

REVIEW PAPER

Achilles Tendon Stiffness in Sprinters and Distance Runners: A Critical Narrative Review

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Abstract

Achilles tendon stiffness is frequently proposed to distinguish sprint from endurance adaptations, but the evidence combines different populations and mechanical outcomes. This narrative review critically examines direct comparisons between sprinters and distance runners, measurement methods, training responses, and associations with running performance and injury. Targeted searches and citation checking used PubMed, Web of Science, Scopus records, publisher websites, and institutional repositories, with verification completed in September 2026. Findings were interpreted according to study design, tendon region, and measurement construct; no meta-analysis was performed. One direct comparison reported greater force-strain stiffness of the tendon-aponeurosis complex in sprinters, whereas smaller collegiate and older-athlete comparisons found no significant differences in longitudinal stiffness. Greater stiffness has been associated with lower running energy cost in some endurance samples, and loading interventions demonstrate that tendon properties can change. However, structural stiffness, material modulus, shear-wave speed, and myotonometric stiffness are not interchangeable. Cross-sectional differences cannot establish training effects, and changes in stiffness do not independently demonstrate improved performance or altered injury incidence. Available evidence supports context-dependent variation rather than a universal stiffness hierarchy across running disciplines. Future comparisons should standardise measurement conditions and examine tendon properties alongside muscle strength, morphology, running mechanics, and prospectively recorded outcomes.

Keywords: tendon mechanics, sprinting, endurance running, running economy, ultrasonography

Introduction

The Achilles tendon links the triceps surae to the calcaneus and contributes to force transmission and elastic energy exchange during running. Its function depends on the interaction between tissue deformation and muscle force production rather than on stiffness in isolation. The potential benefits of elastic recoil therefore need to be considered alongside the metabolic demands of the muscles that load the tendon (Blazevich & Fletcher, 2023).

Sprinting and distance running impose different demands on this system. Sprint performance requires rapid force application during short ground contacts, whereas distance per-

formance depends partly on sustaining locomotion at a manageable energy cost. These distinctions provide a rationale for investigating different tendon phenotypes, but do not establish that sprinters invariably have stiffer tendons. Moreover, middle-distance runners, long-distance specialists, older master athletes, and recreational runners should not be treated as equivalent populations.

The available literature presents apparently conflicting observations. A direct comparison reported higher force-strain stiffness in sprinters than in endurance runners (Arampatzis, Karanidis, Morey-Klapsing, et al., 2007), whereas other compari-

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sons did not identify significant group differences (Kurihara et al., 2012; Stenroth et al., 2016). Differences in measured structures and testing procedures may contribute to these discrepancies. The purpose of this review is to distinguish direct evidence from contextual evidence and to clarify what each permits us to conclude about athlete characteristics, training adaptation, running performance, and injury. This focus complements broader accounts of plantar flexor function in sprinting (Crotty et al., 2024).

Review approach

This is a critical narrative review, not a systematic review. We conducted targeted electronic searches and citation verification on 29 September 2026 using web-based retrieval of PubMed, Web of Science, Scopus records, publisher websites, and institutional repositories. Searches combined Achilles tendon, stiffness, sprinters, distance runners, running economy, training, elastography, and myotonometry, supplemented by author and title searches for relevant studies. We consulted accessible full texts where available; otherwise, we limited interpretation to information supported by the indexed abstract or publisher record. Bibliographic details were checked against those records.

Human studies were selected for relevance to direct discipline comparisons, tendon measurement, loading adaptation, or running-related outcomes. Studies involving middle-distance athletes, other sports, or inactive controls were retained as contextual evidence and identified accordingly. Reviews were used to frame interpretation, not counted as additional independent athlete samples. The synthesis considered population, study design, anatomical region, mechanical outcome, and the distinction between association and intervention. Selection was purposive and non-exhaustive; there was no protocol registration, duplicate independent screening, formal risk-of-bias scoring, or pooled effect estimation. These limitations constrain the comprehensiveness and certainty of the conclusions.

Biomechanical interpretation

Longitudinal structural stiffness is the slope of a tendon force–elongation relationship over a specified loading interval, commonly expressed in N/mm. Material stiffness is represented by the slope of a stress–strain relationship and incorporates cross-sectional area and reference length. Consequently, two tendons can have similar material properties but different structural stiffness because their geometry differs. A larger cross-sectional area or shorter loaded segment can increase structural stiffness without establishing a change in tissue material quality (Devaprakash et al., 2020).

The relationship between stiffness and stored energy depends on what is held constant. In an ideal linear spring, a stiffer spring stores less energy at the same applied force but more energy at the same elongation. Running fixes neither variable across individuals or speeds. Statements that greater stiffness necessarily increases or decreases elastic energy storage are therefore incomplete. The real

tendon also exhibits nonlinearity and energy dissipation, so stiffness should not be equated with resilience or strength at failure.

The relevant functional unit includes muscle fascicles, aponeuroses, tendon, and joint geometry. Tendon deformation can allow muscle fascicles to operate over a different shortening range and velocity from the whole muscle–tendon unit. A mechanically plausible benefit of stiffness must consequently be evaluated against muscle force capacity and the running task. Neither maximal stiffness nor maximal compliance is a defensible universal target (Blazevich & Fletcher, 2023).

Measurement methods and comparability

Ultrasonography combined with dynamometry estimates longitudinal stiffness by relating tendon elongation to tendon force during controlled contractions. Force is derived from joint moment and an estimated moment arm, with appropriate treatment of antagonist activity and other moment contributions. Ignoring an antagonist contribution to the net plantar flexion moment can underestimate agonist force. Joint rotation, probe movement, tracking location, loading rate, and the force interval used for curve fitting also influence interpretation.

The anatomical segment must be specified. Displacement measured at the gastrocnemius junction represents a different effective structure from deformation of the free tendon between the soleus junction and calcaneus. Regional differences were demonstrated using three-dimensional ultrasound (Lichtwark et al., 2013). MRI and three-dimensional ultrasound can characterise geometry, but morphology alone is not a direct measurement of longitudinal stiffness. Devaprakash et al. (2020) combined mechanical testing with imaging and found greater free-tendon stiffness in middle-distance runners, without a corresponding difference in Young's modulus.

Shear-wave elastography measures wave propagation within a loaded, anisotropic structure. Probe orientation and tendon tension affect the result, and a device-derived modulus depends on modelling assumptions. Aubry et al. (2013) demonstrated differences between imaging planes and increasing wave speed with dorsiflexion; interobserver reproducibility was limited in their protocol. Elastographic values should therefore be interpreted in relation to the measurement plane and loading conditions, and should not be substituted for a longitudinal force–elongation slope.

Myotonometry uses a local impulse applied perpendicular to the skin and quantifies the oscillatory response. Sohrad et al. (2017) reported excellent test–retest reliability for Achilles measurements, but this supports repeatability of that local measurement rather than interchangeability with tensile testing. The distinction also applies to the twin study by Sichtung et al. (2022), in which the reported exercise association concerned myotonic stiffness. Converting N/m to N/mm does not make different measurement constructs equivalent. Table 1 summarises the principal distinctions.

Table 1. Measurement constructs relevant to Achilles tendon comparisons

Approach	Measured quantity	Key dependencies	Interpretation
Ultrasound with dynamometry	Longitudinal force–elongation slope; N/mm	Force estimate, moment arm, loading interval, tendon region	Not equivalent to force–strain slope or local device measurements
Stress–strain analysis	Material modulus; MPa or GPa	Area, reference length, strain range and loading method	Structural stiffness may differ even when modulus is similar
Shear-wave elastography	Wave speed; m/s; model-derived modulus	Tension, joint angle, anisotropy, orientation, equipment	Wave speed is not a direct longitudinal force–elongation slope
Myotonometry	Local oscillatory response; dynamic stiffness in N/m	Contact site, preload, overlying tissue and joint position	Unit conversion cannot establish equivalence with tensile testing

For comparative work, reporting should include the tested side and tendon region, knee and ankle position, recent activity, preconditioning, contraction protocol, force range, moment-arm estimation, tracking method, and reliability under the actual conditions used. Both absolute and appropriately scaled measurements can be informative, but any normalisation must be defined. Reliability coefficients alone do not establish validity, responsiveness, or a clinically meaningful threshold.

Evidence across running disciplines

The most relevant evidence comes from studies comparing sprint and endurance groups within the same protocol. Arampatzis, Karamanidis, Morey-Klapsing, et al. (2007) studied 28 sprinters, 28 endurance runners, and 10 inactive men. Sprinters had greater normalised stiffness, defined through the force–strain relationship of the triceps surae tendon–aponeurosis complex,

and greater maximal tendon force. This supports a discipline-associated difference in that sample. It does not isolate free-tendon material properties or determine whether training, selection, or muscle strength produced the difference.

Kurihara et al. (2012) reported no significant differences in stiffness or Young's modulus across five collegiate groups, including eight sprinters and seven distance runners. This conference report offers a direct comparison but has small subgroup sizes and limited reporting. Stenroth et al. (2016) likewise found no significant stiffness differences when comparing older sprint and endurance athletes with older and younger controls, despite differences in tendon size and material properties. Neither result establishes equivalence, and findings in older athletes cannot be assumed to describe young elite runners. Table 2 distinguishes these direct comparisons from contextual studies.

Table 2. Direct and contextual evidence concerning running specialisation

Study	Sample	Outcome	Main finding	Scope
Arampatzis, Karamanidis, Morey-Klapsing, et al. (2007)	28 sprinters; 28 endurance runners; 10 inactive men	Tendon–aponeurosis force–strain relationship	Higher normalised stiffness in sprinters	Direct comparison; cross-sectional; not isolated free tendon
Kurihara et al. (2012)	35 men; sprint $n = 8$, distance $n = 7$, three other groups	Ultrasound and dynamometry; stiffness and modulus	No significant between-group differences	Direct comparison; small conference report; no equivalence test
Stenroth et al. (2016)	Older sprint $n = 10$; older endurance $n = 10$; older controls $n = 33$; young controls $n = 18$	Longitudinal stiffness and tendon morphology	No significant stiffness differences	Direct comparison in older athletes; limited generalisability
Devaprakash et al. (2020)	16 middle-distance runners; 16 controls	Free-tendon mechanics and geometry	Higher stiffness in runners; similar Young's modulus	Contextual evidence; no sprinters; mechanical data from 15 runners
Römer et al. (2023)	65 professional athletes from five sports	Longitudinal-plane shear-wave elastography	Highest wave speeds in sprint subgroup	Contextual evidence; no distance-running group; different construct
Kovács et al. (2025)	14 sprint; 15 distance runners	MRI-derived moment-arm length	Longer moment arms in sprinters; no performance association	Direct morphological comparison; does not measure stiffness

Indirect comparisons broaden understanding but cannot resolve the same question. Wiesinger et al. (2016) identified differences in normalised tendon properties among ski jumpers, distance runners, water polo players, and sedentary controls; there was no sprinter group. Römer et al. (2023) reported the highest shear-wave speeds in the sprint subgroup of 65 professional athletes from several sports, but included no dedicated distance-running group. Both studies are relevant to sport-associated variation, while neither directly establishes a sprinter-versus-distance-runner difference in longitudinal Achilles stiffness.

Morphology is another distinct domain. Kovács et al. (2025) compared 14 sprint and 15 distance runners and found longer Achilles moment arms in the sprint group, without a significant association with personal-best performance within either group. Moment-arm length affects the relationship between joint moment and estimated tendon force, but is not a measurement of stiffness. Anatomical differences should therefore be interpreted as components of a mechanical system rather than stand-alone explanations of superiority in one discipline.

Training responses and running performance

Interventions provide stronger evidence of adaptation than cross-sectional athlete comparisons. Arampatzis, Karamanidis,

and Albracht (2007) assigned different strain magnitudes to the two legs of an exercise group during a 14-week intervention. Mechanical adaptations occurred in the higher-strain condition. This finding supports the importance of the applied loading stimulus, but does not establish an exact universal strain threshold or show that sprint training is inherently more effective than endurance training.

Werkhausen et al. (2019) examined ten weeks of isometric plantar flexion training, with 11 participants in the training group and 10 controls. Stiffness increased by 18%, while tendon recoil during running decreased by 30% and muscle fascicle shortening patterns were preserved at the tested speed. These findings demonstrate that adaptation measured during controlled contractions does not translate into a simple proportional change in running behaviour. The study did not establish a corresponding improvement in race performance or injury prevention.

Habitual activity studies address a different question. In 40 identical twin pairs, Sichtung et al. (2022) found higher myotonometric stiffness in active than inactive twins. Controlling genetic similarity strengthens the comparison, but exercise exposure was not randomised and the measurement was local rather than longitudinal tensile stiffness. Such observations should not be presented as controlled training effects or pooled directly with force–

elongation measurements.

Associations with running economy are also outcome-specific. Rogers et al. (2017) found that greater Achilles stiffness was associated with lower running energy cost in 11 trained male middle-distance runners, with a correlation of -0.70 . Pinto et al. (2021) compared six long-distance runners with six pentathletes and reported higher tangent modulus and better economy in the distance runners. Their modulus estimate came from passive ankle mobilisation, adding a methodological distinction from active contraction protocols. These small cross-sectional samples support an association in particular settings, not a universal optimum or a demonstrated dose–response effect of weekly running distance.

Sprint performance comprises distinct phases with different requirements. A property that assists force application during acceleration may not have the same relationship with maximal velocity or fatigue resistance. Crotty et al. (2024) emphasised the combined contributions of plantar flexor function, ankle mechanics, and other musculoskeletal characteristics. The current evidence does not justify using a single stiffness value to rank sprint potential, prescribe talent selection, or infer faster neural conduction.

Acute loading responses and injury interpretation

Fletcher and MacIntosh (2018) studied 14 trained runners before and after 90 minutes of running. Tendon stiffness decreased from 328 ± 172 to 299 ± 148 N/mm while running energy cost increased. The changes were associated, but prolonged running simultaneously affects several physiological and mechanical variables. This design does not establish that the stiffness reduction alone caused the higher energy cost, and the estimated tendon energy return did not increase despite reduced stiffness.

Responses are not uniform across protocols. Lichtwark et al. (2013) observed small free-tendon lengthening without a significant stiffness change after a 5 km run. Ackermans et al. (2016) reported a 22% post-half-marathon stiffness reduction in middle-aged runners, with recovery within 20–28 hours; younger runners did not show the same stiffness response. These findings concern acute mechanical behaviour under specific conditions and should not be converted into universal recovery intervals.

An acute stiffness change is not itself a diagnosed injury or a validated predictor of future injury. Neither an inferred viscoelastic response nor a between-group stiffness difference demonstrates tissue microdamage. Lorimer and Hume (2016) examined relationships involving vertical, leg, and joint stiffness and Achilles injury risk factors, highlighting the need for prospective evidence. Their review should not be interpreted as establishing a safe longitudinal tendon-stiffness range. Mechanical findings can contribute to assessment, but injury prediction requires clinical outcomes and cannot be inferred from the mechanical measure alone.

Discussion

The principal conclusion is that a discipline-associated difference is plausible and supported by some direct evidence, but is not consistently reproduced across populations or measurement constructs. A positive result for the tendon–aponeurosis force–strain relationship and a null result for another anatomical or age-defined comparison need not be mutually exclusive. The present synthesis therefore supports conditional interpretation rather than either a universal hierarchy or a claim that sprint and endurance tendons are identical.

Three questions should remain separate. A cross-sectional comparison asks whether selected athletes differ. A loading intervention asks whether a specified programme changes a measured

property. A performance study asks whether that property is associated with, or mediates a change in, a functional outcome. Evidence answering one question cannot automatically answer the other two. In particular, the available intervention studies do not provide a direct comparative estimate of sprint versus endurance training effects.

Methodological heterogeneity is central to the disagreement. A study of local wave speed, a study of impulse-induced oscillation, and a study of longitudinal force–elongation behaviour may all use the word stiffness while characterising different responses. Similarly, differences between passive and active loading, free tendon and tendon–aponeurosis, or force–strain and force–elongation slopes cannot be resolved by relabelling the units. Future syntheses should stratify these constructs before considering quantitative pooling.

The findings also challenge a simple trade-off between rapid force transmission and elastic energy storage. The energetic consequence depends on the force and deformation trajectory, the timing of recoil, and muscle fascicle behaviour. The association between greater stiffness and better economy in some samples does not mean that further stiffening will benefit every runner. A convincing intervention study would assess changes in muscle strength and running mechanics alongside tendon properties and determine whether the tendon change explains the functional response.

For practitioners, the defensible application is repeated assessment within a clearly defined protocol rather than pursuit of a universal stiffness target. A change should be interpreted alongside measurement error, recent loading, symptoms, force capacity, and performance. Results from different devices should not be used interchangeably for return-to-running decisions. Likewise, observations in healthy athletes do not establish treatment efficacy in symptomatic tendinopathy.

This review has limitations beyond those of its component studies. Purposive searching and the absence of duplicate screening create a risk of selection bias. Some interpretations were necessarily restricted to accessible abstracts, and no formal certainty assessment was undertaken. Several direct comparisons were small, predominantly male, or restricted to older athletes, and the collegiate comparison was a conference report. Unmeasured training history, body size, strength, footwear, and prior symptoms may confound associations. The review cannot quantify the average difference between disciplines or define an optimal value.

Future research should prioritise sufficiently powered direct comparisons with clearly defined event specialisation and balanced recruitment of women and men. Measurements should describe the same tendon region and report both force capacity and the analysed loading interval. Longitudinal comparisons should document training dose and test performance at relevant speeds, while injury studies should prospectively record exposure and incident symptoms or diagnoses. Reporting effect estimates with confidence intervals and protocol-specific measurement error would improve interpretation of both positive and null findings.

Conclusions

Achilles tendon properties vary with athlete characteristics, loading conditions, and the measurement method. Some direct evidence supports greater tendon–aponeurosis stiffness in sprinters, but other comparisons do not reproduce a significant difference. Training can modify tendon properties, and greater stiffness is associated with better running economy in some endurance samples; neither observation establishes a universal target. Performance and injury implications should be evaluated separately, with tendon findings interpreted within the wider muscle–tendon system.

Ethics and data availability

This review analyses published literature and reports no new participant-level data or experiments involving humans or animals. No new dataset was generated.

Funding

The authors received no specific funding for this work.

Conflict of interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization: RT, VA; methodology: RT, VA; investigation, including literature search and synthesis: RT, VA; writing, original draft: RT, VA; writing, review and editing: JR, IR.

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Received: 17 June 2026 | **Accepted:** 30 September 2026 | **Published:** 15 October 2026

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