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EFFECTS OF ECCENTRIC TRAINING ON THE MECHANICAL AND GEOMETRICAL PROPERTIES OF THE MUSCLE-TENDON PLANTAR FLEXORS SYSTEM

Ben Jeddou I.[1], Ben Salah F. Z.[1], Arfa Y.[2], Dustin c.[1].

[1] *Service of physical medicine and rehabilitation functional of the National Orthopaedic Institute "Mohamed KASSAB" (KSAR SAÏD, TUNIS).*

[2] *Institut supérieur de Sport et Education Physique -Ksar Saïd, University of Manouba-Tunis.*

yessinearfa@gmail.com

Abstract

Aim: Determine the adjustments to the structures of the musculo-tendinous system of the Plantar flexors of the ankle 10 weeks of eccentric training, as well as the geometry of the triceps surae and muscles of the tendon of Achilles and the mechanical properties of the elastic components of the rheological model of Zajac (1989).

Methods and equipment: Sixty two topics were randomly distributed in a training group (GE, *n* = 31, 5 beginnings, 6 boxers, 5 wrestlers, 7 jumpers in lengths and 8 basketball: 20.9 ± 2.6 years, 178.1 ± 8.3 cm, 68.4 ± 9.2 kg) and a group control (GC, *n* = 31, students of the Military Academy of sports: 23.6 ± 1.8 years, 176.6 ± 11.4 cm 72.0 ± 7.7 kg). All subjects were involved in regular sporting activity (10.5 ± 6.2 hours per week) and have not changed their usual activity during the duration of the study. The 3 experimental sessions were carried out in random order one to two weeks before the start of the training Protocol (pre-test) then a week after the end of the 10 weeks of training (post-test).

Parameters studied: Characterization of the geometry of the muscles of the triceps surae, tendon of Achilles and the stiffness of these and properties mechanical tendon and the stiffness of the PRC.

Results: The results showed that the mechanical properties of the tendon and muscle adapt specific and different way depending on the type of training to optimize the transmission process of skeletal muscle tension and storage-restitution of the elastic potential energy during movement.

Conclusion: The 10 weeks of eccentric training did not alter performance vertical relaxation, flexibility, and strength of the trained subjects. Despite this lack of evolution of functional parameters, eccentric training would induce rather at the level of the intrinsic mechanical properties of muscle tissue (decrease in stiffness of these1) on the mechanical and geometrical properties of the tendon. The nature of the adaptations of the mechanical properties of the muscle and the tendon is associated with a change in intrinsic mechanical properties of muscle and tendon tissue rather than a change to the level of the geometric parameters of the muscle and the tendon.

Keywords: Eccentric training, flexibility, elastic component, musculo-articular stiffness, muscle architecture, dissipated energy.

1. INTRODUCTION

A muscle contraction is eccentric when the mechanical stress imposed on a muscle or muscle group is greater than the force generated by all of the motor units activated involving an increase in the length of the SMT (Enoka, 1996). During this process, the SMT absorbs mechanical energy developed by external work and dissipate this energy as heat with a functioning similar to a shock absorber (Cavagna et al., 1994; Dickinson et al., 2000). Stresses induced by eccentric exercise ranged from strengthening and stretching of the structures of the SMT (Allison and Purdam, 2009). This type of exercise is typically used in the context of training and programs for functional rehabilitation (Figure 1) (Stanish et al. 1986; Alfredson et al., 1998). In addition, changes in the functional behavior of the GTS after eccentric training could be explained by a change in its mechanical and/or geometric properties. The studies presented in this review will concern, insofar as possible, the effects of purely eccentric training (implying that axcentriques shares) on the Plantar flexors of the *vivo*ankle. Studies in animals will be also used to support the assumptions associated with potential physiological mechanisms involved in mechanical and geometrical properties changes observed.

Figure 1: Type of eccentric exercise performed during a rehabilitation program in the context of the treatment of tendinitis of the Achilles (Alfredson et al., 1998).

Data from the literature show that the eccentric training improves performance in force (Duclay et al., 2009). This increase in performance was often associated with an optimization of the nervous mechanisms (modification of muscle activation patterns) and adaptations of mechanical properties of the SMT (stiffness). Similarly to the effects of eccentric on the mechanical properties of the SMT, the assumption of a specific and different from the elastic components of the SMT adaptation was issued in previous work (Pousson et al.., 1990).

Thus, we present in this study the known potential adaptations associated with eccentric training on: *i*) functional performance (strength, flexibility), *ii*) muscle geometry (architecture, Casa, volume) and tendon (CSA, length) and, *iii*) at the level of the elastic components of the model of Zajac (1989) (stiffness of these and the CEP).

1. Effects of eccentric on functional parameters

1.1 The vertical relaxation

Unlike the plyometric training, eccentric exercises promote the power dissipation of the SMT (Cavagna et al., 1994; Dickinson et al., 2000). The performance of relaxation are therefore much less increased after a strength compared to a workout training plyometric (Baker, 1996; Hawkins et al., 2009). Thus, it has been shown that jump squat performance increased from 2 to 3 cm after a workout to eccentric dominant. Whereas the functional role of the eccentric contraction and the need to reuse the elastic potential energy stored by the structures of the SMT to allow a maximum vertical jump performance, eccentric training is very little used in the context of the development of the vertical jump.

1.2 Flexibility

The ankle joint flexibility is not a parameter classically evaluated after eccentric training. It has however been shown that maximum range of motion of the ankle determined dorsal flexion and leg extended increased significantly by about 6 ° after an eccentric Protocol of 6 weeks (Mahieu et al. 2008).

On the other hand, 12 weeks of eccentric training were not sufficient to increase the range of motion of ankle dorsiflexion in patients with tendinopathy (Silbernagel et al., 2001). As previously mentioned, the stresses induced by eccentric exercise ranged from strengthening and stretching of the structures of the SMT (Allison and Purdam, 2009). So similar (to the study of Mahieu et al. (1998)) the flexibility of the ankle after a program of static stretches for 6 weeks was observed (Nelson and Bandy, 2004).

1.3 Isometric force maximum torque

To our knowledge, only two studies have tested the effects of purely eccentric training on the level of CMV in Plantar flexion and showed an increase of this parameter. Duclay and al. (2009) have shown an increase of 13% of the CMV in Plantar flexion in subjects trained in eccentric for 7 weeks confirming the increase of 22% of the CMV in Plantar flexion after 6 weeks of eccentric training (Willems and Stauber, 2002).

However, other studies carried out on other groups muscle *in vivo* or on isolated muscle enhance the effects of eccentric training on maximum force production capacity. If we consider the couple relationship of strength - angle, some authors show that eccentric training improves production force capacity at extreme angles (high muscle lengths) rather than on the entire test range (Blazevich et al. 2007). Also studies in animals show that eccentric training does not necessarily increase the maximum voltage produced by the muscle (Reich et al., 2000).

2. EFFECTS OF TRAINING ON THE GEOMETRY OF SMT

2.1 The triceps surae muscles

Beyond 6 to 8 weeks of training, the improvement of production capacity of force would, regardless of the mode of training (concentric, eccentric and isometric or coupling concentric-eccentric), increased muscle mass (Moritani and deVries, 1979) involving mainly muscle hypertrophy provided that the request is sufficient (Wernbom et al.., 2007).

Muscle hypertrophy in humans is the result of the increase of the muscle fiber CSA. Preferentially affected by muscle hypertrophy fibers are fibers of type II (Hather et al., 1991). The hypertrophic muscle potential is thus linked to the proportion of type II fibres already present within muscle (Hather et al., 1991). The typological changes induced by eccentric training are similar to those caused by other strength training programs, it means increasing the share of intermediate type muscle fibers in muscle (IIa, IIa/IIb) up to 12% of the initial level (Hortobagyi et al., 1996a). Hypertrophy of the muscle fibers can lead to an increase in overall Casa of the muscle but also a change in the muscle architecture.

2.2 Achilles tendon

Although most studies have shown that training in force had no effect on the CSA of the tendon (Kubo et al. 2001a; Kubo et al. 2002b. Hansen et al., 2003; Reeves et al. 2003 a), an increase of the volume of the Achilles tendon has been shown by MRI after 3 months of eccentric training using exercises prescribed by Alfredson et al. (1998) this volume increase was explained by potential hyperemia and/or an increase in the water content of the tendon after training (Shalabi et al.., 2004). In addition, a study on the effects of eccentric training involving heavy loads showed an increase of CSA of the patellar tendon after 12 weeks but only at the level of inserts of the tendon, and not in its central part (Kongsgaard et al.., 2007). Langberg and al. (2007) have also highlighted, after 12 weeks of eccentric exercises, an increase in the synthesis of collagen type I, main component of the tendon tissue, without increase of the degradation processes, within the injured tendon in patients with tendinopathy.

3 Effects of training on the mechanical properties of these

To our knowledge, only one study has evaluated the effects of purely eccentric training on the mechanical properties of the these (Pousson et al. 1990). This study showed an increase in the stiffness of the these, determined by the *quick release*method after 6 weeks of eccentric training of flexor of the elbow for torque strength values relatively low (30 and 45% of CMV) but not to force higher torques (60 and 80% of CMV). However, the authors could not determine if specific adaptations of the fractions active (these1) and passive (these2) of these had occurred.

3.1 Active fraction of these (etuc1)

Characterization of the mechanical properties of these 1 is very difficult *in vivo*, and to our knowledge, no study has evaluated the effects of purely eccentric training on the specific mechanical properties of this component *in vivo*. However, from the data obtained on isolated muscle, it is possible to make some additional hypotheses on the effects associated with eccentric training on the stiffness of the active fraction of these.

3.2 passive fraction of the these (these2) / of the Achilles tendon

Training most often generates an increase in stiffness of Achilles (Magnusson et al., 2003b; Reeves et al. 2003b; Kubo et al. 2006; Burgess et al., 2007). Only two studies have evaluated the effects of eccentric training on the stiffness of Achilles (Mahieu et al., 2008; Duclay et al., 2009). The study of Duclay et al. (2009) showed a significant increase of approximately 20% of the Achilles tendon stiffness after 7 weeks of training. In a less obvious way, a tendency to the insignificant increase in the stiffness of the Achilles tendon was determined by Mahieu et al.. (2008) after 6 weeks of training. Can noted that a study evaluating the effects of ballistic stretching 6 weeks showed a significant decrease in stiffness of the tendon (Mahieu et al., 2007).

The objective of the eccentric contraction to dissipate the elastic energy, no study reported the effects of this type of Protocol on the CD of the Achilles tendon. It may be noted that some authors have reported a decrease in the energy dissipated by the tendon after strength training and stretching chronic (Kubo et al. 2002a protocols; Kubo et al. 2002b. Reeves et al., 2003b).

4 Effects of training on the stiffness of the CEP

Effects of eccentric training on the passive mechanical properties have been evaluated in only one study in humans. Thus, a decrease of 23% of the torque force passive resistive during dorsiflexion of the ankle has been characterized after 6 weeks of eccentric training (Mahieu et al., 2008), showing an adaptation of the overall mechanical properties of the CEP of the ankle Plantar flexors.

1. Materials and methods

1.1 Population

Sixty two subjects have volunteered to participate in this study and were randomly distributed in a training group (GE, *n* = 31, 5 beginnings, 6 boxers, 5 wrestlers, 7 jumpers in lengths and 8 basketball: 20.9 ± 2.6 years, 178.1 ± 8.3 cm, 68.4 ± 9.2 kg) and a group control (GC, *n* = 31, students of the Military Academy of sports: 23.6 ± 1.8 years) (, 176.6 ± 11.4 cm 72.0 ± 7.7 kg). All subjects were involved in regular sporting activity (10.5 ± 6.2 hours per week) and have not changed their usual activity during the duration of the study.

1.2 Eccentric training Protocol

Eccentric training program was based largely on the Protocol of plyometric training, where possible (subjects not realizing that eccentric contraction of the jumps below). More specifically, the subjects of the GE performed: *i)* exercises described by Alfredson et al. ((1998) (figure 1), and *ii)* functions below (i.e., from a platform whose height varies between 40 and 80 cm). For all the eccentric exercises, subjects had to achieve eccentric actions on the right leg or both legs, and then perform the concentric action with left leg only. The progression of training was conducted in terms of volume (number of exercises per session, number of eccentric exercise solicitations) and intensity (height of the functions below, exercises on one or two supports). The Protocol of eccentric training lasted 10 weeks and included 24 hour sessions for a total of approximately 4800 eccentric contractions (from 200 to 600 eccentric contractions by sessions).

1.3 Experimental protocol

The objective was to include the most relevant tests in two experimental sessions of reasonable duration (less than or equal to 1 h 15'). For studies assessing the effects of workouts eccentric and eccentric, the global protocol was thus consists of 2 sessions including various tests: 1) characterization of the geometry of the triceps surae muscles (architecture and Casa: anatomical cross-sectional), of the Achilles tendon (CSA: Surface cross section and length) and these: stiffness of elastic component series (etuc1 and CES2 stiffness dissociation) and 2) the evaluation of the mechanical properties of the tendon (stiffness and dissipative properties) and the stiffness of the CEP: parallel elastic component (dissociation of the stiffness of pec1 and pec2). A third session was then designed to assess performance in vertical jump. These 3 sessions were conducted in random order one to two weeks before the start of the training Protocol (pre-test) then a week after the end of the 10 weeks of training (post-test). The tests were as far as possible at the same time of day in pre-test and post-test.

The experimental protocol was identical to that used in a plyometric training. However, an additional measurement of the surface of section of the tendon (CSAT SO) was realized at the level of the insertion of the Achilles tendon on the SO under the same procedure used for the measurement of CSAT.

2 analysis Statistics

After checking the normality of the distribution data, parametric statistical tests were conducted using Statistica software ® software (Statsoft Inc., Tulsa, OK, had). Analysis of variance for repeated two-factor (group × test) measures was used to evaluate changes in performance in vertical jump as well as all of the listed parameters. A Newman-Keuls post-hoc analysis was performed if necessary. The threshold of significance was set at $P < 0.05$

3. RESULTS

3.1 Functional parameters

Table 1: Performance in vertical jump training and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

GE GC

Pre-test post-test pre-test post-test

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
SJ (cm)	32.1 ± 4.4	34.7 ± 6.7	34.6 ± 6.4	35.2 ± 6.9
CMJ (cm)	40.3 ± 6.8	41.6 ± 6.5	40.1 ± 6.5	39.9 ± 5.7
Multibond (cm)	25.6 ± 4.3	25.0 ± 4.1	26.2 ± 3.7	23.0 ± 5.4
DJ (cm)	37.0 ± 8.5	40.7 ± 6.8	35.6 ± 6.3	36.7 ± 5.8

SJ: jump squat, CMY: counter movement jump, multibond, DJ: jump below (50cm), GE:

Group training, GC: control group. Mean ± standard deviation.

There is no interaction between the factors "group" and "test" for SJ, the CMJ and the multibond after 10 weeks of eccentric training ($P > 0.05$). However, it may be noted a trend towards the increase in performance by DJ for GE ($P = 0.10$). Relaxation test results are presented in table 1.

Table 2: Maximal voluntary Contraction and rate of climb in maximum force for training and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
CMV (N.m)	136 ± 22	132 ± 26	129 ± 18	127 ± 17
RTDmax (N.m.s-1)	1536 ± 297	1515 ± 319	1437 ± 335	1394 ± 316

CMV: maximal voluntary contraction, RTD max: rate of climb in maximum force, GE: Group Training, GC: control group. Mean ± standard deviation.

No significant changes at the level of the CVMP and the RTD Max was found (P > 0.05). The values of CMV and RTDmax are presented in table 2

Table 3: Maximum Amplitudes of the ankle for the training group and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
RoMT FP (°)	61.4 ± 5.7	63.4 ± 4.2	58.8 ± 9.1	57.6 ± 7.8
RoMT FD (°)	49.1 ± 4.2	52.4 ± 6.0	50.2 ± 8.0	49.4 ± 6.6
RoMF FD (°)	60.0 ± 6.3	62.2 ± 6.5	56.6 ± 10.0	56.4 ± 11.2

RoM T FP: maximum amplitude of the measured ankle leg cocked in plantar flexion, RoM T FD: Maximum amplitude measured ankle leg cocked in dorsiflexion, RoM F FD: amplitude Maximum ankle knee flexed to 80 ° in dorsiflexion, GE: Group training, GC: control group. Mean ± standard deviation.

There is no interaction between factors 'group' and 'test' for RoM T FP and RoM F FD after the 10 weeks of eccentric training (P > 0.05). However, it may be noted a trend towards the increase of RoMT FD for GE (P = 0.07). The results of flexibility are presented in table 3

3.2 Geometry of the muscle-tendon of the triceps surae system

3.2.1 Achilles tendon

Table 4: Lengths, maximum elongation and cross sectional area of the tendon of Achilles for the training group and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
LT GL (mm)	222 ± 19	219 ± 19 †	220 ± 16	220 ± 16
LT GM (mm)	197 ± 25	194 ± 24 †	194 ± 25	196 ± 24
LT SO (mm)	49 ± 14	48 ± 13	43 ± 15	43 ± 15
△Lmax (mm)	14.4 ± 2.6	15.2 ± 2.9	15.6 ± 2.9	15.7 ± 2.2
CSAT (mm²)	67.6 ± 7.2	66.6 ± 10.4	59.2 ± 11.6	58.9 ± 9.2
CSAT SO (mm²)	52.8 ± 8.6	57.0 ± 9.2	59.1 ± 9.4	55.3 ± 6.1

L T GL: length of the lateral gastrocnemius, L Achilles tendon T GM: length of the medial gastrocnemius, L Achilles tendon T SO: the Achilles of the soleus tendon length, ΔL max: maximum elongation of the tendon of the medial gastrocnemius to 90% of contraction maximum voluntary, CSA T: area of cross section of the Achilles tendon, GE: Group training, GC: control group. Mean ± standard deviation. Post-hoc † P < *0.05* analysis

Interaction between factors "group" and "test" has been found for L T GL and L T GM (P < 0.05) (table 4). For GE, significant decreases of 1.3% (i.e., 3 mm) and 1.7% (i.e., 3.5 mm) for LT GL and LT GM respectively were determined after the eccentric training ($P < 0.05$) (table 4). On the other hand, no interaction was determined for the other Achilles tendon ($P > 0.05$) geometrical parameters even though we may note a tendency to the insignificant increase in CSAT SO of around 8.5% ($P = 0.09$). No significant difference was found for the whole of the geometric parameters of the tendon of Achilles GoC ($P > 0.05$) (table 4).

3.2.2 The lever arm

No interaction between the factors "group" and "test" found after the eccentric training for GE and the GC on the lever arm of the Plantar flexors of the ankle ($P > 0.05$) (Figure 2).

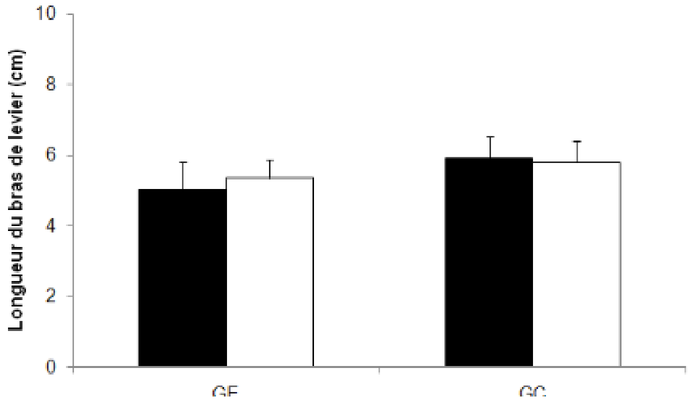

Figure 2: Length of the lever arm of the Plantar flexors for group training (GE) andthe group control (GC) (■) and after (□) 10 weeks of eccentric training.

These results show the absence of effect of eccentric training on the length of the arm of the ankle Plantar flexors.

3.2.3 Stiffness of these

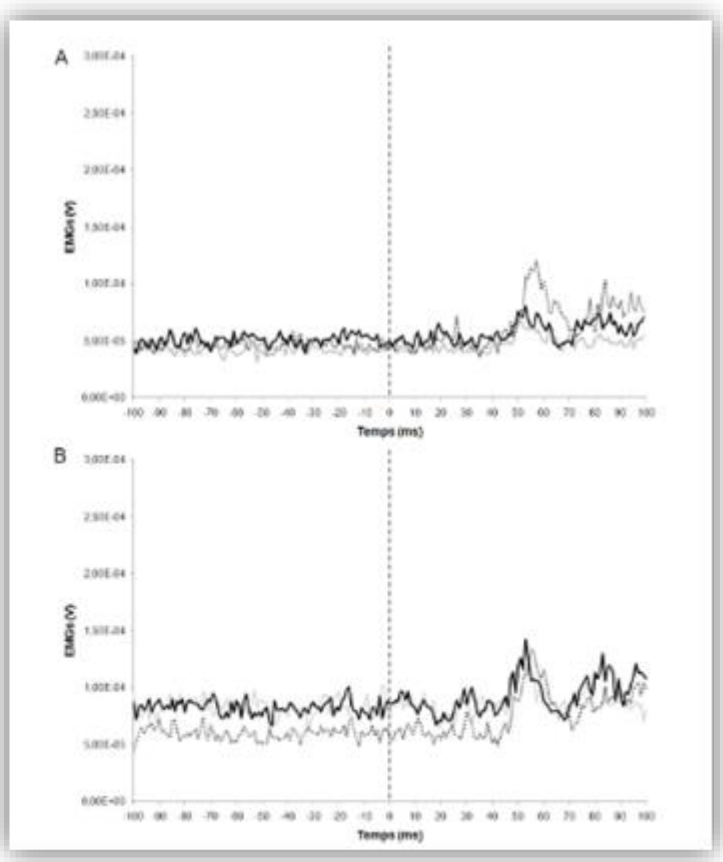

Figure 3: Relations averaged between the lateral gastrocnemius muscle EMG activity ( ), medial gastrocnemius ( ) and soleus ( ) before 100ms and after the start of

(i.e., 0) stretching for valid tests for group training before (A) and after

(B) 10 weeks of eccentric training.

To check the time of appearance of the stretch reflex, relations EMG of the muscles of the TS according to the time when the stretching associated with the SRS method are presented in Figure 3.

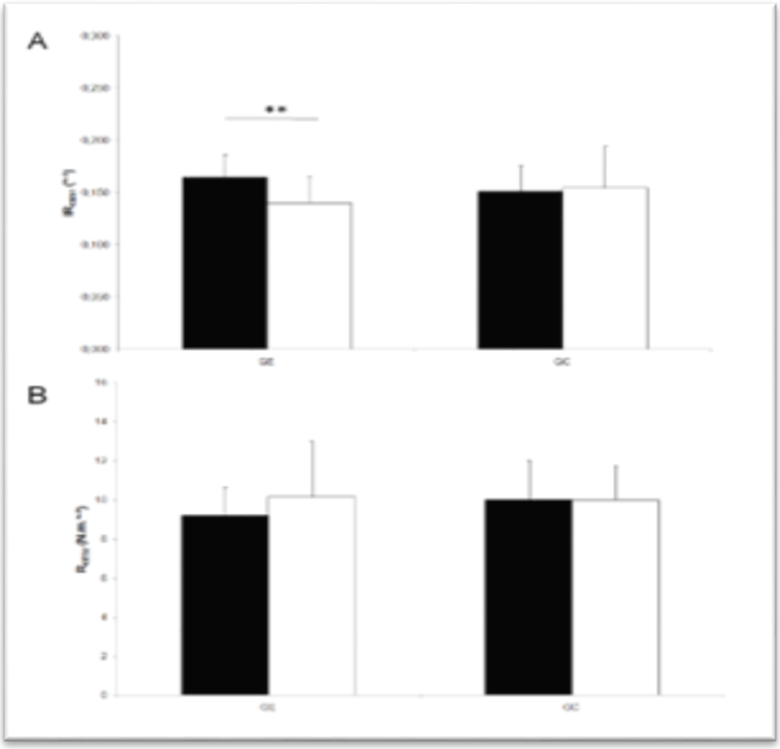

Figure 4: A - average index of stiffness of the active of the elastic component fraction series (IRCES1) and B - stiffness of the passive fraction of the elastic component series (RCES2) for the Group

Training (GE) and the control (GC) Group (   ) and after (   ) 10 weeks of training

Eccentric. * Significant difference between the pre-test and post-test (P < 0.05) values.

It not been observed change of EMG activity during the first 45 milliseconds after the onset of stretch. The activity of the TA does not change during the 100ms after the start of the stretch. Thus, reflex activity did not affect the settings characterized from the SRS method and their potential evolutions with the drive later in this chapter. The interactions between the factors "group" and "test" were found for RminIRetuc1 and Retuc1 90% ($P < 0.05$). The post-hoc analysis shows, for GE, a decrease of Rmin ($P < 0.05$) and a significant decrease of IRetuc1 and Retuc1 90% 14.2% and 11.9% respectively ($P < 0.05$) (Figure 4). No significant differences in the level of Rmax and RCES2 was found after the 10 weeks of training for the GE ($P > 0.05$).

3.2.4 Mechanical properties of the Achilles tendon

Mean relations between force and elongation of Achilles tendon for the two groups are presented in Figure 5. The application of linear regression and the Sten-Knudsen model on the relations of force-elongation of each topic for the two tests show a very good correlation coefficient (R2 way = 0.97 ± 0.02 and 0.99 ± 0.01, respectively), which allows us to identify the tendon stiffness (RTA) estimated at between 50 and 90% of the minimum CMV and Sten-Knudsen stiffness index (IRSK) before and after training.

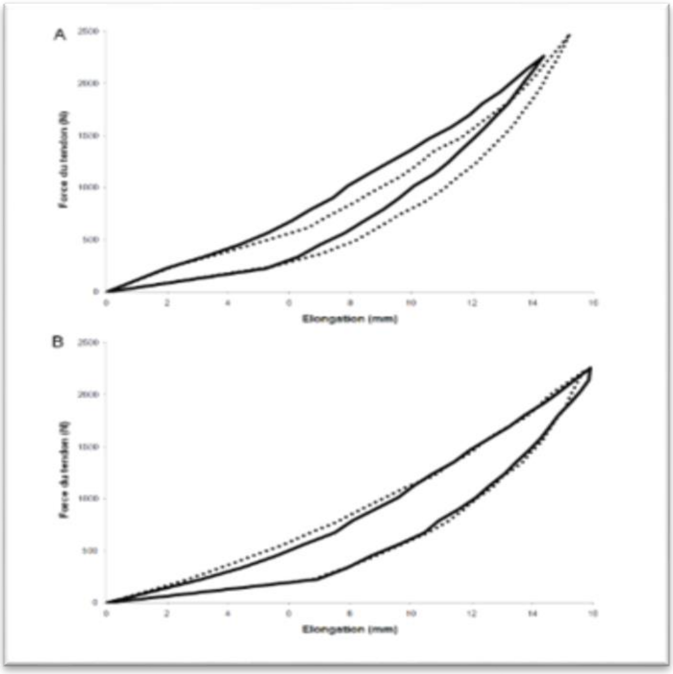

Figure 5: Average relationships between force and elongation of Achilles for the Group gear box (A) and (B) before controlled the Group ( ) and after ( ) 10 weeks of training eccentric.

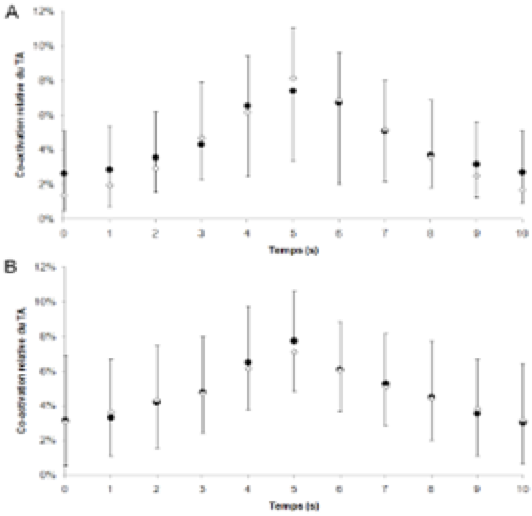

Figure 6: Average relationships between the relative of the Tibialis Anterior (TA) co-stimulation during the ramp Isometric Contraction for training (A) and (B) control group ( ) and After ( ) 10 weeks of eccentric training.

These force-length relationship were not corrected the co-stimulation of the TA during ramp contraction but this co-stimulation has not evolved significantly after 10 weeks for the GE and GC (Figure 6). The co-stimulation has no influence on potentially eccentric training effects on the mechanical properties of the tendon so characterized.

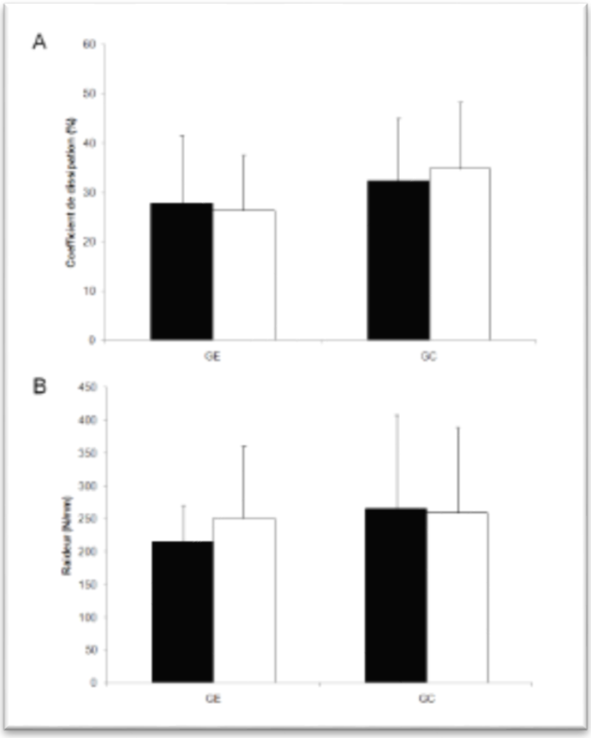

Figure 7: Average values of coefficient of dissipation (A) and (B) tendon stiffness for the Group training (GE) and the control (GC) Group ( ) and after ( ) 10 weeks eccentric training.

No interaction between factors "group" and "test" was found after the eccentric for the GE and GC for IR SK R TA R TA CSA **T** and CD (P > 0.05) (table 5 and Figure 7). No significant difference in the stiffness and the dissipative properties of the Achilles tendon was found after the eccentric for the GC (P > 0.05).

Table 5: Settings of stiffness of tendon of Achilles for the training group and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		**GC**	
	Prétest	**Posttest**	**Prétest**	**Posttest**
IRSK (mm-1)	0.076 ± 0.049	0.096 ± 0.050	0.114 ± 0.074	0.089 ± 0.065
RTA (N.mm-1)	215.8 ± 55.0	251.1 ± 109.2	265.5 ± 143.2	259.9 ± 129.9
RTA/CSA**T** (N.mm-3)	3.24 ± 0.96	3.83 ± 1.75	4.60 ± 2.39	4.53 ± 2.45

IR SK: StenKnudsen stiffness index, R TA: stiffness of the Achilles tendon, R TA/CSA T: normalized stiffness of the Achilles tendon, GE: Group training, GC: control group. Mean ± standard deviation.

The average stress-strain relations of the tendon of the GE before and after training are presented in Figure 8.

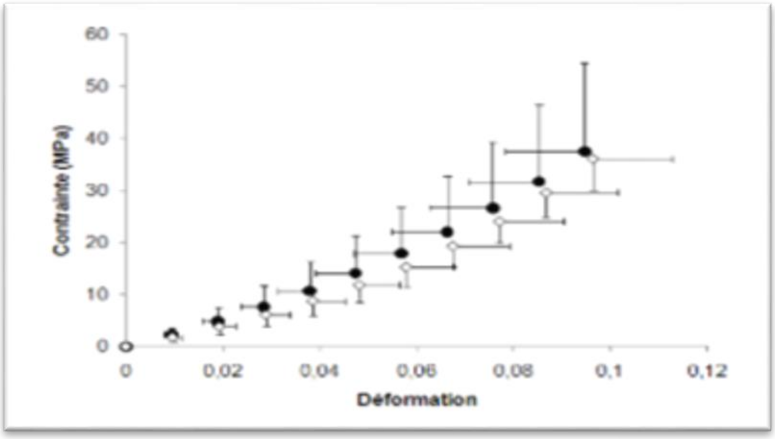

Figure 8: Average relationships between stress and deformation of the Achilles tendon for the Group before training ( ) and after ( ) 10 weeks of eccentric training.

4. STIFFNESS OF THE CEP

4.1 Relationship couple - elongation

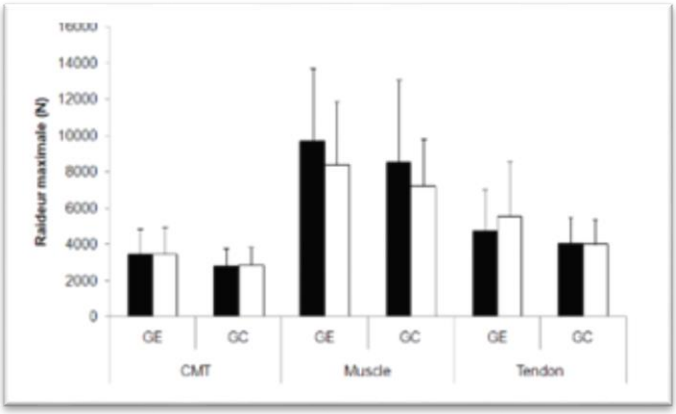

Figure 9: Average values of maximum muscle-tendon (SMT), System stiffness of the muscle and the tendon of the Plantar flexors for group training (GE) and group control (GC) Front ( ) and after ( ) 10 weeks of eccentric training.

No significant difference was found after 10 weeks of eccentric training for maximum passive stiffness of the SMT, muscle and tendon (RSMTmaxRMmax and RTmax respectively) whatever the relevant group (P > 0.05) (Figure 9).

Similarly, no significant change was observed between the pre-test and post-test for IR SMT and IR M for both groups (*P* > 0.05).

4.2 The gastrocnemius SMT force-length relationship

Table 6: Values of different mechanical parameters determined from the relationship forcelongueur of system musculo-tendon of the gastrocnemius for group training and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
IRG (m-1)	87.46 ± 12.86	89.22 ± 11.22	85.32 ± 10.49	83.79 ± 15.47
RGmax (N.m-1)	62450 ± 25975	66273 ± 15705	46140 ± 16675	48254 ± 19785
L0 G (m)	0.372 ± 0.019	0.373 ± 0.018	0.371 ± 0.026	0.366 ± 0.031
LF=1 SMT (m)	0.423 ± 0.018	0.424 ± 0.017	0.423 ± 0.022	0.421 ± 0.025

IR G: passive stiffness index, R Gmax : maximum passive stiffness, L 0 G : initial length, L F = 1 SMT : length for a passive 1N force developed by the GTS of the gastrocnemius, GE: Group training, GC: control group. Mean ± standard deviation.

No significant difference was found for IR G R Gmax L 0 G and L F = 1 in the two groups considered (P > 0.05) between the pre-test and post-test (table 6).

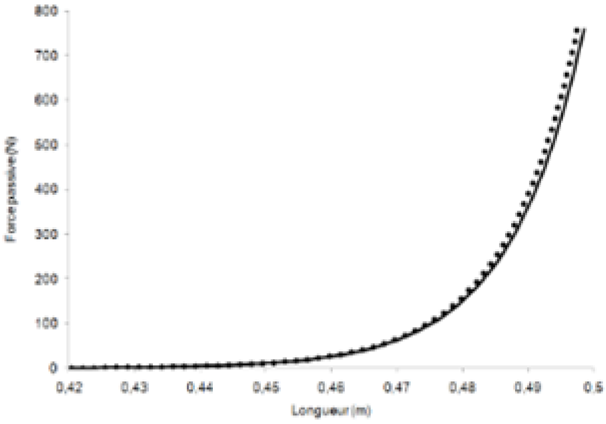

Figure 10: Average relationships between passive strength and the length of the musculo-tendon system of the gastrocnemius for the front drive Group (   ) and after (   ) 10 weeks of eccentric training.

The GE relations between force passive and the length of the GTS of the gastrocnemius for both tests are presented in Figure 10.

4.3 Force-length of the muscle and the tendon of the gastrocnemius relationships

IR G T and L 0 T increased significantly by 21.8% and 6.4% respectively for GE (P < 0.05) (table 7).

Table 7: Values of different mechanical parameters evaluated from the relationship forcelongueur of the muscle and the tendon of the gastrocnemius for group training and group control before (pre-test) and after (post-test) 10 weeks of eccentric training.

	GE		GC	
	Prétest	**Posttest**	**Prétest**	**Posttest**
IRG M (m-1)	168.1 ± 44.0	153.8 ± 27.7	152.7 ± 36.5	144.0 ± 40.2
L0 M (m)	0.216 ± 0.029	0.212 ± 0.029	0.216 ± 0.016	0.212 ± 0.022
LF=1 M (m)	0.247 ± 0.026	0.246 ± 0.027	0.251 ± 0.017	0.248 ± 0.020
IRG T (m-1)	152.9 ± 16.6	185.9 ± 32.6 †	168.0 ± 22.8	170.9 ± 36.6
L0 T (m)	0.137 ± 0.022	0.145 ± 0.024 †	0.137 ± 0.026	0.136 ± 0.032
LF=1 T (m)	0.170 ± 0.023	0.174 ± 0.024 †	0.168 ± 0.025	0.167 ± 0.028

IR G M : index of stiffness of the muscle of the gastrocnemius, L 0 M : initial length of the muscle of the gastrocnemius, L F = 1 M : length of the muscle of the gastrocnemius for a passive force of 1N, IR G T : index of stiffness of the tendon of the gastrocnemius, L 0 T : initial length of the tendon of the gastrocnemius, L F = 1 T : length of the tendon of the gastrocnemius for a passive force of 1N, GE: Group training, GC: control group. Mean ± standard deviation. Post-hoc † P < 0.05 Analysis

No significant changes were observed for IR G M and L 0 M in the two groups (P > 0.05) (table 7). Relations for the GE of the gastrocnemius muscle and Achilles tendon force-length and stress deformation are presented in Figure 11

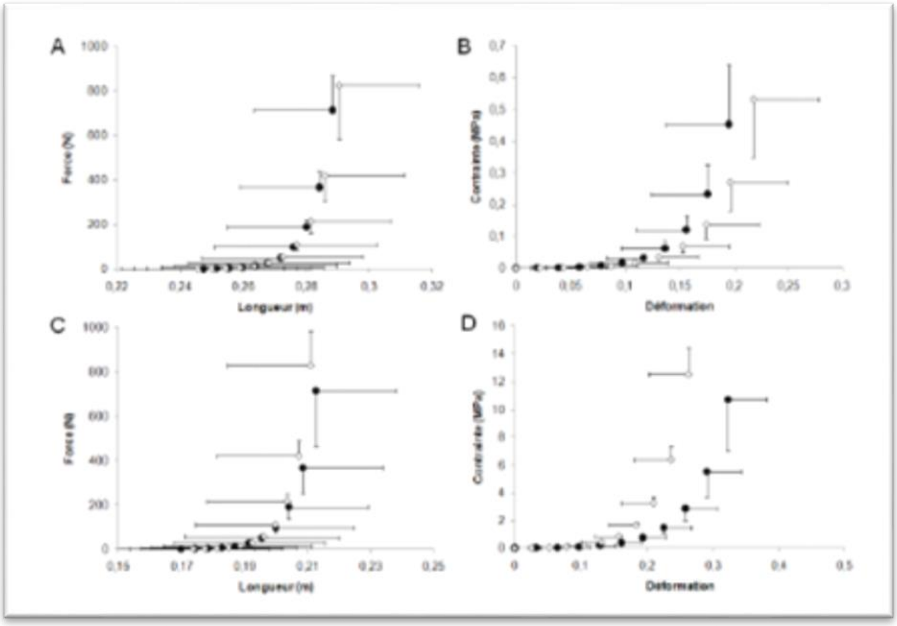

Figure 11: Average relationships between strength and length (A and C) and the stress and strain (B and D) of the gastrocnemius muscle (A and B) and Achilles (C and D) for the Group before workout ( ) and after ( ) 10 weeks of eccentric training.

5. DISCUSSION

The purposes of this study were to determine the effects of 10 weeks of eccentric training on the stiffness of the various components of the geometric model of Zajac (1989) and the properties of dissipative of the Achilles tendon. The results showed a decrease in stiffness of these1 and an increase in the stiffness of the passive of the tendon of the gastrocnemius.

5.1 Functional parameters

No significant changes of functional parameters after the 10 weeks of eccentric training was found. Trends in DJ performance increase and greater joint flexibility of the ankle were observed. These results are consistent with those of the literature that generally show a low performance scales in vertical jump (+ 2.6 cm after eccentric training (Friedmann-Bette et al., In press)). Same way, Mahieu et al. (2008) had found a tendency to the increase of flexibility (non-significant increase of 6 ° in dorsiflexion) after 6 weeks of eccentric training using exercises recommended by Alfredson et al. (1998) performance in CMV have not changed after the training period in our study, which differs from conventionally eccentric training results that show an improvement of the maximum force capacity (Duclay et al., 2009). Earnings strength are more important after eccentric training involving heavy loads and thus inducing a greater constraint (Higbie et al., 1996; Hortobagyi et al., 1996 Farthing and Chilibeck, 2003). Indeed, some studies have shown that the optimal effects of eccentric muscle solicitation on the maximum force mode occur from supramaximal or maximum loads (Johnson, 1972; Hortobagyi and Katch, 1990). Eccentric training carried out in our study mobilised no additional charges and has been done with the body weight (in order to standardize protocols plyometric workouts and eccentric). The exercises made during our eccentric training Protocol did not force maximum levels except perhaps during the receptions below. In addition, the eccentric exercises in our study were not strictly controlled (like on isokinetic cycle Ergometer or on a weight machine) and compensation during the creation of the movement might have occurred in the mobilization of the body segments (the constraint may be distributed on the knee and hip joints during these receptions below). The relatively low stress in our study level probably explains the absence of significant changes in isometric maximum force production capacity. Furthermore, it has been shown that eccentric exercise causes a shift of the relationship between the maximum force torque and joint angle after workout (Blazevich et al. 2007). Thus, the evolution of the torque force may produce significantly more extreme articular amplitudes (Talbot and Morgan, 1998; Bowers et al., 2004). However, we cannot support this hypothesis insofar as the relationship between the maximum force level and the ankle joint angle was not determined in this study.

5.2 Geometry of the muscle-tendon of the triceps surae system

Although a study on isolated muscle showed no change in the size of the muscles in rats after eccentric training (Reich et al., 2000), most of the studies being interested in the effects of eccentric training on muscle geometry, including one on the muscles of the TS (Duclay et al., 2009), showed an increase of pennation angle the length of the fascicles or Casa after this type of training therefore that the solicitation was important (Higbie et al., 1996; Blazevich et al., 2007 Duclay et al., 2009). In our study, no changes of architecture and Casa of the muscles of the TS was shown. However, an increase in the length of the gastrocnemius muscle was indirectly shown by decreasing length of the tendons of the GL and GM after drive about 1.5% on average. This slight increase in the length of the muscle does not seem to have had an impact on the architecture of the concerned muscles.

On the tendon, structures a decrease in the length of the tendon of the gastrocnemius was characterized in our study unaltered from the CSA T. Adaptations localized CSA of the tendon had yet been shown at the level of the inserts on the bone and muscle of the patellar tendon after a slow but realized eccentric workout with heavy loads (Kongsgaard et al.., 2007). As mentioned, the CSA of the tendon is not homogeneous throughout its length and small variations in the CSA of the Achilles tendon can occur locally. Therefore, we decided to perform an additional step to also measure the CSA of the tendon insertion on the SO level. Only a trend in the increase of this tendon section was observed ($P = 0.09$). Also, all these results suggest that the intensity of the eccentric load applied during this training Protocol (submaximal contractions) do not constitute sufficient mechanical stress to induce changes in the geometry of muscle and tendon of the TS in subjects with regular physical activity (~ 9 h of activity per week on average). This might also explain the weak evolution of functional parameters characterized in this study (CMV, flexibility).

5.3 Mechanical properties of the these

A significant decrease in stiffness of the these for low values of torque force (30% of the CMV) has been shown in our study no change in stiffness characterized for a high level of CMV. Insofar as the geometric parameters are not changed by the completed training, changes in the behaviour of elastic components seem be explained only by changes in the intrinsic mechanical properties of underlying tissues. Although our results are different from those obtained by Pousson et al. (1990) (increase in stiffness of the these low couples for), the hypothesis issued a specific adaptation of these1 or these2 to explain our results could be tested using the method alpha.

5.4. Active fraction of the these (these1))

A decrease in stiffness of the fraction activates of the these was found in our study. It would allow the muscle more elastic energy stored during the eccentric contraction. Although the modification of stiffness of tendon / these2 was not significant after the 10 weeks of eccentric training, the decrease of stiffness of these1 could be compensated to achieve, to force high torques, non-significant changes in the overall stiffness of the these (Rmax). This decrease in stiffness of these1 and the lack of change in stiffness of these however explain the decrease of Rmin2. Some physiological mechanisms could not be evaluated in our study and already mentioned previously can, however the decrease of stiffness of these1 after training. Indeed, it has been shown that strength training increased the number of fast-twitch fibers and implied a decrease in stiffness of the muscle in the animal (Don and Marini, 1987). More specifically, eccentric training would alter the typological profile of muscle fibers by an increase in selective hypertrophy of the II fibres and increasing the share of intermediate muscle fibres in muscle IIa, IIa/IIb up + 12% of the initial level (Hortobagyi et al., 1996b). This increase in the relative number of fast-twitch fibers in the muscle would influence the mechanical properties of the muscle towards an increase in muscle compliance (Kovanen et al.., 1984 ;) Gregory et al., 2007). However, these assumptions are to be considered carefully insofar as no significant changes of muscle ACSA and CMV were found in our study.

5.5 Passive fraction of these (CES2) / of the Achilles tendon

No modification of the R CES2 and R TA has been shown after the workout in our study. An increase in the stiffness of the tendon had been determined after several protocols (Reeves et al., 2003b strength training; Kubo et al. 2006) or eccentric (Duclay et al., 2009). In effect, Duclay et al. (2009) showed increased the stiffness of the Achilles tendon after 7 weeks of eccentric training carried out in a muscle building apparatus. The authors explained this increase in stiffness by increasing the synthesis of collagen type I (Kim et al., 2002; Yang et al. 2004) based on studies carried out *in vitro*stretch-induced.

However, our results on the evolution of the stiffness of the Achilles tendon after the workout are in agreement with those of Mahieu et al. (2008) which had tested the effects of 6 weeks of eccentric training mobilizing exercises prescribed by Alfredson et al. (1998) the differences between our results, those of Mahieu et al. (2008) and those of Duclay et al. (2009) tend to show the same kind of phenomenon could occur during eccentric contractions and to impose an important to get chronic tendon stiffness changes tendinous stretch. Furthermore, any modification of the elastic potential energy dissipated by the tendon was observed in our study. We mentioned in the review of literature that some authors had obtained a reduction of the energy dissipated by the tendon after a workout in force or chronic stretching (Kubo et al. 2002; Kubo et al. 2002b. Reeves et al., 2003b). However this result seemed inconsistent with the role of the tendon energy absorber during the eccentric contraction. In our study, the CD of the Achilles tendon has not changed with the drive. Thus, the decrease in CD shown after trainings in strength or chronic stretching (Kubo et al. 2002a; Kubo et al. 2002b. Reeves et al., 2003b) could be qualified by the sink role of tendon in the eccentric contraction. On the other hand, muscle could have participated more significantly than the tendon in the dissipation of this energy during eccentric contractions.

5.6 Stiffness of the CEP

No significant change the stiffness of the rated CEP in a comprehensive manner was shown in our study. These results differ from those obtained by Mahieu et al. (2008) after 6 weeks of eccentric training which showed a reduction in the passive torque resistive product by dorsal flexion of the ankle. Yet the training protocols used in our study and that of Mahieu et al. (2008) mobilized eccentric exercises without additional charges. However, the duration of the Protocol was longer in our study (almost twice as long). Thus, changes in mechanical properties evaluated after 6 weeks of eccentric training could be compensated to the scale of the overall assessment of the CEP by changes in mechanical properties could intervene in the longer term. We will try to explain this difference in results through the specific mechanical properties of CEP1 and CEP2 evaluated in our study.

Only adaptations notable of mechanical properties passive of the SMT after the 10 weeks of eccentric training are the increase in the index of passive stiffness of the tendon of the gastrocnemius (IRG T) and the increase of the initial length (i.e., L0 T, length for which product tendon one force passive significant resistive). The increase in the stiffness of CEP2 diverges from the evolution of the stiffness of these2. This observation also made after the 10 weeks of plyometric training clearly shows that these two parameters do not exactly match the behaviour same structures. The constraints when tested in the laboratory on the tendinous structures do not report the same mechanical properties (according to the experimental condition active or passive). Furthermore, different constraints within the tendon can induce the implementation of specific physiological mechanisms depending on the type of solicitation (contraction or passive mobilization of the joint). These specific constraints on the various parts of the tendon could lead to adaptations different properties geometric (Kongsgaard et al., 2007) or mechanical (Lyman et al., 2004) according to the considered tendon area. The tendon composed, like muscle, hierarchically, preferentially could involve different structures in active and passive conditions. Although the adaptations of the stiffness of CEP2 do not correspond to the evolution of the stiffness of tendon of Achilles and RCES2, a modification of physiological processes associated with the synthesis of collagen at the level of the tendon may be considered. Thus, an increase in the synthesis of collagen type I fibers has highlighted in the peri-tendineuse region after eccentric training (Langberg et al. 2007). This increase of collagen type I could contribute to increasing the stiffness of CEP2. Yet no change to RTmax (parameter from the couple-lengthening of tendon relationship) was found after the workout. This can be explained by the fact that in this relationship, the force overall torque is put in relation to the lengthening of the tendon of the GM. This global data and lengthening of a local association can hide the characterization of specific adaptation of the gastrocnemius mono-articulaires structures of the ankle. Indeed, one can hypothesize that the gastrocnemius and soleus muscles respond differently to the eccentric training.

On the other hand, an increase in the number of sarcomeres in series identified in animals (Proske and Morgan, 2001) and then indirectly in humans (Brockett et al., 2001) after eccentric training could occur in our study without significantly altering the length of muscle fascicle. This increase of sarcomeres in series would contribute to a small but significant increase in the length of the muscle and change the length for which the muscle or by impact, product tendon one force passive during the stretch. This increase in the number of sarcomeres in series may also explain the increase in compliance of these1. However, these assumptions are to be considered with caution because no significant changes CMV was found in our study.

Thus, the eccentric training generates different adaptations of these 1 and CEP 1 to the extent where these two elastic components of the model are not behaviours of the same structures at the muscle level (the bridges between actin and myosin for these1 mainly muscle for CEP envelopes1)).

6. CONCLUSION:

The 10 weeks of eccentric training did not alter performance vertical relaxation, flexibility, and strength of the trained subjects. Despite this lack of evolution of functional parameters, eccentric training would induce rather at the level of the intrinsic mechanical properties of muscle tissue (decrease in stiffness of these1) on the mechanical and geometrical properties of the tendon. The decrease of stiffness of these1 increase the storage of the elastic potential energy by the muscle. If more energy is stored, the muscle may also dissipate further. Thus, the muscle seems participate predominantly to the dissipation of the potential energy elastic stored and the regulation of global stiffness during the production of couples force relatively weak. On the other hand, the mechanical properties of these2 seem very little to adapt to chronic eccentric solicitation. Only increases the stiffness and the length of the tendon of the gastrocnemius index have been highlighted, which would indicate that during a passive joint and ankle muscle contraction movement of the muscles of the TS, different (with specific mechanical properties) structures may be involved and adapt differently to eccentric training.

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