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The importance of functional diagnostics in preventing and rehabilitating gymnast injuries with the assistance of the tensiomyography (TMG) method: A case study

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Background: The tensiomyography assessment offers information, in the time domain, regarding the following parameters: maximal radial deformation or displacement of the muscle belly, contraction time, reaction time, sustain time and relaxation time. The aim of this study is to provide information about muscle stiffness, the mechanic and contractile properties using the TMG muscles after 4 months rehabilitation process gymnast. Material/Methods: Four muscles were chosen on both lateral sides involved in artistic gymnastics performance: biceps femoris, erector spinae, gluteus maximus, rectus femoris. The testing sample in this study was taken from the Croatian Republic's senior representative who won third place 2012 and eighth place 2015 in the floor routine at the ECh. Results: The testing and measuring took place after the subject injured the lumbar region of the spinal cord and after a four-month prevention exercise program. After the first two stages of measuring, the differences can be found in: BF: -7%; ES: +17%; GM: -8%; RF: +11%. Generally speaking, a dependent t-test did not reveal significant differences in between the first and second measurement point ($t = 1.941$, $df = 39$, $P < 0.059$). Conclusions: This approach can be used to investigate top athletes who are in the process of training for muscle recovery as a result of skeletal muscle injury.

Keywords

skeletal muscle, contraction time, lateral symmetry, tensiomyography, men's artistic gymnastics, muscle injury

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INTRODUCTION

The tensiomyography method, or in short TMG, was invented in 1983 by a group of experts from various fields at the Faculty for Electrical Engineering in Ljubljana (Slovenia), in cooperation with many institutions which were the method's early users and implementers [1]. The method has been improved since then through many prototypes and developed to the stage when commercial application of the method was possible. Although it was initially intended for medical use, the TMG method was also introduced in sports in 1996. The method was introduced by Professor Vojko Valenčič [2] and evaluated with histochemical results [3, 4], muscle force and torque [5] and EMG [6]. Skeletal muscles' velocity of the contraction is beside muscle force another very important parameter and speaks about the quality of the muscle tissue. As such it is very difficult to detect because of the subjective standardization of the measurement protocol and muscle specifics that could affect the results. To avoid those impediments, a new TMG methodology has been developed and evaluated during the last few years [7].

TMG is a non-invasive method for measuring the contractile properties of skeletal muscles. It requires no effort on the part of the subject being assessed and provides rapid, accurate information, without disrupting the daily working lives of sportsmen and women. It is used to assess muscle contraction characteristics and the contractile capacity of the superficial muscles [8, 9, 10, 11]. TMG measures geometrical changes (radial enlargement) taking place in the muscle belly during isometric contraction in response to an electrical stimulus. The assessment is made using a pressure sensor connected to a high-precision digital displacement transducer placed perpendicular to the muscle belly. The muscle is stimulated with single twitch stimulus (pulse of 1-ms duration) using two self-adhesive electrodes (2–5 cm apart) placed symmetrically to the sensor, in such a way so as not to affect the tendons [12].

The contractile properties of muscles are measured with a digital radial displacement sensor. The sensor converts physical displacement to electric impulses. These are then transported through a cable to a device that adds up the impulses and sends them to a computer with a 1 kHz frequency. The sensor response is linear with negligible noise. The dynamic response of the sensor is also very high, allowing us to distinguish differences in reaction between the fast and the slow muscle fibres. The mechanical sensor components are of the highest quality. The pressure and the resistance of the displacement rod, when placed on the muscle, does not significantly restrain the movement of the muscle.

A special sensor is placed on the muscle we wish to measure – the sensor is designed to register the muscle contraction. The muscle contraction is induced artificially with an electro stimulator, and consequently its middle part (muscle belly) enlarges. With a displacement sensor the radial enlargement of the muscle belly is measured. During measurement, the displacement sensor is pressed to the skin above the measured muscle belly radial to the muscle surface. Measuring results are presented as time/displacement curves. The newly developed report is able to provide an immediate reflection of the results obtained during the test. This report designates: optimal 90-100%, average 80-89% (monitor), and poor (concern) <80% muscle responses and muscle symmetries. In this study we will present just a few possibilities of the methods' application in men's artistic gymnastics: analyses of lateral and functional symmetry, muscle adaptation to a specific sport or exercise, muscle potentiation and fatigue and muscle recovery from injury. The main aim of this study is to provide information about muscle stiffness, the mechanic and contractile properties of the sceletal muscles using the TMG with high level gymnast from men's artistic gymnastics as well as to demonstrate the usefulness of this method to evaluate the muscles after rehabilitation process.

MATERIAL AND METHODS

SUBJECT

The testing sample in this survey was taken from the Croatian Republic's senior representative in gymnastics, Andrej Korosteljev, born on December 15th 1996 in Osijek (Croatia). In 2012 in Montpellier in France, he qualified for the finals at the European Juniors Championships and won the third place in the floor routine and the eighth place for seniors three years later in 2015. The subject's morphological characteristics are: body height 172 cm, body weight 63 kg and the body mass index 21.3 kg/m2. In the past six months he has trained on average for 4 hours 5 times a week (twice a day). The mechanism of the lumbar region of spinal cord injury occurred after a bad landing caused by a mat slip during his training. The injury diagnosis was given by a specialist physician after receiving the results of the magnetic resonance imaging (MRI). The injury was followed by a prevention program which lasted from the 6th of June 2014 till the 24th of October 2014. All the measuring and testing was conducted in the Center for Sports Medicine, Ljubljana, Slovenia [ID: 15121995].

The participant of this study was fully informed of the potential risks associated with the study and signed written consent forms previously approved by the Research Ethics Committee of the University of Tuzla in line with the criteria of the Helsinki Declaration for research involving human beings.

ELECTRICAL STIMULATION

Two circular (5 or 3 cm in diameter depending on the muscle belly size), self-adhesive electrodes (Axelgaard, Pulse) were placed bipolarly on the skin above the muscle belly. The diameter of the electrodes was chosen on the basis of the muscle size to avoid activation of the synergistic muscles or co-activation. Electrodes were placed 5 cm medially and laterally from the measuring point. A single rectangular monophasic pulse of 1 ms duration from an electro-stimulator (TMG-S1, Furlan & Co. ltd.) was delivered to the electrodes, transcutaneously eliciting a twitch muscle contraction.

SIGNAL RECORDINGS

The TMG signals were stored on a portable PC. The digital TMG signal was directly sampled with the Matlab Compiler Toolbox using a sampling frequency of 1 kHz. Two maximal responses were stored and averaged for further analyses. The maximal stimulation amplitude was identified as the minimal stimulation amplitude needed for the response with the highest displacement amplitude (Dm) [13].

Four time parameters as a measure for contractile dynamics were calculated from the response: Delay time (Td) as the time between the electrical impulse and 10% of the contraction; Contraction time (Tc) as the time between 10% and 90% of the contraction; Sustain time (Ts) as the time between 50% of the contraction and 50% of relaxation; Relaxation time (Tr) as the time between 90% and 50% of relaxation. These parameters are used to assess the stiffness of the muscle and its balance in relation to other muscle structures, muscle chains (flexion-extension) and extremities (right and left) [2].

MEASURED MUSCLES

Four muscles were chosen on both lateral sides involved in artistic gymnastics performance: Biceps Femoris (BF), Erector Spinae (ES), Gluteus Maximus (GM), Rectus Femoris (RM).

STATISTICAL ANALYSIS

SPSS 21.0 was used for statistical analysis, which included descriptive statistics (means and standard deviations), correlational analyses, t-tests. Paired t-test was performed to determine whether there were any significant differences after the recovery program. The significant level was defined as ($P < 0.05$).

RESULTS

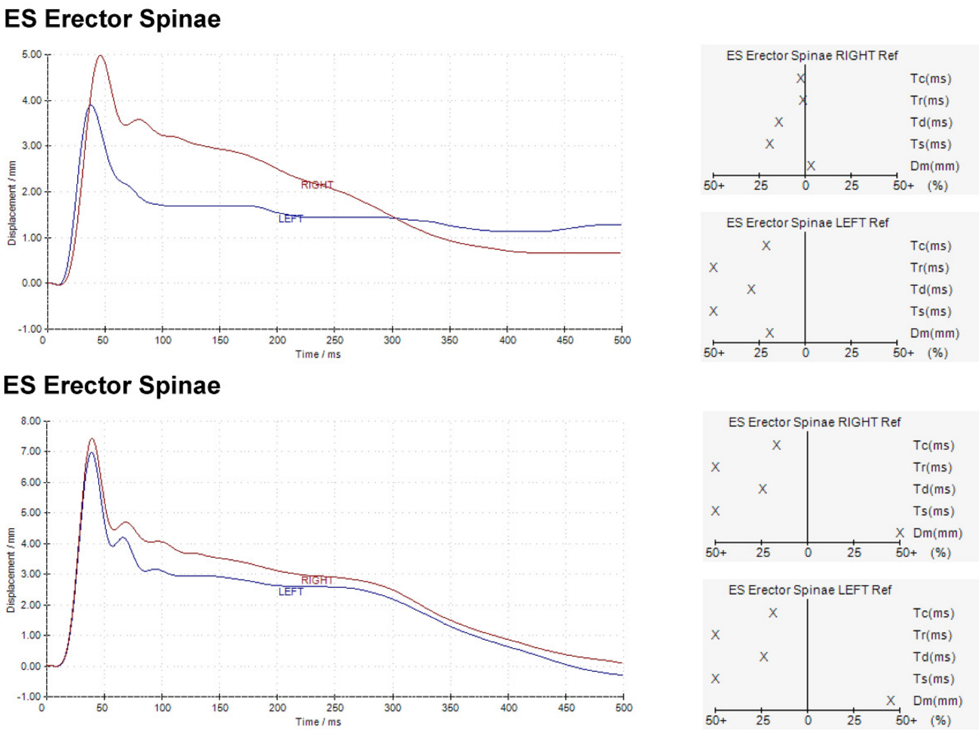
General Biceps Femoris (BF) muscle LS is very high, 95%. General Erector Spinae (ES) muscle LS is slightly lower than recommended, 76%. LS of the contraction time is significantly lower than recommended. The muscle on the right side is slower. We recommend activation exercises for the right side. General Gluteus Maximus (GT) muscle LS is very high, 92%. The muscle is slightly faster than the reference value. General Rectus Femoris (RF) muscle LS is slightly lower than recommended, 79%. LS of maximal displacement is significantly lower than recommended. It is lower on the left side. The muscle is significantly faster than the reference value. We recommend strength exercises for both sides. The relatively good bilateral symmetry in delay times (Td) between muscles indicates that neural transmission to the muscles is not compromised by the disc protrusion. Bilateral symmetry in the rectus femoris is low; the left rectus femoris is slower/weaker. Bilateral symmetry in the erector spinae is also low; here there could be 2 scenarios. First: The right erector spinae is slow/weak, which - combined with the weak/slow left RF - could be the origin of the low back pain problems. In this case the pelvis would be rotated to the right in the transverse plane during dynamic movements. Second: An alternative scenario is that the left erector spinae is tightened (low Dm and low Tc) because of pain/herniation to the left. In our opinion we believe the first scenario is the most likely. We can conclude that there is a no statistically significant difference between the mean in the first and the second measurement point ($t=1.941$, $df=39$, $P < 0.059$).

Table 1. Statistical parameters TMG for Tc, Ts, Tr, Dm, Sim – Lateral Symmetry

Parameters	DM	Muscle/Side			Muscle/Side			Muscle/Side			Muscle/Side		
		BF		R-L	ES		R-L	GM		R-L	RF		R-L
		Right	Left	%	Right	Left	%	Right	%	%	Right	Left	%
Tc [ms]	1	29.78	30.61	2.1	18.58	15.03	19.10	40.91	37.46	8.43	19.79	21.62	8.51
	2	24.35	28.30	13.95	15.84	15.49	2.20	34.15	39.97	14.56	18.24	19.86	8.15
Ts [ms]	1	218.00	185.65	14.83	169.99	52.97	68.83	79.02	65.45	17.17	188.66	59.33	68.55
	2	233.10	224.62	3.63	89.00	49.46	44.42	91.26	169.41	46.13	30.04	41.28	27.22
Tr [ms]	1	69.38	52.00	25.0	147.40	33.26	77.43	32.44	25.14	22.50	166.15	32.03	80.72
	2	87.28	55.73	36.14	71.33	32.44	54.52	50.31	127.05	60.40	10.84	18.56	41.59
Dm [mm]	1	8.03	8.74	8.12	4.98	3.90	21.68	9.83	9.86	0.30	7.64	4.21	44.89
	2	9.63	8.34	13.39	7.45	6.99	6.17	14.74	14.58	1.08	6.98	6.09	12.75
Td [ms]	1	24.35	25.53	4.62	21.95	18.09	17.58	52.47	47.13	10.17	22.14	21.37	3.47
	2	24.33	23.31	4.19	19.41	19.51	0.51	47.05	36.47	22.48	21.42	21.75	1.51
Sim [%]	1	95			76			92			79		
	2	88			93			84			90		

Legend: (DM) Date of first measurement 06.06.2014; second measurement 24.10.2014.

1st measurment



2nd measurment

Legend: ms - time in milliseconds; mm - displacement in mm

Fig. 1. Erector Spinae (ES) at the 1st and the 2nd measurement – the right and the left side comparison

DISCUSSION

The main aim of this study is to provide information about muscle stiffness, the mechanic and contractile properties of the sceletal muscles using the TMG with high level gymnast from men's artistic gymnastics as well as to demonstrate the usefulness of this method to evaluate the muscles after rehabilitation process.
From a general point of view the picture is much better. The parameters which were weak in the first measurement ES and GM testing have increased and improved their values. In addition, other muscles have also improved their contraction time which is now faster than it was after the first measuring. Measuring has also shown improvement during the period between two measurements. The improvement itself is visible in the stabilization of parameters which can affect the appearance of the injury. The risk is now satisfactory and significantly decreased. The TMG method can be used as a further contribution to optimizing the process of rehabilitation and physical recovery of athletes with muscle injuries. When athletes get injured, they, the team, the coach, and the organization, all suffer. TMG assessments could be useful in identifying and selecting young athletes. A simple methodology is an important factor for the feasibility of the method. In addition, it is objective, non--invasive, rapid and selective, and can give repetitive information.

In the available publications, many authors describe skeletal muscles. Zagorc et al. [13] made a comparison of contractile parameters among twelve skeletal muscles of inter-dance couples. From the sample of 8 top dancers in Slovenia (average age: 19.1 ±3.6 years). Tc is for BF R: 34.2 ±7.7, L: 34.3 ±9.1, ES R: 18.3 ±2.2, L: 17.5 ±2.2, GM R: 23.5 ±2.5, L: 23.2 ±1.6, RM R: 32.9 ±5.8, L: 35.5 ±6.5. García-García's study [14], the sample was composed of ten professional road cyclists (age 27.5 ±5.5 years old; height 178.2 ±7.8 cm; body mass 65.6 ±5.4 kg) who had planned the "Vuelta a España" as the main competition of the season. Tc for RF: 45.9 ±16.2 and BF: 28.2 ±5.2. Samardžija Pavletić et al. [15] focused on the contractility comparison between 10 sample muscles of (n = 26) Slovenian gymnasts. The tests showed similar results in three muscles BF: 25.0 ±9.0; ES: 14.8 ±1.7; RF: 21.1 ±3.2. According to internet source and results of Spanish football club Rayo Vallecano, [16] based on a case study of 1 top male football player who plays center position (age: 18 years, height 172 cm, weight 68 kg) for the junior team Rayo Vallecano in Spain, a comparison of contractile parameters was made among four skeletal muscles. Tc for BF R: 22.19, L: 22.11, Sim (94%), RF R: 20.38, L: 22.85, Sim (80%). In a study on athletes in sprint discipline [17] (age: men 25 years, height 173 cm, weight 79 kg). Tc for BF R: 19.65, L: 27.37, Sim (76%), ES R: 11.81, L: 12.51, Sim (93%), GM R: 27.73, L: 27.35, Sim (97%), RM R: 22.75, L: 24.41, Sim (89%). In Loturco et al. study [18] on forty-one high-level track and field athletes from power (n = 22; age 27.2 ±3.6 years; height 180.2 ±5.4 cm; weight 79.4 ±8.6 kg) and endurance events (endurance runners and triathletes; n = 19; age 27.1 ±6.9 years; height 169.6 ±9.8 cm; weight 62.2 ±13.1 kg) had the mechanical properties of their rectus femoris (RF) and biceps femoris (BF) assessed by TMG. Tc BF = 14.3 ±2.3 vs. 19.4 ±3.3 ms, Tc RF = 18.3 ±2.8 vs. 22.9 ±4.0 ms.

Floor exercies in men's artistic gymnastics is one of the most technically complex and the most difficult events, requiring a gymnast to have adequate physical fitness skeletal muscle of the lower extremities and low back. Most injuries in artistic gymnastics are related to floor landing [19, 20, 21, 22, 23, 24, 25]. This phase not only affects the gymnast's final rank during competition [26], but also entails a high risk of injury, mainly due to the high impact magnitudes of 14 to 18 body weight applied to one leg [19], and to the mat's instability [27, 28]. Landing imposes forces on the body that must be absorbed primarily by the musculoskeletal components of the lower extremities. If the loads become too great for the body to accommodate, a potential injury situation arises [29, 30]. Designing programs with exercises for prevention and good landing in gymnastics, separated from the whole routine, would help to decrease impact forces during landing and reduce the possibility of injury.

CONCLUSION

TMG results can help the coach to establish the future training load and this is very important for prevent muscle injuries. Coaches should monitor such muscle adaptation more often at different training or competition periods during the year. All of these facts suggest that organised and strict work should be undertaken to maintain health, reduce the risk of injuries and ensure proper body development in artistic gymnastics.

Limitation of this study is that the sample size was small and other limitation is this relatively new method of testing skeletal muscle and for now there is no large number of studies for comparison with other similar studies. We believe that this TMG method, after traning program of rehabilitation can be a useful device for muscle mechanic diagnostics.

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