Original Article

Muscle contractile properties on different sport surfaces using tensiomyography

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ABSTRACT

Propose: the propose of this study was to discover the influence of sand and natural grass on muscle overuse in female rugby players after an induced fatigue test. Methods: the participants of this study were 15 female amateur rugby players (23.4 ± 4.42 years). RSA Test consisted of six-sprints of 40 m (20 + 20 m) and was performed in two different surfaces (natural grass and sand). Before and immediately after completing the RSA, the contractile capacity of the biceps femoris and the rectus femoris of both legs was evaluated through Tensiomyography (TMG). Results: players also did 2 CMJ jumps before and after the RSA to assess the muscle fatigue. CMJ jump high decreased (-2.89 cm; ES= 0.67; IC: to -4.59 to -1.18) after having performed the RSA Test on sand versus natural grass. Rectus femoris presented higher values of Tc (11.66 ms; ES= 1.00; IC: 4.03 to 9.29; $p \leq 0.01$) and Dm (1.20 mm; ES= 0.80; IC: 0.21 to 2.61; $p < 0.05$) on sand than on natural grass after finishing the RSA while the biceps femoris do not display any differences regarding surfaces. Conclusion: therefore, muscular response on rectus femoris after repetitive-sprint-actions differ between different surfaces (sand and natural grass). **Key words:** FATIGUE, EXERCISE, MUSCLE, PERFORMANCE

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INTRODUCTION

Overuse or fatigue injuries are caused by repeated micro-trauma, without any actual moment causing the injury (Fuller et al., 2006). Overuse injuries are responsible for 63% of relapse injuries, with 75% occurring during training and 51% during the preseason (Walden et al., 2005). According to Petibois et al. (2002) fatigue plays an important role in the risk of injury. Acute fatigue generates a reduction in strength and motor control of the implicated muscle groups, making them more susceptible to injury, especially during high-intensity exercises at the end of a training session or a competition (Hawkins et al., 2001).

Sport injuries can be caused by intrinsic factors of the player and by extrinsic factors of the environment (Orchard, 2001). Among the extrinsic factors, the game surface represents one of the main causes of sport injuries. To date, research has been conducted on artificial turf, natural grass, and rigid surfaces to determine their influence on performance and sport injuries through injury registration (Hughes et al., 2013; Iacovelli et al., 2013; Sánchez-Sánchez et al., 2014).

Tensiomyography (TMG) is a non-invasive method developed to evaluate the mechanical properties and muscle contractility in response to electric stimulation. This method provides information on muscle stiffness, contraction speed, predominant muscle fibre types, and muscle fatigue (Rey et al., 2012). TMG has been demonstrated as a reliable method that can predict the risk of injury during sport practice (Alentorn-Geli et al., 2015).

This study is the first to analyse the differences in the muscle response after induced fatigue on sand and grass. Research conducted on sand and grass is related with other parameters. Alcaraz et al. (2011) studied the kinematics of sprint running between sand and an athletic track, finding differences in the players' biomechanical use. Binnie, Dawson, Arnot et al. (2014) demonstrated that sport practice on sand significantly increases the heart rate and involves a higher-intensity load compared to natural grass. In volleyball, the difference in the height of a vertical jump between sand and a firm surface was studied (Giatsis et al., 2004), noting that less jump height was reached on sand.

On the other hand, Brito et al. (2012) analysed the differences in football players' performance during simulated game situations on sand, grass, and concrete. Sand was the most demanding surface during the match, with higher levels of lactate, higher perceived exertion, and an elevated heart rate of the players. Finally, there is research on plyometric intervention training on sand, resulting in a recommended surface for improving neuromuscular adaptations and in analysing running economy on sand (Impellizzeri et al., 2008; Mirzaei et al., 2013; Pinnington et al., 2005).

There is a lot of controversy regarding the relationship between the game surface and injuries. Previous research has shown that playing on sand increases the risk of injury (Knobloch et al., 2008). In contrast, another study has shown a decrease in injury incidence compared to firm surfaces (Impellizzeri et al., 2008). Ekstrand et al. (2006) associate firmer surfaces (natural grass) with a higher musculoskeletal impact on the player, and Inklaar (1994) with overuse injuries. Therefore, during the formation period of the athlete in the preseason, training on a surface like sand could be more recommended compared to a firmer surface like natural grass, as there is a higher incidence of overuse injuries during this period of time (Woods et al., 2002). Also, sand can be more useful to improve the aerobic capacity of athletes who have suffered an injury (Impellizzeri et al., 2008).

Despite these studies, no scientific evidence exists on the risk or injury incidence according to the sport surface (Binnie, Dawson, Pinnington et al., 2014). The differences in fatigue produced on different game surfaces could be an indicator of the risk of muscle injury for the athlete. For this reason, the aim of this study was to discover the influence of sand and natural grass on muscle parameters in female rugby players after an induced fatigue test.

MATERIALS AND METHODS

Participants

A total of 15 healthy female amateur rugby players between 18 and 28 years old (23.4 ± 4.42) from the province of Toledo participated in the study. All of the participants signed a consent form to take part in the study, which detailed the tests and the possible risks. The study protocol was approved by the local ethics committee (Toledo Hospital) and was done according to the ethical code of the World Medical Association (Helsinki Declaration). The general characteristics of the participants are described in Table 1.

Table 1. Descriptive characteristics of the participants.

	Average	**SD**
Age (years)	23.40	3.36
Weight (kg)	65.21	12.08
Height (cm)	165.08	7.53
Fat (%)	27.25	6.11
Fat (g)	17987.66	1286.95
Muscle (g)	43705.20	1056.67
BMC (g)	2231.19	293.39
BMD (g/cm^2)	1.15	0.07

BMC: bone mineral content; BMD: bone mineral density.
SD= Standard Deviation

Study design

Previous to the start of the study, the players carried out an initial pilot test on a neutral surface to familiarize with all of the tests included in the study protocol. These tests were repeated on the rugby pitch of natural grass and on a beach sand surface in two different days during the same week, with a separation between them of 48h. The tests were developed in October between 16:00h and 20:00h in the same city and at the same altitude (529 m above sea level), under dry conditions, at a temperature between 18-22.5ºC and with a relative humidity of 20-30%.

The study was performed during a non-competitive week so that the players had not made any intense physical exertion before the tests. The players were asked not to do any exhausting activities for 72h before each test and to maintain the same food habits. They were also asked to use the same footwear on both surfaces. Before the start of the study, a global positioning system was attached to each player's back (GPS, HPU, GPSports, Australia) together with a monitoring heart rate band (Polar Team System, Kempele, Finland), which were proven to be valid and reliable (Barbero- Álvarez et al., 2010).

Prior to the different tests, the participants completed a standardised warm-up that consisted of 5 minutes of continuous running, 5 minutes of joint mobility, and three 30-m sprints, increasing the intensity with a 2-minute recovery between each sprint (Sánchez-Sánchez et al. 2014). No stretching was done either during or after the warm-up. In baseline, the contractile capacities of participants were measured and the participants performed a countermovement jump (CMJ). After, the players completed an RSA test in the specific surface (artificial turf and sand). Straight after, the contractile capacities of participants and CMJ were measured again.

Repeated-Sprint ability (RSA) shuttle test

The players completed an RSA test that consisted of six sprints of 40 m (20 + 20 m) with 20 s of passive recovery (Sánchez-Sánchez et al. 2014). The players began on the start line and ran 20 m, turning 180º and returning to the start line as quickly as possible.

Prior to the RSA test, each participant completed a preliminary maximum sprint that was used as a score criterion to validate the RSA test, resting for 5 minutes after this sprint before starting the RSA test. This way, if the performance of the first sprint of the RSA test was worse than the preliminary sprint, the test was not considered valid and the participant had to immediately stop and repeat the RSA test at a maximum exertion after a 5-minute recovery (Chaouachi et al., 2010).

The total time (RSATT) and the decrease percentage (%BEST) were calculated. The %BEST ([mean time/best time*100] –100) has been identified as the most valid and reliable method to evaluate fatigue in this type of test (Chaouachi et al. 2010). These data were collected using four pairs of photocells (Microgate, Bolzano, Italy) placed at the start line, at 5 m, at 10 m, at 30m, and at 40 m with a 0.001 s sensibility. The maximum speed (V_{MAX}) and maximum heart rate (HRmax) of players during the RSA test were monitored with GPS at 10 Hz and heart rate bands (Polar Team System, Kempele, Finland).

Vertical jumping

A CMJ was done before and after the RSA test using an infrared system (Optojump Next, Microgate, Bolzano, Italy) in a neutral surface (smooth concrete). The participants had to keep their hands on their hips to avoid the influence of arm movement on the jump performance. Each player did two CMJ jumps before and after the RSA test (2-minute recovery between jumps). The best jump was selected for the statistical analysis.

Tensiomyograpy (TMG)

The following procedures have already been described by other authors (Rey et al. 2012; Tous-Fajardo et al., 2010). The contractile capacity of the biceps femoris and the rectus femoris of both legs was evaluated using TMG (BMC Ltd., Ljubljana, Slovenia) before (resting state) and immediately after doing the RSA test and the CMJ with the aim of evaluating muscle fatigue. TMG is a non-invasive technique that measures maximal displacement (Dm) given by the radial movement of the muscle belly expressed in mm and depends on the muscle tone or stiffness; contraction time (Tc), the time between 10 and 90% of Dm; sustain time (Ts), the time in which the muscle response remains >50% of Dm; delay time (Td), also known as reaction or activation time, the time between the initiation and 10% of Dm; and half-relaxation time (TR), the time in which the muscle response decreases from 90 to 50% of Dm muscle (Figure 1).

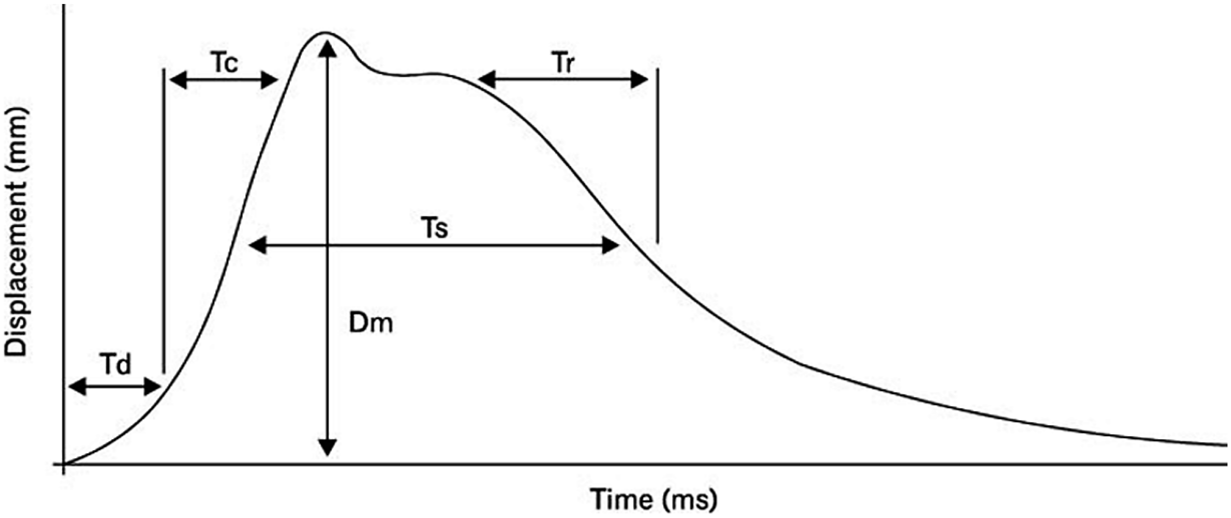

Figure 1. TMG parameters definition (Carrasco et al., 2011)

A small electric stimulation is produced on the required muscle. This stimulus is measured by placing a digital transducer perpendicular to the muscle belly Dc-Dc Trans –Tek® (GK 40, Panoptik d.o.o., Ljubljana, Slovenia). The stimulation of the selected muscle is made using two self-adhesive electrodes (TMG electrodes, TMG-BMC d.o.o. Ljubljana, Slovenia) placed equidistant to the point where the measurement will be made. The proximal electrode corresponds to the anode and the distal to the cathode. The stimulus is produced by a TMG-100 system electrostimulator (TMG-BMC d.o.o., Ljubljana, Slovenia) of 1 ms duration. The amplitude range of the electrical stimulus can be from 0 to 110 mA.

The rectus femoris was measured with the individual in a supine position with a 60º knee flexion with the help of a foam triangular-shaped cushion. The biceps femoris was measured with the individual lying face down and with the knee flexed at 5º with the help of a foam cushion. The digital transducer was placed following Delagi et al. (1975) indications. The electrodes were placed symmetrically from the sensor at the same distance of 50–60 mm. Both the sensor and electrode positions were marked with a permanent marker to guarantee that the measurements in the research were made at the same point. Ultimately, the stimulation was of 1 ms, giving four stimulations to each muscle, varying the amplitude (25, 50, 75, and 100 mAp). All of the measurements were done by the same technical expert in this type of measurement.

Statistical analysis

The reliability of the TMG parameters was calculated through intraclass correlation coefficient reliabilities (ICCRs). Results are presented as mean and standard deviation (SD). The verification of the normality and homogeneity of the variances was assumed by means of the Kolmogorov–Smirnov test and the Leven's statistic. The comparison between results collected in the RSA test on different surfaces and TMG assessment before and after the RSA test on both surfaces (natural grass and sand) was analysed using a T-Student test. Data were analysed with the statistic software SPSS v 20.0. The level of significance was established at $p<0.05$. The effect size (ES; Cohen's d) was evaluated according to the following criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate, and 0.8 = significant (Cohen, 1992). In addition, the confidence interval (CI of 95%) was calculated to identify the magnitude of changes. Statistical significance level was set at $p<0.05$.

RESULTS

In relation to the RSA test results, the RSATT (grass 10.04 ± 0.68 s and sand 10.65 ± 0.93 s; -0.61 s; ES= 0.75; IC: -0.87 to -0.34) and the VMAX (grass 4.00 ± 0.26 m/s and sand 3.78 ± 0.32 m/s; 0.22 m/s; ES= 0.76; IC: 0.12 to 0.31) showed significant differences between the surfaces (p<0.01). The %BEST of the RSA test were significant in the fifth and sixth sprint when comparing natural grass and sand (Figure 2). In this context, HRmax during the RSA test was higher on the sand (192.15 ± 11.82 b.p.m.) with respect to natural grass (189.46 ± 11.82 b.p.m.), but significant differences were not found (p=0.54). On the other hand, CMJ height decreased (-2.89 cm; ES= 0.67; IC: to -4.59 to -1.18) after performing the RSA test on sand versus natural grass.

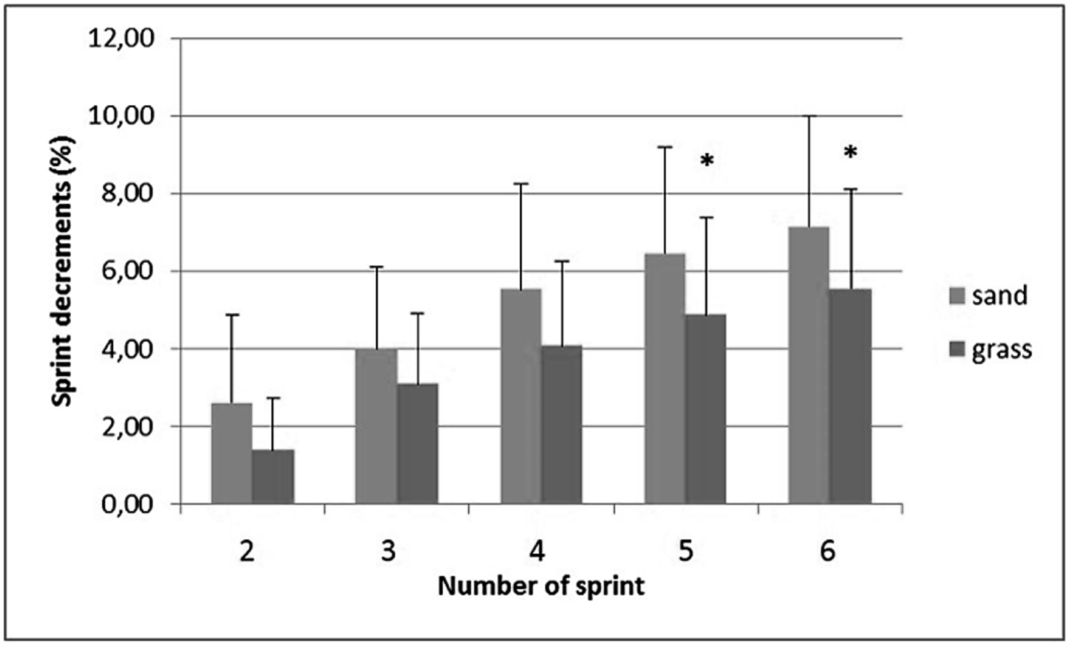

Figure 2. Profile of mean sprint decrements (%Best) compared to the first sprint of the 6 x 40-m test RSA. *Significantly different from the 6 x 40-m sprint decrement between surfaces $p<0.05$.

Table 2 shows the results between pre- and post-variables on natural grass and sand of Tc, Tr, Td, and Ts of the rectus femoris and the biceps femoris after completing the RSA test. When comparing the pre- and post-variables of the same surface, the female rugby players showed significant differences in the rectus femoris in the Tr (8.15 ms; ES= 0.81; IC: 5.90 to 10.40; p<0.05) and Ts (31.88 ms; ES= 0.70; IC: 17.87 to 45.89; p<0.05) variables on natural grass and in the Tr variable (11.21 ms; ES= 1.30; IC: 1.72 to 20.70; p<0.01) on sand. The biceps femoris results showed significant differences in the Tr (54.04; ES= 1.28; IC: 37.32 to 75.40; p<0.01) and Td variables (7.13 ms; ES= 0.68; IC: 5.90 to 20.16; p<0.01) on natural grass and in the Tr variable (40.17 ms; ES= 1.07; IC: 31.68 to 112.02; p<0.01) on sand. Once the RSA test was completed on both surfaces, the results revealed significantly higher values on the sand for the rectus femoris for the Tc variable (11.66 ms; ES= 1.00; IC: 4.03 to 9.29; p≤0.01).

Table 2. Comparison of the Tc, Tr, Td and Ts variables of the rectus and biceps femoris.

	Natural grass			**Sand**			***P***
Variable	Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Post
RF							
Tc (ms)	37.43 ± 10.86	39.31 ± 12.22	8.22 ± 11.25	39.76 ± 6.17	50.97 ± 11.01**	30.77 ± 14.11	0.010†
Tr (ms)	28.46 ± 9.45	36.61 ± 10.60*	41.47 ± 12.43	31.69 ± 7.39	33.39 ± 12.46	6.91 ± 2.03	0.388
Td (ms)	27.10 ± 3.14	30.43 ± 9.60	12.39 ± 8.64	25.30 ± 3.18	29.05 ± 9.75	16.96 ± 6.72	0.601
Ts (ms)	118.07 ± 20.03	149.95 ± 12.88*	38.70 ± 10.19	118.16 ± 29.21	132.46 ± 25.06	17.37 ± 12.95	0.221
BF							
Tc (ms)	31.36 ± 7.30	31.54 ± 6.79	3.75 ± 8.14	28.87 ± 8.18	28.49 ± 8.42	0.64 ± 1.05	0.284
Tr (ms)	49.19 ± 18.92	103.23 ± 65.53**	35.22 ± 15.55	58.75 ± 19.12	98.92 ± 55.78**	45.98 ± 27.81	0.794
Td (ms)	29.08 ± 7.16	36.21 ± 13.81**	26.05 ± 8.99	28.45 ± 7.01	29.52 ± 7.82	5.44 ± 4.11	0.056

Ts (ms)	204.19 ± 75.62	203.95 ± 96.18	15.51 ± 11.67	217.53 ± 77.83	219.98 ± 91.42	8.11 ± 2.84	0.616

*Significant differences between pre and post on the same surface (*p*<0.05).

** Significant differences between pre and post on the same surface (*p*≤0.01).

† Significant differences between surfaces (*p*<0.05).

Dif. (%): difference of percentage between pre and post.

RF: rectus femoris; BF: biceps femoris; Tc: contraction time; Td: delay time; Tr: half-relaxation time; Ts: sustain time.

In Table 3 we can observe the differences in the Dm variable. Between TMG pre- and post- after the RSA test, the results showed significant differences on grass and sand in the rectus femoris (grass: 0.94 mm; ES= 0.64; IC: 0.57 to 2.45; p<0.05; sand: 1.76 mm; ES= 1.77; IC: 1.19 to 2.33; p<0.01) and biceps femoris (grass: 0.78 mm; ES= 0.42; IC: 0.25 to 1.31; p<0.05; sand: 2.14 mm; ES= 1.66; IC: 0.65 to 3.63; p<0.01). When the post-tests between the two surfaces were compared, significantly higher values in the Dm of the rectus femoris on the sand were obtained (1.20 mm; ES= 0.80; IC: 0.21 to 2.61; p<0.05).

Table 3. Comparison of maximal displacement (Dm) between natural grass and sand in post-test

		Natural Grass			**Sand**			***P***
Variable		Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Post
RF								
	Dm (mm)	2.46 ± 1.09	3.40 ± 1.86*	55.03 ± 13.11	2.84 ± 0.85	4.60 ± 1.14**	75.44 ± 5.66	0.042†
BF								
	Dm (mm)	3.87 ± 2.01	4.65 ± 1.74*	57.63 ± 8.48	3.36 ± 1.67	5.50 ± 0.91**	62.61 ± 11.73	0.162

*Significant differences between pre and post on the same surface (*p*<0.05). ** Significant differences between pre and post on the same surface (*p*≤0.01). † Significant differences between surfaces (*p*<0.05).

Dif. (%): difference of percentage between pre and post.

RF: rectus femoris; BF: biceps femoris; Dm: maximal displacement.

DISCUSSION

The main findings of this study were that the RSA test done on the sand produces a different muscle response compared to physical exercise done on natural grass. In recent years, there has been an increase of studies that use TMG in their investigations of diverse topics, such as sport and rehabilitation (García-Manso, Rodríguez-Ruiz et al., 2011; García-Manso, Rodríguez-Matoso et al., 2011), among others.

This technique has been validated and evaluated by various authors, proving to be reliable for collecting this type of data (Tous-Fajardo et al., 2010), with a high sensitivity for detecting changes in the characteristics of the leg muscles (Rodríguez-Ruiz et al., 2011). Various studies have proven their use for professionals and researchers for detecting muscle damage and recovery (García-Manso, Rodríguez-Matoso et al., 2011). Because it is a non-invasive evaluation technique and is independent of motivation, TMG has recently been incorporated in the rehabilitation and sport training fields (Tous-Fajardo et al., 2010). However, it has never been used to measure the contractile capacity of the muscles after an induced fatigue test on different sport surfaces.

In relation to performance parameters during the RSA test, players reached higher speed peaks on natural grass. In this way, the total times of the test are lower on this surface compared to on the sand, and the differences in fatigue start to be more evident between the two surfaces at the fifth sprint. Our results coincide with studies like that of Alcaraz et al. (2011) who concluded that sand reduces running speed due to a higher overuse of the athlete. Studies on runners using electromyography prove high energy expenditure associated with higher muscle activity during running on sand compared to a firm surface (Pinnington et al., 2005). Also, when comparing an eight-week training session on grass and sand, a higher fatigue is perceived on sand compared to natural grass (Binnie, Dawson, Arnot et al., 2014). Other studies using reduced game situations in football players have proven that players have a higher fatigue perception when they play on sand compared to asphalt (Brito et al., 2012).

In TMG, fatigue is manifested by a reduction in the capacity to maintain a determined level of strength during a sustained contraction or the inability to reach an initial strength level in repeated contractions, along with changes in electric muscle activity (Rodríguez-Matoso et al., 2012). Using TMG, fatigue is detected by increments in Dm (García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al., 2011), in Td (Šimunič et al., 2005), in Tc (Smith et al., 2006), in Ts (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012), and in Tr (García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al., 2011). The results that we obtained in each surface between TGM pre- and post- are of a higher Tr and Ts in the RF and a higher Tr and Td in the BF on natural grass, and a higher Tc and Dm in the RF and a higher Tr and Dm in the BF on sand. When we compare between surfaces, sand provokes higher muscle fatigue in the RF with 29.66% more contraction time and 35.29% more muscle belly deformation.

These findings coincide with studies like that of García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al. (2011) who evaluated the state of the muscle immediately after an ultra-resistance triathlon and found an increase in the BF in the Tc, Tr, and Dm once the race was finished. The effect of muscle fatigue generates a loss in contractile capacity shown by changes in neuromuscular response and muscle contractile capacity (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012). Wiewelhove et al. (2015) observed a significant increase in Tc in the RF and BF after high-intensity interval training during six days, which is a potential marker for fatigue and recovery control. A reduction of stiffness (increasing Dm) causes a loss of strength and explosive power, decreasing the ability to generate force rapidly (Wiewelhove et al., 2015).

In contrast, authors like López-Rovira and Amorrich-del Fresno (2014) revealed a statistically significant decrease in Dm after exercise (p<0.01). However, after a recovery muscle massage, they detected a significant maximum deformation increment (p<0.01) due to a decrease in muscle stiffness and tone. In short- to medium-duration resistance events with an elevated intensity (2 minutes on a cycle ergometer), the participants showed statistically significant decreases in Dm values (Carrasco et al., 2011). These results highlight the importance of controlling parameters like the intensity of the exercise, the duration, the type of activity practiced, and the magnitude of the stimulation, as very short stimulations will not fatigue type I fibres (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012).

Resistance to fatigue and muscle stiffness can be a risk factor for injury. Alentorn-Geli et al. (2015) analysed the risk of anterior cruciate ligament injury in male football players. Their results were that the players with an injury at the time of the test had higher values in Tc, Tr, and Ts in the RF and in Dm in the BF compared to those players without injuries. These results must be taken into account when choosing athletes with a high anterior cruciate ligament injury risk and also for designing adequate prevention programmes for anterior cruciate ligament injuries in female rugby players. As an alternative use, sand can also be used as an effective rehabilitation surface, as it reduces force impact due to its ability to absorb impact, which is useful for adequate injury rehabilitation (Impellizzeri et al., 2008). However, the higher fatigue on the sand surface demonstrated in this study requires a higher control of training load. This control would allow the use of sand for sport training due to the benefits in the athlete's performance, incorporating exercises on sand during their firm surface training (Mirzaei et al., 2013).

Although TMG is a reliable method, various methodological factors exist that can affect its reliability, such as the position of the sensor in relation to the muscle belly, the pressure point of the sensor, and the placement of the electrodes (Tous-Fajardo et al., 2010). To minimise these factors, the zone where the electrodes were placed were marked with a felt-tip pen so that they were always put in the same place; the measure of the sensor point was also marked, and the tests were always measured by the same person. One of the limitations of this study was the evaluation of only two muscle groups. It is possible to evaluate other lower trunk muscle groups, as well as increase the number and intensity of the stimulations in each muscle group. In future research, the measurement of serum concentrations of creatine kinase (CK), C-reactive protein (CRP), and urea, as well as of delayed onset muscle soreness (DOMS) at the end and after 72h, could provide information on the evolution and correlation of these parameters with the TMG variables.

CONCLUSION

Information on skeletal muscle structure is very important for observing changes in the muscles and improving training processes of athletes (Dahmane et al., 2001). Also, the follow up and control with TMG helps training, as it allows an adequate monitoring and improves injury prevention programmes, decreasing their incidence (Vasilescu et al., 2008). Nonetheless, its use in the sport field is still incipient. Therefore, the main conclusion of this research is that repetitive-sprint-actions on sand regarding the natural grass produces higher levels of muscle fatigue on rectus femoris but not on biceps femoris. Hence, this research can help technical and medical personnel for predicting and orientating future prescription of training load and avoid muscle injury risk.

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