

# SCIENTIFIC

## PHYSICAL THERAPY

### **Article Review: The Effect of running, strength, and vibration strength training on the mechanical, morphological, and biomechanical properties of the Achilles tendon in rats.**

By

Sam Betts, PT, DPT, MOMT, FAAOMPT

Kirsten Legerlotz, Peter Schjerling, Henning Langberg, Gert-Peter Bruggemann, and Anja Niehoff. J Appl Physiol 102: 564-572, 2007.

The purpose of the study was to analyze the effects of different exercise modes having very different and distinct loading patterns on the mechanical, morphological, and biomechanical properties of the Achilles tendon. The authors felt that compared with muscle and bone there was a lack of information about the relationship between tendon adaptation and the applied loading characteristics.

To apply different training protocols the authors on one hand chose running, which created single impacts with little rests in between, at a frequency between 2-4 Hz. On the other hand, a high dynamic-vibration strength training protocol was applied that created closely following impacts with a frequency of 25Hz. The authors chose vibration as an examination method, as the technique has shown positive correlations to improvements in bone strength, so wanted to see if there were effects to the tendons also. The 2 groups receiving vibration were divided into one part that was loaded with a high amount of vibration exercise,

#### **Abstracts:**

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By Ben Grotenhuis, PT, MOMT, FAAOMPT

and one with a low amount of vibration exercise. Furthermore a conventional strength training program without vibration; and a strength program with irregular more static loading. They hypothesized that different exercise modes with very distinct loading patterns created different adaptation effects concerning gene expression, morphological properties, and mechanical properties of the Achilles tendon.

Sixty-four 10 week-old female Sprague rats were randomly divided into 5 groups: non active age-matched control (AMC,) voluntary wheel running (RT,) low-vibration strength trained (LVST,) high vibration strength trained (HVST,) and a high strength trained group (HST.) Standard food, water and a special food that was preferred by the rats served as a motivation for them to exercise. The HST and HVST groups had to use a squat rack apparatus to get any food at all, whereas the LVST group only had to use the squat rack apparatus intermittently to get the special food only. The strength training group used a squat rack with no vibration applied. After a 1-week acclimatization period, the rats trained for 12 weeks.

At 12 weeks the Achilles tendon of the left hind limb was dissected and tested mechanically, biochemically, and morphologically. To test the tendons mechanical properties the Achilles tendon aponeurosis was fixed between 2 clamps, and the calcaneus was fixed by 2 screws. The tendon was then tested by cyclic loading and unloading phases. The tendon was tested for creep and hysteresis. After the cyclic modulus tests the tendons were loaded until failure to determine the ultimate load, deformation, stiffness, energy, stress, strain, and elastic modulus.

Biochemical testing involved the Achilles tendon being frozen in liquid nitrogen directly after the mechanical testing. Total RNA was isolated from the tendon specimens by phenol extraction. The analysis sought to reveal mRNA concentration levels of collagen I, collagen III, tissue inhibitor of metalloproteinase-1 (TIMP-1,) transforming growth factor- $\beta$ , connective tissue growth factor, and matrix metalloproteinase-2. Morphological analysis involved light microscopy analysis of embalmed, decalcified longitudinal tendon sections. Images of the sections were digitized and the cross sectional area of the tendon was determined by a computerized image processing program.

The significance of difference between the groups was determined by a one-way ANOVA. Post-hoc differences were determined with the Tukey test. All statistical tests were evaluated using  $\alpha < 0.05$ .

In a general summary of the results, the main findings were that the cross-sectional area and the mechanical properties of the Achilles tendon determined by the failure test did not change in response to any exercise. The analysis of TIMP-1 expression was higher in the running group, whereas the creep, which was determined by the cyclic test, was higher in the high strength training group. Furthermore the animals in the running group had a greater ratio of soleus muscle mass per body mass.

The vibration strength training did not induce any changes in the LVST group or the HVST grouping all mechanical properties determined by the failure or cyclic loading test, the cross-sectional area, or the mRNA level. However in the HST group, there was a greater creep effect compared with the LVST group in 11 of the 29 cycles and compared with the non-active age matched controls in 3 of the 29 cycles.

The authors concluded the present study showed regardless of the loading pattern, that moderate exercise does not seem to induce any changes of the Achilles tendon in cross-sectional area, and by failure test-determined mechanical properties. They did show, however, that running exercise seems to be a more potent stimulus than strength training to induce changes in the mRNA level, although these changes do

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not seem to affect the mechanical properties of the tendon.

### **Tensile loading/ unloading: do tendons grow when exercised?**

Several studies have documented that tendons are able to grow under intense loading<sup>1,2</sup>, but they all required long periods of time before the tendon was observed to adapt, and were in animals that were constantly growing or were in childhood/adolescence. As we know connective tissues grow during development normally, matching the overall growth and size of the body, so tendon cross-sectional area changes are normally expected. In adult humans it has been much harder to document increases in tendon structure. Cross sectional area changes have been mainly reported in men<sup>3</sup>, longitudinal studies have only been able to demonstrate increased cross-sectional area in the patella tendon<sup>4</sup>, and not of the Achilles tendon<sup>5</sup>. Because research shows that acute exercise increases collagen synthesis<sup>6</sup> it is also suggested that collagen degradation occurs simultaneously and/or that increased collagen turnover does not result in any new formation of assembled non-soluble collagen in tendon structures.

This study has attempted to study whether there an effect to the Achilles tendon during different training stimuli. One of the strengths of the study is that it is comprehensive in researching biomechanical, morphological and biochemical changes simultaneously, in a set-up with many exercise parameters. The combination of evaluating changes in protein expression, and protein content of growth modifying factors along with determination of the mechanical properties of the tendon is necessary to fully understand tissue adaptations to imposed exercise demands.

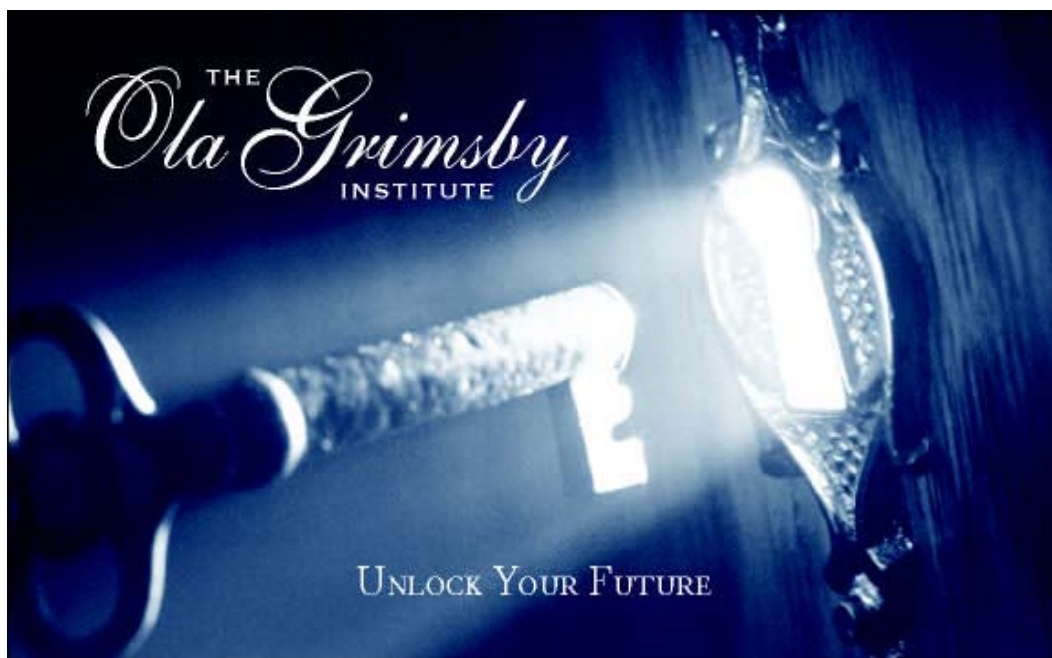
A possible weakness of the study is that the training environment does not exactly match what humans would follow in a training regimen. Also one could question whether the non-active controlled group was forced from any activity and thus is not a control, but an ‘inactive’ grouping.

Maybe tendons have the size they should be as adults, and what is needed throughout life is continuous

activity to keep the tendons fit? Furthermore the study shows that there are many more aspects of connective tissue training effect than the outer diameter of the tendon<sup>7,8</sup> and we are far from understanding how mechanical loading is sensed by the tendon, converted to chemical signaling, leading to protein matrix formation.

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# Clinical Tests for Dysfunction of the Subscapularis Muscle and Tendon: Differentiation between the Lower and Upper Subscapularis Muscle. A Review of the Literature

By

Ben Grotenhuis, PT, MOMT, FAAOMPT

## Introduction

The primary function of the four rotator cuff muscles of the shoulder is to dynamically stabilize the spheroidal humeral head in the smaller articular glenoid fossa by balancing the force couples about the glenohumeral joint. Rotator cuff pathology is a frequent clinical diagnosis in daily manual therapy practice. Tears within the musculotendinous unit of the supraspinatus are the most common, followed by the infraspinatus and teres minor tendons.

Despite its importance as a major stabilizer of the glenohumeral joint, the subscapularis muscle has largely been ignored in the published literature (Lo IKY et al 2003)[1]. Isolated or combined tears, partial and full thickness tears of the subscapularis tendon have historically been less recognized. This may be the reason that the subscapularis tendon is therefore not commonly considered as a major source of shoulder pain and dysfunction. The incidence of subscapularis tears during open surgical exploration as first reported by Codman in 1934 was estimated to be only 3.5% of all visible rotator cuff tears (n=200). More recent arthroscopic evaluation of injured shoulders found evidence of a total of 29.4% partial or complete subscapularis tendon tears in 68 patients scheduled for arthroscopic surgery (Barth RH et al 2006)[2].

The subscapularis muscle originates from the subscapularis fossa and inserts at the lesser tubercle of the humerus. Its main function during normal daily activities is to assist in opposing the abduction force created by the deltoid muscle during abduction in the coronal plane. A second force couple in the transverse plane exists between the subscapularis muscle anteriorly and the posterior rotator cuff muscles (the infraspinatus and the teres minor muscles). Clinical, cadaver and electromyographic studies have shown

the subscapularis to be innervated by two or more distinct nerves, suggesting that it should be considered two independent muscle units which function in different ways depending on the position and activity of the shoulder. The upper and lower portions of the subscapularis muscle have been shown to have different EMG activity during voluntary shoulder movements and rehabilitation exercises (Kadaba et al 1992 [3], Decker et al 2003[4], O'Connell et al 2006 [5]).

More recent studies have also made a distinction between the upper and lower portion of the subscapular muscle when validating several clinical special tests. The following review will briefly discuss causes, symptoms, and signs of subscapularis tears. The current literature on five special tests that can assist the clinician in making a diagnosis of subscapularis pathology, will be reviewed.

## Subscapularis Pathology: Etiology, Symptoms and Signs

A rupture of the subscapularis tendon as a result of anterior dislocation of the shoulder has been described in patients older than 35 years of age. Two other potential mechanisms of injury causing partial or complete subscapularis tears have been described by Gerber et al in 1991[6], and are usually forceful hyperextension or external rotation of the adducted arm.

Patients with symptoms of subscapularis dysfunction typically will complain of anterior shoulder pain, night pain, and weakness when the arm is used below or above shoulder level. Difficulty reaching for a wallet in a back pocket or problems with tucking in a shirt, are common functional limitations associated with

subscapularis weakness. Differential diagnosis should include but is not limited to shoulder instability, glenohumeral arthritis, tendinopathy of the shoulder, and cervical spine pathology.

Physical examination of the shoulder may reveal increased external rotation in the case of a complete tear of the subscapularis tendon, and pain and weakness for resisted shoulder internal rotation with a partial or complete subscapularis tear. Isolated strength testing for muscle strength of the subscapularis muscle has been shown to be most effective by performing the Gerber push off test, which is performed by resisting shoulder internal rotation while the patient has the hand placed behind his back (Kelly BT et al 1996)[7].

Since the subscapularis is a powerful internal rotator, various special tests have been used to look for dysfunction of shoulder internal rotation. The most common tests are: the Lift-Off test, Internal Rotation Lag Sign (IRLS), the Belly-Press test, and the Napoleon sign. Two new tests, the Belly-Off sign and the Bear-Hug test, have recently been described and validated.

### **The Lift-Off Test and Internal Rotation Lag Sign**



Fig. 1: During the Lift-Off test, the patient is asked to maintain the space between the back and the hand. Inability to hold this position indicates a torn subscapularis tendon.

The Lift-Off test was originally described by Gerber and Krushell in 1991[6]. During the Lift-Off test, the arm is extended and near maximum internal rotation.

The test is considered positive if the patient is unable to raise the arm posteriorly off the back.

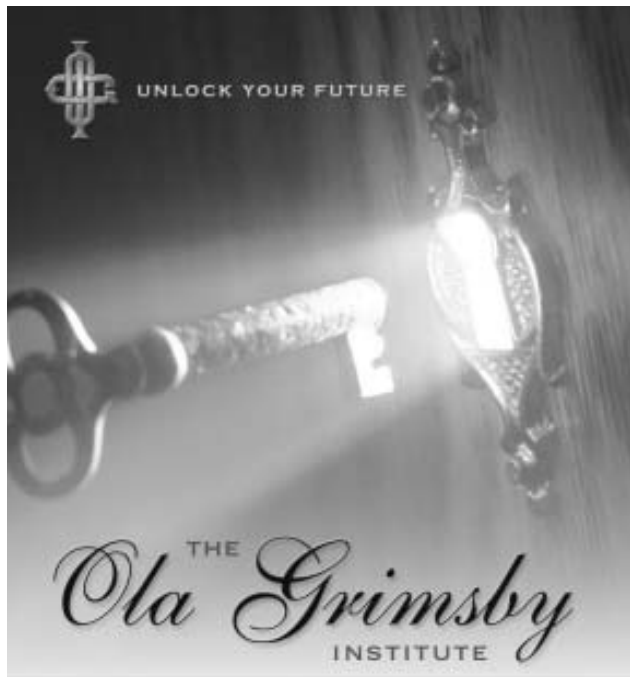
The presence of an Internal Rotation Lag Sign (IRLS) as described by Hertel et al (1996)[8] is evaluated from a similar starting position. The affected arm of the patient is held by the examiner in extension and maximal internal rotation. The dorsum of the hand is passively lifted away from the lumbar spine by the therapist until almost full internal rotation is reached. The patient is then asked to maintain this position. The IRLS is considered positive when the patient is unable to do so and the hand falls back to the patient's body.

Electromyographic studies have shown greater activation of the lower subscapularis muscle compared to the upper portion of the subscapular muscle during the Lift-Off test (Tokish JM et al 2003)[9]. Also, the pectoralis, the latissimus dorsi and the teres major muscles are relatively inactive in this position and contribute very little to internal rotation (Greis PE et al 1996)[10].

However, both the Lift-Off test and the IRLS are of limited value in patients who cannot bring the affected arm into the starting position behind their back because of too much pain and/or restricted range of motion, which is not an uncommon clinical feature in a patient with rotator cuff pathology.

### **The Belly-Press Test**

The Belly-Press test was first described by Gerber et al in 1996. During this test, which activates more the upper subscapularis muscle (Tokish et al 2003)[9], the patient presses the abdomen with the hand flat and attempts to keep the arm in a maximum internal rotation. The test is considered positive when the elbow visibly drops in a posterior direction due to a loss in shoulder internal rotation and pressure against the stomach is now exerted by the patient pushing into shoulder extension and performing wrist flexion (fig. 2). This particular position is often indicated as the Napoleon sign referring to Napoleon Bonaparte.



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Fig. 2: During the Belly-Press test, the patient applies pressure against the stomach. The elbow should be maintained in the coronal plane without flexing the wrist. The test is positive when the elbow moves posteriorly after the clinician removes his hand or the patient flexes his wrist to maintain contact with his belly.

### The Belly-Off Sign

Scheibel et al in 2005 [11] described a new clinical sign for lesions of the subscapularis, which they named the Belly-Off sign. The test for the Belly-Off sign starts with the examiner bringing the affected arm passively into flexion and maximum internal rotation with the elbow flexed to 90°. The elbow of the patient is supported by one hand of the examiner, while the other hand places the palm onto the abdomen (fig. 3A).



Fig.3A. The Belly-Off sign

The patient is asked to keep the wrist against straight and to actively maintain the position of internal rotation as the examiner releases the wrist while maintaining support at the elbow. If the patient cannot maintain this position, the hand lifts off the abdomen resulting in a positive Belly-Off sign (fig. 3B).



Fig 3B. The Belly-Off sign (positive test).

The Belly-Off sign represents the inability of the patient to maintain the palm of the hand attached to the abdomen after the arm is passively brought into flexion and internal rotation, provided there is no dysfunction of the shoulder external rotator muscles.

Scheibel et al compared the Belly-Off sign with other traditional tests for a subscapularis dysfunction: Lift-Off test, Internal Rotation Lag Sign (IRLS), and the Belly-Press test/Napoleon sign. They evaluated 60 patients with clinical, surgical, and/or MRI-confirmed evidence of isolated or combined lesions of the subscapularis musculo-tendinous unit. The Belly-Off sign was more reliable than any other diagnostic test or sign in detecting isolated partial tears of the subscapularis tendon, combined partial subscapularis and complete supraspinatus tendon tears, and post-operative subscapularis insufficiency with mild atrophy of the upper aspect of the subscapularis muscle. Similar reliability existed between the Belly-Off sign, the Belly-Press test, Internal Rotation Lag Sign, and Lift-Off test in the presence of complete/near complete subscapularis tendon tears with or without supraspinatus and infraspinatus tendon tears. The Belly-Off sign was less reliable for assessing partial subscapularis tendon tears when insufficiency of the shoulder external rotator muscles was present (Scheibel et al 2005)[11].

### The Bear-Hug Test

More recently, a new test called the Bear-Hug test, shown to stress more the upper portion of the subscapularis muscle, has been described by Barth et al (2006)[2]. This test uses resisted internal rotation as the palm is held on the opposite shoulder with the fingers extended, and the elbow is positioned anterior to the patient's body. The test is considered positive if the patient cannot hold the hand against the shoulder or if a 20% detectable strength deficit is noted when the test is compared with the opposite side.



Fig. 3A



Fig. 3B

Figure 3A and 3B: Bear-Hug test: the patient places the palm of the affected hand on the contra-lateral shoulder with the fingers extended. The examiner tries to displace the patient's arm away from the shoulder while the patient resists internal rotation (fig. 3A). The inability to hold the palm on the shoulder, or a significant difference in strength compared to the other arm, indicates a positive test (fig. 3B).

Barth et al (2006)[2] tested 68 patients with possible rotator cuff tears using the Lift-Off test, the Belly-Press test, Napoleon sign, and the Bear-Hug test. Results were compared with final findings in the arthroscopic examination. The results of their arthroscopic exam showed a prevalence of 29.4% of subscapularis tears and also revealed that 4 out of 10 subscapularis tendon tears were missed with any of the four tests. The Lift-Off test activates the lower portion of the subscapularis muscle, whereas the Belly-Press and the Bear-Hug test activate the upper part of the muscle. The Lift-Off test wasn't positive until more than 75% of the subscapularis



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tendon was torn. The Belly-Press and Bear-Hug tests were positive when at least 30% of the muscle/tendon unit was torn. The Bear-hug test was found to be most sensitive (60%). Sensitivity for the Belly-press test was 40%, Napoleon sign was 25%, and Lift-Off test was 17.6%. All four tests had high specificity (Lift-Off test 100%; Napoleon sign 97.9%; Belly-Press 97.9%; and Bear-Hug test 91.7%).

## **Conclusion**

Pathology of the subscapularis musculotendinous unit as part of rotator cuff dysfunction of the shoulder occurs more frequently than what historically has been documented. Fine wire EMG research has shown a distinction between activity of the upper and lower portion of the subscapularis muscle during various voluntary shoulder movements and positions of the shoulder. The estimated accuracy of clinical examination of the shoulder compared to arthroscopic examination for isolated and combined tears, and partial or complete tears of the subscapularis musculotendinous unit is only 60%. More traditional special tests such as the Lift-Off test and IRLS, which activate predominantly the lower portion of the subscapularis muscle, appear to be less reliable and very often they cannot be tested successfully due to pain or a loss in range of motion. More recently, the Belly-Off sign and the Bear-Hug test have been described and these tests have shown a greater sensitivity when compared to other special tests for the subscapularis tendon.

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