Title

Mechanical properties of the triceps surae: Differences between football and non-football players

Running title

Mechanical properties of triceps surae

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Abstract

We investigated the mechanical properties of the triceps surae between professional, junior, and non-football players. Fifty-nine men participated in this study. The mechanical properties of the right legs' triceps surae were measured *in vivo* using a free oscillation technique; no significant differences existed between the groups. The mean results for musculo-articular stiffness, damping coefficient, and damping ratio were as follows: professional football players (21523 $N.m^{-1}$, 330.8 $N.s.m^{-1}$, and 0.201); junior football players (21063 $N.m^{-1}$, 274.4 $N.s.m^{-1}$, and 0.173); and non-players (19457 $N.m^{-1}$, 281.5 $N.s.m^{-1}$, and 0.184). When analyzed according to position, the results were as follows: defender (21447 $N.m^{-1}$, 308.6 $N.s.m^{-1}$, and 0.189); midfielder (20762 $N.m^{-1}$, 250.7 $N.s.m^{-1}$, and 0.157); winger (21322 $N.m^{-1}$, 335.1 $N.s.m^{-1}$, and 0.212); forward (22085 $N.m^{-1}$, 416.2 $N.s.m^{-1}$, and 0.254); and non-players (19457 $N.m^{-1}$, 281.5 $N.s.m^{-1}$, and 0.184).

Thus, football training, football games, and the position played had no effect on triceps surae mechanical properties. These results may be attributed to opposing adaptations between different types of training that are usually implemented in football. Alternatively, the minimum strain amplitude and/or frequency threshold of the triceps surae required to trigger adaptations of mechanical properties might not be achieved by football players with football training and matches.

1. Introduction

Stiffness is a mechanical property often addressed in human studies. As a general definition, stiffness (the ratio of force change-to-length change) can be described as the relationship between the deformation of an elastic structure and the force applied to it (Butler et al., 2003). Different techniques to measure stiffness of different biological structures that use specific terminology exist (Ditroilo et al., 2011). In the present study, the triceps surae stiffness was assessed using a valid and reliable free oscillation technique (Murphy et al., 2003, Walshe et al., 1996). The term that more appropriately describes this type of measurement is the musculo-articular stiffness and therefore it will be used throughout the text (Ditroilo et al., 2011). This technique consists of applying a perturbation to the ankle joint and measuring the natural damped oscillations produced (Faria et al., 2011, Shorten and Kerwin, 1987).

Problems experienced at the ankle-foot complex may have repercussions to the entire lower extremity (Abboud, 2002, Faria et al., 2009b). The foot has passive and active functions, with the former function responsible for protecting the human body from impact forces imparted during daily and sport activities, and the latter function responsible for transferring internal forces generated by the muscular system to the ground to accelerate the body in the push-off phase of gait (Rosenbaum and Becker, 1997, Mueller, 2005). Triceps surae play an important role in these functions, which highlights the importance to investigate the mechanical properties (e.g. musculo-articular stiffness) of the triceps surae. Additionally, it has been suggested that the control of musculo-articular stiffness is one of the main components of stability and neuromotor function (Granata et al., 2004, Houk, 1979). Apart from the above studies mentioned other reports have related stiffness to the risk of injury and to sports performance (Butler et al., 2003).

Football is one of the most popular sports worldwide. The people actively involved in football represent 4% of the world's population (Kunz, 2007), and this figure is on the rise. According to Hoff (2005), physiologic capacities, such as muscular strength, power, and endurance, are important physical attributes required to play football. Football training strives to improve these attributes and therefore, as part of the training process musculoskeletal changes are expected to occur. Several studies have shown that muscle tendon unit mechanical properties (e.g. musculo-articular stiffness) may be altered with strength training. These studies reported an increase in tendon stiffness (Kubo et al., 2002, Kubo et al., 2001) and musculo-articular stiffness (Spurrs et al., 2003) as well as an increase in Young's modulus (i.e. slope of stress-strain curve) of human tendon structures (Kubo et al., 2001, Reeves et al., 2003, Woo et al., 1980), muscle size (Kubo et al., 2002, Kubo et al., 2001, Narici et al., 1996) and tensile strength (Woo et al., 1980). In addition to strength training, endurance training has also been reported to affect these mechanical properties (Kubo et al., 2000, Hobara et al., 2010). More specifically, it has been reported that leg stiffness is greater in endurance-trained athletes than untrained participants due to ankle and knee joint stiffness (Hobara et al., 2010). The same trend (i.e. higher stiffness) was also reported for the vastus lateralis muscle between distance runners and untrained participants (Kubo et al., 2000). Additionally, endurance activities conducted in rats have been linked to greater stiffness of the series elastic component, which is associated with a decrease in type II fibers (Goubel and Marini, 1987).

Thus, it is plausible that with football training sessions, changes to the mechanical properties (e.g. musculo-articular stiffness) of the muscle-tendon unit occur. Considering these potential changes in muscles and tendons with football training, we hypothesized that significant differences exist between football players and non-football players. More specifically, we expected to demonstrate higher values of the triceps surae musculo-articular stiffness in football than non-football players.

Although the goal of the present study was not to determine the relationship between the mechanical properties of the triceps surae and the risk of injury, an understanding of these properties may also provide some insight for injury prevention in football because excessive or insufficient stiffness levels have been related to the risk of bone and soft tissue injuries, respectively (Faria et al., 2009a, Butler et al., 2003). Moreover, as damping can be related to energy absorption, an increase in damping characteristics (i.e., damping coefficient and damping ratio) may indicate an increased ability to absorb energy and minimize the risk of injuries (Hunter et al., 2001).

An improved understanding of the mechanical properties of the triceps surae will provide a foundation for better evaluating changes which accompany training regimens, particularly in football, that could aid in the development of more effective training and injury prevention programs for sports activities. Therefore, the aim of this study was to determine the mechanical properties of the triceps surae in professional and junior football players, taking also into account their playing positions, along with non-football players. This is the first comparative study examining the mechanical properties of the triceps surae in the aforementioned categories

2. Methods

2.1 Participants

Fifty-nine men participated in this study. Seventeen participants were professional football players (26.0 ± 5.5 years; height, 1.79 ± 0.07 m; body mass, 74.6 ± 7.1 kg; body mass index, 23.2 ± 1.0 kg/m^2); 17 were junior football players (17.8 ± 1.0 years; height, 1.71 ± 0.04 m; body mass, 64.9 ± 6.9 kg; body mass index, 22.1 ± 1.8 kg/m^2), and 25 were non-football players (20.7 ± 1.8 years; height, 1.74 ± 0.06 m; body mass, 66.2 ± 7.6 kg; body mass index, 21.7 ± 1.7 kg/m^2). The professional team played in the second division of honor. The professional and junior football players trained six and 3 times per week, respectively. Both football groups played one official match per week. The non-players were university students and did not engage in physical activity on a regular basis.

All participants were healthy and had no injuries. The body mass and height of each participant were measured by a conventional scale and a stadiometer (Seca 220; Seca Corporation, Hamburg, Germany), respectively.

Once each participant was informed of the nature of the study, an informed written consent was obtained. This research was performed in accordance with the Declaration of Helsinki and ethical approval was obtained.

2.2 Instruments

The vertical ground reaction force to assess the maximal voluntary isometric contraction and musculo-articular stiffness was obtained using a Kistler force plate (Kistler 9281B; Kistler Instruments, Amherst, NY, USA). Kinetic data were collected with BioWare 4.0 type 2812A software (Kistler Instruments). The equipment illustrated in Fig. 1 was used in conjunction with the force plate with a sampling rate of 1000 Hz. The vertical ground reaction forces were used to calculate the maximal voluntary isometric contraction and free oscillation data, in this order. Two wooden blocks (10 cm in height) were placed on top of the force plate to serve as a support for the calcaneus and forefoot. As illustrated by the equipment in Fig. 1, standard weights were used as external loads and placed on top of the lever.

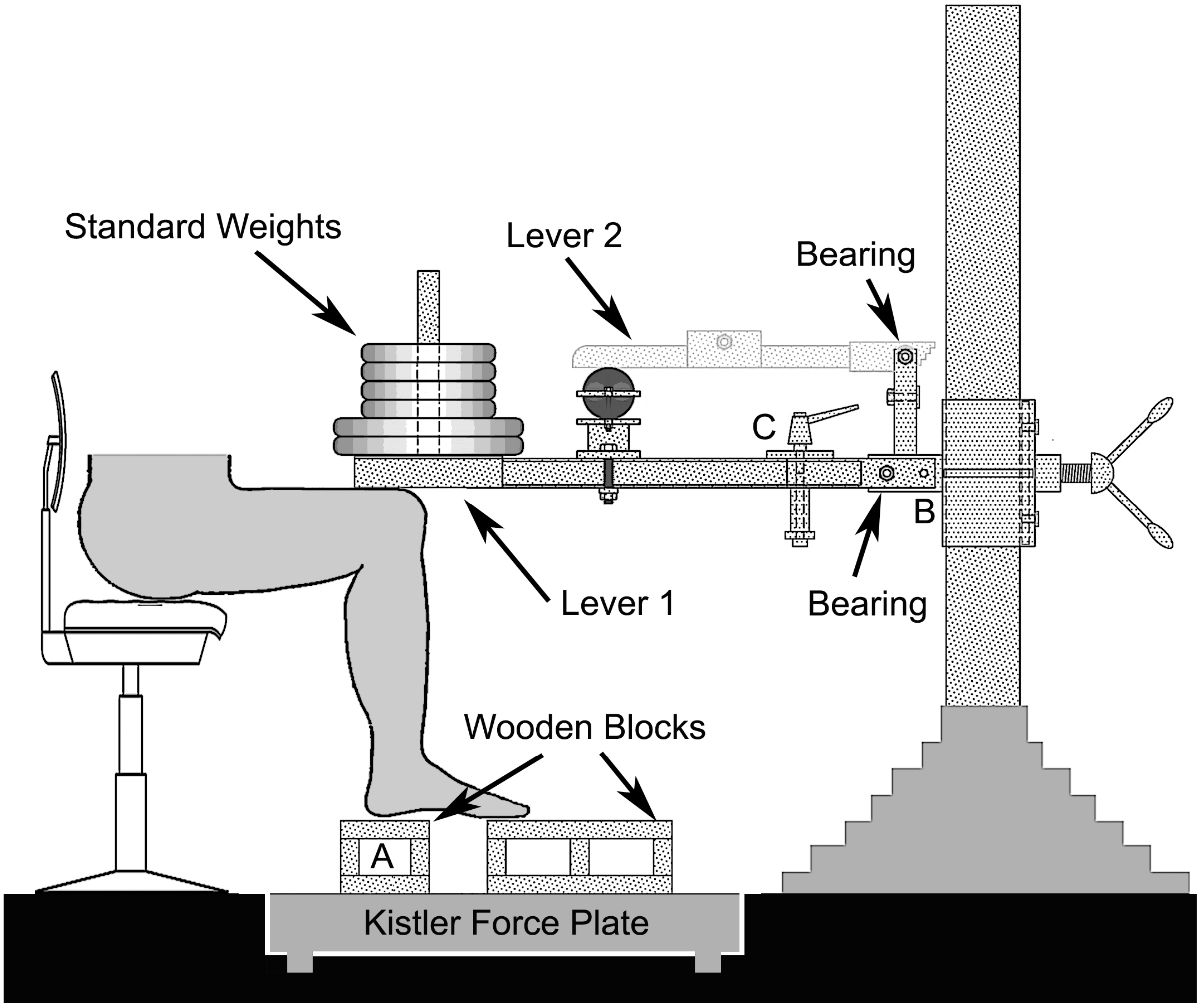

Fig. 1 Equipment and position used to determine the muscle-tendon unit (MTU) stiffness

2.3 Maximal voluntary isometric contraction measurement

To evaluate the maximal voluntary isometric contraction, participants sat in a chair without any thigh support with the angles of the trunk-thigh, leg-thigh, and leg-foot at 90°, and the arms folded across the chest. In this position the metatarsal-phalangeal joint of the right barefoot was aligned with the edge of one wooden block and the calcaneus was supported by another wooden block. Data were only collected from the right ankle, as muscle stiffness does not vary between the dominant and non-dominant limbs (Faria et al., 2009a, Murphy et al., 2003). The right foot was also the preferred foot for all of the participants.

Lever 1 was locked with the mechanisms represented by letter Bs and C, as illustrated in Fig. 1, and rested on the knee of each participant. The participants were then instructed to perform a plantar flexion and produce a force as hard and as quickly as possible against the locked lever with the right foot for 4 seconds. Verbal encouragement was given during this period and the peak force generated was taken as the maximal voluntary isometric contraction value. Three maximal voluntary isometric contraction measurements were obtained and the best of the three attempts was designated as the maximal voluntary isometric contraction value. Further details about maximal voluntary isometric contraction assessment have been published elsewhere (Wilson and Murphy, 1996).

2.4 Free oscillation data measurement

Using the free oscillation technique, it is assumed that the muscle-tendon unit is modeled as a mass-spring system with a damping element (Shorten, 1987). A brief downward force applied to the loaded system initiates an oscillatory movement that decays towards zero due to the viscoelastic properties of the muscle-tendon unit (Shorten, 1987). Free oscillation data were assessed using the same equipment and position utilized to collect maximal voluntary isometric contraction data; however, Lever 1 (Fig. 1) was unlocked and rested on the knee of each participant. The wooden block (designated by the letter A in Fig. 1) that supported the calcaneus was removed so that the right foot could move in the sagittal plane. Each subject was then instructed to activate the plantar flexors isometrically, maintaining the leg–foot at a 90° angle and sustaining a steady state muscle contraction for a period of 10s. During this period, standard weights representing 30% of the maximal voluntary isometric contraction were placed on top of Lever 1 (Fig. 1).

To disturb the foot–ankle angle, Lever 2 was dropped onto Lever 1, producing a force of 100 N. After impact, Lever 2 rebounded and during this time period the technician grabbed Lever 2. The oscillations produced at the ankle-foot (plantarflexion/dorsiflexion) were registered and used to assess the musculo-articular stiffness. Participants were prevented from seeing the application of the impulse and were instructed not to react to any stimulus (Faria et al., 2009a, Faria et al., 2010, Hunter and Spriggs, 2000). The impulses were applied randomly to prevent participants from anticipating the impulses. Moreover, a previous pilot study using electromyography suggested that no reflex activity prior to the application of the impulse influenced the results. After a familiarization period with the procedures, two trials were collected.

2.5 Data analysis

Fourier analysis was performed on kinetic data, and frequencies > 15 Hz were filtered out with a low-pass filter. Using the procedures described in the literature (Faria et al., 2009a, Faria et al., 2010, Hunter and Spriggs, 2000), the triceps surae musculo-articular stiffness was calculated for each of the two trials and the mean was calculated. The musculo-articular stiffness (k) was calculated from the free oscillation data using Eq. (1), as follows:

$$k = 4\pi^2 f_d^2 m + \frac{c^2}{4m} \quad (1)$$

where $\boldsymbol{m}$ represents the total mass (kg) of the system (leg, foot, lever, and standard weights), $\boldsymbol{c}$ is the damping coefficient (Ns/m), and $\boldsymbol{f_d}$ is the damped natural frequency of oscillation.

From the inverse of the time period (T) between force peaks ($\boldsymbol{F_1}$, $\boldsymbol{F_2}$) the damped natural frequency of oscillation ($\boldsymbol{f_d}$) was obtained using Eq. (2), while the logarithmic decrement was given by Eq. (3), as follows:

$$f_d = \frac{1}{T} \quad (2) \qquad\qquad \lambda = \ln\frac{F_1}{F_2} \quad (3)$$

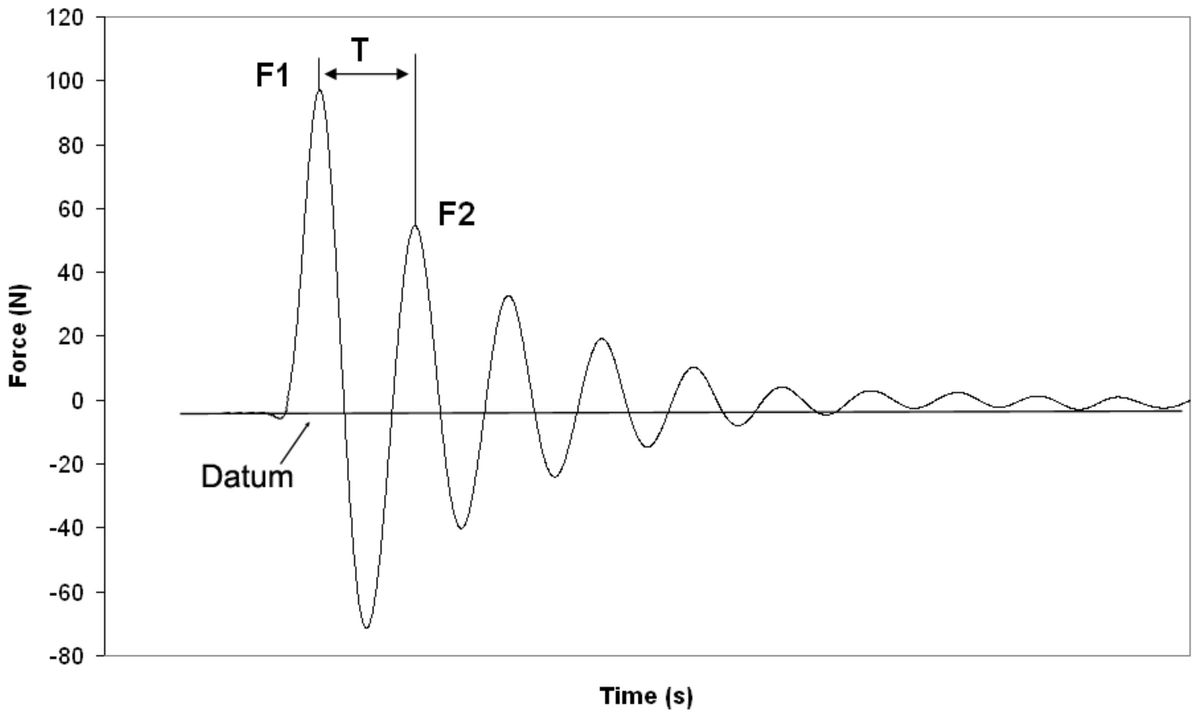

Fig. 2 Free oscillation trace and the points used to calculate the natural frequency of oscillation and logarithmic decrement.

After calculating the logarithmic decrement the following equations (4–6) were used to calculate the damping ratio (ζ), damped circular frequency ($\boldsymbol{\omega_d}$), and undamped circular frequency ($\boldsymbol{\omega_0}$):

$$\zeta = \frac{\lambda}{\sqrt{4\pi^2 + \lambda^2}} \quad (4) \qquad \omega_d = 2\pi f_d = \frac{2\pi}{T} \quad (5) \qquad \omega_0 = \sqrt{\frac{k}{m}} = \frac{\omega_d}{\sqrt{1-\zeta^2}} \quad (6)$$

Using the total mass of the system, the damping ratio (ζ) and the undamped circular frequency ($\boldsymbol{\omega_0}$), the damping coefficient (***c***) was obtained from Eq. (7). After calculating the damping coefficient (***c***), the musculo-articular stiffness (k) was assessed with Eq. (1).

$$c = 2m\zeta\omega_0 \quad (7)$$

2.6 Statistical procedures

The Statistical Package for Social Sciences (SPSS 17.0; SPSS, Inc., Chicago, IL, USA) was used to perform statistical analyses between professional, junior, and non-football players. A p-value of 0.05 was considered statistically significant. The normality of data was checked with the Shapiro-Wilk test, and the Levene test assessed homogeneity of variance. One-way ANOVA tests were performed to identify differences between groups for the following variables: natural frequency of oscillation; damping ratio; damping coefficient; maximal voluntary isometric contraction; and musculo-articular stiffness. The Shapiro-Wilk test revealed that data were not normally distributed for musculo-articular stiffness normalized for mass. Thus, the Kruskal-Wallis test was utilized to detect statistical differences between groups for this variable. When the sample size is small it is not possible to test if data is normally distributed thus the use of non-parametric methods in statistical procedures is advocated (StatSoft Inc., 2011). To test for differences in the mechanical properties of the football players according to the playing position (i.e., defender, midfielder, winger, and forward) a Kruskal-Wallis test was used because of the small sample size of the sub-groups. However, even when a normal distribution was assumed and additional statistical procedures using parametric tests (ANOVA) were applied, the results did not change (data not shown).

An intra-session reliability analysis for the overall sample was also carried out between the musculo-articular stiffness using the test-retest standard deviation of differences with 95% limits of agreement. Procedure details can be found elsewhere (Atkinson and Nevill, 1998, Bland and Altman, 1999).

3. Results

The musculo-articular stiffness mean data obtained for the overall sample in the present study was 20515 $N.m^{-1}$. One-way ANOVA tests revealed that the mean musculo-articular stiffness of the professional football players was slightly greater (21523 $N.m^{-1}$) than the junior football players (21063 $N.m^{-1}$) and the non-football players (19457 $N.m^{-1}$); however, no statistically significant differences were shown for the musculo-articular stiffness between these groups. Additionally, no significant differences were noted for the natural frequency of oscillation, damping ratio, damping coefficient, maximal voluntary isometric contraction and musculo-articular stiffness normalized for body mass (Table 1).

Table 1

Statistical analysis for natural frequency of oscillation, damping ratio, damping coefficient, maximal voluntary isometric contraction (MVIC), MAS, and MAS normalized by body mass (MAS / body mass) between groups

Variables	Professional Football Players (n = 17)	Junior Football Players (n = 17)	Non- football Players (n = 25)	ANOVA	Kruskal-Wallis
Natural frequency of oscillation (Hz)	4.14 (0.29)	4.18 (0.35)	4.05 (0.33)	$F_{2,56} = 0.809$; $p = 0.450$	-----------
Damping ratio	0.201 (0.06)	0.173 (0.08)	0.184 (0.06)	$F_{2,56} = 0.817$; $p = 0.447$	-----------
Damping coefficient ($N.s.m^{-1}$)	330.8 (116)	274.4 (134)	281.5 (117)	$F_{2,56} = 1.130$; $p = 0.330$	-----------
MVIC (N)	766 (104)	739 (113)	728 (105)	$F_{2,56} = 0.636$; $p = 0.533$	-----------
MAS ($N.m^{-1}$)	21523 (4145)	21063 (3207)	19457 (4004)	$F_{2,56} = 1.711$; $p = 0.190$	-----------
MAS / Body mass ($N.m^{-1}.kg^{-1}$)	290 (102)	328 (122)	297 (166)	-----------	$p = 0.171$

Values are the mean (standard deviation). Subscript numbers represent the degrees of freedom (i.e. between groups and within groups)

No significant differences were found in the mechanical properties of the football players according to their playing positions (Table 2).

Table 2

Statistical analysis for natural frequency of oscillation, damping ratio, damping coefficient, maximal voluntary isometric contraction (MVIC), MAS, and MAS normalized by body mass (MAS / body mass) between non-football and football players according to their playing position

Variables	Defender (n = 10)	Midfielder (n = 13)	Winger (n = 5)	Forward (n = 4)	Non-players (n = 25)	Kruskal-Wallis
Natural frequency of oscillation (Hz)	4.15 (0.24)	4.13 (0.38)	4.25 (0.18)	4.14 (0.53)	4.05 (0.33)	p = 0.686
Damping ratio	0.189 (0.06)	0.157 (0.06)	0.212 (0.06)	0.254 (0.05)	0.184 (0.06)	p = 0.119
Damping coefficient ($N.s.m^{-1}$)	308.6 (128)	250.7 (123)	335.1 (109)	416.2 (116)	281.5 (117)	p = 0.221
MVIC (N)	753 (119)	744 (107)	725 (96)	793 (123)	728 (105)	p = 0.829
MAS ($N.m^{-1}$)	21447 (3317)	20762 (4626)	21322 (1249)	22085 (4799)	19457 (4004)	p = 0.423
MAS / Body mass ($N.m^{-1}.kg^{-1}$)	305 (55)	294 (66)	348 (32)	322 (90)	297 (69)	p = 0.359

Values are the mean (standard deviation). Goalkeepers were not considered in this analysis and the two football groups were combined.

From the limits of agreement reported in Table 3 it can be said that for any individual from the population, assuming the bias (2%) is negligible, any two tests will differ due to measurement error by no more than 12% either in a negative or positive direction. It is worth to note however, that if we remove the four most extreme values a bias of 1% and a measurement error of 9% is obtained.

Table 3

Intra-session reliability of the whole sample between the tests adopted to determine MAS

MAS ($N.m^{-1}$) Test (1)	MAS ($N.m^{-1}$) Test (2)	Mean and SD of the differences ($N.m^{-1}$)	95% limits of agreement ($N.m^{-1}$)
			Mean + 1.96*SD = 2871
20330 (3848)	20700 (4021)	371 (1276)	Mean - 1.96*SD = -2129

Values are the mean (SD); MAS represents musculo-articular stiffness

4. Discussion

The purpose of this study was to determine the differences in mechanical properties of the triceps surae between professional, junior, and non-football players, and the behavior of these properties between football players according to the playing position. No statistical differences existed between the three groups with respect to natural frequency of oscillation, damping ratio, damping coefficient, maximal voluntary isometric contraction, musculo-articular stiffness, and musculo-articular stiffness normalized for body mass (Table 1). Further analysis between football positions did not reveal any significant differences in the mechanical properties of the triceps surae (Table 2). The results obtained in the present study are in agreement with the findings reported in other studies that used the same free oscillation technique and participants randomly recruited through advertising (Hunter et al., 2001, Murphy et al., 2003). The overall musculo-articular stiffness mean value obtained in the present study was 20515 $N.m^{-1}$. Murphy et al. (2003) reported mean values of approximately 16000 $N.m^{-1}$ for a load representing 25% of the maximal voluntary isometric contraction; however, we used a 30% maximal voluntary isometric contraction load, therefore this difference might be explained by the higher load used. Moreover, Hunter et al. (2000) using a load of 30% maximal voluntary isometric contraction reported stiffness values of 22730 $N.m^{-1}$ in one of the tests.

In many sports, the implementation of both strength and endurance training into workout programs is of importance. Muscular strength, power, and endurance have been highlighted as important physical resources in terms of basic physiologic capacities required to play football (Hoff, 2005).

Several studies have shown that strength training leads to an increase in the mechanical properties of the muscle-tendon unit. Spurrs et al. (2003), using the free oscillation technique, studied the effects of plyometric training on distance running performance and reported an increase in musculo-articular stiffness. Wilson et al. (1994), using the same technique, reported that participants with greater musculo-articular stiffness had a superior rate of force development in concentric and isometric bench press, as well as greater overall force in isometric bench press compared to individuals with lower musculo-articular stiffness. Additionally, Walshe et al. (1996) demonstrated that maximal stiffness was significantly correlated with the isometric and concentric rates of force development. In addition to the three aforementioned studies, other studies using different methods also reported an increase in tendon (Kubo et al., 2002, Kubo et al., 2001) and muscle-tendon stiffness (Narici et al., 1996).

With respect to endurance training, there are few studies that relate this type of training with the mechanical properties of the muscle-tendon unit and even fewer studies have used the free oscillation technique to assess mechanical properties of the plantar flexors (Dumke et al., 2010, Spurrs et al., 2003). Using a group of distance runners with an average training history of 10 years Spurrs et al. (2003) reported significant differences for musculo-articular stiffness due to plyometric training but not with endurance training. While Dumke et al. (2010) reported similar values of musculo-articular stiffness for distance runners when compared with supposedly untrained participants reported by Fukashiro, et al. (2001).

The regulation of leg stiffness during hopping has been compared between endurance-trained athletes and untrained participants (Hobara et al., 2010). The endurance-trained group showed significantly higher leg stiffness than the untrained group. These differences were attributable to differences in ankle and knee joint stiffness. The ultrasonographic findings of Kubo et al. (2000) also showed this trend. Kubo et al. (2000) reported significantly higher stiffness of the vastus lateralis tendon of long-distance runners compared with control participants. Using the quick-release method, a similar trend (i.e., higher stiffness) was reported for the triceps surae by Grosset and co-workers (2009), who studied the relationship between eletromechanical delay and muscle-tendon stiffness after endurance training of sedentary college students.

Animal studies in rats and guinea fowl have also reported an increase in stiffness due to endurance activities (Buchanan and Marsh, 2001, Goubel and Marini, 1987). More specifically, an increase in tendon stiffness in guinea fowl using an *in situ* technique that involved measuring fiber length and the amount of force generated by the lateral gastrocnemius of an immobilized hind limb was shown after following a long-term running program (Buchanan and Marsh, 2001). An increase in the series elastic component stiffness of the soleus muscle of rats, associated with an increase in type I fibres and a decrease in type II fibers, was also reported by Goubel and Marini (1987) using a controlled release method.

The studies quoted above reported that stiffness tends to increase with strength training while with endurance training it tends to increase or not to change. Nevertheless, there are additional human and animal studies that show contradictory results. For example, in addition to the increase in stiffness due endurance training, Grosset et al. (2009) reported that human plyometric training is associated with a decrease in stiffness. Similarly, Cornu and colleagues (1997), using a sinusoidal perturbation technique, showed that musculo-articular stiffness decreased after seven weeks of plyometric training.

Furthermore, animal studies using the controlled release method also suggest opposing results between endurance and strength training (Almeida-Silveira et al., 1994, Goubel and Marini, 1987, Pousson et al., 1991). The underlying rationale is that endurance training tends to recruit slower twitch fibers, while plyometric training tends to recruit fast twitch fibers. Bosco et al. (Bosco et al., 1982) has hypothesized that slow and fast twitch fibers differ in their elastic properties and this hypothesis agrees with other results (Almeida-Silveira et al., 1994, Goubel and Marini, 1987, Pousson et al., 1991).

Considering that the implementation of muscular strength, power, and endurance in football players has been reported as important physical resources to play football (Hoff, 2005) the opposing adaptations between different types of training (i.e., strength vs. endurance) could explain the non-significant results in the mechanical properties of the present study. Nevertheless, different methods have been used between these studies, and therefore future studies are needed to substantiate results.

The non-significant results found may also have another explanation. Arampatzis et al. (2007) determined whether or not the mechanical properties of the triceps surae tendon and aponeurosis relate to the performed sport activity in an intensity-dependent manner by comparing sprinters, endurance runners, and inactive participants using an ultrasonographic method. Arampatzis et al. (2007) showed that an increase in the intensity of the sporting activity did not result in graded adaptations to the mechanical properties, instead they seemed to remain at a controlled level in a wide range of applied strains until the frequency and/or amplitude of the strain applied was large enough for a critical threshold to be surpassed. Therefore, with football training and matches, football players might be unable to exceed the aforementioned threshold and the mechanical properties are similar between the groups.

Conflicting results on the existence (Dunbar and Power, 1996) or absence (Yildirim et al., 2008, Chamari et al., 2004) of different physiologic characteristics between football players according to the playing position have been reported. We did not find any significant differences between the groups with respect to triceps surae mechanical properties (Table 2). In spite of the non-parametric tests most suitable for small sample sizes, there was a lack of statistical power with small samples, thus further studies with larger sample sizes are required to corroborate these results. Nevertheless, the present results provide suggestions for future research and may be incorporated into meta-analyses.

4.1 Limitations

In the procedures, participants sat in a chair with their knees flexed at 90°. In this position, the gastrocnemius may be too short to contribute significantly to the musculo-articular stiffness, indicating that the musculo-articular stiffness is mainly influenced by structures that do not cross the knee, such as the soleus and the Achilles tendon (Shorten, 1987, Faria et al., 2009a). Under active conditions, ankle plantar flexors were considered the main contributors to the musculo-articular stiffness. Nevertheless other small contributions also arise from other passive structures, such as fascia, ligaments, cartilage, and bone, as well as from other musculotendinous structures in the lower leg and thus caution should be exercised when comparing results obtained with different methods.

To assess the statistical differences in mechanical properties between groups defined according to football positions, small groups were created (Table 2). As non-parametric tests lack statistical power with small samples, future studies utilizing larger sample sizes are needed to substantiate the results.

In the present study a load of 30% maximal voluntary isometric contraction was used to assess triceps surae musculo-articular stiffness because most of the football match time is used in endurance activities, such as walking or running at low intensity; however, it is possible that higher loads can elicit some mechanical property differences between groups, and thus future studies are needed to address this issue. Most of the published literature assessing musculo-articular stiffness only uses the mean of two trials in the calculations. The limits of agreement found in this study appear reasonable however as the possibility exists to have some more trials without affecting the procedures to much it is advisable that future studies increase the number of trials performed.

5. Conclusion

The similarity in the results shown between football players and non-football players suggest that neither the football training nor the football games themselves affect the mechanical properties of the triceps surae. Football encompasses endurance power and strength training. The opposing adaptations that these different types of training can induce possibly explain the non-significant results demonstrated in the mechanical properties. Another possibility is that the minimum strain amplitude and/or frequency threshold of the triceps surae required to trigger mechanical properties adaptations might not be achieved by football players with football training and matches. The results also suggest that the position played in football does not influence the mechanical properties of the triceps surae.

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