THE RELATIONSHIP BETWEEN ACHILLES TENDON DIMENSIONS AND FOOT STRIKE INDEX IN REARFOOT AND NON-REARFOOT RUNNERS

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The purpose of this study was to describe the relationship between Achilles tendon dimensions and foot strike index in rearfoot and non-rearfoot runners. 107 recreational runners were divided into a group of rearfoot (n = 88) and a group of non-rearfoot runners (n = 19). Achilles tendon dimensions were measured by a combination of ultrasonography imaging and kinematic analysis. To analyse the footfall pattern, each participant performed 8 successful trials of running at their stated self-preferred endurance speed. Partial correlation was used for statistical analysis. Runners in the group of non-rearfoot runners, whose footfall pattern is more over forefoot, have a longer and thinner Achilles tendon.

KEYWORDS: Achilles tendon length, Achilles tendon thickness, running biomechanics.

INTRODUCTION: The Achilles tendon (AT) saves up to 60% of the mechanical work of the plantar flexors (PF) during the running at a speed of 3.5 ms^{-1}. In addition, as running speed increases, so does the contribution of AT to the PF mechanical work (Lai et al., 2014). Anthropological research suggests that elongation of the AT may have allowed the genus Homo endurance running (Bramble & Lieberman, 2004; Malvankar & Khan, 2011). Following these findings, Kubo et al., (2015) investigated the effect of AT stiffness on differences in the footfall pattern in highly trained endurance runners. Footfall pattern was considered to be key to running efficiency (Gruber et al., 2011). However, there were no differences in AT stiffness among runners with different footfall patterns.
There is large AT dimension variability in healthy athletes and athletes with AT injury (Jandacka et al., 2018; Kunimasa et al., 2014). Moreover, AT length has been shown to be a factor affecting economical running (Kunimasa et al., 2014; Ueno et al., 2018). However, non-rearfoot runners use AT and its elastic energy more than rearfoot runners (Gruber et al., 2011). Therefore, the purpose of this study was to describe the relationship between AT dimensions and foot strike index in rearfoot runners and non-rearfoot runners. We hypothesised that there would be a relationship between foot strike index and AT dimensions in non-rearfoot runners.

METHODS: 107 healthy recreational runners without a history of musculoskeletal injuries of the lower extremities participated in the present research study. Based on their footfall pattern, the participants were divided into two groups (rearfoot and non-rearfoot runners). Table 1 provides descriptive characteristics of the sample.

Table 1. Participants characteristics

	Rearfoot runners [n=88]		Non-rearfoot runners [n=19]	
	Mean	**SD**	**Mean**	**SD**
Age [years]	36.84	8.06	33.64	10.02
Mass [kg]	72.83	12.94	63.72	9.27
Height [m]	1.72	0.08	1.71	0.09
BMI [kg/m²]	24.40	3.18	21.80	2.46
Male/Female	43/45		5/14	

SD – Standard deviation; *BMI* – Body Mass Index

Experimental set-up: Ultrasonography imaging was measured using a diagnostic ultrasound system set in orthopaedic mode at 10 MHz (Mindray Z5, Shenzhen, China) with a 50 mm electronic linear ultrasound transducer probe Mindray 75L38EA. A synchronized system of 10 infrared cameras (Qualisys, 9 x Oqus 700, 1x Oqus 510, 240 Hz, Sweden) and a single force plate 90 x 90 cm (Kistler, 9287CAQ02, 1200 Hz, Switzerland) was used for measurement in kinematic a kinetic analysis.

Protocol:
Each participant underwent the measurement of AT length and thickness on the right lower limb and an analysis of running biomechanics. AT length, detected from the proximal attachment of the calcaneus osteotendinous junction to the musculotendinous junction of the gastrocnemius (Skypala et al., 2019), was measured by a combination of ultrasonographic imaging and kinematic analysis. AT thickness was determined by ultrasonographic measurement at a distance of 2 cm from the proximal attachment of calcaneus osteotendinous junction (Cassel et al., 2017). Subsequently, running biomechanics was measured at the self-preferred endurance speed of the participant. Each participant performed eight successful trials of running at their stated self-preferred endurance speed of ± 3% over a 17 m long track. During the running biomechanics analysis, the participants wore neutral road running shoes Brooks Launch 5 with a midsole drop of 10 mm.

Data analysis:
AT length was determined in Visual3D (C-Motion, Rockville, MD, USA) according to Skypala et al. (2019). Subsequently, it was normalized to shank length (shank length = (AT length / Shank Length) * 100). Raw measured data from running biomechanics were processed using Qualisys Track Manager (Qualisys, Gothenburg, Sweden) and Visual3D (C-Motion, Rockville, MD, USA). For ground-reaction force data and kinematic data, we applied fourth-order Butterworth low-pass filter with a cut-off frequency of 50 Hz and 12 Hz, respectively. Foot strike index was determined on the right lower limb (Cavanagh & Lafortune, 1980). In the group of rearfoot runners, we included participants whose foot strike index was less than 33 %. Participants who had a foot strike index greater than 33% were included in the non-rearfoot runners. Running speed was detected based on the magnitude of the pelvis velocity at initial right foot contact.

Statistical analysis:
Mean and standard deviation of AT length and AT thickness were calculated from three trials of the right lower limb. Relationships between: 1) AT length and strike index; and 2) AT thickness and strike index of the rearfoot runners and non-rearfoot runners were investigated using the partial correlation coefficient. The control variable was set to pelvis velocity. The level of significance was set at $p < 0.05$. The statistical analyses were conducted using the IBM SPSS Statistics 24.

RESULTS: Table 2 and Figure 1 indicate the relationship between the AT dimensions and the strike index of the non-rearfoot runners.

Table 2. Results of Partial correlations

Control variable			Relative AT Length		AT Thickness	
			RF	NRF	RF	NRF
Pelvis velocity	Strike index	Correlation	-0.070	**0.470**	0.168	**-0.548**
		Significance	0.521	**0.049**	0.120	**0.019**

RF – rearfoot runners; *NRF* – non-rearfoot runners; *AT* – Achilles tendon

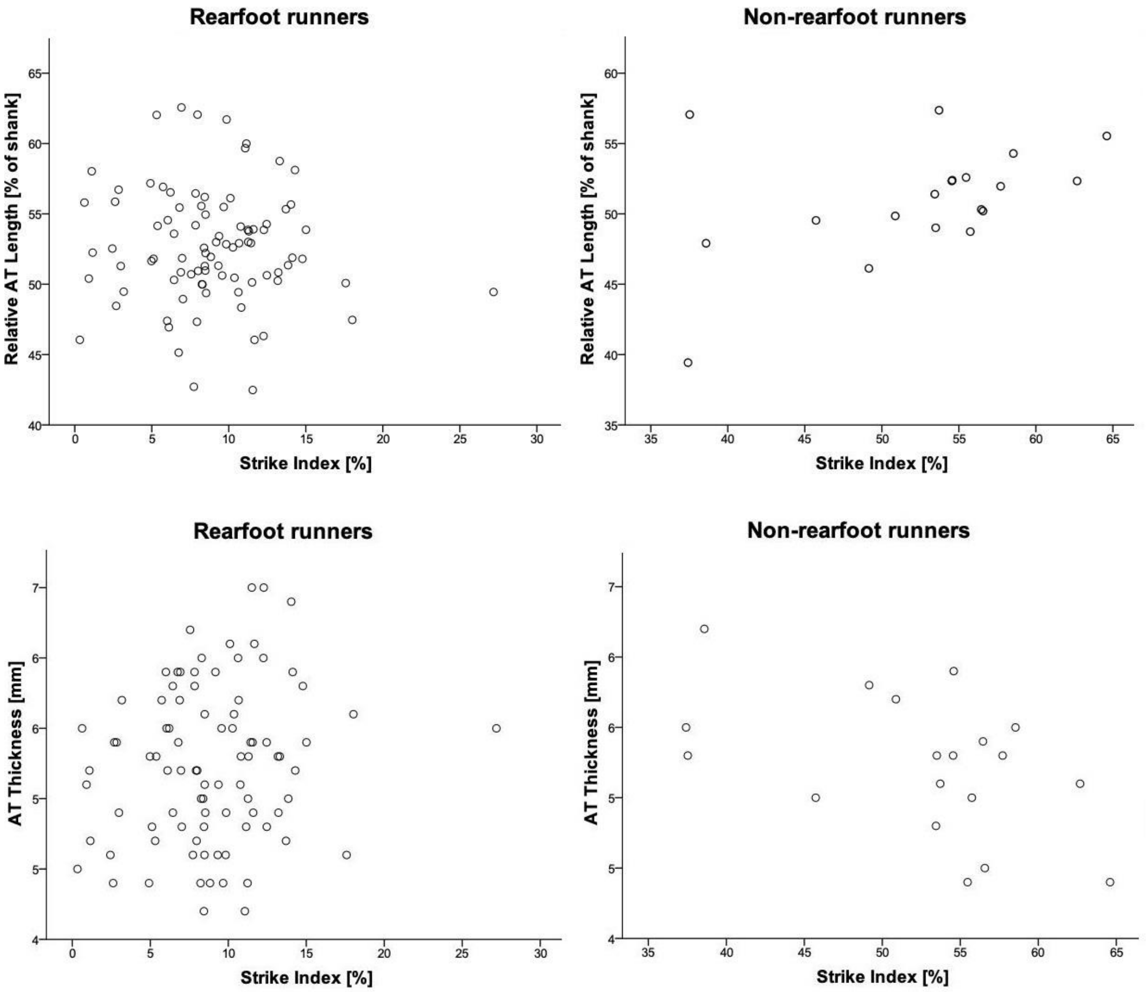

Figure 1. Relationship between AT dimensions and Strike index for rearfoot runners and non-rearfoot runners

DISCUSSION: The purpose of this study was to describe the relationship between AT dimensions and foot strike index in groups of rearfoot and non-rearfoot runners. We expected to find a connection between the foot strike index and AT dimensions in non-rearfoot runners. The hypothesis was confirmed. Non-rearfoot runners tend to have greater strike index when they have longer and thinner AT (Figure 1). It appears that the length of AT may influence footfall pattern only in non-rearfoot runners. Only recreational runners participated in our research, but Kubo et al., (2015) did not find a relationship between AT properties and foot strike patterns in highly trained long-distance runners. These authors suggested that long distance runners' foot strike pattern did not affect the morphological or mechanical properties of their AT. However, while Kubo et al., (2015) compared mechanical properties in three different groups of runners (rearfoot, midfoot, forefoot), they did not have quantitative information about the foot strike index. Their analysis was then limited only to methods which compare mean values of each group according to categorized types of footfall pattern.

From an evolutionary perspective, elongation of AT has been considered as a key factor which allowed for humans endurance running – barefoot non-rearfoot running (Bramble & Lieberman, 2004). In addition, from the mechanical perspective, there are higher AT forces when non-rearfoot running is used (Gruber et al., 2011). As a result, it seems logical that there is a link between the footfall pattern and AT length particularly in the non-rearfoot running group.

The results for the group of non-rearfoot runners have indicated that the higher the strike index, the thinner the AT. There is evidence that people with tendinopathy have a thicker AT (Morales et al., 2019). Although our runners did not report any acute AT problems, they may

have developing symptoms of AT tendinopathy. Therefore, they would then try to lessen stress on the AT and possibly adjust the footfall pattern. Alternatively, a thinner AT may be a sign of improved functionality. Further research using magnetic resonance imaging and the T2* measure of the AT might show whether there is a relationship between the quality of the AT tissue and its thickness.
A possible limitation of the present study is its cross-sectional design. We also do not know if the AT dimensions are the cause, or the result of a given running footfall pattern. In addition, the number of non-rearfoot participants in the study was relatively small. In our future research, we should focus on knee mechanics, since the gastrocnemius is a two-joint muscle.

CONCLUSION: In the rearfoot runners, no relationship was found between AT dimensions and the foot strike index. In non-rearfoot runners, we found a relationship between the AT dimensions and foot strike index. Runners in the group of non-rearfoot runners, whose footfall pattern is more over forefoot (greater foot strike index), have a longer and thinner AT.

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ACKNOWLEDGEMENTS: All authors were supported by a grand HAIE – Healthy Aging in Industrial Environment (CZ.02.1.01/0.0/0.0/16_019/0000798).