Assessment of muscle fatigue after an ultra-endurance triathlon using tensiomyography (TMG).

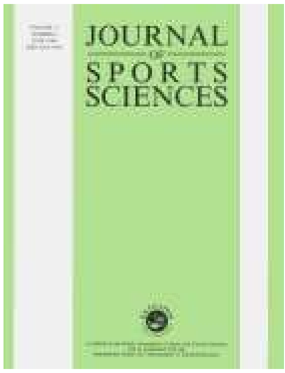
Juan Manuel García-Manso

To cite this version:

Juan Manuel García-Manso. Assessment of muscle fatigue after an ultra-endurance triathlon using tensiomyography (TMG).. Journal of Sports Sciences, 2011, 29 (6), pp.619. 10.1080/02640414.2010.548822 . hal-00730726

HAL Id: hal-00730726
https://hal.science/hal-00730726

Submitted on 11 Sep 2012



ASSESSMENT OF MUSCLE FATIGUE AFTER AN ULTRAENDURANCE TRIATHLON USING TENSIOMYOGRAPHY (TMG)

Journal:	*Journal of Sports Sciences*
Manuscript ID:	RJSP-2010-0042.R4
Manuscript Type:	Original Manuscript
Keywords:	Tensiomyography, Ironman, Long-distance race, Neuromuscular fatigue, Mechanical characteristics of the muscle

TITLE:

ASSESSMENT OF MUSCLE FATIGUE AFTER AN ULTRAENDURANCE TRIATHLON USING TENSIOMYOGRAPHY (TMG)

ACKNOWLEDGEMENTS

The authors would like to thank Heather Adams and Gloria Perdomo Bautista, ULPGC, for translating this article into English.

ABSTRACT

This study used Tensiomyography (TMG) to assess muscle status immediately after an ultraendurance triathon Maximal Radial Displacement or Deformation of muscle belly (Dm), Contraction Time (Tc), Delay Time (Td), Sustain Time (Ts) and Relaxation Time (Tr), for both legs, were measured and dependent t-tests were used for comparison of means between the beginning and end of race. The 19 men assessed (age. 37.9 ±7.1 years; height: 177.5 ±4.6 m; weight: 73.6 ±6.5 kg) participated in the 2009 edition of the Lanzarote Ironman. A deterioration in the neural response was observed Contraction Time (p∠0.008), Relaxation Time (p∠0.011) and Sustain Time, with a moderate decrease in the response time (Sustain Time) and a loss in muscle stiffness (Deformation of muscle belly). The effect of muscle fatigue on rectus femoris (RF) was different from that on biceps femoris (BF). Barely any changes in Contraction Time, Relaxation Time, Sustain Time and Deformation of muscle belly were observed, while only the contraction response time decreased to a significant extent (↓Td; p∠0.003). The considerable loss in contractile capacity induced by a long-distance race was reflected in changes in the neuromuscular response and fluctuations in the contractile capacity of the muscle. These modifications derived from a prolonged, exhausting effort, can be assessed in a simple, non-aggresive, non-invasive way using Tensiomyography.

KEYWORDS

Tensiomyography, Ironman, Long-distance race, Neuromuscular fatigue, Mechanical characteristics of the muscle.

INTRODUCTION

Fatigue is any decline in muscle performance associated with muscle activity (Fitt, 1994; Allen et al., 2008). In sport, the causes of muscle fatigue are complex and not totally understood. They vary in type and degree depending on the characteristics of the exercise that brings on the fatigue. Numerous factors related to the central nervous system and/or peripheral factors within the skeletal muscles lead to muscle fatigue (Gibson & Edwards, 1985; Allen, et al., 2001, Gandevia, 2001; Westerblad et al., 1998; Fitts, 2006).

In long distance sports (marathon, cycling or ultra-endurance triathlon), the repeated, prolonged use of muscle structures produces changes in the muscle fibre that affect its mechanical capacities and performance possibilities (Viitasalo, et al., 1982; Hakkinen, and Komí, 1983; Nicol et al., 1991; Millet et al., 2000; Millet et al., 2002). These modifications are reflected in a reduction in force output (Sargeant et al., 1981; Bigland-Ritchie, et al., 1986; Nosek et al., 1987; Cooke et al., 1998; Coupland et al., 2001; Debold, 2004), a decrease in shortening velocity of muscle fibres, particularly FT fibres (Bigland-Ritchie, et al. 1986, Colliander et al., 1988; Linssen, et al., 1991; Karatzaferi et al., 2008), and a slowing down of relaxation time (Edman and Mattiazzi, 1981; Metzger and Moss, 1987 Thompson et al., 1992).

For sports entailing several hours of exercise during which a significant number of stretch-shortening cycles occurs, the greatest modification of the muscle is generated during the eccentric stage of the muscular contraction, leading to considerable deleterious effects on the muscular function (Davies, and Thompson, 1986; Radin, 1986; Newham et al. 1987; Clarkson et al. 1992; Howell et al. 1993; Sayers et al. 2003; Prasartwuth et al. 2005). In this case, the worst-affected muscles will be the extensor muscles of the knee joint (in the landing and take-off stages) and/or their antagonist muscles (traction in rear foot and leg recovery).

In most studies, muscular fatigue has been assessed by monitoring static or dynamic force, measuring substrates, metabolites or other chemical substances using biochemical techniques, such as lactates, creatine phosphokinase (CPK), hormones, etc., or with electromyographic (EMG) readings. This often entails examining muscles using techniques that are either invasive or require the athletes to exercise at times when they are very tired and not in an appropriate state for assessment. We have not found any studies that assess muscular fatigue after long duration exercise using the non-invasive technique of tensiomyography (TMG). Krizj et al. (2008) and Rosu et al. (2009)'s studies present protocols that differ considerably, based on the origin of the fatigue and lasting less time than a long endurance resistance race. For this reason, we decided to examine the effects of localized muscle fatigue (rectus and biceps femoris), after an ultra-endurance triathlon (UET) using this methodology. The ultra-endurance triathlon is a long endurance sport consisting of a 3.8 km swim and a 180 km cycle, followed by a 42.2 km marathon run.

METHODS

Experimental Approach to the Problem

This study used the tensiomyography (TMG) like a useful tool to assess the possible relationship, immediately after a competition, between a long-distance race and neuromuscular fatigue. We also endeavoured to evaluate the way in which the ultra-endurance triathlon affects the mechanical characteristics of the muscle. Thus, Maximal Radial Displacement or Deformation of muscle belly (Dm), Contraction Time (Tc), Delay Time (Td), Sustain Time (Ts) and Relaxation Time (Tr) of both legs were measured and dependent *t-tests* were used for mean comparisons between beginning and end of race.

Participants. 19 male participants (age. 37.9 ±7.1 years; height: 177.5 ±4.6 m; weight: 73.6 ±6.5 kg) with a mean of 12 experience years in the ultra-endurance event were assessed. The performance best in the 2009 edition of the Lanzarote Ironman (time: 747.1 ±105.4; range: 576.5-959.2 min) for our subjects (Table 1). And we can show the information about the last month average training (Table 2).

****INSERT TABLE 1 ABOUT HERE, PLEASE****

****INSERT TABLE 2 ABOUT HERE, PLEASE****

All participants were fully informed of the potential risks associated with the study and signed written informed consent forms previously approved by the Research Ethics Committee of the ULPGC in line with the criteria of the Helsinki Declaration for research involving human beings.

Tensiomiography. Radial displacement was measured on rectus femoris (RF) and biceps femoris (BF) muscles of both legs using Tensiomyography the day before the event and immediately after the subjects had crossed the finishing line at the end of the ultra-endurance triathlon. Post-race assessments were conducted within 15 min of finishing the race. Assessments lasted no more than 10 min. The test consisted of the assessment of the Rectus Femoris and Biceps Femoris of both legs.

This technique constituted a method of non-invasive muscular assessment in which no physical effort is required of the subject under evaluation. A pressure sensor recorded the geometric changes (radial displacement) that occured in the muscle belly when a contraction was produced in response to an external electrical stimulus. (Valencic et al, 1997; Dahmane et al., 2000; Valencic et al., 2000; Valencic et al. 2001). The sensor used in this investigation was a high precision digital displacement transducer that was placed perpendicular to the muscle belly with a controlled pre-tension of the sensor tip to the muscle. It gave information as to the mechanical characteristics and the contractile capacity of the superficial muscles measured according to the parameters of Maximal Radial Displacement or Deformation of muscle belly (Dm), Contraction Time (Tc), Delay Time (Td), Sustain Time (Ts) and Relaxation Time (Tr) (Figure 1).

****INSERT FIGURE 1 ABOUT HERE, PLEASE****

Maximal radial displacement or deformation (Dm) was given by the radial movement of the muscle belly expressed in millimetres. It represented and evaluated muscle stiffness, and varies in each subject depending on his morphological characteristics and the way in which these structures have been trained. Low results, compared to the average, demonstrate high muscle mass and stiffness whereas high results show a lack of muscle mass or significant muscle fatigue (Valencic et al, 2001; Dahmane et al, 2001 and Krizaj et al, 2008). The *delay time (Td),* also known as reaction or activation time represented the time it took to reach 10 % of total movement after stimulation. However, it depended on the predominance of the fibre in that skeletal muscle structure, its degree of fatigue, and activation level (Dahmane et al, 2005). C*ontraction time* (Tc) was obtained by determining the time lag from the end of the reaction time (10% Deformation of muscle belly) until 90% of the maximum deformation. *The sustain time (Ts)* which is also known as the contraction duration, was the theoretical duration of the contraction. It was calculated by determining the time between the instant when deformation reaches 50% of its maximum value until the deformation levels, during relaxation, return to levels of 50% of maximum deformation. *Relaxation time* (Tr) provided information about the levels of fatigue, with high levels of this parameter, as compared to normal levels for the particular subject under assessment, indicating the presence of fatigue.

The extent to which this method may be reproduced and is considered valid was assessed by Krizaj et al., (2008) and Rodríguez-Matoso et al., (2009) following the measurement protocol proposed by the manufacturers.

Statistical Analyses

Starting with a Kolmogorov-Smirnov to verify the data distribution, we applied a test for related averages (students t-test) to compare the results obtained from the Tensiomyography before and after test. Statistical significance was inferred $p < 0.05$. All statistics were performed using the statistical packages 14.0 version of the SPSS (SPSS Inc., Chicago, IL, USA).

RESULTS

The electrical stimulation needed to produce the maximum muscle response was not equal for each of the subjects included in the sample, but in the pre-test and in the post-test we followed the same protocol of increasing the values of the electrical stimulus of progressive form at four frequencies (40, 70, 90 and 110 Hz), being registered the best response of every subject. Muscle fatigue, dehydration, changes in skin temperature or alteration in skin conductivity constitute some of the factors that may justify this behaviour.

Mean values and standard deviation for the sum of Delay Time, Contraction Time, Relaxation Time, Sustain Time and Maximal Radial Displacement or Deformation of Biceps Femoris before and after ultra-endurance triathlon, are presented in Table 1. Muscle fatigue and potentiation are important physiological processes and are being investigated by practically all methods studying muscle contraction properties. In our study, an overall deterioration in the neural response (increase Contraction Time, Relaxation Time and Sustain Time) was observed, together with a moderate decrease in response time (Delay Time) and a loss of muscle stiffness (increase Maximal Deformation). Significant statistical differences were found between Pre-Post values of Contraction Time ($p \leq 0.008$), Maximal Radial Displacement or Deformation ($p \leq 0.006$) and Relaxation Time ($p \leq 0.011$). A statistically non-significant variation was observed in Delay Time and Sustain Time. When the parameters are analysed individually (only leg-right or leg-left) the results obtained differ. The statistically significant differences in the right leg were only found for Biceps Femoris at Maximal Radial Displacement or Deformation ($p \leq 0.006$) values, whereas statistically significant variations were observed in the left leg for Contraction Time ($p \leq 0.038$) and Relaxation Time ($p \leq 0.012$). A non-significant but suggestive trend was also found in Maximal Radial Displacement or Deformation ($p \leq 0.077$).

****INSERT TABLE 3 ABOUT HERE, PLEASE****

Mean values and standard deviation for the sum of Delay Time, Contraction Time, Relaxation Time, Sustain Time and Maximal Radial Displacement or Deformation for Rectus Femoris before and after ultra-endurance triathlon are presented in Table 2. Here, we can also observe an increase in the neural control of the muscle (increase Contraction Time, Delay Time, Relaxation Time and Sustain Time) and a decrease in stiffness (Maximal Deformation muscle belly). As far as Rectus Femoris is concerned, statistically significant differences before and after ultra-endurance triathlon only occur in the Delay Time variable ($p \leq 0.003$)

****INSERT TABLE 4 ABOUT HERE, PLEASE****

DISCUSSION

The main findings of this study are that an ultra-endurance triathlon race constitutes a physical effort that causes a large impact on the organism, bringing about a severe depression in the functional capacities of the muscles involved in the activity. Several hours of swimming, cycling and running, with strenuous stretch-shortening cycle exercise, as occurs in an ultra-endurance triathlon, have considerable deleterious effects on the neuromuscular function. These results coincide with those obtained by other authors studying fatigue in long endurance running events (Viitasalo, et al., 1982; Nicol et al., 1991; Millet et al., 2000; Millet et al., 2002) or cycling (Hakkinen, and Komí, 1983; Gerdle et al., 1997; Crenshaw, et al., 1997; St Clair-Gibson et al., 2001). This has been detected very easily in our study using the Tensiomyography technique .

In our opinion, radial muscle displacement, as well as the time values provided by Tensiomyography, has been found to be very sensitive to muscle fatigue and to a certain extent also to the initial pressure of the sensor tip on the muscle. This same conclusion was drawn by Krizaj et al. (2008) in a study in which the short-term repeatability of Tensiomyography is analysed.

The Contraction Time values observed in Rectus Femoris and Biceps Femoris in this study are more than 30 ms, which indicates muscles with a high prevalence of slow fibre, (Dahmane et al., 2001) and therefore highly resistant to fatigue. Even so, events such as this lasting 9 - 12 hr produce levels of fatigue in those muscles that have been put to work. However, muscular fatigue affects each muscle assessed in a very different way. This is due to the varying degree to which the muscles examined participate at the very end of the ultra-endurance triathlon. In our study, a larger functional reduction was recorded in the posterior musculature of the leg (Biceps Femoris) than the anterior (Rectus Femoris).

We should bear in mind that the participation of Rectus Femoris and Biceps Femoris varies, in form and intensity, during the stages of cycling and running. During the run, the last discipline of the ultra-endurance triathlon race, the hamstring muscles (Semitendinosus, Semimembranosus and Biceps Femoris) do not play a relevant role in the action of flexing the knee joint, as, over long distances, the raising of the heel during recovery phase is a short and not very intense action, as can easily be shown. The main function of the hamstring muscles in this case, is to provide traction on the ground during the support stage. During this stage, the Hamstring muscles carry out a synergic action with the quadriceps muscles (Rectus Femoris, Vastus Laterales, Vastus Mediales and Vastus intermedius). In any case, the double function of support-extension and flexion of the knee joint leads to evident and significant fatigue in the Biceps Femoris that affects the neural and morpho-functional mechanisms and which can be seen in the Tensiomyography parameters: increase Contraction Time, Relaxation Time and Sustain Time but decrease Delay Time and stiffness (increase Maximal Deformation). These results confirm those obtained by other authors (Edman and Mattiazzi, 1981; Bigland-Ritchie et al., 1986; Metzger and Moss, 1987; Colliander et al., 1988; Linssen, et al., 1991; Thompson et al., 1992; Karatzaferi et al., 2008).

An interesting aspect revealed by the data is the existence of a functional asymmetry between each leg during the physical activity. (Figure 2). Tensiomyography shows us clearly that muscle work carried out by each leg during the ultra-endurance triathlon race is different, corresponding to technical errors by the athlete and the fact that this musculature is not in optimum conditions. More intense activity is normally carried out by the dominant segment. In the long term this would represent high injury risk for the athlete. We believe that in top-level athletes, with better pedal technique, these differences should be less evident.

****INSERT FIGURE 2 ABOUT HERE, PLEASE****

The other muscle assessed in our study was the Rectus Femoris (RF), an anterior muscle of the thigh that is unusual in that it is the only muscle in the quadriceps group that is involved in hip flexion, since it is the only one that originates in the pelvis and not the femur. This morphological characteristic leads the Rectus Femoris to fulfill support and impulse (take-off) roles during the rear foot and those of synergist muscles in the flexing of the hip joint (lifting the thigh). During the support phase, the foot is in contact with the ground and supports the body against gravity. In the extension of the knee joint Rectus Femoris helps the free leg to move forwards by raising the thigh. Rectus Femoris and other flexor muscles of the hip, together with the hamstring muscles, carry out the recovery action during the pedalling motion. The behaviour of this muscle during the last two stages of the ultra-endurance triathlon led us to choose the Rectus Femoris rather than other quadriceps structures.

The effect of muscle fatigue on Rectus Femoris was, in our case, different from that found and described for Biceps Femoris. Hardly any changes were observed in, Contraction Time, Relaxation Time, Sustain Time and Maximal Radial Displacement or Deformation, while only the response time (Delay Time) to contraction fell significantly (decrease Delay Time; $p \leq 0.003$). This could be due to the fact that the Rectus Femoris only has a relevant function during the cycling stage, and is less evident during the run. This obliges us to try to assess it on another occasion during the second transition (cycling-run) of the race.

In summary, the large loss in contractile capacity of the muscle following an ultra-endurance triathlon race is reflected in changes in the neuromuscular response and alterations in the contractile capacity of the muscle. These modifications, derived from prolonged, exhausting effort, can be evaluated in a simple, non-aggressive way using Tensiomyography.

PRACTICAL APPLICATION

In conclusion, this research provides additional evidence of the importance of being able to assess our athletes during training and/or competitions without the subject having to modify his normal working and resting routines. At the same time, the quality of the assessment is ensured and yields important information as to the effects that the training process used causes on the musculature.

REFERENCES

Allen, DG and Westerblad, H. (2001) Role of phosphate and calcium stores in muscle fatigue. *Journal of Physiology* 536: 657–665.

Allen, DG, Lamb, GD and Westerblad, H**.** (2008) Skeletal Muscle Fatigue: Cellular Mechanisms *Physiological Reviews.* 88: 287-332.

Baker, AJ, Kostov, KG, Miller, RG and Weiner, MW. (1993) Slow force recovery after long-duration exercise: metabolic and activation factors in muscle fatigue. *Journal of Applied Physiology* 74: 2294–2300.

Beelen, A, Sargeant AJ, Jones, DA and de Ruiter, CJ. (1995) Fatigue and recovery of voluntary and electrically elicited dynamic force in humans. *Journal of Physiology (Lond)* 484: 227–235.

Bigland-Ritchie, B, Furbush, F and Woods, JJ. (1986) Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors. *Journal of Applied Physiology*. 61: 421–429.

Clarkson, PM, Nosaka, K and Braun, B. (1992) Muscle function after exercise-induced muscle damage and rapid adaptation. *Medicine & Science in Sports & Exercise* 24, 512–520.

Colliander, EB, Dudley, GA and Tesch, PA. (1988) Skeletal muscle fibre type composition and performance during repeated bouts of maximal, concentric contractions. *European Journal of Applied Physiology and Occupational Physiology*. 58: 81–86.

Cooke, R, Franks, K, Luciani, G and Pate, E. (1988) The inhibition of rabbit skeletal muscle contraction by hydrogen ions and phosphate. *Journal of Physiology* 395: 77–97.

Coupland, ME, Puchert, E and Ranatunga, KW. (2001) Temperature dependence of active tension in mammalian (rabbit psoas) muscle fibres: effect of inorganic phosphate. *Journal of Physiology* 536: 879–891.

Crenshaw, AG, Karlsson, S, Gerdle, B and Friden, J. (1997) Differential responses in intramuscular pressure and EMG fatigue indicators during low- vs. high-level isometric contractions to fatigue. *Acta Physiologica Scandinavica* 160: 353-361.

Dahmane, R, Djordjevic, S, Simunic, B and Valencic, V. (2005) Spatial fiber type distribution in normal human muscle Histochemical and tensiomyographical evaluation. *Journal of Biomechanics*, 38: 2451-2459.

Dahmane, R, Knez, N, Valencic, V and Erzen, I. (2000) Tensiomyography, a non-invasive method reflecting the percentage of slow muscle fiber in human skeletal muscles. Book of Abstract: *Life Sciencies 2000*, Gozd Martuljek, Slovenia, September 28th to October 1st, 2000, pp./str. 29.

Dahmane, R, Valencic, V, Knez, N and Erzen, I. (2001) Evaluation of the ability to make non-invasive estimation of muscle contractile properties on the basis of the muscle belly response. *Medical and Biological Engineering Computering*, 39: 51-55.

Davies, CTM and Thompson, MW**.** (1986) Physiological responses to prolonged exercise in ultramarathon athletes. *Journal of Applied Physiology* 61: 611-617.

Debold, EP, Dave, H and Fitts, RH. (2004) Fiber type and temperature dependence of inorganic phosphate: implications for fatigue. *American Journal of Physiology - Cell Physiology* 287: C673–C681.

Edman, KAP and Mattiazzi, AR. (1981) Effects of fatigue and altered pH on isometric force and velocity of shortening at zero load in frog muscle fibers. *Journal of Muscle Research and Cell Motility* 2: 321–334.

Fitts, RH. (1994). Cellular mechanisms of muscle fatigue. *Physiological Reviews* 74: 49–94.

Fitts, RH. (2006) The muscular system: fatigue processes. In: *Advanced Exercise Physiology*, edited by Tipton C. Philadelphia, PA: Lippincott Williams and Wilkins, chapt. 8:178–196.

Gandevia, SC. (2001) Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews* 81: 1725–1789.

Gerdle, B, Karlsson, S, Crenshaw, AG and Friden, J. (1997) The relationship between EMG and muscle morphology throughout sustained static knee extension at two submaximal force levels. *Acta Physiologica Scandinavica* 160: 341-351.

Gibson, H and Edwards, RH. (1985) Muscular exercise and fatigue. *Sports Medicine*. 2(2): 120-132.

Hakkinen, K and Komi, PV. (1983) Electromyographic and mechanical characteristics of human muscle during fatigue under voluntary and reflex conditions. *Electroencephalography and Clinical Neurophysiology* 55: 436-444.

Howell, JN, Chleboun, G and Conatser, R. (1993) Muscle stiffness, strength loss, swelling and soreness following exercise-induced injury in humans. *Journal of Physiology* 464, 183–196.

Karatzaferi, C, Franks-Skiba, K and Cooke, R. (2008) Inhibition of shortening velocity of skinned skeletal muscle fibers in conditions that mimic fatigue. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology* 294: R948-R955.

Krizaj, D, Simunic, B and Zagar, T. (2008) Short-term repeatability of parameters extracted from radial displacement of muscle belly. *Journal of Electromyography and Kinesiology*, 18: 645-651.

Linssen, WHJP, Stegeman, DF, Joosten, EMGH, Merks, JH, Ter Laak, HJ, Binkhorst, RA and Notermans, SLH. (1991) Fatigue in type I fibre predominance: a muscle force and surface EMG study on the relative role of type I and type II fibres. *Muscle & Nerve* 14: 829–837.

Metzger, JM and Moss, RL. (1987) Greater hydrogen ion-induced depression of tension and velocity in skinned single fibres of rat fast than slow muscles. *Journal of Physiology* 393: 727–742.

Millet, GY, Lepers, R, Lattier, G, Martin, V, Babault, N and Maffiuletti, N. (2000) Influence of ultra-long term fatigue on oxygen cost of two types of locomotion. *European Journal of Applied Physiology* 83: 376-380.

Millet, GY, Lepers, R, Maffiuletti, NA, Babault, N, Martin, V and Lattier, G. (2002) Alteration of neuromuscular function after an ultra-marathon. *Journal of Applied Physiology* 92: 486-492.

Newham, DJ, Jones, DA and Clarkson, PM. (1987) Repeated high-force eccentric exercise: effects on muscle pain and damage. *Journal of Applied Physiology* 63: 1381–1386.

Nicol, C, Komi, PV and Marconnet, P. (1991) Fatigue effects of marathon running on neuromuscular performance II: changes in force, integrated electromyographic activity and endurance capacity. *Scandinavian Journal of Medicine & Science in Sports* 1: 18-24.

Nosek, TM, Fender, KY and Godt, RE. (1987) It is diprotonated inorganic phosphate that depresses force in skinned skeletal muscle fibers. *Science* 236: 191–193.

Prasartwuth, O, Taylor, JL and Gandevia, SC. (2005) Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. *Journal of Physiology* 567, 337–348.

Radin, EL. (1986) Role of muscles in protecting athletes from injury. *Acta Medica Scandinavica 711* (Suppl.), 143–147.

Rodríguez-Matoso, D, Quiroga, ME, da Silva-Grigoletto, M, Bautista, P, Sarmiento, S and García-Manso, JM. (2009) Evaluación de la reproducibilidad de la TMG. Congreso Internacional de Ciencias del deporte de la UCAM. 17-19 de mayo de 2009. Murcia.

Rusu L, Cernaianu S, Vasilescu M, Baltac G, Ciocanescu D, Fortan C. (2009) Assessment of knee stability using neuromuscular measurement in soccer players. XVIII International Congress on Sports Rehabilitation And Traumatology.

Sargeant, AJ, Hoinville, E and Young, A. (1981) Maximum leg force and power output during short-term dynamic exercise. *Journal of Applied Physiology* 51: 1175–1182.

Sayers, SP, Peters, BT, Knight, CA, Urso, ML, Parkington, J and, Clarkson, PM. (2003) Short-term immobilization after eccentric exercise. Part I: contractile properties. *Medicine & Science in Sports & Exercise* 35, 753–761.

St Clair Gibson, A, Schabort, EJ and Noakes, TD. (2001) Reduced neuromuscular activity and force generation during prolonged cycling. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology* 281: R187-R196.

Sweitzer, NK and Moss, RL. (1990) The effect of altered temperature on Ca2_-sensitive force in permeabilized myocardium and skeletal muscle. Evidence for force dependence of thin filament activation. *Journal of General Physiolpgy* 96: 1221–1245.

Thompson, LV, Balog, EM, Riley, DA and Fitts, RH. (1992) Muscle fatigue in frog semitendinosus: alterations in contractile function. *American Journal of Physiology - Cell Physiology* 262: C1500–C1506.

Valencic, V and Knez, N. (1997) Measuring of skeletal muscles dynamic properties. *Artificial Organs* 21: 240-242.

Valencic, V, Djordjevic, S, Knez, N, Dahmane, R, Coh, M, Jurcic-Zlobec, B, Praprotnik; U, Simunic, B, Kersevan, K, Bednarik, J and Gomina, N. (2000) Contractile properties of skeletal muscles detection by tensiomiographic measurement method. *2000 Pre-Olympic Congress*, Brisbane, Australia, Abstract 507.

Valencic, V, Knez, N and Simunic, B. (2001) Tenziomiography: Detection of skeletal muscle responce by Means of radial muscle belly displacement. *Biomedical Engineering*, 1: 1-10.

Viitasalo, JT, Komi, PV, Jacobs, I and Karlsson, J. (1982) Effects of prolonged cross-country skiing on neuromuscular performance. *Exercise & Sport Biology* 12: 191-198.

Vøllestad, NK, Sejersted, OM, Bahr, R, Woods, JJ and Bigland-Ritchie, B. (1988) Motor drive and metabolic responses during repeated submaximal contractions in man. *Journal of Applied Physiology* 64: 1421–1427.

Westerblad, H, Allen, DG, Bruton, JD, Andrade, FH and Lännergren, J. (1998) Mechanisms underlying the reduction of isometric force in skeletal muscle fatigue. *Acta Physiologica Scandinavica* 162: 253–260.

LEGENDS TO FIGURES AND TABLES

		Fractions			Transitions	
Store	**Final time**	**Swimming**	**Cycling**	**Running**	**Swimming-Cycling**	**Cycling-Running**
Average	12h 27' 02"	1h 11'57"	6h 35' 56"	4h 23' 14"	0h 08' 34"	0h 08' 01"
Maximum	15h 59' 24"	1h 35' 45"	7h 57' 27"	6h 18' 40"	0h 10' 48"	0h 09' 38"
Mínimum	9h 36' 46"	0h 57' 47"	5h 19' 03"	3h 00' 21"	0h 04' 00"	0h 03' 11"

Table 1: Average times of the swimming, cycling, and running performances during the race Lanzarotes' Ironman 2009 for our subjects

	Last mesocycle (average)					
	Swimming		**Cycling**		**Running**	
Modality	**Distance**	**Time**	**Distance**	**Time**	**Distance**	**Time**
1ª week	2.0 km	0h 40'	254 km	12 h 10'	22 km	2 h 10'
2ª week	7.6 km	2h 22'	340 km	14 h 15'	30 km	2 h 45'
3ª week	10.2 km	3h 3'	360 km	14 h 45'	62 km	5 h 40'
4ª week	4.0 km	1h 20'	220 km	8 h 20'	14 km	1 h 20'

Table 2: Last month (mesocycle) average training for our subjetcs.

Biceps Femoris (BF) Right + Left	**Pre (n=19)**	**Post (n=19)**	**T-test**
Tc	65.1 ± 22.1	$77.4^{1} \pm 28.5$	^{1} $p \leq 0.008$
Dm	10.8 ±3.5	$13.4^{2} \pm 4.6$	^{2} $p \leq 0.006$
Td	44.1 ± 5.4	43.6 ± 5.6	-
Ts	436.8 ± 68.1	472.1 ± 110.1	-
Tr	124.6 ± 33.8	$151.8^{3} \pm 35.9$	^{3} $p \leq 0.011$

Table 3. Sum of Tc (ms), Dm (mm), Td (ms), Ts (ms) and Tr (ms) values in BF of right and left legs, before (Pre) and after (Post) EUT. ^{1} $p \leq 0.008$; ^{2} $p \leq 0.006$; ^{3} $p \leq 0.011$.

Rectus Femoris (RF) Right + Left	Pre (n=19)	Post (n=19)	T-test
Tc	63.5 ± 13.1	63.1 ± 8.3	-
Dm	16.5 ±3.3	16.7 ± 5.5	-
Td	45.6 ± 4.1	42.8 [1] ± 4.1	[1] $p \leq 0.003$
Ts	233.7 ± 76.8	246.6 ± 85.4	-
Tr	142.6 ± 67.9	157.8 ± 73.9	-

Table 4. Sum of Tc (ms), Dm (mm), Td (ms), Ts (ms) and Tr (ms) values in RF of right and left legs, before (Pre) and after (Post) UET. [1] $p \leq 0.003$.

Figure 1: Diagram showing the muscular response to an electrical stimulus obtained by TMG. Deformation or Maximal Radial Displacement of muscle belly (Dm), Contraction Time (Tc), Delay Time (Td), Sustain Time (Ts) and Relaxation Time (Tr).

Figure 2. Graph showing muscle response to an electric stimulus obtained using TMG on the BF of both legs (____ right and ----- left) before and after EUT race for a subject who completed the race in 12h:33min.

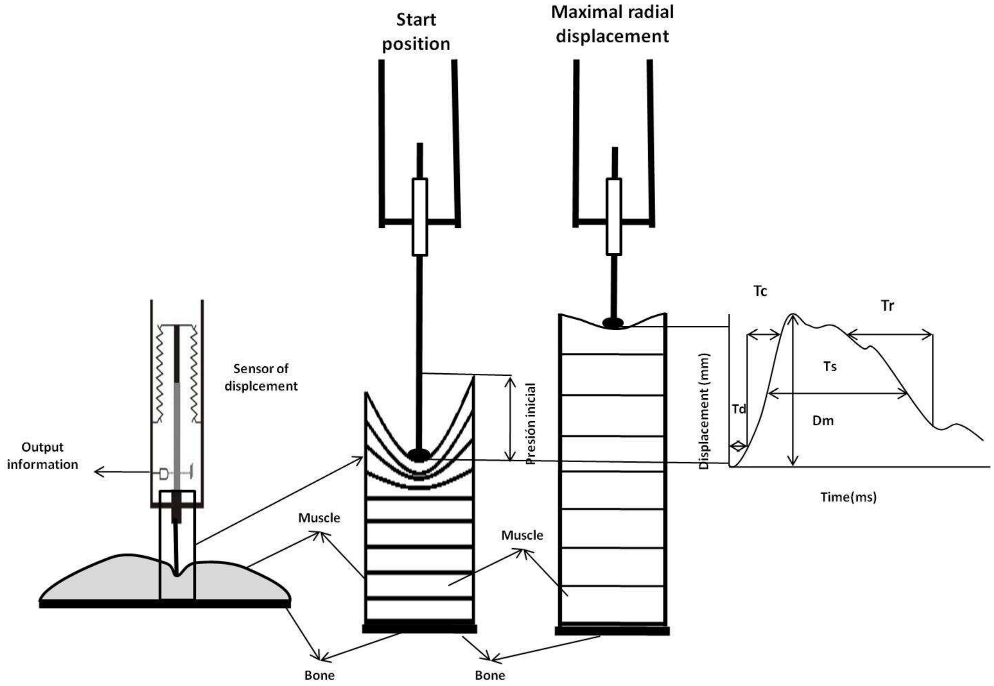
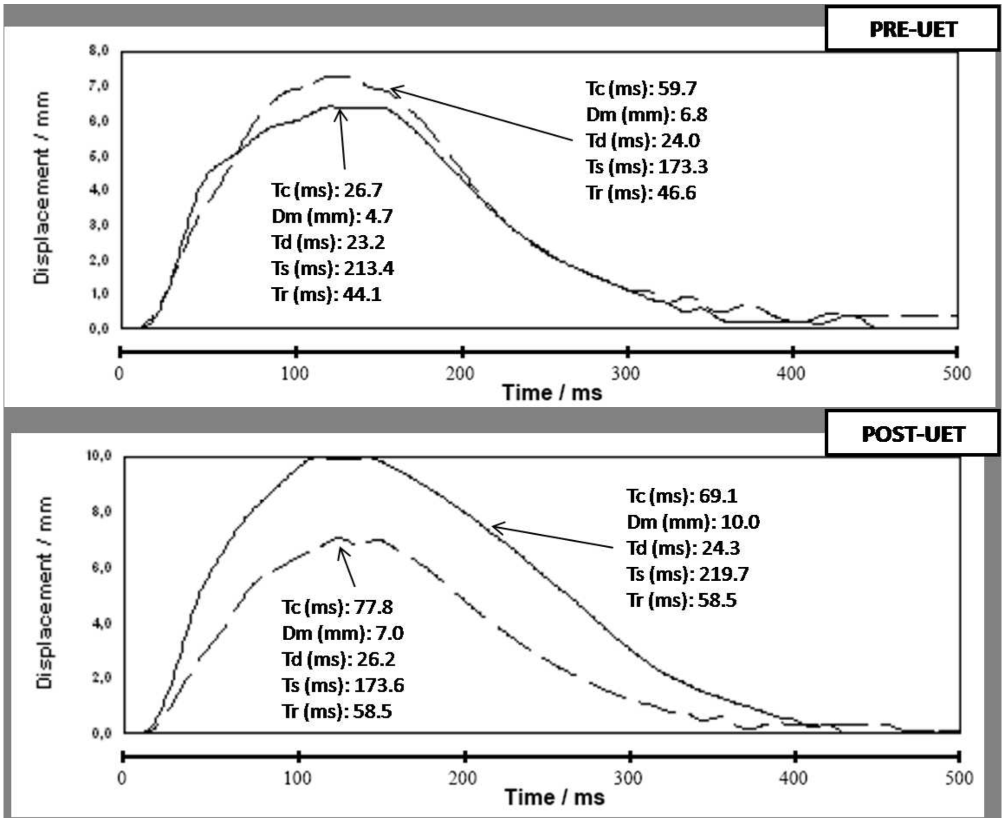


Diagram showing the muscular response to an electrical stimulus obtained by TMG. Deformation or Maximal Radial Displacement of muscle belly (Dm), Contraction Time (Tc), Delay Time (Td), Sustain Time (Ts) and Relaxation Time (Tr).
243x170mm (150 x 150 DPI)



Graph showing muscle response to an electric stimulus obtained using TMG on the BF of both legs right (___) and left(----) before and after EUT race for a subject who completed the race in 12h:33min.