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Achilles Tendon Changes in Downhill, Level and Uphill Running

Katy Andrews Neves

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Achilles Tendon Changes in Downhill, Level and Uphill Running

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In this study, we examined how hill running affects the Achilles tendon, which is a common location for injuries in runners. Twenty females ran for 10 min on three randomly selected grades (-6%, 0%, +6%). Achilles tendon (AT) cross-sectional area (CSA) was imaged using Doppler ultrasound and peak vertical forces were analyzed using high-speed (240 Hz) videography. A metabolic cart and gas analyzer ensured a similar metabolic cost across grades. Data were analyzed using a forward selection regression. Results showed a decrease in AT CSA from pre-run to post-run ($p = .0001$). Peak vertical forces were different across grades ($p = .0001$) with the largest occurring during downhill running and smallest during uphill running. The results suggest that the Achilles tendon is affected by running and a decrease in CSA appears to be a normal response. The AT CSA does not differ between grade conditions when metabolic cost of running is matched, suggesting an adaptive effect of the AT. Coaches and athletes can use this knowledge to develop workout protocols that transition runners to downhill running and allow them to adapt to these greater forces.

Keywords: Achilles tendon, ultrasound, tendon size, cross-sectional area, peak vertical force, incline running, decline running, constant effort, females

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I would like to thank my committee. Dr. Johnson inspired me to pursue graduate school and was ready and willing to help at all times, from brainstorming through problems to operating the ultrasound during data collection. Dr. Myrer promptly made meaningful edits to all my work and thought through every aspect. Dr. Hunter readily shared his technical intellect and repairing skill in the laboratory. I would like to thank my research crew leaders Chelsea Rozsa and Steven Bunker who were constantly dependable, the runners for being enthusiastic to participate, and my close friends for encouraging me to press forward. My biggest thanks go to my husband and parents. My mom forever believed in my abilities and buoyed me up. My dad taught me the value of time and how to prioritize. My husband Coulter persistently and patiently supported me through each step, difficulties and all. I truly appreciate all those who helped me complete this venture.

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Introduction

Hill running can provide many health benefits to runners, but there are also potential associated risks (Koji et al., 2012; Jamurtas et al., 2013; Ferley et al., 2013). Understanding physical changes to body tissues during hill running is important for training and competition. Of particular relevance is how hill running affects the Achilles tendon (AT), which is a common location for injuries in runners. An estimated 52% of recreational and competitive distance runners have an AT injury at some point (Kujala et al., 2005). Thinning of the AT following exercise may be indicative of micro-damage and thus injury risk (Ker et al., 2000). One method of monitoring tendon size changes is to measure the cross-sectional area (CSA) using ultrasound imaging (Farris et al., 2011).

The properties of tendons allow them to stretch, withstand tension, and change length and thickness, thus allowing for economical locomotion (Wilson and Lichtwark, 2011). Tendons stretch up to 10% of their resting length, so this gives the tendon a large stretch ability relative to the length of the muscle (Wilson and Lichtwark, 2011). Recent in vivo studies that used ultrasound have shown that the human AT rapidly lengthens and shortens during the stance phase of running, which stores and returns elastic energy (Ker et al., 2000; Magnusson and Kjaer, 2003; Wilson and Lichtwark, 2011). The reutilization of this elastic energy in tendons greatly reduces energy demands in running (Cavagna et al., 1964). Researchers claim that this increase in elastic energy force in the muscle can decrease the amount of muscle activation, and consequently improve performance (Arampatzis et al., 2006; Magnusson and Kjaer, 2003; Wilson and Lichtwark, 2011; Lichtwark and Wilson, 2006).

Tendons have been shown to be adaptive (Magnusson et al., 2008), but whether the tendon adapts to physical activity by changing the CSA remains unknown (Magnusson and

Kjaer, 2003). In most geographic areas, runners encounter hills, yet little published data limits our understanding of hill running (Gottschall and Kram, 2005). The majority of races include hills in their course profiles. For example, the Boston, Chicago, New York City, Los Angeles, and St. George marathons claim hill grades ranging from 0.2% to 5%. In selecting a test grade, 6% would realistically be seen in racing and has also been shown to produce optimal running economy for the participants being studied (Minetti et al., 2002). Conflicting study results, many being animal studies, report that during running the tendon size increased (Sommer, 1987; Woo et al., 1980; Woo et al., 1982), remained unchanged (Buchanan and Marsh, 2001), or decreased (Woo et al., 1982; Tardioli, 2011). Thus, there remains uncertainty as to how AT CSA responds to exercise, particularly to grade running.

In addition to CSA, alterations in ground reaction force and ankle joint velocity may affect the AT across grades, because varying forces and joint velocities relate to the stress placed on a tissue (Gottschall and Kram, 2005). These variables are defined as: (1) peak vertical force, the vertical component of ground reaction force that occurs at midstance, and (2) plantar-flexion velocity, the average velocity from maximum dorsiflexion to maximum plantar-flexion of the ankle. All measurements involving the AT aid in investigation of adaptation to training methods and prevention of training injuries. No researchers have reported a direct correlation between grade running and injury risk.

Over 40% of all runners are female (Paluska, 2005), yet most running studies use elite male subjects. Involving females and/or non-elite runners would provide a meaningful comparison and add to the scientific literature. The common, non-elite runner who runs for health and enjoyment would benefit from information about a frequent runner population, as we have termed it. The primary purpose of this study was to determine the relationship between the grade of the running surface and the change in AT CSA in a population of female frequent runners. We hypothesized: (1) the percent change of the AT CSA would have the greatest decrease after running on the incline grade, (2) the percent change of the AT CSA would decrease after running on the decline grade, and (3) the percent change of the AT CSA would have the smallest decrease after running on the level grade.

Methods

Research Design

This study was a crossover design. Each individual was measured three times on different days and in different running grade conditions. We used Latin-square randomization, with participants drawing their treatment order from a container. Intra-individual comparisons were made with the independent variable being grade of the running surface (-6%, 0%, +6%). The dependent variables were change in Achilles tendon cross-sectional area from pre-run to post-run measurement, peak vertical force and plantar-flexion velocity.

Participants

Twenty female runners (age = 20.7 ± 1.8y, height = 165.1 ± 6.2cm, mass = 60.5 ± 7.2kg, weekly mileage = 43.1 ± 19.5mi, fastest 5000m time = 18:31.59 ± 2:11.32 min, mean ± standard deviation) volunteered for this study (Table 1). They ranged from recreational to collegiate Division I runners. None of the participants had suffered an Achilles tendon injury within six months or a lower extremity injury within three months of data collection, or were pregnant. Inclusion criterion was current capability of the female runners to run 5000m in under 24:00 min. All procedures were granted approval by the Institutional Review Board. Power assessment indicated that with a SD of 0.04, 16 participants were needed to detect a significant difference of

$4 mm^2$ between pre and post-run AT CSA measurements ($p = 0.05$, $ß = 0.8$). We collected data on 20 participants, assuming a 20% dropout rate. All participants completed the study.

Procedures

Each approved participant came to the biomechanics lab on Brigham Young University campus on three separate days. The time between visits was at least 48 hours. Participants came at approximately the same time of day for each visit. Participants completed a pre-participation questionnaire to determine eligibility before any data collection. Prior to arrival, each participant received instructions to maintain normal eating and hydration habits, refrain from eating a meal within two hours of testing, follow normal sleep patterns and avoid any exercise on test day previous to testing. Accordance with these parameters was assured by the pre-participation questionnaire. On the first visit they signed an approved Informed Consent form.

Data Collection

At the start of each of three visits, the participant rested prone on a treatment table for 15 minutes to adapt to lab conditions, similar to a recently established protocol (Kubo and Ikebukuro, 2012). A pillow under the ankles created a neutral resting position at the ankle joint. Following the rest period, a strap connected to the end of the table was fit around each foot to create a 90 degree angle at the ankle, which was measured by a goniometer. Doppler ultrasound (GE Logic E, GE Healthcare, Little Chalfont, UK) was used to image the Achilles tendon with a 12L probe. Test and retest reliability had an $ICC_{3,1}$ of 0.97 (95% CI: 0.959, 0.986). Ultrasound transmission gel (Accelerated Care Plus, UG250, CAN) was applied to the head of the probe to collect three transverse images of the AT CSA before and after running. Images were taken between the lateral and medial malleolus. An oblique line was made midway between the two landmarks and the location was marked with a permanent marker to ensure consistency within and between trials.

High-speed videography (VICON Motion Technologies, Centennial, CO, USA) was used for kinematic and kinetic data collection. Ten cameras (240 Hz) recorded the motion of the runners. A wide sliding caliper was used for anthropometric measurements including: leg length (ASIS to medial malleolus), ASIS-trochanter distance (in the sagittal plane), inter-ASIS distance, knee width, and ankle width (Scholz et al., 2008), which measurements were input into the individual subject profile on VICON. Reflective markers were placed on the participant according to the VICON Plugin Gait setup. Sixteen total markers were placed bilaterally using double-sided adhesive tape on the lower extremity over the following anatomical landmarks: anterior and posterior superior iliac spines, mid-lateral thigh, lateral knee joint center, mid-lateral shank, lateral malleolus, posterior heel, and head of second metatarsal (Figure 1).

Participants ran on the indoor treadmill at three different grades on three separate days. They ran in their personal running shoes, and the sequence of running grades was randomly selected for each person (-6%, 0%, +6%). The runner ran at a speed of 3.13m/s (7 mph) on the 0% grade, 3.80 m/s (8.5 mph) on the -6% grade, and 2.46m/s (5.5 mph) on the +6% grade. These differing speeds were determined in pilot testing to elicit similar metabolic cost. A metabolic cart and gas analyzer (TrueMax 2400, Metabolic Measurement System, PARVO Medics, UT, USA) were used to ensure similar effort across running grades via collection of steady-state oxygen consumption data. The subject ran at the designated grade for 10 min (Figure 2). These speeds and time period were chosen to represent recreational running as well as to minimize fatigue and prevent any confounding effects that fatigue may have on muscle and tendon behavior (Farris et al., 2012). Avoiding the creeping effects of fatigue was the same reason there was no warm-up.

Data Processing

Three images were taken of each right and left AT CSA, outlined manually using internal software of the GE Logic (Figure 3), and averaged (Farris et al., 2011). The right and left CSA were then averaged together for pre-run measurements and post-run measurements for each of the grade conditions.

Position data, collected from the locations of the reflective markers, were reconstructed into three-dimensional coordinates using VICON Nexus software (VICON Motion Technologies, Centennial, CO, USA). An AMTI instrumented treadmill recorded ground reaction forces at 1200 Hz. A static trial was recorded before running, where the participant stood still on the treadmill for 1 s in anatomical position. These coordinate data were smoothed with a 50 Hz low-pass Butterworth filter. Kinetic data were recorded for 10 s at the zero, second, fourth, sixth, eighth and tenth minute of running. We used the data from the eighth minute for analysis, which included the last 2 min of the 10-min run. This ensured that subjects were thoroughly warmed-up physiologically and biomechanically prior to this part of data collection. The data were then imported into custom-made software using Microsoft Visual Basic 2012 (Microsoft Corporation, Redmond, WA, USA) for additional calculations. Software analyzed and averaged peak vertical force and plantar-flexion velocity for 8 steps of the runner.

Statistical Analysis

A forward selection regression was performed to determine the effect of grade on Achilles tendon cross-sectional area, peak vertical force and plantar-flexion velocity. The alpha level was set at $\alpha \leq 0.05$. Leg dominance and foot length were used as co-variates in the analysis. Statistical analysis was performed using Statistical Analysis Software (SAS Version 9.3, SAS Institute, Inc. Cary, NC, USA).

Results

Table 2 lists the results, means, standard deviations and statistical significances for the dependent variables. There was a significant change in AT CSA from pre-run to post-run measurement (F = -6.62, $p < 0.001$). The average pre-run value was 0.39 cm^2 while the average post-run value was 0.36 cm^2. The average percent changes were as follows: -7.14% for downhill running, -6.30% for level running, and -4.87% for uphill running. While this looks like a trend across surfaces, the grades were non-significant (F = 1.29, $p = 0.284$).

Peak vertical forces were statistically different from one another across grades (F = 45.54, $p < 0.001$). The greatest average peak force was 2.72 BW for the downhill grade, the second largest was 2.52 BW for the level grade, and the smallest was 2.36 BW for the uphill grade. Average plantar-flexion velocity during uphill running was statistically different from downhill running ($p = 0.013$) and level running ($p = 0.039$). Leg dominance ($p = 0.013$) and foot length ($p = 0.035$) were significant covariates in analysis of plantar-flexion velocity.

Discussion

The aim of this study was to determine the relationship between the grade of the running surface (-6%, 0%, +6%) and AT CSA changes in female runners. Our findings suggest that running does indeed affect AT CSA. Running at a consistent energy output for a ten minute run at submaximal effort caused a decrease in AT CSA. We attribute this decrease in AT CSA to be a result of the tendon stretching and thinning (Lichtwark and Wilson, 2006). While CSA decreased after running on every grade condition, comparing the magnitudes of change across grades was non-significant.

We hence reject our hypothesis that the greatest decrease in AT CSA would occur after uphill running and the smallest decrease would occur after downhill running. Our results agree with a previous finding that the AT of trained runners was already adapted to the loads of running, so the changes in AT CSA in response to running were not remarkable (Magnusson and Kjaer, 2003). The AT has been noted for its dynamic behavior during exercise (Farris et al., 2012) and its adaptive nature affords it the ability to respond to changing demands (Magnusson et al., 2008). We thought the tendon would change across grades because of different forces that hill running causes. Hill running seems demanding on a runner because it requires synchronized muscular contraction around the hips, knees, and ankles while simultaneously supporting a runner's full body mass. Though peak vertical forces were significantly different across grades, as will be further discussed, they did not cause significant change in AT CSA across grades. The benefit or harm in the extent of AT CSA changes, along with the exact reason why these changes occur, has not yet been elucidated.

We did find significant differences in peak vertical force across grade conditions. The peak force for level running at 3.13 m/s was 2.52 BW. This agrees with the previously reported value of 2.5 BW reported at a pace of 3 m/s, which force was just slightly smaller and pace slightly slower than ours (Gottschall and Kram, 2005). We reported the greatest peak vertical force resulting on a downhill grade and the smallest peak force on the uphill grade, +8% larger and -6% smaller when compared to level running, respectively. The results obtained in our study agree with those of previous researchers and support the theory that uphill, downhill and level grade conditions result in different peak vertical forces (Iversen and McMahon, 1992; Hreljac et al., 2000). Our findings differ from a study which found that neither downhill nor uphill running affected peak vertical force likely because our study matched metabolic cost across grades, while theirs used the same speed across grades. (Gottschall and Kram, 2005). Our different speeds matched metabolic cost for recreational running at the three slopes, as determined in pilot data.

As previously described, plantar-flexion velocity is the average velocity from maximum dorsiflexion to maximum plantar-flexion at the ankle. Compared to uphill running, our results showed plantar-flexion velocity to be statistically different than downhill and level running. It is well known that force equals mass multiplied by acceleration. In relating this formula to our results, a slower plantar-flexion velocity is expected to be related to a decreased force. Our results confirm this idea, showing both the slowest plantar-flexion velocity and lowest peak vertical force occurring on the uphill grade. A slower velocity may indicate a physiological burden during harder exercise, similar to responses like increased heart rate or respiration. A greater force can relate to injury, so it is possible that a greater plantar-flexion velocity may have a similar effect (Gottschall and Kram, 2005). Differing velocities affect forces and thus affect joints in different ways, but whether an increased plantar-flexion velocity benefits or harms the AT remains unknown.

The participants were trained and well-accustomed to the demands of running. They were also habituated to running at a moderate pace for durations much longer than ten minutes, which was the greatest running time in our study. Our study design did not include sufficient time or intensity for the runners to experience notable fatigue. Faster speeds result in greater stress on tendons and tissues (Harrison et al., 2014). Uphill running causes greater ankle range of motion while the foot is in contact with the ground (Swanson and Caldwell, 2000). We found no difference in CSA changes across grades. The lack of differences can perhaps be explained by greater stress on the tendon in the faster downhill trials, but also a smaller ankle range of motion. Conversely, there is a larger ankle range of motion and less stress on the tendon in the slower uphill trials. To fully understand the effect of uphill and downhill running on CSA, future research should look at constant speed running across grades. Other future studies should look at how duration of run and recovery time between exercise bouts affects CSA.

Our findings, along with other investigations, lead to a better understanding of how uphill and downhill running relate to injury. Force data suggests that the probability for musculoskeletal injury increases during downhill running and decreases during uphill running (Hreljac et al., 2000). However it is usually unaccustomed exercise that can induce tissue damage, especially eccentric exercises such as downhill running (Koji et al., 2012). Many athletes want to capitalize on the benefits of hill running while avoiding injuries. Benefits and consequences of hill running should be weighted and considered. Among benefits are improved cardiovascular conditioning and increased strength (Telhan et al., 2010), favorable blood lipid changes (Jamurtas et al., 2013), reduced risk of injury due to an adaptive effect of training (Proske and Morgan, 2001), and improved performance with specificity of exercise. The main risk of hill running is an overuse injury; downhill running increases the risk of injury because of increased impact force peaks, which occur at heel strike (Gottschall and Kram, 2005). Our results, along with previous studies, can help coaches and athletes in selecting workouts and training methods that minimize injury risk. If an athlete is injury-prone, they may need a greater transition period to adapt to these larger loads associated with downhill running. Once an athlete has had enough time to adapt to the loads imposed through different types of training, they should be able to continue with minimized injury risk.

There were some limitations related to this study. All participants were trained runners so results may have been skewed because of well-adapted tendons. There may be a greater change in AT CSA among untrained participants, because of the lack of adaptation of the AT. Reflective markers were manually placed on the anatomical landmarks for each participant, so that they may have been placed on slightly different positions of the body for each running session.

We made one main inference. The order of grade treatment (-6%, 0%, +6%) was randomly assigned, so we can claim that the changes in vertical peak force and plantar-flexion velocity were caused by the individual grade conditions. Participants were not randomly selected from a population, so results may only be attributable to a population of female runners with similar characteristics.

Conclusion

Downhill, uphill and level running do cause a statistically significant decrease in the AT CSA. This appears to be a normal response to running. The AT CSA does not differ between grades when metabolic cost of running is matched. The Achilles tendon is capable of adapting and this may have been the case with our participants, as our study used all trained runners. Downhill running resulted in the largest peak vertical force. Coaches and athletes can use this knowledge to develop workout protocols that transition runners to downhill running and allow them to adapt to these greater forces.

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Table 1. Physical characteristics of the participants.

Variables	**Mean ± SD**
Age (y)	20.7 ± 1.8
Body mass (kg)	60.54 ± 7.16
Height (cm)	165.1 ± 6.17
Best 5000m time (min:s)	18:31.59 ± 2:11.32
Weekly mileage run (km)	26.8 ± 12.1

Table 2. Comparison (mean ± SD) of the differences in peak vertical force, plantar-flexion velocity, and Achilles tendon cross-sectional areas (AT CSA) in running on a downhill (-6%), level (0%), and uphill (+6%) grade.

	Downhill (-6%)	Level (0%)	Uphill (6%)
Difference in AT CSA from pre-run to post-run (cm^2)	-.028 ± .025	-.025 ± .024	-.019 ± .034
Percent change (%)	-7.14	-6.30	-4.87
Peak vertical force (BW)	2.72 ± .20*	2.52 ± .16*	2.37 ± .13*
Plantar-flexion velocity (deg/s)	187.8 ± .45†	182.9 ± .93‡	154.8 ± .55

**indicates significance between grade conditions (p = .0001)*
† indicates significance from uphill running (p = .01)
‡ indicates significance from uphill running (p = .04)

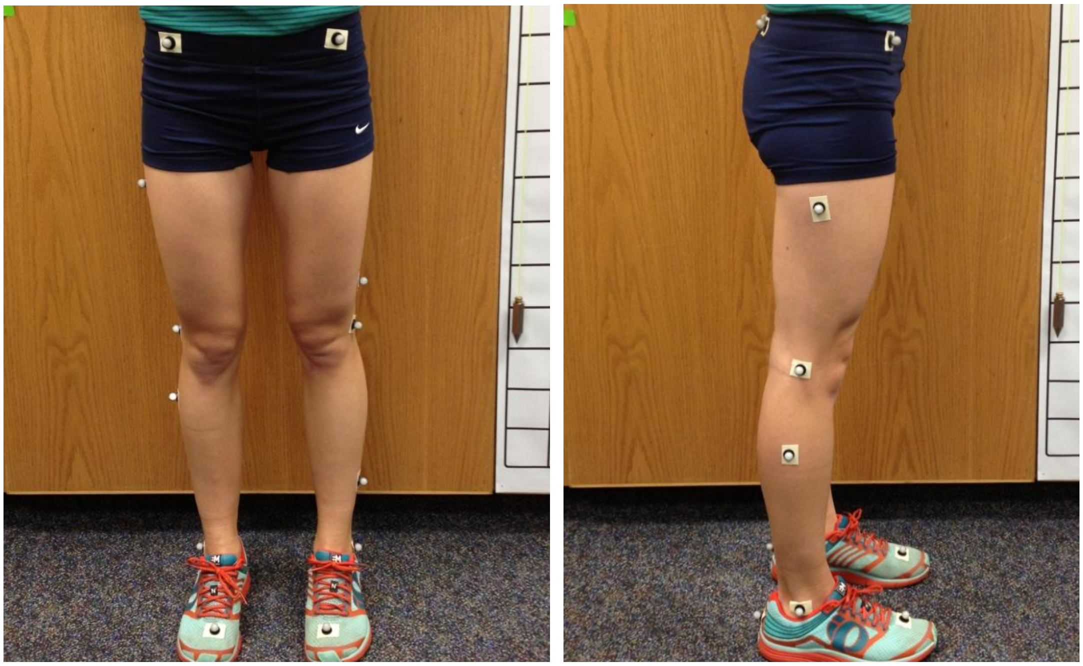

Photo: Coulter Neves

Figure 1. The placement of the reflective markers. All markers were attached using double-sided tape.

Photo: Katy A. Neves

Figure 2. Running protocol. The participant wore reflective markers, which were filmed by ten high-speed cameras to record the motion of the runner. A metabolic cart and gas analyzer were also used.

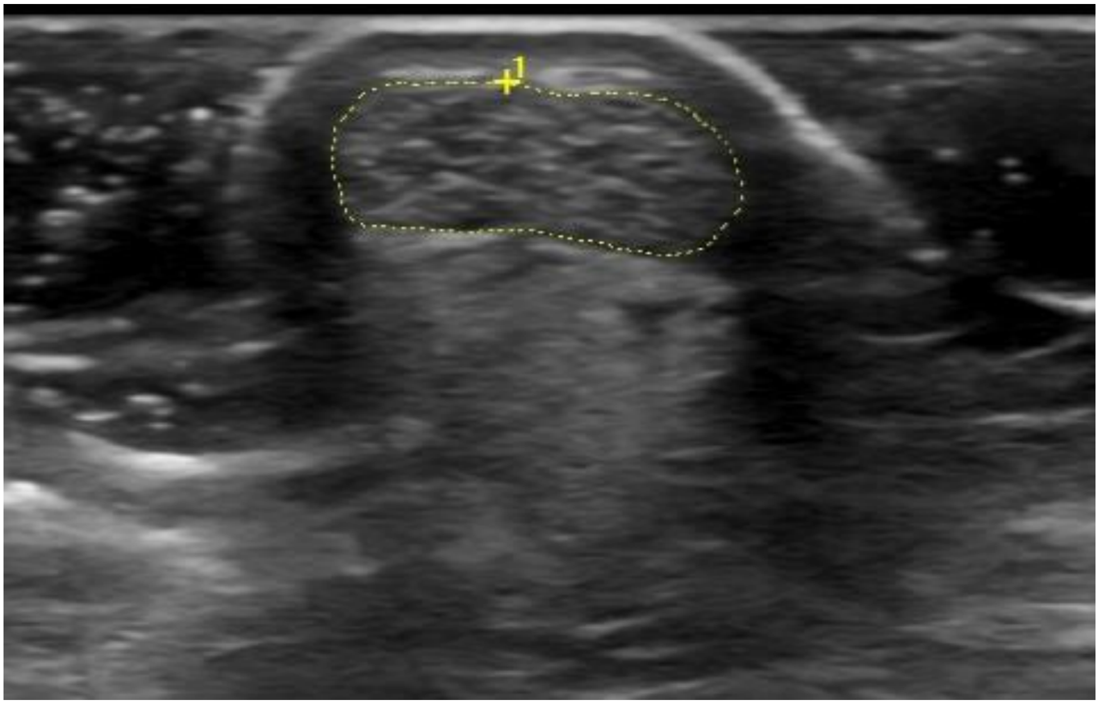

Photo: A. Wayne Johnson

Figure 3. Outline of the Achilles tendon (AT) cross-sectional area (CSA). Internal software of the GE Logic was used.

Appendix A: Raw Data

Raw data of participant characteristics and measurements.

Sub	**Age**	**Ht**	**Wt**	**Dom Leg**	**5K**	**Mi/wk**	**Foot length**
	y	*in*	*lbs*		*min:s*	*mi*	*cm*
1	22	63	101.3	R	16:34	50	21.7
2	18	62	110	L	19:10	50	22.1
3	19	68	137.5	R	16:35	70	24.5
4	20	69	144.5	R	18:07	25	24
5	22	63	121	R	20:00	16	22.9
6	21	64	103	R	16:30	70	22.3
7	21	63	123.5	R	23:59	15	22.5
8	23	67	123	R	16:24	25	24.6
9	19	69	145	R	18:20	50	24.3
10	21	63	126	R	17:13	75	23.5
11	21	69	138	R	18:30	55	24.3
12	19	64	120	R	17:50	50	22.9
13	18	64	117	R	18:17	45	23.2
14	21	65	110	L	20:31	15	23.7
15	23	66	145.2	R	17:00	20	24.6
16	18	64	117	R	18:08	50	22.4
17	19	65	126	R	17:25	50	24.2
18	23	64	120	L	19:00	40	23.2
19	22	61	95	R	17:00	65	20.7
20	23	67	123	R	23:59	25	22.9

Sub	Grade	Peak ForceR	Peak ForceL	Plant VelR	Plant VelL	Pre CSA	Post CSA
		BW	*BW*	*deg/s*	*deg/s*	cm^2	cm^2
1	0	2.4	2.5	171.3	168.4	0.27	0.25
1	-6	2.8	3.0	141.3	145.6	0.30	0.22
1	6	2.4	2.5	131.1	167.0	0.26	0.24
2	0	2.7	2.6	261.1	148.4	0.34	0.33
2	-6	2.9	2.8	206.3	171.1	0.34	0.32
2	6	2.3	2.3	220.6	141.6	0.36	0.35
3	0	2.4	2.4	134.5	109.9	0.44	0.40
3	-6	2.5	2.3	160.8	148.6	0.48	0.43
3	6	2.5	2.3	160.8	148.6	0.41	0.38
4	0	2.8	2.7	245.8	161.1	0.40	0.33
4	-6	2.9	2.8	223.6	157.9	0.42	0.37
4	6	2.6	2.5	274.5	158.5	0.42	0.40
5	0	2.5	2.4	213.8	135.0	0.48	0.42
5	-6	2.6	2.5	258.1	166.9	0.47	0.44
5	6	2.2	2.2	178.8	100.9	0.43	0.40
6	0	2.4	2.5	414.5	173.5	0.47	0.42
6	-6	2.7	2.8	460.4	157.9	0.53	0.52
6	6	2.3	2.3	236.5	138.4	0.53	0.48
7	0	2.7	2.6	200.1	206.6	0.37	0.34
7	-6	3.2	2.9	198.3	198.1	0.34	0.32
7	6	2.7	2.6	186.9	139.5	0.35	0.33
8	0	2.5	2.5	166.1	145.1	0.35	0.34
8	-6	2.4	2.5	157.8	159.1	0.36	0.36
8	6	2.4	2.3	114.5	120.4	0.35	0.34
9	0	2.4	2.5	151.5	127.1	0.44	0.45
9	-6	2.6	2.7	158.0	166.5	0.43	0.40
9	6	2.3	2.3	142.9	149.9	0.41	0.40
10	0	2.4	2.4	159.1	158.4	0.45	0.41
10	-6	3.0	2.9	196.9	161.4	0.40	0.37
10	6	2.3	2.3	145.6	145.1	0.40	0.40
11	0	2.5	2.8	175.6	180.0	0.41	0.37
11	-6	2.8	2.8	227.0	162.3	0.37	0.35
11	6	2.4	2.5	182.9	145.9	0.37	0.34
12	0	2.8	2.8	286.0	150.8	0.35	0.34
12	-6	3.0	2.9	223.5	171.0	0.36	0.34
12	6	2.3	2.4	124.5	140.0	0.32	0.35
13	0	2.5	2.6	192.3	113.1	0.34	0.32
13	-6	2.8	2.8	183.3	147.8	0.31	0.30

13	6	2.4	2.5	152.3	137.3	0.36	0.35
14	0	2.4	2.4	170.8	109.9	0.39	0.37
14	-6	2.5	2.6	174.9	162.3	0.40	0.35
14	6	2.4	2.4	183.5	120.0	0.41	0.36
15	0	2.5	2.4	131.0	127.4	0.49	0.46
15	-6	2.7	2.6	203.6	159.6	0.47	0.45
15	6	2.3	2.3	124.0	104.9	0.47	0.39
16	0	2.5	2.5	189.1	122.9	0.37	0.36
16	-6	2.6	2.5	207.6	138.1	0.37	0.37
16	6	2.5	2.4	174.4	135.1	0.37	0.39
17	0	2.6	2.5	142.0	140.8	0.43	0.40
17	-6	2.8	2.6	218.9	178.9	0.42	0.41
17	6	2.4	2.2	155.0	110.0	0.38	0.37
18	0	2.3	2.1	439.1	133.9	0.41	0.38
18	-6	2.9	2.5	218.9	211.5	0.42	0.37
18	6	2.2	2.1	158.1	126.3	0.38	0.37
19	0	2.9	2.6	272.0	191.6	0.29	0.28
19	-6	2.7	2.5	162.8	154.3	0.30	0.26
19	6	2.5	2.3	178.9	146.3	0.32	0.30
20	0	2.4	2.3	131.1	153.0	0.32	0.33
20	-6	2.8	2.5	142.5	154.0	0.35	0.31
20	6	2.3	2.2	145.0	132.4	0.34	0.34