Online Resource 1 for:

Aging and the effects of a half marathon on Achilles tendon force-elongation relationship.

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Methodological Considerations and Pilot Data

Before conducting the current study we performed several pilot studies in order to test the accuracy of the current method to examine the mechanical properties of the AT. While a 90 degree knee position, with more secure fixation of the limb, may result in much less ankle joint angular rotation than straight knee set ups (average changes of 14-18 degrees at the ankle joint have been reported when using a fully extended knee; see e.g.: Arampatzis et al., 2005; Karamanidis et al., 2005), examining the force-elongation relationship of the tendon in this way could potentially place the GM in a less favorable position on the force-length relationship, when compared to a fully extended knee. This might be problematic, since we calculated the net joint moment at the ankle joint, but measured the elongation of the GM tendon. Moreover, the AT cannot be considered as a single tendon that extends uniformly during plantarflexor contractions, which might lead to an erroneous calculation of the stiffness in absolute terms. In order to address this drawback we conducted a pilot study using a more dorsiflexed ankle joint position (85 degrees ankle joint ankle). As a result we lengthened the entire TS MTU and in particular, tensed the GM tendon, causing a rightwards shift in the force-length relationship of the contractile element of the *gastrocnemii.* This increased its force potential and hence the contribution of the GM to the net joint moment (Arampatzis et al., 2006). In this pilot study, with 10 healthy subjects, we compared an ankle angle of 90 degrees to the dorsiflexed ankle joint angle of 85 degrees. An ankle angle of 90 degrees resulted in a significantly ($P < 0.05$) lower ankle joint moment (90 degrees: 277 ± 35 N·m *vs.* 85 degrees: 322 ± 46 N·m; mean and SD) and maximal tendon elongation (90 degrees: 12.3 ± 2.3 mm *vs.* 85 degrees: 13.6 ± 2.8 mm) compared to a dorsiflexed ankle joint angle of 85 degrees. However, there was no significant difference in tendon stiffness between the two setups (85 degrees: 1219 ± 461 N·mm^{-1} vs. 90 degrees: 1210 ± 283 N·mm^{-1}; see Fig S1). Therefore, while a flexed knee joint reduces *triceps surae* force generation capacity, and the contribution of the gastrocnemii to this force potential (decreasing total tendon lengthening) and, in addition, might place the GM tendon in more slack position, it appears not to lead to changes in the force-length relationship of the tendon during loading.

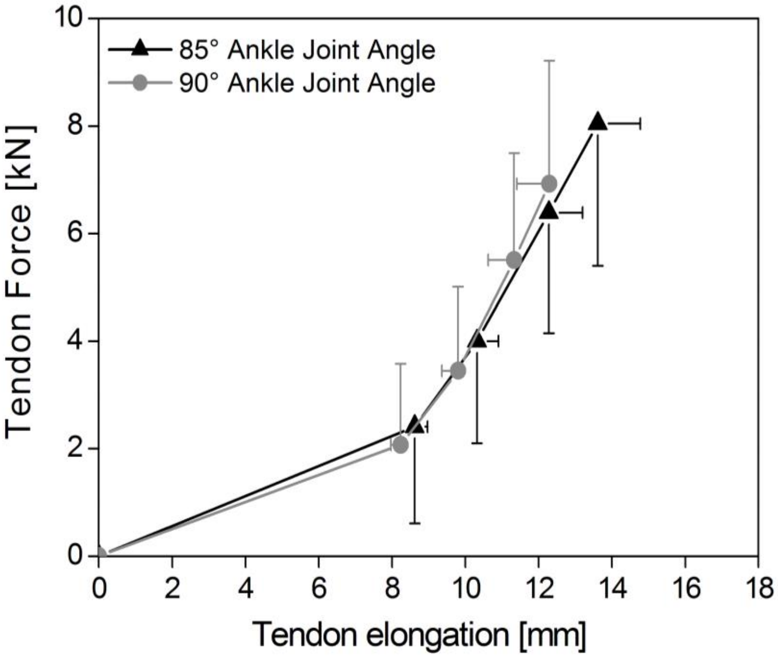

Fig S1 Force-length relationship (mean and SD) of the tendon measured with an ankle joint angle of 90 degrees (foot perpendicular to the shank) and a more dorsiflexed angle of 85 degrees, each with a knee joint angle of 90 degrees (thigh perpendicular to shank), for 10 healthy young subjects. No significant differences in force-elongation relationship of the tendon were found when comparing the ankle joint angles (tendon stiffness at 85 degrees: 1219 ± 461 Nmm^{-1} vs. tendon stiffness at 90 degrees: 1210 ± 283 Nmm^{-1}).

In a second pilot study, with nine healthy subjects, we compared ankle joint angle changes during isometric contractions estimated using different calculation methods. The ankle joint angle changes in the sagittal plane (2D analysis), calculated by inverse kinematics using reflective markers fixed at the lower extremity of the subjects acquired by a motion capture system (120Hz, Qualisys, Gothenburg, Sweden) together with a force plate (1080 Hz, 400 x 600 mm, Bertec, Columbus OH, USA), were compared to the method used in the current study that estimated ankle joint angle changes based on data from a potentiometer located under the heel (current method). The potentiometer used in the current study measured any heel elevation and, thereby, calculated changes in the ankle joint angle from rest until maximal (Fig. 1 of the original manuscript) plantarflexion moment via the inverse tangent of the ratio of the heel lift to the distance between the head of the fifth metatarsal bone and the potentiometer axis. Our pilot study found this to be in accordance with the motion capture results, with an absolute difference of less than 1.1 degrees in ankle joint angle changes during maximal isometric plantarflexion contractions (from rest to the maximal ankle joint moment; current method: 3.8 ± 1.1 degrees; 2D analysis: 4.9 ± 1.4 degrees).

In order to investigate the influence of ankle joint-dynamometer axis misalignment during contractions, which is not accounted for in the current setup, we examined the maximal anterior displacement of the ankle joint axis in our pilot subjects during maximal isometric plantarflexion contractions. The maximal anterior shift of the ankle joint axis during contraction was on average 3.4 ± 2.1 mm, thereby leading to an overestimation of our calculated joint moments. However, relating this anterior shift to the moment arm of the ground reaction force (GRF) acting about the ankle joint, the relative change was approximately 1.7 %. Hence, this drawback has only a negligible effect on our joint moment calculations. Furthermore, the resultant ankle joint moments in the current study were calculated using the vertical component of the GRF, neglecting any force vector direction changes during contraction. Using our pilot data, we compared the maximal ankle joint moments calculated by the vertical component of the GRF to the moments calculated using all three dimensions of the GRF. The maximal ankle joint moment calculated using the vertical component was on average 8% higher compared to the 3D calculations (157.8 ± 47.7 N·m *vs.* 146.3 ± 40.9 N·m). However, there was a significant correlation in maximal ankle joint moment between the two methods ($R^2 = 0.996$, $P < 0.01$; see Fig S2) showing that the relative difference between methods was constant, and that calculating the ankle joint moments during isometric contractions using only the vertical component of the GRF is a valid method.

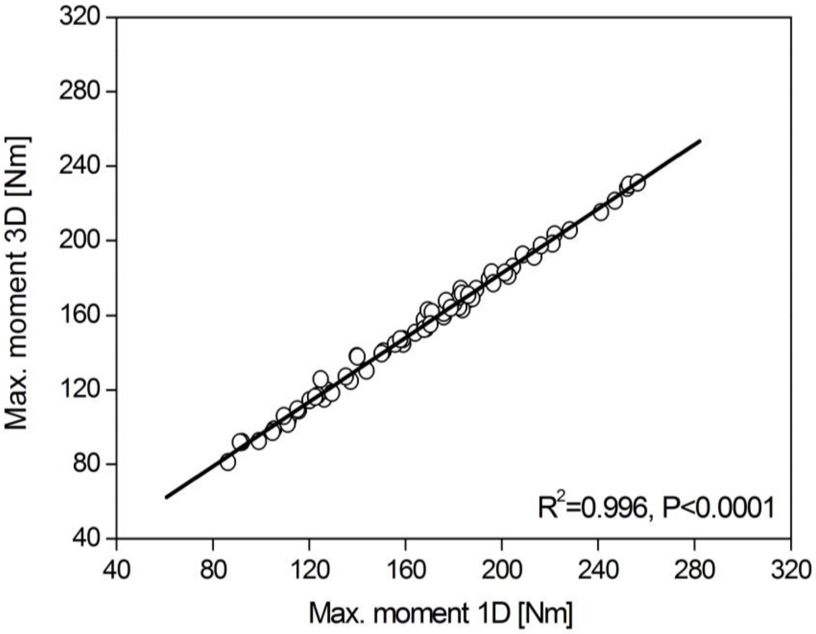

Fig S2 Relationship between the maximal ankle joint moments measured during a isometric voluntary plantarflexion contraction calculated by talking into account solely the vertical component of the ground reaction force (1D) and by considering the 3D vector of the of the ground reaction force (3D).

One might argue the fact that we calculated the secant stiffness and not the tangential stiffness of the tendon. Currently the tendon stiffness is determined by the divided change in force by change in elongation from 30-80% of MVC and, thus, only two data points are used to examine the tendon stiffness. However, using the current method, we have a clear steady state in the ultrasound image at target force making digitalization easier than in dynamic contractions, when the tendon deforms quite rapidly during MVC which is in particular problematic when using ultrasound sampling frequencies lower than 30 Hz. By using a constant force held by the subjects for a given time, we may be better able to exclude potential measurement errors due to the ultrasound sampling frequency or small time delays of synchronization between ultrasound and force data when performing ramp contractions. In addition, we were able to negate the effect of loading rate dependency on tendon strain, because the object of interest (in this case a tendon) is given enough time to respond to the applied force (Oberländer et al. 2015). Moreover, before applying the current method we extensively tested this method and compared the calculation of the secant tendon stiffness during sustained contractions with the tangential tendon stiffness during slow and fast isometric ramp contraction and hence using a set of data points digitized over the entire path of the length changes. Although, the stiffness of the tendon is slightly affected by the contraction type, potentially due to the viscoelastic properties of the tendon, we found a similar day-to-day reliability in tendon stiffness between slow ramp contractions and our sustained contraction method, when a skilled and experienced investigator tracked the data points used in the current study (Oberländer et al. 2015).

References Online Resource

Arampatzis A, Karamanidis K, Stafilidis S, Morey-Klapsing G, DeMonte G, Brüggemann GP (2006) Effect of different ankle-and knee-joint positions on gastrocnemius medialis fascicle length and EMG activity during isometric plantar flexion. J Biomech 39:1891-1902.

Arampatzis A, Stafilidis S, DeMonte G, Karamanidis K, Morey-Klapsing G, Brüggemann GP (2005) Strain and elongation of the human gastrocnemius tendon and aponeurosis during maximal plantarflexion effort. J Biomech 38:833-841.

Karamanidis K, Stafilidis S, DeMonte G, Morey-Klapsing G, Brüggemann GP, Arampatzis A (2005) Inevitable joint angular rotation affects muscle architecture during isometric contraction. J Electromyogr Kines 15:608-16.

Oberländer KD, Epro G, Krauss P, Karamanidis K (2015) Loading rate dependency on in vivo gastrocnemius medialis tendon elongation. 9. Jahrestagung der Deutschen Gesellschaft für Biomechanik, Bonn, Germany:115.