Aktuelle Forschung in der Biomechanik

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Sehnen

Sehnen

Regelmäßige Belastung stärkt Sehnen

Sehnenkraft nimmt mit Alter ab

Sehnenkraft variiert mit Hydrierung, pH Wert, Temperatur

Sehnen adaptieren sich sehr langsam
Verletzungen heilen sehr langsam

Foure et al. (2010) Plyometric training effect on Achilles tendon stiffness and dissipative properties

19 Teilnehmer:
Trainingsgruppe: n=9. 18.8±0.9 Jahre, 1.77±0.06 m, 68.4±6.5 kg
Kontrollgruppe: n=10. 18.9±1.0 Jahre, 1.80±0.05 m, 73.3±8.0 kg

Plyometrisches Training hat das Ziel Sprung und Schnellkraft zu erhöhen.
Trainingsgruppe führte innerhalb 14 Wochen 34 Stunden Training mit 200-600 Sprünge pro Einheit.

Vor und eine Woche nach der Trainingsintervention wurden spezielle Sprungkrafttests zur Erhebung der Sprungkraft von der Trainings- und der Kontrollgruppe durchgeführt.

Foure et al. (2010) Plyometric training effect on Achilles tendon stiffness and dissipative properties

Von allen 19 Teilnehmern der Studie:

Geometrie der Achillessehne mittels Ultraschall
(Philips HD3, Philips Medical Systems, Andover, MA, US)

Maximales, isokinetisches Drehmoment, Winkel und Winkelgeschwindigkeit im Sprunggelenk
(Biodex Medical, Shirley, NY, US)

Foure et al. (2010) Plyometric training effect on Achilles tendon stiffness and dissipative properties

Kraft-Längen Beziehung der Achillessehne für
(A) Trainingsgruppe
(B) Kontrollgruppe

Durchgezogen vor dem Training
Strichliert nach dem Training

Hysterese bei Trainingsgruppe ist kleiner!

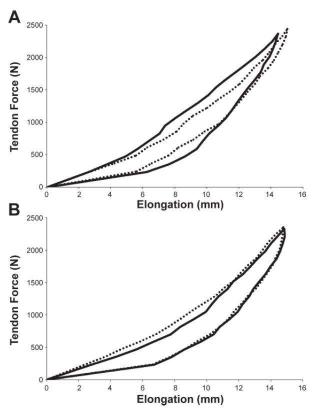


Fig. 1. Mean relationship between the tendon force (Ft) and the Achilles tendon elongation (ΔL) in the trained group (A) and the control group (B) in pretest (solid line) and posttest (broken line). Standard deviation bars were removed for clarity.

Foure et al. (2010) Plyometric training effect on Achilles tendon stiffness and dissipative properties

14 Wochen Sprung-Training bewirkt signifikante Verbesserung in der entsprechenden Sprungübung sowie eine Vergrößerung der Steifigkeit der Achillessehne.

Werte in Kontrollgruppe bleiben gleich!

Table 2. *Functional performances for trained and control groups*

	Trained Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
SJ maximal height, cm	37.5 ± 4.4	41.5 ± 4.2*	34.7 ± 7.8	35.5 ± 8.3
CMJ maximal height, cm	44.5 ± 4.8	47.5 ± 3.8†	40.3 ± 7.8	39.5 ± 6.9
Average height on 8 RJ, cm	32.3 ± 5.1	40.6 ± 3.0*	27.8 ± 2.8	25.2 ± 4.2
MVC, N·m	133 ± 16	141 ± 18‡	131 ± 16	132 ± 15
RTD_{max}, N·m/s	1,389 ± 447	1,490 ± 426	1,448 ± 362	1,386 ± 331

Jump performances (SJ, squat jump; CMJ, counter movement jump; RJ, reactive jump), MVC, and RTD_{max} in trained and control groups before (pretest) and after (posttest) 14 wk of plyometric training. Results are presented as means ± SD. Post hoc test: *$P < 0.001$; †$P < 0.02$; ‡$P < 0.01$.

control group, no significant changes were observed, whatever the considered parameters ($P > 0.05$).

Table 3. *Tendon geometric and mechanical parameters for trained and control groups*

	Trained Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
L, mm	199 ± 24	200 ± 25	198 ± 24	200 ± 25
ΔL_{max}, mm	14.5 ± 2.8	15.1 ± 2.5	14.8 ± 2.1	14.8 ± 2.8
CSA, mm^2	55.6 ± 12.2	57.3 ± 13.1	53.8 ± 9.7	55.3 ± 8.6
SI_{SK}, mm^{-1}	0.09 ± 0.07	0.11 ± 0.06	0.13 ± 0.07	0.09 ± 0.07
S_{AT}/CSA, N/mm^3	4.40 ± 2.47	5.54 ± 3.74*	5.54 ± 2.25	5.15 ± 2.55

Achilles tendon L, ΔL_{max}, CSA, SI_{SK}, and S_{AT}/CSA before and after plyometric training period for both control and trained groups. Results are means ± SD. Post hoc test: *$P < 0.01$.

Onambele et al. (2005) Calf muscle-tendon properties and postural balance in old age

90 potentielle Probanden

Hohes Alter: 17 Männer, 19 Frauen, 68±1 Jahr
Mittleres Alter: 5 Männer, 5 Frauen, 46±1 Jahr
Niederes Alter: 12 Männer, 12 Frauen, 24±1 Jahr

Von den 90 Probanden wurden 20 wegen medizinischer Indikatoren von der Studie ausgeschlossen.

Onambele et al. (2005) Calf muscle-tendon properties and postural balance in old age

Bestimmung der maximalen isometrischen Plantar- und Dorsiflexion, maximales Beugemoment
(Cybex Norm, Phoenix Healthcare Products, Nottingham, UK)

Bestimmung der Dicke des Gastrocnemius mittels Ultraschall
(Esaote Biomedica, Florence, IT)

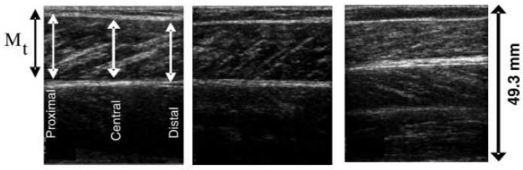


Fig. 2. Gastrocnemius muscle thickness (M_t) in three female participants with the same body mass index (23 kg/m²). *Left*: younger individual (22 yr of age); *middle*: middle-aged individual (43 yr of age); *right*: older individual (67 yr of age).

Onambele et al. (2005) Calf muscle-tendon properties and postural balance in old age

Kraft der Achillessehne nimmt im Verlauf des Alterns stark ab!

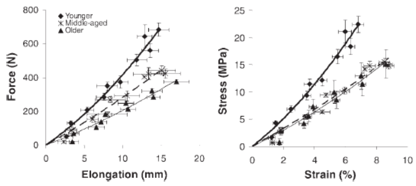


Table 2. *Relevant muscle-tendon parameters*

	Younger	Middle-Aged	Older
Plantar flexion MVC, N·m	144.2±8.9	93.6±9.6*	69.2±3.0*†
Antagonist muscle co-contraction, %	5±1	9±2	23±6*†
AC, %	95.1±1.5	87.8±2.0*	82.4±2.7*
Maximal gastrocnemius tendon force, N	684±42.4	440±28.1*	375±16.6*†
Maximal gastrocnemius tendon elongation, mm	14.7±1.3	15.1±1.8	17.3±1.6*†
Resting gastrocnemius tendon length, mm	215±4	177±5*	180±7.5*
Resting gastrocnemius tendon CSA, mm²	30.5±2.8	28.5±4.5	24.8±0.5*
Achilles tendon moment arm, mm	51.6±0.9	50.8±0.8	49.4±1.0
Maximal gastrocnemius tendon stress, MPa	22.4±1.5	15.4±0.6*	15.1±3.1*
Maximal gastrocnemius tendon strain, %	6.8±0.4	8.5±0.3*	8.8±0.5*
K, N/mm	53.3±7.5	39.5±3.9*	32.5±4.1*†
YM, GPa	0.36±0.05	0.26±0.03*	0.26±0.03*
M_t, mm	15.9±0.47	14.7±0.98*	13.8±0.93*

Values are means ± SE. Stress is the ratio of tendon force over resting tendon cross-sectional area (CSA). Strain is the ratio of tendon elongation over the tendon resting length. MVC, maximal voluntary contraction; AC, activation capacity; *K*, tendon stiffness; YM, tendon Young's modulus; M_t, muscle thickness. *$P < 0.05$ compared with the younger group. †$P < 0.05$ in middle-aged vs. older subjects comparisons.

Sehnen: In Vivo Belastung von Sehnen

Martin et al. (2018)

Messprinzip: Geschwindigkeit der Wellenausbreitung ist proportional zur Wurzel der Spannung in der Sehne

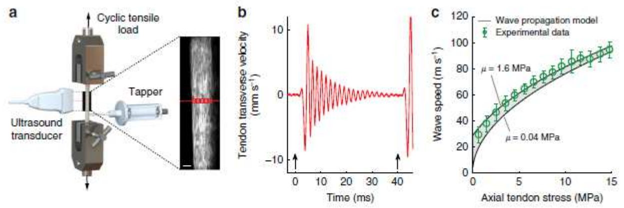


Fig. 1 Ex vivo experiment. **a** Porcine tendons were clamped and cyclically loaded up to 300 N. A tapper device (Supplementary Fig. 2) delivered an impulsive 20 μm tap in the transverse direction at 40 ms intervals. Ultrasound radiofrequency data were collected at 14,100 frames per second from a single location along the tendon and used to track transverse tendon displacements. Scale bar, 2 mm. **b** An underdamped standing wave emerged in response to each tap (indicated by arrows) and was used to ascertain the natural frequency and corresponding shear wave speed. **c** Plotted are the mean (±1 s.d.) wave speeds versus the corresponding tendon stress for 10 porcine digital flexor tendons. The shaded region reflects the wave speed predictions using the wave propagation model (Eq. 2) with the following parameters: $\rho = 1730\,kg\,m^{-3}$; $\mu = 0.04$–1.6 MPa; $k' = 0.9$ (see Supplementary Methods, Supplementary Tables 1 and 2)

Sehnen: In Vivo Belastung von Sehnen

Martin et al. (2018)

Anwendung: Gehen am Laufband bei 0.75-1.75 m/s

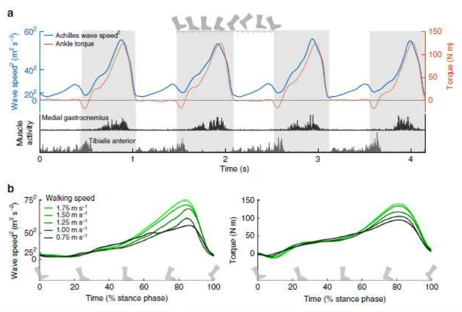


Fig. 4 In vivo gait experiment. **a** Achilles tendon wave speed, ankle plantarflexion torque, and medical gastrocnemius and tibialis anterior muscle activity over 4 consecutive strides of treadmill walking at $1.5\,m\,s^{-1}$. The primary peak in wave speed corresponds to push-off in late stance (stance indicated by shaded regions), when the gastrocnemius is active and ankle torque is high. However, a secondary peak in wave speed is seen in late swing and likely reflects passive tendon stretch due to antagonistic tibialis anterior activity. **b** Stance phase plots, ensemble averaged over multiple gait cycles for a representative subject show speed-related modulation of both Achilles tendon wave speed and ankle plantarflexion torque

Sehnen: In Vivo Belastung von Sehnen

Martin et al. (2018)

Anwendung: Laufen in Abhängigkeit von Kadenz und Geschwindigkeit

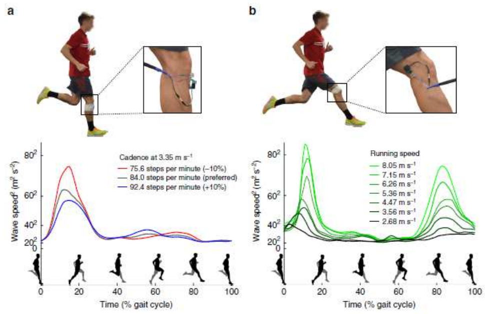


Fig. 5 Running experiments. **a** Patellar tendon wave speeds speed over the gait cycle when running at a fixed speed with different step rates. **b** Lateral hamstring (biceps femoris) tendon wave speeds detect utilization of this muscle with increasing speed during both mid-stance (15% of gait cycle), and late swing (85% of gait cycle). Hamstring loading during both phases increased markedly with speed, though stance phase demands greater tissue loads than swing phase in this individual

Rowson et al. (2010) Can footwear affect Achilles tendon loading

Kadaverfüße werden auf definierte Art gebeugt und resultierende Belastung der Achillessehne gemessen.

2 männliche Spender

frische untere Extremitäten

TABLE 1. Donor Data for Each of the Lower Extremities

Lower Extremity	Side	Sex	Age at Death, y	Body Mass, kg	Body Height, cm	BMI, kg/m^2
1	Right	Male	62	59.5	177.8	18.8
2	Left	Male	62	59.5	177.8	18.8
3	Left	Male	76	44.1	170.0	15.3
4	Right	Male	76	44.1	170.0	15.3

2 Schuharten

Schuhe geknüpft und lose

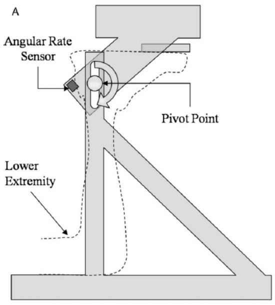
Je 3 Testwiederholungen für jede Konfiguration (Schuhe, Bindung, Kadaver)

FIGURE 2. Air Jordan XV SE (left) and Nike Dart IV (right).

Rowson et al. (2010) Can footwear affect Achilles tendon loading

Messanordnung:

Es wird ein definiertes Drehmoment um die Sprunggelenksachse aufgebracht.



Achillessehne freigelegt
Vorkehrungen gegen Austrocknen
Belastung der Achillessehne mittels Kraftmessdose
(6730 LC-79,Denton, Rochester, MI, US)

Rowson et al. (2010) Can footwear affect Achilles tendon loading

Hohe geknüpfte Schuhe verringern die Belastung der Achillessehne und den Beugungswinkel des Sprunggelenkes.

Aufgebrachtes Moment wird zum Teil von den Schuhen aufgenommen.

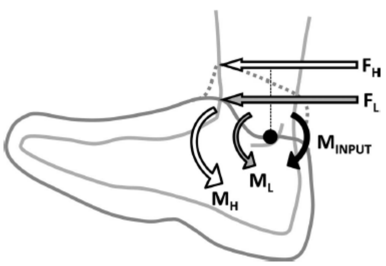


TABLE 5. Average Values and SDs for Peak Achilles Tendon Tension and Peak Dorsiflexion Angle for Each Testing Configuration

ID	Shoe	Laces	Average Tension, N	Average Angle, degrees
1	High	Tied	614.9 ± 20.9	47.0 ± 0.9
1	High	Untied	671.4 ± 20.9	47.3 ± 0.8
1	Low	Tied	763.7 ± 5.0	50.0 ± 0.8
1	Low	Untied	746.9 ± 5.2	51.2 ± 0.3
2	High	Tied	403.3 ± 9.1	46.1 ± 1.3
2	High	Untied	419.2 ± 3.7	49.4 ± 1.1
2	Low	Tied	431.8 ± 6.4	52.8 ± 0.4
2	Low	Untied	445.5 ± 17.9	52.2 ± 1.1
3	High	Tied	936.1 ± 82.1	64.4 ± 2.3
3	High	Untied	1073.2 ± 11.2	71.6 ± 1.2
3	Low	Tied	992.2 ± 6.4	67.6 ± 1.4
3	Low	Untied	1064.0 ± 40.5	65.2 ± 3.8
4	High	Tied	729.3 ± 27.6	70.5 ± .85
4	High	Untied	997.7 ± 43.6	71.5 ± 1.9
4	Low	Tied	793.3 ± 22.0	74.7 ± 0.4
4	Low	Untied	864.0 ± 4.9	78.8 ± 1.2

Hagen & Henning (2009)
Shoe-lacing techniques, running shoes

Abstract

In the present study, we examined the influence of shoe lacing on foot biomechanics in running. Twenty experienced rearfoot runners ran in six different lacing conditions across a force platform at a speed of 3.3 m · s^{-1}. Foot pronation during contact, tibial acceleration, and plantar pressure distribution of the right leg were recorded. The test conditions differed in the number of laced eyelets (1, 2, 3, 6 or 7) and in lacing tightness (weak, regular or strong). The results show reduced loading rates ($P < 0.05$) and pronation velocities ($P < 0.01$) in the tightest and highest lacing conditions. The lowest peak pressures under the heel and lateral midfoot ($P < 0.01$) were observed in the high (seven-eyelet) lacing pattern. Regular six-eyelet cross-lacing resulted in higher loading rates ($P < 0.05$) and higher peak heel pressures ($P < 0.01$) than seven-eyelet lacing, without any significant differences in perceived comfort. The low lace shoe conditions resulted in lower impacts ($P < 0.01$) and lower peak pressures under metatarsal heads III and V ($P < 0.01$), which is probably induced by the foot sliding within the shoe. A firm foot-to-shoe coupling with higher lacing leads to a more effective use of running shoe features and is likely to reduce the risk of lower limb injury.

Hagen & Henning (2009)
Shoe-lacing techniques, running shoes

Verschieden feste und verschiedene Knüpfarten für Schuhbänder:

a) leicht, mittel und fest geschnürt
b) Nur untere zwei Löcher
c) Löcher 1, 3, und 5
d) Spezielle Knüpftechnik vorgeschlagen von Nike

Schuhe von Nike, US 10.5

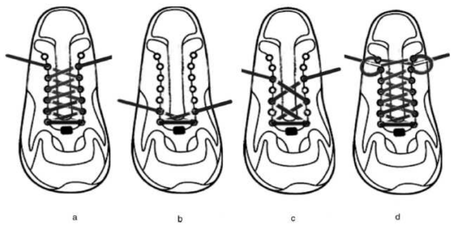


Figure 1. Lacing conditions: (a) 6-eyelet cross-lacing of conditions REG6, WEAK6, TIGHT6; (b) EYE12; (c) EYE135; (d) ALL7.

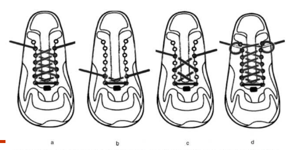
Hagen & Henning (2009)
Shoe-lacing techniques, running shoes

20 erfahrene, verletzungsfreie, männliche Fersenläufer
32±10 Jahre, 1.78±0.06 m, 73±9 kg

Laufen (v=3.3 m/s) über Kraftmessplatte von Kistler
Laufgeschwindigkeit wurde mittels Fotozellen überprüft
Beschleunigung der Tibia mittels Beschleunigungssensoren
Druck an Fußsohle mittels angetapten Piezosensoren
Orientierung des Fußes mittels Goniometer

Alle Daten gleichzeitig mit 1000 Hz erhoben und gespeichert.

Ergebnisse



Vertikale Beschleunigung

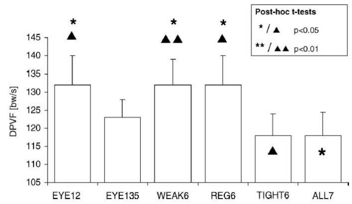


Figure 3. Maximum vertical force rates (group mean values and standard errors) in different lacing conditions. bw = body weight.

Geschwindigkeit der Pronation

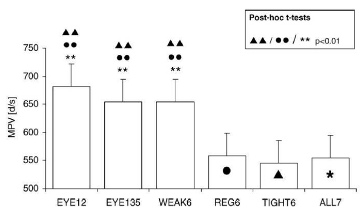


Figure 4. Maximum pronation velocities (group mean values and standard errors) in different lacing conditions. d/s = degrees/second.

Ergebnisse

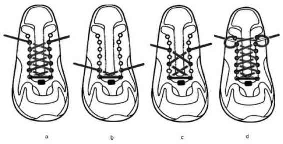


Figure 1. Lacing conditions: (a) 6-eyelet cross-lacing of conditions REG6, WEAK6, TIGHT6; (b) EYE12; (c) EYE135; (d) ALL7.

Knüpftechnik hat gravierenden Einfluss auf Kraftübertragung und Stabilität des Fußes

Feste und vollständige Knüpfung verringert maximalen Druck unter Ferse und Mittelfuß

Ebenso verringerte Pronationsgeschwindigkeit

Komfort gut bei mittelfester und vollständiger Knüpfung, schlecht bei unvollständiger bzw. sehr fester Knüpfung

Ergebnisse treffen vermutlich auch auf Gehen zu
→ sehr alte und bewegungseingeschränkte Patienten!