

Influence of exercise intensity on training-induced tendon mechanical properties changes in older individuals.

GROSSET, J.-F., BREEN, L., STEWART, C.E., BURGESS, K.E. and ONAMBÉLÉ, G.L.

2014

This version of the contribution has been accepted for publication, after peer review (when applicable) but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: <https://doi.org/10.1007/s11357-014-9657-9>. Use of this Accepted Version is subject to the publisher's [Accepted Manuscript terms of use](#).

1 Influence of Exercise Intensity on training-induced Tendon Mechanical Properties changes in
2 Older Individuals

3

4 Jean-Francois Grosset^{1,2}, Leigh Breen^{3,4}, Claire E. Stewart^{5,6}, Katherine E. Burgess⁷,
5 Onambélé Gladys L. ^{4,8}

6

7¹ CNRS UMR 7338, Biomécanique et Bioingénierie, Université de Technologie de
8Compiègne, 60205 Compiègne cedex, France

9² Université Paris 13, Sorbonne Paris Cité, UFR Santé Médecine et Biologie Humaine, 93017
10Bobigny, France

11³ School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham,
12Birmingham, UK.

13⁴ Department of Exercise and Sports Sciences, Manchester Metropolitan University, Crewe,
14UK

15⁵ Institute for Biomedical Research into Human Movement and Health, Manchester
16Metropolitan University, Manchester, UK

17⁶ School of Sport and Exercise Sciences, Liverpool John Moores University, UK

18⁷ School of Health Sciences, Robert Gordon University, Aberdeen, UK

19⁸ Institute for Performance Research, Manchester Metropolitan University, Crewe, UK

20

21Running head: Loading magnitude and tendon adaptations in elderly subjects

22

23Corresponding author: Dr Jean-Francois Grosset. CNRS UMR 7338, Biomécanique et

24Bioingénierie, Université de Technologie de Compiègne, 60205 Compiègne cedex, France

25Tel +33 (0) 3 44 23 43 92; Email: jgrosset@utc.fr

1

1

2

1Abstract

2This study compared the effects of low versus high intensity training on tendon properties in
3an elderly population.

4Participants were pair-matched (gender, habitual physical activity, anthropometrics, and
5baseline knee extension strength) and then randomly assigned to low (LowR, ie. ~40% 1RM)
6or high (High R, ie ~80% 1RM) intensity resistance training programmes for 12 weeks, 3×
7per week (LowR, n=9, age 74±5 years; HighR, n=8 age 68±6 years).

8Patellar tendon properties (stiffness (K), Young's Modulus (YM), cross sectional area
9(TCSA), and tendon length (TL)) were measured pre and post training using a combination of
10Magnetic Resonance Imaging (MRI), B-mode ultrasonography, dynamometry,
11electromyography and ramped isometric knee extensions.

12With training K showed no significant change in the LowR group while it incremented by
1357.7% in the HighR group ($p < 0.05$). The 51.1% group difference was significant ($p < 0.05$).

14These differences were still apparent when the data was normalized for TCSA and TL, i.e.
15significant increase in YM post-intervention in HighR ($p < 0.05$), but no change in LowR.

16These findings suggest that when prescribing exercise for a mixed genders elderly
17population, exercise intensities of $\leq 40\%$ 1RM may not be sufficient to affect tendon
18properties.

19

20Key words: Elderly; Tendon Properties, Resistance training, Load Intensity;

1 Introduction

2 Over the last twenty years, the number of people in the United Kingdom (UK) aged
3 above 65 years has increased by 16%, and this age bracket currently accounts for 17% of the
4 total population. These figures are set to rise with the percentage of the UK population aged
5 over 65 years estimated to reach 21% in 2026 . Aging is associated with a significant decline
6 in neuromuscular function and performance, which can lead to the loss of functional mobility
7 and independence, resulting in reliance on long-term care services . The increase in the
8 elderly population size is set to place a growing burden on these care services. Whilst life
9 expectancy has increased, the number of years lived in good health has not risen at the same
10 rate .

11 One of the major problems contributing to impaired mobility in aging adults is the
12 increasing occurrence of serious falls . Approximately 28-35% of people aged 65 years and
13 older, fall each year, leading to injury and subsequent decreases in quality of life, and often
14 death . The majority of falls occur due to a sudden loss of balance and/or inherent ageing-
15 related decline in balance ability . The ability to maintain balance or stability has previously
16 been associated with the structural and mechanical properties of tendons in the lower limbs,
17 with stiffer tendon structures associated with increased balance ability . A proposed
18 explanation for this finding is related to the force transmission which is the primary function
19 of tendons. Specifically, stiffer tendon structures enable more rapid, and ultimately higher,
20 force transfers than compliant systems and thus, increase the efficiency of the muscle tendon
21 complex in correcting the ‘catch and throw’ actions involved in maintaining postural
22 balance . Indeed stiffer tendon structures are shown to improve postural balance
23 performance . Tendon properties also have the capacity to affect muscle force output and
24 function, especially in the early stages of muscle contraction, with increased tendon
25 compliance associated with detrimental muscle contractile characteristics .

1 The previously reported decline in tendon stiffness with aging is a reversible process.
2 Indeed, mechanical loading has been shown to influence tendon properties. It has been
3 demonstrated previously that high intensity exercise training increases the stiffness of
4 tendons . In an elderly population, 14 weeks of high load resistance training (at 80% 5RM)
5 has been shown to increase the stiffness of the patella tendon by 65% . Similar findings have
6 been reported by others including descriptions on how training modality and/or gender
7 impact on the tendon responses . In contrast, it has been observed that lower intensity
8 exercise in the form of a 6-month progressive walking program does not influence tendon
9 properties in older adults . In younger habitual distance runners (age <65 years), tendon
10 stiffness is similar to that in non-running controls . Similarly, six months of training using
11 body weight squats (50 repetitions (reps) daily) has been reported to have no significant
12 effect on the stiffness of the vastus lateralis tendon , thereby further indicating the possibility
13 of loading threshold for tendon stiffness increments.

14 The majority of exercises prescribed for an elderly population is of a lower intensity
15 than that which has produced beneficial adaptations in tendon properties. These
16 recommendations are due to age-related co-morbidities such as osteoarthritis, in order to
17 prevent older adults lifting heavy weights . However, it is possible that lower intensity
18 exercise does not produce the required stimulus for tendon adaptation. Given the aging
19 population demographics, and the barriers that exist in this population in terms of exercise
20 participation, determining the level of exercise intensity required to induce tendon
21 adaptations is of paramount importance in this population. Therefore the purpose of this study
22 was to: 1) determine whether a low intensity exercise training program (resistance ~40%
23 1RM) affects tendon mechanical properties in an elderly population, and 2) compare these
24 effects to those of a higher intensity exercise training protocol (resistance ~80% 1RM).

25

1 **Methods**

2 **Participants**

3 Twenty elderly adults participated in the present study. All participants gave their
4 written informed consent to take part in the study. The participants were healthy, non-obese
5 (BMI<28), did not take any prescription medication, had no known joint, muscle or tendon
6 pathology, and no known history of cardiovascular, inflammatory, or myopathic disease, and
7 were community-dwelling, habitually active individuals (as determined using an abbreviated
8 version of the Allied Dunbar Activity Survey questionnaire which helps to quantify habitual
9 activity in min/week), with no recent history of structured resistance training (i.e., had
10 partaken in ≤ 1.0 hour/week of resistance training in the 12 months prior to participating in
11 this study). The local Human Ethics Committee approved all experimental procedures.

12 Of the twenty participants who started the study, seventeen completed the 12-week
13 exercise intervention (see table 1). Participants were pair-matched in terms of: gender,
14 habitual physical activity level, anthropometrics, and baseline strength. Subjects were
15 assigned to either a low (LowR) or a high (HighR) resistance training group. In the LowR
16 group, 9 individuals completed the intervention (5 females, 4 males) while 8 individuals
17 completed the intervention (5 females 3 males) in the HighR group.

18

19 **Assessment of Tendon Mechanical Properties**

20 Prior to (no more than 14 days (range 4-14 days)) and following (no more than 7 days
21 (range 4-7 days)) the 12-week exercise intervention, the patellar tendon mechanical
22 properties were determined using the following procedures:

23

24 **Measurement of patellar tendon forces**

1 Torque output during isometric knee extension was determined using a dynamometer
2(Cybox NORM, New York, USA) with data sampled at 2000Hz. The knee was fixed at 90°
3flexion (full extension = 0°), and hip at 85° (supine = 0°). The centre of rotation of the
4dynamometer lever arm was aligned with the knee joint centre, and straps were fixed across
5the chest, hip, and thigh of the test limb to prevent any extraneous movement. A lever
6attachment cuff was placed on the lower leg at 3cm above the medial malleolus. Three
7maximal isometric knee extension efforts were carried out to ensure tendon pre-conditioning
8prior to the test. Participants were instructed to perform ramped isometric knee extensions to
9maximum over a 4s time period. Two trials of the test were performed with 3 minutes rest
10between the contractions. Tendon force was calculated as $F_{tend} = (P + P_{antag}) / T_{arm}$ where F_{tend} is
11the force in the patellar tendon, P is the observed knee extensor torque output, P_{antag} is the
12antagonistic (hamstring) co-contraction torque, and T_{arm} is the patellar tendon moment arm. In
13order to measure T_{arm} participants laid on their side with the knee joint of their dominant leg
14held straight in a 0.2-Tesla Magnetic Resonance Imaging (MRI) scanner (E-scan, Esaote
15Biomedica, Genoa, Italy). MRI scans were taken in the sagittal plane using a spin-echo TI
16(time to inversion or delay time) half fourier (HF) sequence with a slice thickness of 8mm,
17inter-slice gap of 0.6mm and the parameters time to repetition/echo time/number of
18excitations (TR/TE/NEX), 420/18/1; field ofview, 160·160mm; matrix, 256·256 pixels.

19

20 **Estimation of hamstring co-contraction during knee extension - using** 21**electromyographic activity**

22 The electromyographic activity (EMG) of the long head of the biceps femoris muscle
23(BF) was measured in order to ascertain the level of antagonistic muscle co-contraction
24during the isometric knee extension performances in order to accurately quantify quadriceps
25muscle forces. Assumptions were that BF was representative of its constituent muscle group

1 and the BF EMG relationship with knee flexors torque was linear . Two self-adhesive Ag-
2 AgCl electrodes 10mm in diameter (Medicotest, Rugmarken, Denmark), were placed in a
3 bipolar configuration with a constant inter-electrode distance of 20mm, at a site
4 corresponding to the distal one-third of the length, in the mid-line of the belly of the BF. Prior
5 to electrode attachment the skin was prepared by shaving, abrading, and cleaning with an
6 alcohol-based solution in order to minimise its resistance. The reference electrode was placed
7 on the lateral tibial condyle of the test limb. The raw EMG signal was sampled at 2000Hz,
8 preamplified, and filtered using high- and low-pass filters set at 10 and 500Hz, respectively
9 (Biopac Systems Inc., CA, USA). All EMG and torque signals were displayed in real time in
10 Acknowledge software (Biopac systems, Inc., CA, USA) via a computer (Macintosh G4).
11 Two maximal isometric knee flexion contractions were carried out to obtain the EMG at
12 maximal flexion torque. The root mean square (RMS) EMG activity corresponding to the
13 peak torque period was analysed over 50ms epochs and averaged for a 1s period during the
14 plateau of peak torque. This has previously been suggested to be acceptable in terms of signal
15 to noise ratio . Electromyographic activity of the BF during knee extension was divided by
16 the maximal BF flexor EMG, and the maximal flexor torque was then multiplied by this
17 value to determine co-contraction torque .

18

19 **Measurement of patella tendon elongation.**

20 Elongation of the patella tendon was assessed during the graded isometric knee
21 extensions using a 7.5MHz, 40mm linear array, B-mode ultrasound probe (AU5, Esaote
22 Biomedica, Italy) with a depth resolution of 49.3mm. The probe was positioned in the sagittal
23 plane over the patella tendon at the apex of the patella. Three efforts graded to maximum
24 were recorded. An echo-absorptive marker was placed between the probe and the skin to act
25 as a fixed reference from which measures of elongation could be made.

1 Ultrasound images were recorded in real time onto mini DV via S-video output and
2 captured onto PC at 25Hz using Quintic Biomechanics (9.03 v 11). The ultrasound output
3 was synchronized (using an electronic square-wave signal generator) with the force and EMG
4 records to allow temporal alignment. Tendon displacements were determined at intervals of
5 10% of the maximal force (from 0 to 100%) using image J (National Institute of Health,
6 Bethesda, MD, USA).

7

8 **Calculation of tendon properties.**

9 The tendon force-elongation relationships were fitted with second order polynomial
10 functions forced through zero. Tendon stiffness (K) measures (in $\text{N}\cdot\text{mm}^{-1}$) were calculated
11 from the slopes of the tangents at 10% force intervals. In addition, K was also computed
12 from the gradient of a linear fit between 60 and 100%MVC to allow comparison with
13 previous studies that have used this method . Patella tendon resting length (T_L) and cross-
14 sectional area (T_{CSA}) were also assessed with the knee joint at 90° . T_L was determined from
15 sagittal-plane ultrasound images and measured from the inferior pole of the patellar to the
16 superior aspect of the tibial tuberosity. T_{CSA} was measured as the average from transverse-
17 plane ultrasound images taken at 25, 50, and 75% T_L . Young's modulus (YM) was calculated
18 as the product of stiffness and the ratio between T_L to T_{CSA} . Tendon strain (%) was calculated
19 as the ratio of tendon elongation to the T_L . Tendon stress was calculated by dividing force in
20 the tendon by T_{CSA} .

21

22 **Exercise Intervention**

23 **Determination of one repetition maximum (1RM)**

24 During a familiarisation session 2-7 days prior to the 12-week intervention, the 1RM
25 of the participants were determined for all exercises included in the training programme: the

1

8

2

1 seated leg press (to load the quadriceps, hamstrings, gluteus maximus & minimus muscle
2 groups), leg extension (to load the quadriceps muscle group), calf rotator (to load the triceps
3 surae muscle group), and gluteal conditioner (to load both the gluteal and hamstring muscles)
4 machines (Technogym, Gambettola, Italy). The participants first performed a standardised
5 warm-up on the leg press (6×50% perceived 1RM; 4×70% perceived 1RM with 3-min
6 recovery). The perceived sub maximal efforts (as determined through both individual
7 heart/pulse rate monitors and a 10-point Borg RPE scale) were used to ensure fatigue was not
8 induced in the participants and to reduce the risk of injury by asking them to perform a
9 maximal contraction on a ‘cold’ muscle. After warming up, the load was set at 90% of the
10 initially estimated 1RM and increased after each successful lift by 5kg until failure. Each
11 participant was given six lifting attempts in order to achieve their 1RM, and a maximum of
12 two attempts to lift the weight, once it had been established. The greatest amount of weight
13 lifted successfully was recorded to determine the training load. Between successive attempts,
14 3-min rest periods were allowed. A repetition was valid if the participant used correct form
15 and was able to complete the entire lift in a controlled manner without assistance up to full
16 extension or flexion depending on the exercise. The 1RM of the participants in each of the 4
17 exercises performed in the training program were reviewed every 2nd week during training. If
18 1RM had increased, the training load was adjusted accordingly. Additionally, if any
19 participants felt that in-between 1RM assessments the training load was not providing
20 adequate resistance, the load was increased so they were always lifting at the desired
21 percentage of their maximum.

22

23 **Training programme.**

24 The training programme was twelve weeks in duration and consisted of one
25 supervised gym-based class, and two home-based sessions per week in LowR. In HighR, the

1 programme was two supervised gym based classes, and one home-based session per week.
2 All exercise sessions were 1h in duration. Briefly, the supervised exercise classes consisted of
3 a 10-15min warm-up (stretching, aerobic, and coordination work), and resistance exercises
4 using cable weight machines for the lower limb muscles of interest (detailed above).
5 Progression was from 8–11 reps in 2–4 sets at 40% (LowR) or 80% (HighR) 1RM). A cool-
6 down (i.e., static stretches, Pilates, Tai Chi) was also incorporated at the end of each training
7 session (~5min).

8 The unsupervised home-based exercises were similar in design to the supervised
9 classes, with the exception that all the resistance work was carried out using resistance bands
10 (Thera-band, The Hygenic Corporation, Akron, USA), and a 20-min brisk walk was also
11 included. The home-based training lasted ~1h-1h20min. A custom-made exercise booklet
12 illustrated, using photographic and/or cartoons, all the home exercises in detail, with a
13 demonstration of each exercise carried out at the onset of the study. The exercise band
14 protocol used in the home-based programs loaded the same muscle groups as those used for
15 the gym equipment, though at much lower intensities (repetitions and numbers of sets were
16 matched for the gym and home-based sessions). Home-based exercise was not to be
17 performed the day preceding or following the supervised class exercise.

18

19 **Statistical Analyses**

20 SigmaPlot 11.0 (Systat Software, San Jose, CA) was used to run statistical analyses.
21 The data obeyed the assumptions of parametricity (as determined using the Shapiro-Wilk and
22 Levene's tests). Hence, independent samples Student's *t*-tests were used to test for
23 differences between the LowR and HighR groups at baseline. For all reported variables,
24 differences in time (pre- and post-intervention, the within factor) and group (LowR and
25 HighR, the between factor) were tested using a factorial mixed-design analysis of variance (2

1× 2 ANOVA), with post hoc Tukey tests applied where a significant main effect was identified. Data are presented as mean ± SEM (unless otherwise stated). Statistical significance was set at $p \leq 0.05$.

4

5 **Results**

6 The mean anthropometric and habitual physical activity data for the two groups are reported in Table 1. The two intervention groups did not differ significantly in age, habitual physical activity levels, height, mass, 1RM measures, or any of the measured patella tendon properties (Table 2) at the onset of the study ($p > 0.05$).

10

→TABLE 1 NEAR HERE

11 At baseline, the maximal patella tendon force was also not significantly different between the two groups ($p > 0.05$). With training, maximal tendon force was significantly increased in HighR group by $13.6 \pm 6.9\%$ (2428.8 ± 293.7 N and 2725.6 ± 330.4 N respectively pre and post-intervention) ($p < 0.05$), while the increase was $17.8 \pm 5.5\%$ in the LowR group (2346.7 ± 265.8 N and 2751.6 ± 330.4 N respectively pre and post intervention) ($p < 0.05$).

17 As shown in Table 2, with training, anatomical characteristics of the Patella tendon (T_L and T_{CSA}) were neither significantly altered in the LowR group nor in the HighR group ($p > 0.05$).

20

→TABLE 2 NEAR HERE

21 Following the completion of the training programme a two-way ANOVA for tendon stiffness (K) at 100% MVC revealed a significant $57.7 \pm 15.7\%$ increase in the HighR group (940.7 ± 91.4 N·mm⁻¹ pre intervention vs. 1461.0 ± 192.7 N·mm⁻¹ post intervention, $p < 0.05$). However, no significant change was observed in the LowR group (953.3 ± 121.0 N·mm⁻¹ pre-intervention vs. 1016.4 ± 139.4 N·mm⁻¹, $p > 0.05$). Where all the force levels at 10% intervals

1

11

2

1 of MVC were taken into account to compute an average K and YM over the entire force-
2 elongation relationship, significantly higher mean K values were reported post-intervention in
3 the HighR group, but not in the LowR group (See Figure 1; $p < 0.05$).

4 →FIGURE 1 NEAR HERE

5 When the maximal tendon stiffness data was normalised for T_L and T_{CSA} by
6 converting to Young's modulus (YM), a two-way ANOVA revealed a significant
7 $757.9 \pm 17.8\%$ increase in YM at 100% MVC in the HighR group after training as compared
8 with pre intervention ($p < 0.01$), while no change was found in the LowR group ($2.0 \pm 8.6\%$)
9 ($p > 0.05$) (Figure 2). The analysis of variance also highlight a significantly higher YM at
10 every 10% relative force (10-100% MVC) post-intervention in the HighR than in the LowR
11 group ($p < 0.01$).

12 →FIGURE 2 NEAR HERE

13 When tendon stiffness and Young's modulus were calculated over the 60-100% MVC
14 linear fit, similar findings were observed. The two-way ANOVA shows that following the
15 intervention period, K_{60-100} significantly increased by $59.0 \pm 16.3\%$ ($p < 0.05$), and YM
16 significantly increased by $58.9 \pm 18.1\%$ ($p < 0.05$) in the HighR group, whereas the LowR
17 group showed non-significant changes in both K and YM_{60-100} (respectively $5.5 \pm 9.7\%$ and
18 $180.7 \pm 8.8\%$) ($p > 0.05$) (Table 2).

19

20 Discussion

21 The purpose of this study was: 1) to determine whether a low intensity exercise
22 training program (resistance $\sim 40\%$ 1RM; LowR) would affect tendon mechanical properties
23 in an elderly population, and 2) to compare these effects to those of a higher intensity
24 exercise training protocol (resistance $\sim 80\%$ 1RM; HighR). The present results show that 12
25 weeks of LowR had no significant effect on the mechanical properties of the patella tendon in

1the elderly ($p>0.05$). As expected however, HighR did produce significant increases in
2tendon stiffness and Young's modulus. Consequently, HighR produced significantly greater
3changes in patella tendon stiffness and Young's modulus than LowR.

4 The results reported in the present study are in line with the previous studies in terms
5of the magnitude of increase in tendon stiffness observed following 'high' intensity resistance
6training protocols. Specifically, the 57.7% increase in patella tendon stiffness at 100% MVC,
7and 59.0% at 60-100% MVC are congruent with previous data from Reeves et al., and
8Onambélé et al.. These previous studies demonstrated an increase in patella tendon stiffness
9in the range of 54-65% when measured at 60-100% MVC following prolonged resistance
10training programmes (≥ 12 weeks) at 80% 1RM. The congruency between findings was
11echoed in the reported changes in Young's modulus, 57.9% reported here at 100% MVC
12versus 69-70% reported previously .

13 The novelty of the present study's findings lies in the observation that no significant
14difference in patella tendon stiffness and Young's modulus were found when the intensity of
15the resistance training was low (~40% 1RM). Although not previously observed, in elderly
16humans this finding is in line with the theory that there is a threshold value for the exercise-
17induced increase in mechanical properties of tendon tissue . This is related to the changes in
18collagen synthesis which are observed following mechanical loading. Thus, the current data
19has important implications for older persons seeking to offset aging-related mal-adaptations,
20given that LowR does not appear to promote similar benefits as HighR, insofar as tendon
21mechanical properties are concerned.

22 When tendon is subjected to repeated mechanical loading, a number of signals at the
23extracellular matrix may be induced . In order to regulate specific alterations in the
24extracellular matrix's composition, tenocytes sense force-induced deformations in their
25extracellular matrix , triggering specific anabolic and catabolic pathways in response to

1loading . It is thought that there is a ‘set point’ beyond which the induction of these
2signals/pathways occurs (which can be regulated by the cells), and when loading is below
3this, the biological response is not initiated . Interestingly, it is thought that once the stimulus
4is beyond this current threshold, the upregulation in collagen synthesis appears to be
5minimally affected by the magnitude of exercise . Given the current findings, it could be
6speculated that LowR was insufficient to meet (or indeed surpass) the threshold required to
7initiate the signaling response required for altering collagen synthesis.

8 Findings from previous studies support the idea that the mechanical loading threshold
9for tendon adaptation was not met with LowR. Kubo et al demonstrated that the
10tendon/aponeurosis properties of the *vastus lateralis* and *medial gastrocnemius* muscles in
11an elderly population were unchanged following a 6 month progressive walking program.
12Kongsgaard *et al* confirmed that in a young male population, high intensity, single leg
13resistance training (70% 1RM) increased patella tendon stiffness in the high intensity
14resistance trained limb. However, in addition these authors also found that performing low
15load resistance training with the contra-lateral leg, produced no significant changes in the
16mechanical properties of the patella tendon in that limb. Not only does this fit with the
17‘threshold’ concept, it also highlights the need for the mechanical loading to be site specific.
18In the current study the training performed would have induced loading in the patella tendon
19leading to changes in its mechanical properties in the HighR group.

20 These findings have implications when prescribing exercise interventions in an
21elderly population. Previous studies and guidelines have advocated the use of progressive
22resistance in an elderly population at moderate-to-high intensity levels , with exercises
23performed using 50-80% 1RM producing more credible results than those using lighter
24weights or elastic bands . These recommendations would also be appropriate to gain
25beneficial changes in the mechanical properties of tendon. However, although this ‘moderate-

1to-high' intensity resistance training is advocated in the literature, very few elderly
2individuals are engaged in this level of exercise. Data from the USA's Centers for Disease
3Control and Prevention indicate that few older persons engage in regular physical activity,
4with only 31% of individuals aged 65 to 74 years reporting participating in 20 minutes of
5moderate physical activity 3 or more days per week. Even with those who were more
6physically active, few would meet the intensity requirements for tendon adaptation.
7Anecdotally, when looking at the provision of exercise classes and exercise regimes for the
8elderly, the majority of these involve little resistance exercise or low-load
9resistance/theraband exercises (similar to the LowR group in this study). In order to get the
10maximum benefits there needs to be alignment between the recommendations and what
11occurs in practice. However, there are many barriers and difficulties in obtaining engagement
12in exercise in an older population, and these might be partially responsible for the disparity
13between recommendations and practice (see Bunn et al. , and Schutzer and Graves for
14reviews).

15 Further to this point, recent evidence in young adults suggests that low-load resistance
16exercise (30% 1RM) performed to volitional failure, promoted an equivalent rise in acute
17rates of myofibrillar protein synthesis to that seen with traditional high-load resistance
18exercise loads lifted to failure . Furthermore, when practiced as part of a regular exercise
19programme, low-load-to-failure lifting, promoted equivalent muscle hypertrophy to high-load
20lifting . It has been suggested that this form of low-load, high-volume resistance exercise is
21an attractive alternative to traditional high-load lifting for older adults, insofar as muscle
22hypertrophy is concerned, due to the reduction in force loading about compromised older
23joints . Based on the current data, it cannot be said whether a greater number of repetitions in
24the LowR group to promote near-fatigue, would have modulated tendon properties similar to
25HighR. However, this seems unlikely given that tendon collagen adaptations are induced

1 through mechanical force which is defined by the load lifted, whereas muscle adaptation is
2 brought about through the orderly and maximal recruitment of muscle fibres, a process that
3 can be achieved through a wider range of loading stimuli. To date, the impact of low-load
4 resistance exercise to failure on acute and chronic muscle/tendon adaptive responses in the
5 elderly has not been investigated, but clearly warrants further study given the practical
6 relevance of lifting lighter loads for geriatric populations.

7 Future work should also determine whether this effect may be gender specific since
8 previous work hints to older females responding to resistance training at loads <40% 1RM,
9 and male counterparts at loads >40%. Similarly, the mixed gender in the current study may
10 have masked such an effect. Indeed the small population size in the current study did not
11 allow for a gender effect to be investigated. Moreover, future work could address the
12 interesting finding of similar degree of maximal force at the tendon increases in the presence
13 of both high and low intensity resistance exercise. It may be that differences in habitual
14 physical activity in the two training populations (which was not controlled in our study), or a
15 negative impact of high intensity exercise induced cytokines elevation, in an already inflamed
16 endocrine milieu (as seen in normal ageing), may have modulated the response we have
17 observed in this study.

18

19 **Conclusion**

20 Low intensity resistance exercise does not result in beneficial tendon adaptations in an
21 elderly population. Increases in tendon stiffness and Young's modulus are possible in an
22 elderly population with high intensity resistance training, and this increased stiffness has been
23 associated with increased balance ability, and hence lower fall risk. In order to gain these
24 beneficial adaptations in this population high intensity resistance training would therefore

1 need to be recommended. Further work needs to be conducted to assist with the
2 implementation of this recommendation in an elderly population.

1References

2

1Table 1: Anthropometric data and physical activity of the investigated population in LowR
2and HighR groups. Data are mean \pm SD.

	LowR Group n = 9 (5 ♀)	HighR Group n = 8 (5 ♀)
Age (yrs)	74 \pm 5	68 \pm 6
Height (m)	1.64 \pm 0.08	1.64 \pm 0.07
Body mass (kg)	71.3 \pm 10.9	73.5 \pm 12.1
Habitual Physical Activity (min/week)	339.8 \pm 42.7	300.0 \pm 56.7

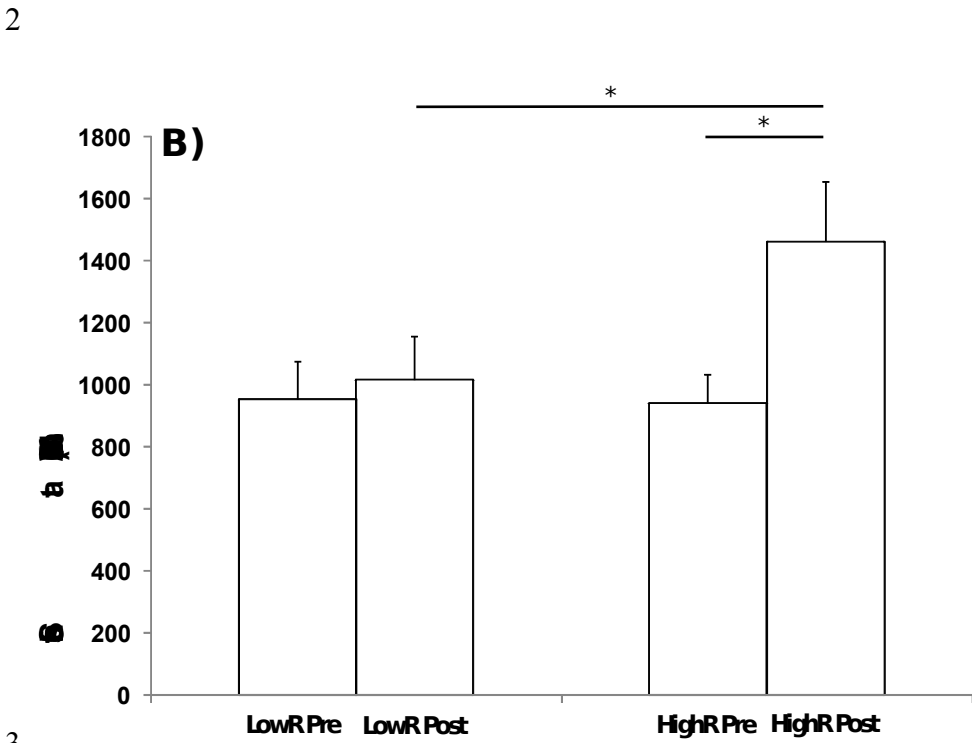
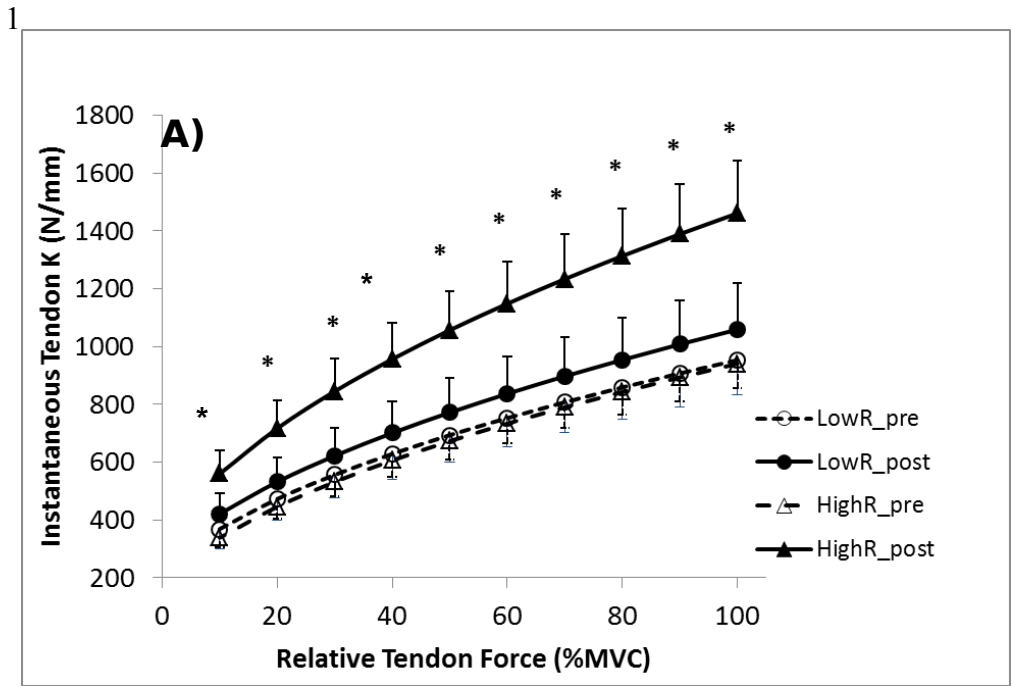
3

1 Table 2: Patella tendon mechanical and structural properties for LowR and HighR, pre and
 2 post intervention.

	LowR Group		HighR Group	
	Pre	Post	Pre	Post
$K_{60-100\% MVC}$ (N/mm)	851 ± 110	891 ± 120	828 ± 83	1295 ± 177 *†
$YM_{60-100\% MVC}$ (GPa)	0.48 ± 0.04	0.48 ± 0.04	0.56 ± 0.07	0.84 ± 0.09 *†
$K_{mean10-100\%MVC}$ (N/mm)	700 ± 95	780 ± 120	680 ± 63	1068 ± 137*†
T_{CSA} (mm ²)	78.5 ± 3.5	80.5 ± 4.0	71.8 ± 5.3	72.1 ± 5.8
T_L (mm)	45.9 ± 1.7	45.0 ± 1.5	47.3 ± 1.3	47.0 ± 1.3

3

4 $K_{60-100\% MVC}$ is Patella tendon stiffness calculated as the gradient of a linear fit between
 5 60 and 100%MVC, $YM_{60-100\% MVC}$ is Young's modulus calculated as the gradient of a
 6 linear fit between 60 and 100%MVC, T_{CSA} is tendon cross-sectional area, and T_L is tendon
 7 resting length. * indicates significant difference between pre and post values. † indicates
 8 significant differences between LowR and HighR groups regarding post-intervention data.
 9 Data are mean ± SEM.



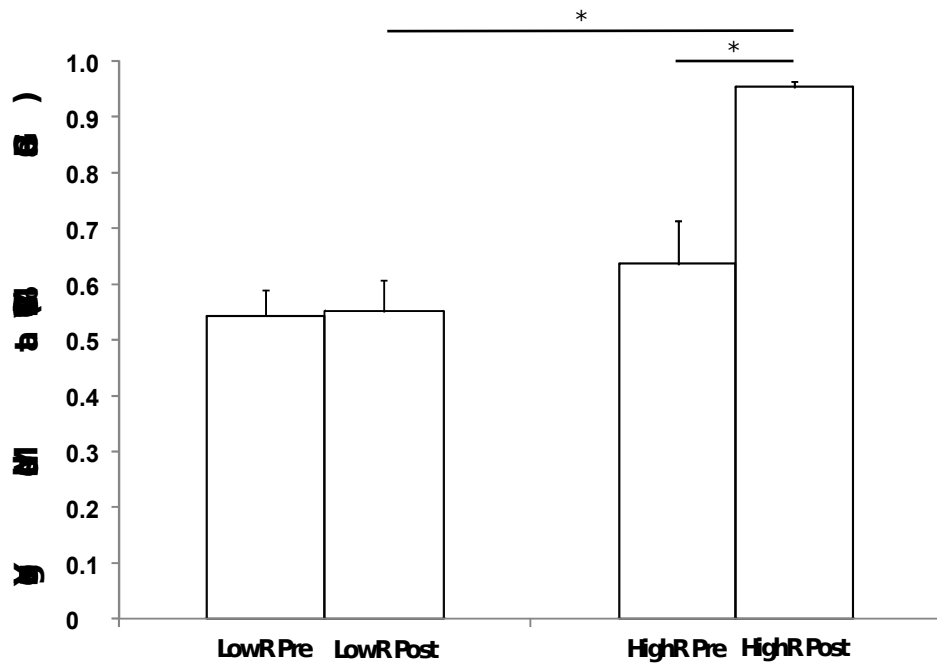
3

4Figure 1 : Patella tendon stiffness at 100% MVC pre and post training intervention for the

5LowR and HighR groups. A) Every 10% MVC; B) Maximal stiffness. * indicates significant

6pre to post training differences as well as significant differences between groups at the post

7training phase. Data are mean \pm SEM.



1

2Figure 2: Young's modulus of the patella tendon pre and post training intervention for the
 3LowR and HighR groups. * indicates significant pre to post training differences as well as
 4significant differences between groups at the post training phase. Data are mean \pm SEM.