	0.788	2.19 (4;52)	0.082	0.96(2.39;31.06)	0.405
	Vrn (mm/s)	0.55(2.11;27.41)	0.592	3.17 (4;52)	0.021	1.90(4;52)	0.124
GM	Tc (ms)	1.74(1.91;24.92)	0.202	1.81 (1.86;14.91)	0.199	1.85(2.25;29.23)	0.171
	Td (ms)	4.22(4;52)	0.005	7.27 (4;32)	0.000	9.35(4;52)	0.000
	Dm (mm)	1.99(4;52)	0.110	1.65 (4;32)	0.185	0.44(4;52)	0.780
	Vrn (mm/s)	2.94(4;52)	0.029	1.89 (1.69;13.56)	0.191	5.11(1.87;24.38)	0.015

VL: Vastus lateralis; RF: Rectus femoris; VM: Vastus medialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: delay time; Dm: radial displacement; Vrn: normalized response speed; F (df): ratio of population variance (degrees of freedom); p: signification ($p \leq 0.05$).

A greater number of significant differences (p≤0.05) were established in tumbling, followed by trampolining and gymnastics floor. The VM was the muscle with the highest variability in all of its parameters and in the three surfaces depending on the recovery time, whereas BF and GM showed fewer differences. In both the tumbling and gymnastics floor, Td and Tc values concerning RF and BF showed a decrease just after training protocol (Pretest-posttest), as a result of enhancement (p≤0.05). Nevertheless, they almost recovered their initial values totally after the first 5 min of rest period (posttest-retest 5 min) for gymnastics floor (RF-Td: p= 0.041) and tumbling (RF-Td: p=0.002). On the trampoline, RF showed a decrease in Td (p=0.019) and Tc as well, whereas in BF the data revealed an increase in the signs of fatigue however these were non-significant (NS) (Table 2).

Table 2. A comparison of factor analysis of repeated measurements (ANOVA) per muscle group among recovery periods.

		Gymnastics Floor			***Tumbling***			***Trampoline***		
Mucle	Variable	Comparison per pairs	t(df)	*p*	Comparison per pairs	t(df)	*p*	Comparison per pairs	t(df)	*p*
VL	Tc			NS	Pr – P3	-4.54(13)	0.006	Pre – P3	-3.67(13)	0.028
					P0 – P3	-3.47(13)	0.041	P0 – P3	-3.87(13)	0.019
								P1 – P3	-3.88(13)	0.019
	Td	P1 – P3	-3.37(13)	0.050	Pr – P3	-4.00(13)	0.015	Pre – P3	-4.09(13)	0.013
		P2 – P3	-3.38(13)	0.049	P0 – P3	-4.04(13)	0.014	P0 – P2	-4.08(13)	0.013
								P0 – P3	-5.18(13)	0.002
								P1 – P3	-4.59(13)	0.005
	Dm			NS			NS			NS
RF	Tc			NS	P0 – P3	-3.42(13)	0.045	P0 – P2	-4.08(13)	0.013
								P1 – P2	-3.64(13)	0.030
	Td	Pr – P0	3.47(13)	0.041	Pr – P0	5.25(13)	0.002	Pre – P0	3.88(13)	0.019
		P0 – P1	-5.73(13)	0.001	P0 – P1	-4.15(13)	0.011	Pre – P1	3.71(13)	0.026
		P0 – P2	-4.89(13)	0.003	P0 – P3	-4.45(13)	0.007			
	Dm			NS	P0 – P2	3.51(13)	0.039			NS
					P1 – P2	4.03(13)	0.014			
VM	Tc	P0 – P1	-5.46(13)	0.001	Pr – P1	-4.33(13)	0.008	Pre – P2	-3.77(13)	0.023
		P0 – P2	-5.35(13)	0.001	Pr – P2	-5.03(13)	0.002	Pre – P3	-4.91(13)	0.003
		P0 – P3	-7.06(13)	0.000	Pr – P3	-6.51(13)	0.000	P0 – P2	-3.99(13)	0.015
					P0 – P2	-4.02(13)	0.014	P0 – P3	-4.48(13)	0.006
					P0 – P3	-3.42(13)	0.045			
	Td	P0 – P1	-3.53(13)	0.037	Pr – P2	-4.21(13)	0.010	Pre – P2	-3.54(13)	0.036
		P0 – P2	-4.51(13)	0.006	P0 – P1	-4.72(13)	0.004	Pre – P3	-4.20(13)	0.010
					P0 – P2	-7.86(13)	0.000	P0 – P2	-4.01(13)	0.015
					P0 – P3	-4.33(13)	0.008	P0 – P3	-3.88(13)	0.019
					P1 – P2	-3.95(13)	0.017	P1 – P3	-3.59(13)	0.033
	Dm	P0 – P1	3.38(13)	0.049	Pr – P0	-3.69(13)	0.027	P0 – P1	4.12(13)	0.012
		P0 – P3	4.10(13)	0.013	P0 – P1	6.00(13)	0.000	P0 – P2	4.04(13)	0.014
					P0 – P2	6.26(13)	0.000	P0 – P3	3.72(13)	0.026
					P0 – P3	3.65(13)	0.029			
BF	Tc			NS	Pr – P2	-3.57(13)	0.034			NS
	Td			NS	P0 – P2	-4.61(13)	0.005			NS
	Dm			NS			NS			NS
GM	Tc			NS			NS			NS
	Td	Pr – P2	-4.44(13)	0.007	Pr – P2	-3.98(8)	0.040	Pre – P1	-3.86(13)	0.019
					P0 – P2	-4.24(8)	0.028	Pre – P2	-5.46(13)	0.001
								Pre – P3	-4.90(13)	0.003
								P0 – P3	-4.40(13)	0.007
	Dm			NS			NS			NS

VL: Vastus lateralis; RF: Rectus femoris; VM: Vastus medialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: delay time; Dm: radial displacement; Pre: pretest; P0: postest 0 min; P1: postest 5 min; P2: postest 15 min; P3: postest 30 min; t (df): Student t-test (degrees of freedom); NS: non-significant; p: signification (p≤0.05).

This table also illustrates significant differences in Dm for VM, after training in fatigue response (p=0.027), and a decrease just 5 min after (posttest) (p<0.001).

The following data is shown only for the VM by repeated measures ANOVA, Bonferroni post hoc and comparison between tests for each protocol (Figure 3).

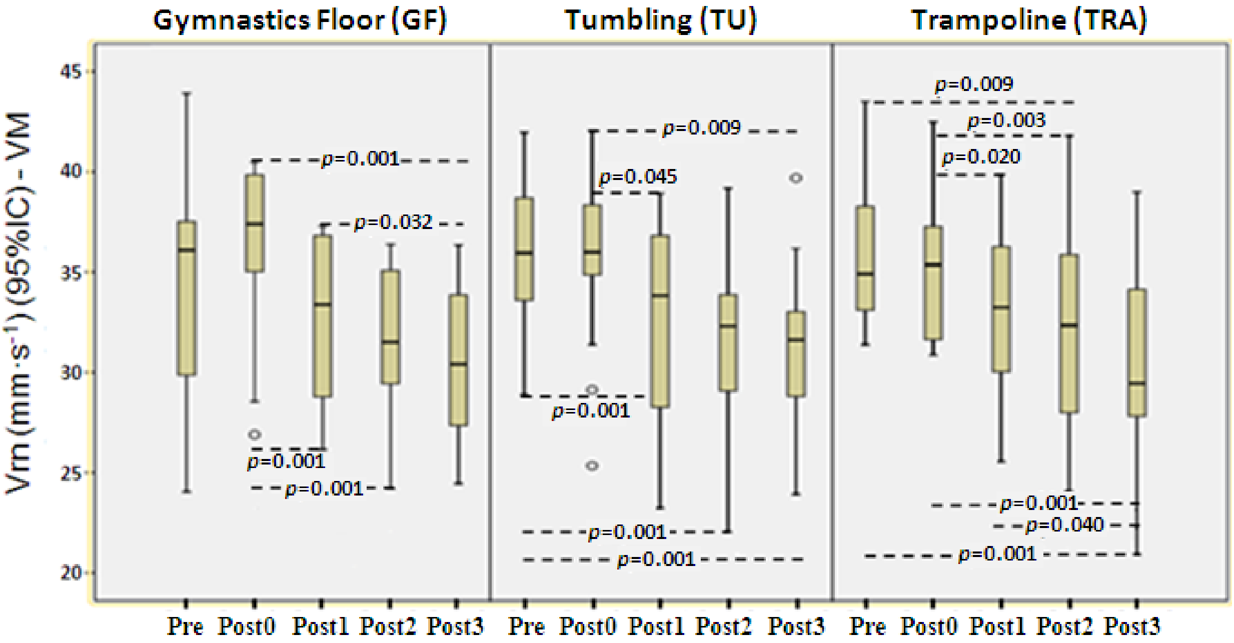

Figure 3. Box-Plot of normalized response speed (Vrn) in mm · s^{-1} (95% of the confidence interval) in vastus medialis (VM). Pre : pretest; Post0: postest 0 min; Post1: postest 5 min; Post2: postest 15 min; Post3: postest 30 min; *p*: signification ($p \leq 0.05$).

Initially, muscle response speed values (Vrn) were higher in VL and VM in the three trainings followed by GM, RF and BF being those which start from the lowest values (Table 3). Statistically significant differences (p≤0.05) appeared in VL-TU after rest periods of 15 and 30 min, VL-TRA after 30 min; RF-TU at 30 min and RF-TRA at 15 min; VM after 5, 15 and 30 min in the three protocols; BF-TU at 15 min; GM at 15 min in the three protocols.

In the comparison between surfaces, few significant differences were found, with few relations after post hoc Bonferroni adjustments (Table 4). Statistical significance was found only in Td for VL between GF and TRA (at 15 min retest) (p=0.022), Tc for BF between TU and TRA (posttest) (p=0.035), and Vrn for BF between TU and TRA (posttest) (p=0.030).

Table 3. Descriptive values for normalized response speed (Vrn), measured in millimeters per second. Mean and standard deviation for each protocol.

Muscle	Measures	Vrn (mm/s)		
		GF	TU	TRA
Group		x̄±SD	x̄±SD	x̄±SD
VL	Pretest	34.66±4.01	36.21±6.65	34.07±3.59
	Postest 0’	33.07±4.49	36.08±5.88	34.34±4.40
	Postest 5’	33.43±4.26	34.57±5.77	34.49±5.02
	Postest 15’	32.93±4.93	33.63±6.90	32.21±3.13
	Postest 30’	32.64±4.63	33.03±5.88	31.13±3.52
RF	Pretest	27.49±5.13	26.54±4.40	26.62±4.76
	Postest 0’	28.52±4.94	28.27±4.53	26.78±4.13
	Postest 5’	25.77±4.20	26.77±4.70	26.88±3.73
	Postest 15’	25.99±4.23	26.05±5.64	24.89±3.95
	Postest 30’	26.96±5.54	24.71±5.03	24.58±4.22
VM	Pretest	34.69±5.40	36.04±3.79	35.90±3.55
	Postest 0’	36.06±4.39	35.38±4.26	35.05±3.46
	Postest 5’	32.79±3.86	32.58±4.65	33.06±4.47
	Postest 15’	31.58±3.37	31.32±4.77	31.92±5.43
	Postest 30’	30.49±3.61	31.25±4.20	30.24±5.21
BF	Pretest	23.04±6.71	27.57±9.16	25.21±9.35
	Postest 0’	24.57±6.80	28.29±8.20	23.65±9.33
	Postest 5’	23.27±7.69	24.91±8.06	22.63±8.65
	Postest 15’	22.19±9.27	23.19±7.83	22.75±8.03
	Postest 30’	22.67±8.10	25.24±9.64	22.22±8.50
GM	Pretest	35.88±5.38	32.75±9.80	33.52±7.56
	Postest 0’	32.10±7.20	31.75±8.63	33.18±6.01
	Postest 5’	33.47±7.04	31.35±5.34	31.62±6.48
	Postest 15’	31.09±6.35	27.18±8.75	29.73±6.07
	Postest 30’	31.00±7.75	30.90±6.47	28.94±4.86

GF: gymnastics floor; TU: tumbling; TRA: trampoline; VL: Vastus lateralis; RF: Rectus femoris; VM: Vastus medialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Vrn: normalized response speed.

Table 4. Results of repeated measurements ANOVA between protocols and post hoc Bonferroni adjustments.

Analysis of variance for repeated measures between protocols						
		Test comparison			Comparison per pairs	
Muscle	*Variables*	*Test*	*F (df)*	*p*	*Protocols (p)*	*ES*
VL	Td (ms)	Postest 2	2.40(1.39;18.19)	0.130	GF-TRA (.022)	0.66
	Vrn (mm/s)	Postest 0	3.20(2;26)	0.057	NS	
RF	Td (ms)	Postest 0	4.57(2;26)	0.020	GF-TRA (.066)	0.58
	Dm (mm)	Postest 0	3.14(2;26)	0.060	NS	
		Postest 2	4.47(2;26)	0.021	NS	
VM				NS	NS	
BF	Tc (ms)	Postest 0	2.76(2;26)	0.082	TU-TRA (.035)	0.63
		Postest 3	2.07(1.40;18.31)	0.146	GF-TU (.058)	0.59
	Td (ms)	Postest 2	3.13(2;26)	0.060	NS	
	Dm (mm)	Postest 0	2.87(2;26)	0.075	NS	
	Vrn (mm/s)	Postest 0	4.39(2;26)	0.023	TU-TRA (.030)	0.64
					GF-TU (.083)	0.56
GM	Dm (mm)	Pretest	2.87(2;16)	0.086	GF-TRA (.061)	0.41

VL: Vastus lateralis; RF: Rectus femoris; VM: Vastus medialis; BF: Biceps femoris; GM: Gastrocnemius medialis; Tc: contraction time; Td: delay time; Dm: radial displacement; Vrn: normalized response speed; F (gl): ratio of population variance (degrees of freedom); p: signification (p≤0.05); GF: gymnastics floor; TU: tumbling; TRA: trampoline; NS: non-significant; ES: Cohen’s d effect size.

DISCUSSION AND CONCLUSIONS

The main findings showed that training on these surfaces induced different levels of propensity to fatigue according to the muscle group involved, although it cannot be specified the exact degree of fatigue reached between them. These results support our hypothesis that the muscle response varies in a different way according to the surface used, a fact that should be taken into account when gymnasts change those surfaces in a short period of time.

The greater the stiffness of the surface, the greater was the muscle enhancement for RF and BF, according to the decrease obtained in pretest – posttest for Tc and Td parameters. In TRA surface, fatigue levels were higher in VM and BF, as well as the time needed to recover their initial values. The decrease in the contraction and delay speed in VM as responsible for the joint stability may explain the instability experienced in performing jumps when the training surface is changed from high to low elasticity in a short period of time in the same routine.

This study focused on the plyometric jump, because it is the predominant action in training and competition. Marina (2003) highlights the raised volume of plyometric jumps that gymnasts perform throughout their sporting life, resulting in greater instability during the execution of vertical jumps. Moreover, he suggests that it should be preferably practiced on elastic surfaces with a similar component to competition.

According to Rodríguez-Matoso et al. (2012), stiffness determines the motor efficiency depending on the sport modality and this is considered a quality of gymnasts in achieving high performance for plyometric jumps, as can be shown through the Drop Jump (DJ) from 60 cm drop, a value that requires greater stiffness (Marina, 2003; Marina et al., 2013), including from 90cm (Seegmiller & McCaw, 2003). As a result of this we decided to start with this standard jump height of 60 cm for all three protocols.

After finalizing the protocol on the gymnastics floor the values of Td and Tc, previously mentioned as predictors of fatigue, decreased, indicating the enhancement effect in RF (p=0.041), VM and BF. In VM the values in Tc decreased indicating a tendency to fatigue, whilst GM experienced an increase for the same values as well as in Dm, a sign of tendency to fatigue, reaching the major differences after 5 min of recovery (p=0.007).

Krizaj et al. (2008), highlighted that Dm is one of the most influenced parameters of fatigue, such as the best measure of the fatigue rate. In this study it was found the major variability in Dm for VL (p=0.001) and VM (p=0.004) was when their values decreased, but no significant differences were found in the post hoc analysis. Such variability was due to the actions of high tension and explosiveness (Rodríguez-Ruíz et al. 2012a), and consequently due to the workload (García-Manso et al., 2012). In cyclical sports, the major neural fatigue occurs during the eccentric phase of the contraction, with Tc not having recovered 15 min after the performance (García-Manso et al., 2011); while the lowest values in Tc for BF and VL were recorded in jumpers and sprinters (Šimunič, Pisot & Rittweger, 2009).

Gastrocnemius, linked to soleus and foot plantar flexors, is one of the foot extensors that provoke a significant improvement in jumping capacity, because of its contribution in the transmission of the power lifting the trunk in the last 20% during the take-off (Pandy & Zajac, 1991). In our study low values for Dm in GM are presented, which indicates high stiffness and strengthened musculature, a beneficial result in achieving greater efficiency in explosive actions such as the jump (Rodríguez-Matoso et al., 2012).

With regard to the protocol in tumbling, the levels of activation were similar to those obtained in the previous surface, whereas RF, VM and BF were enhanced ($p<0.05$) with Tc, Td and Dm values getting lower. In the same way, Šimunič, Rozman and Pisot (2005), pointed out that it is crucial to know the exact point where the fatigue process overcomes enhancement, a key point when planning training, due to the fact that short but prolonged exercise generates fatigue as a parallel process to enhancement. Dm seems to be affected to a lesser extent, with no significant changes, except for VM ($p=0.027$) where the values decreased progressively after 5 min of recovery, indicating muscle strengthening. The VM and BF recovered their initial values for Tc and Td after 5 min of rest ($p<0.05$); while RF needed 15 min for Tc and 30 min for Td ($p=0.007$). The VL did not experience significant changes just after training for Td, Tc or Dm, and GM showed a slight although progressive increase in fatigue, being more noticeable after 15 min recovery ($p=0.040$).

On the third surfaceTd and Tc only decreased slightly for VL and RF at the end of training, as the main muscle groups enhanced, and they required around 15 min to recover their initial values completely. These findings suggest that training on a surface of greater elasticity requires a longer recovery time to achieve an efficient knee extension, due to the fact that VL is involved in the extension mechanism (Rodríguez-Ruíz et al., 2014). Values associated with Tc and Td increased progressively in VM and BF from the end of the protocol, but no significant differences were detected in this process of a tendency to fatigue. Being responsible for stabilizing the knee, VM provokes rapid contractions of motion adjustment in small amplitudes in knee extension (Rodríguez-Ruíz et al., 2014). Furthermore, Kubo, Kanehisa, Ito and Fukunaga (2001), 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. In general, Dm increased in all muscles after the protocol in response to fatigue, highlighting the significant differences exclusively for VM between each recovery period ($p<0.05$), retrieving their initial values after 5 min.

The starting level in the normalized response speed (Vrn) for VL, VM and GM were higher in all three protocols compared to RF and BF. Such results can be compared with those extracted from Valencic and Knez, (1997), where they obtain greater Vrn in the quadriceps muscle due to the fact that they presented a higher percentage of fast fibres, and higher values in VL and BF in an ex-football player (Heredia et al., 2011). Two other studies with professional volleyball players related to jump capacity estimated higher VL and VM compared to RF and BF (Rodríguez-Ruíz et al., 2012b). In this line, excessive muscle tone can generate decompensation, resulting in functional asymmetries in flexo-extensor muscles of the knee, when these values are less than 65% (Rodríguez-Matoso et al., 2012; Rusu, Calina, Avramescu, Paun & Vasilescu, 2009; Šimunič et al., 2005).

After finalizing training, VL, VM and GM decreased their values and Vrn increased for RF and BF in TU, similar to the pattern observed in GF, whereas VM also increased modestly. This loss of response speed is related with the loss of muscle mass, the decrease in contractile elements or due to a decrease in the level of muscular activity (Heredia et al., 2011), which leads us to hypothesize that these muscles were the most fatigued when the training surface was less elastic. For TRA values decreased significantly for the VM at 5 min (33.06 ± 4.47 mm · s^{-1}; $p=0.020$), 15 min (31.92 ± 5.43 mm · s^{-1}; $p=0.003$) and 30 min (30.24 ± 5.21 mm · s^{-1}; $p<0.001$), GM at 15 min (29.73 ± 6.07 mm · s^{-1}; $p<0.05$) and BF on finishing the protocol, to continue progressively decreasing in the retests. Additionally, Vrn is a relevant indicator of functional instability and has an influence on jumping capacity (Rodríguez-Ruíz, Rodríguez-Matoso, Quiroga, Sarmiento and Da Silva-Grigoletto, 2011).

When analyzing the discrepancies between protocols, significant differences were found in GF and TRA, in Td-VL ($p=0.022$; ES=0.66), and TU relative to TRA for Tc-BF ($p<0.035$; ES=0.63) and Vrn-BF ($p<0.03$; ES=0.64). The increase of Td in VL at 15 min indicated that not only was the fatigue level generated slightly higher in TRA relative to GF, but also remained so for longer. Marked differences in Tc from BF between TU and TRA (31.36 ± 12.10 mm · s^{-1} and 39.49 ± 16.23 mm · s^{-1} respectively) in posttest, suggest greater potentiation when the training surface is more elastic and the contact time is longer.

In conclusion, this study reports that the greater the stiffness of the training surface, the greater is the muscle enhancement for rectus femoris and biceps femoris, as it happened on the gymnastic and tumbling floors; whereas on the trampoline, fatigue levels were higher in vastus medialis and biceps femoris, as well as the time needed to recover their initial values.

These differences in the recovery times may explain the instability experienced in performing jumps when the training surface is changed from high to low elasticity in a short period of time for the same routine.

All of those changes could well support our hypothesis that the muscle response varies in a different way according to the surface used, a fact that should be taken into account when gymnasts change those surfaces in a short period of time.

APPLICATIONS OF THE STUDY

TMG is presented as a valuable tool to estimate the activation-enhancement states at which muscle potentiation reaches undesired levels of fatigue from overuse or overtraining (Šimunič et al., 2005). At a practical level, it is recommended to modify the sequence in the planning of training with gymnasts who make use of different contact surfaces, always starting with the lowest elasticity. On the contrary, they should respect a longer recovery time of the musculature responsible for flexo-extension of the knee joint in order to avoid joint instability and to achieve an optimum performance in jumping capacity.

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