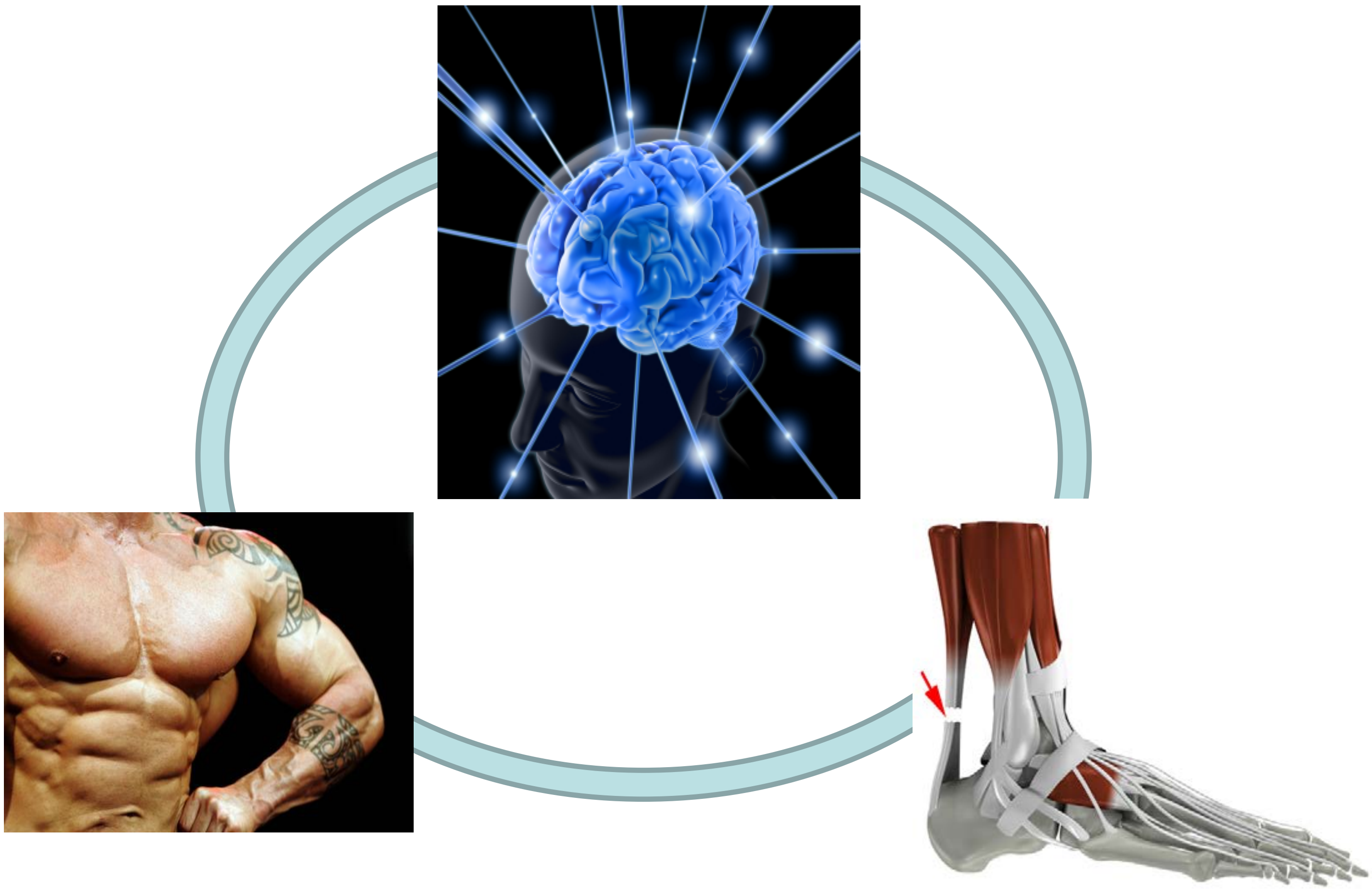

IfSS Universität Freiburg

Nerv – Muskel – Sehne: ~~Warum~~ Ist ein spezifisches Training im Nachwuchsleistungssport notwendig?

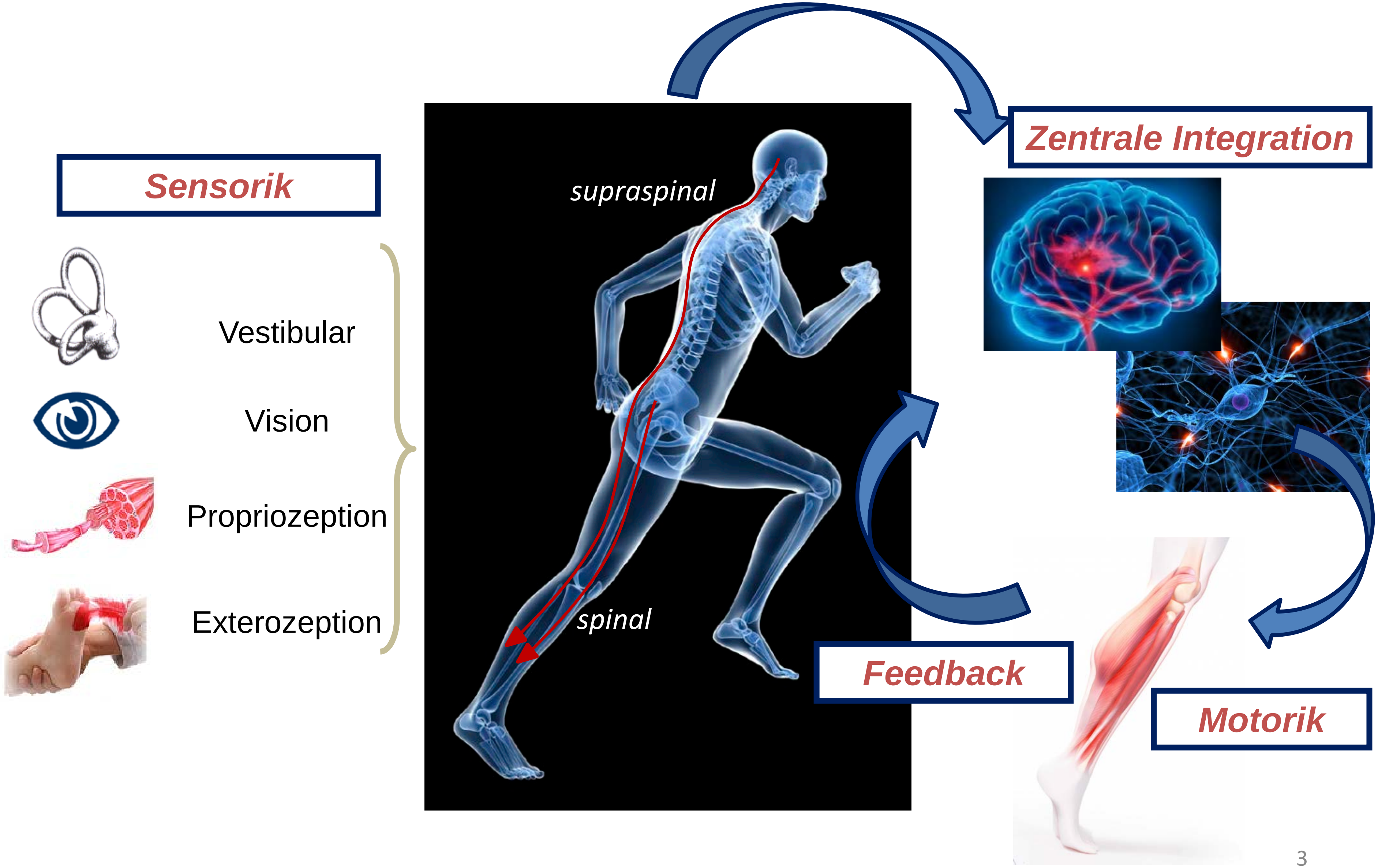
Albert Gollhofer, Uni Freiburg

Ludwigs-Universität Freiburg
Institut für Sport und Sportwissenschaft
UNI FREIBURG



Nerv-Muskel-Kopplung

Interne Modellierung (IM)



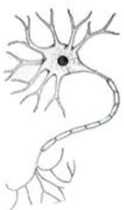
Institut für Sport und Sportwissenschaft

TRAINING oder DEGENERATION

Sensorik

(Taube et al. 2007, Gruber/Gollhofer 2001, Roll et al. 1993)

Zentrale Integration



ZNS

(Taube/Gollhofer 2012)

Motorik

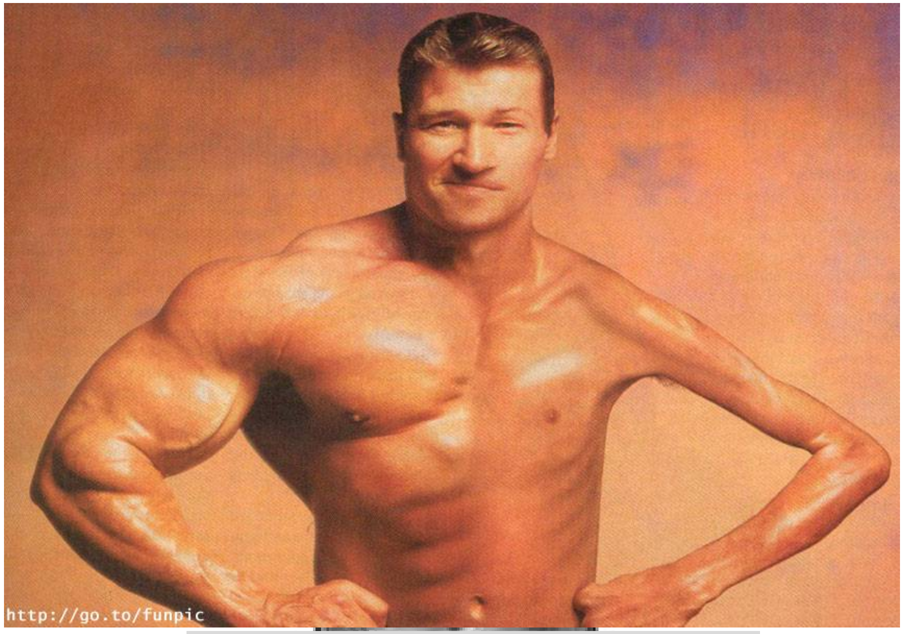
Muskulatur

(Fitts et al. 2001; Hoppeler)

Knochensubstanz

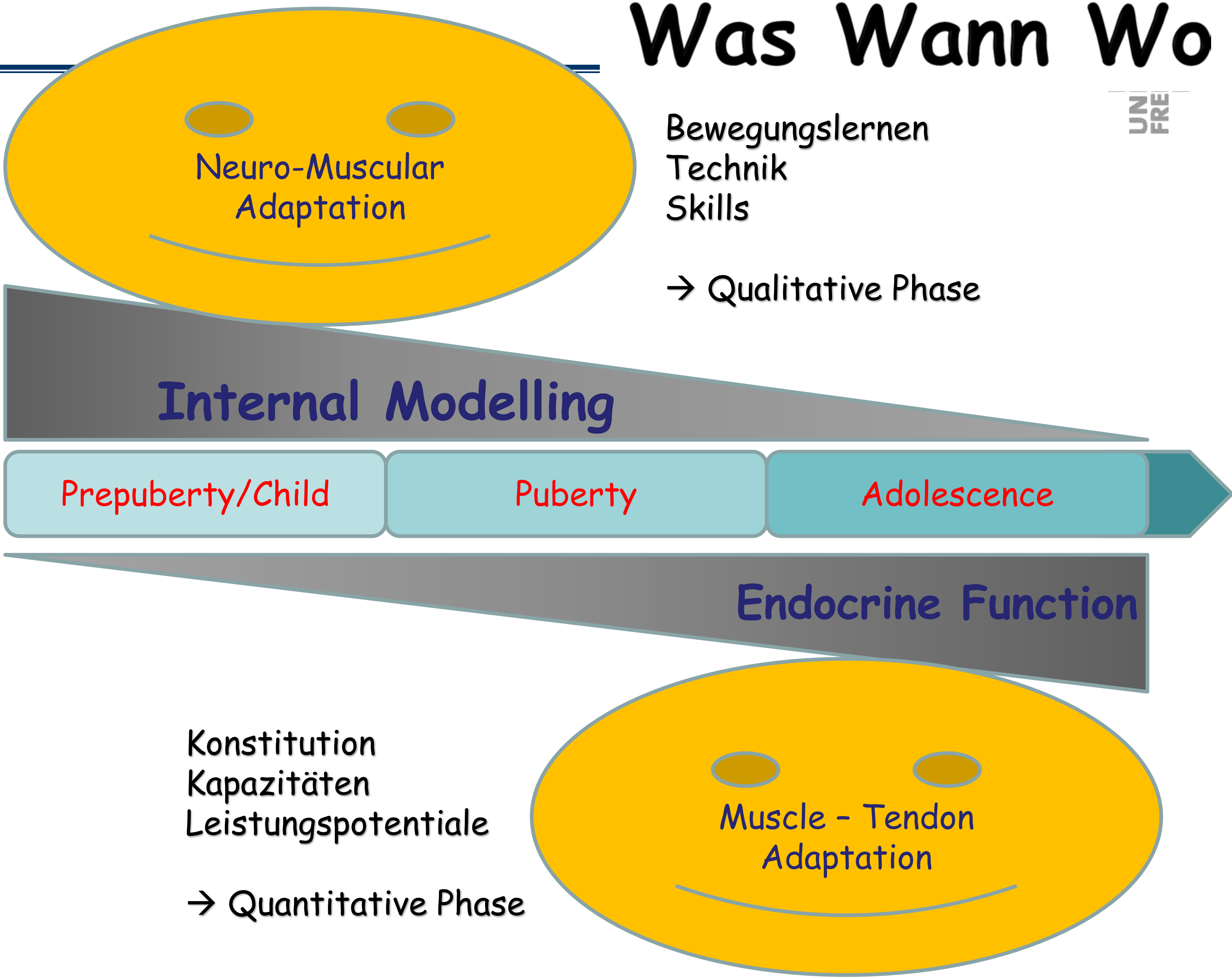
(LeBlanc et al. 2007, Loomer 2001)

Neuronale Aktivierung



- Rekrutierung
- Frequentierung

Was Wann Wo

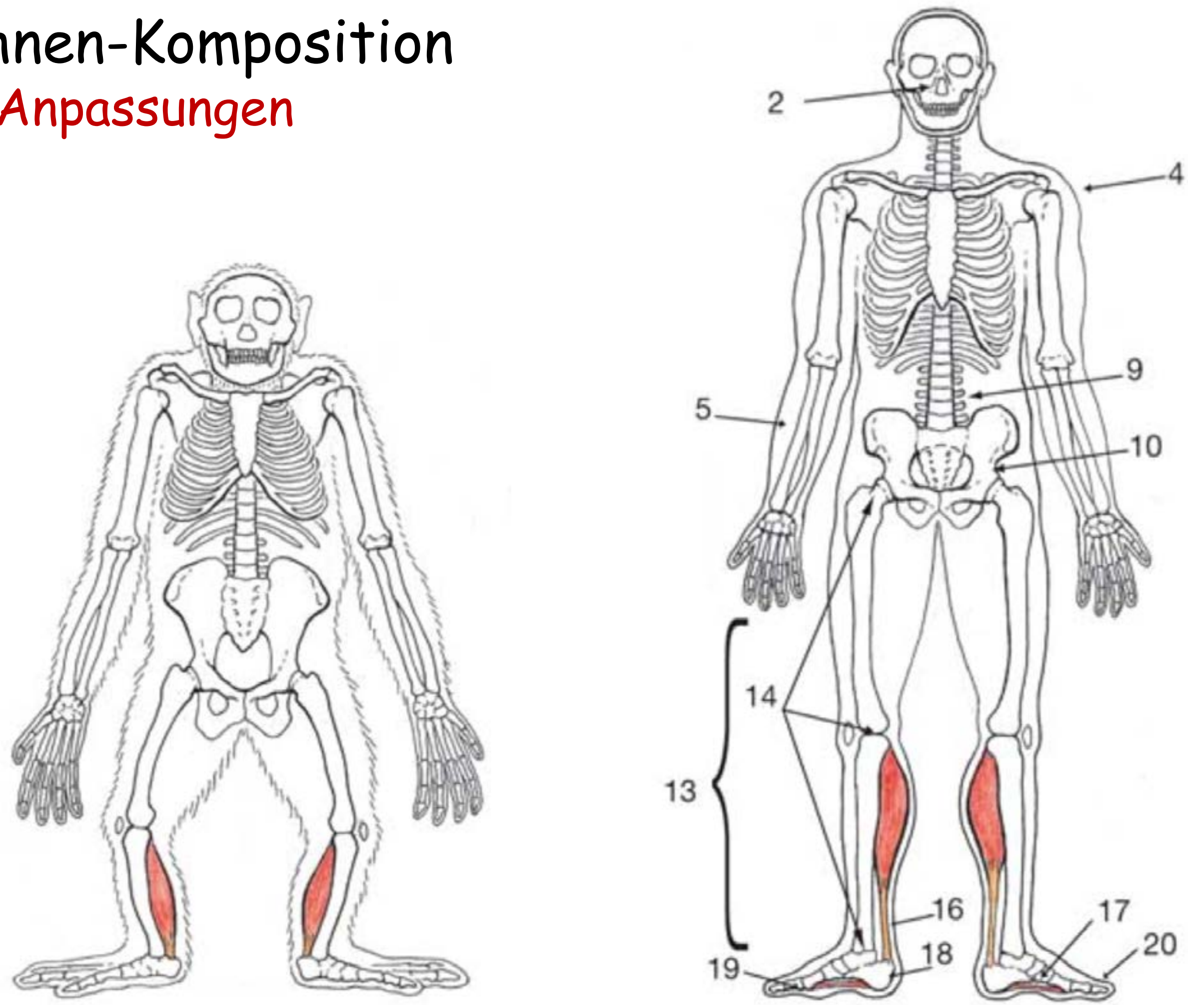


Neuro-Muscular Adaptation
Bewegungslernen
Technik
Skills
→ Qualitative Phase
Internal Modelling
Prepuberty/Child
Puberty
Adolescence
Endocrine Function
Konstitution
Kapazitäten
Leistungspotentiale
→ Quantitative Phase
Muscle – Tendon Adaptation

Kopplung: Sehne-Muskel

Muskel-Sehnen-Komposition

evolutionäre Anpassungen

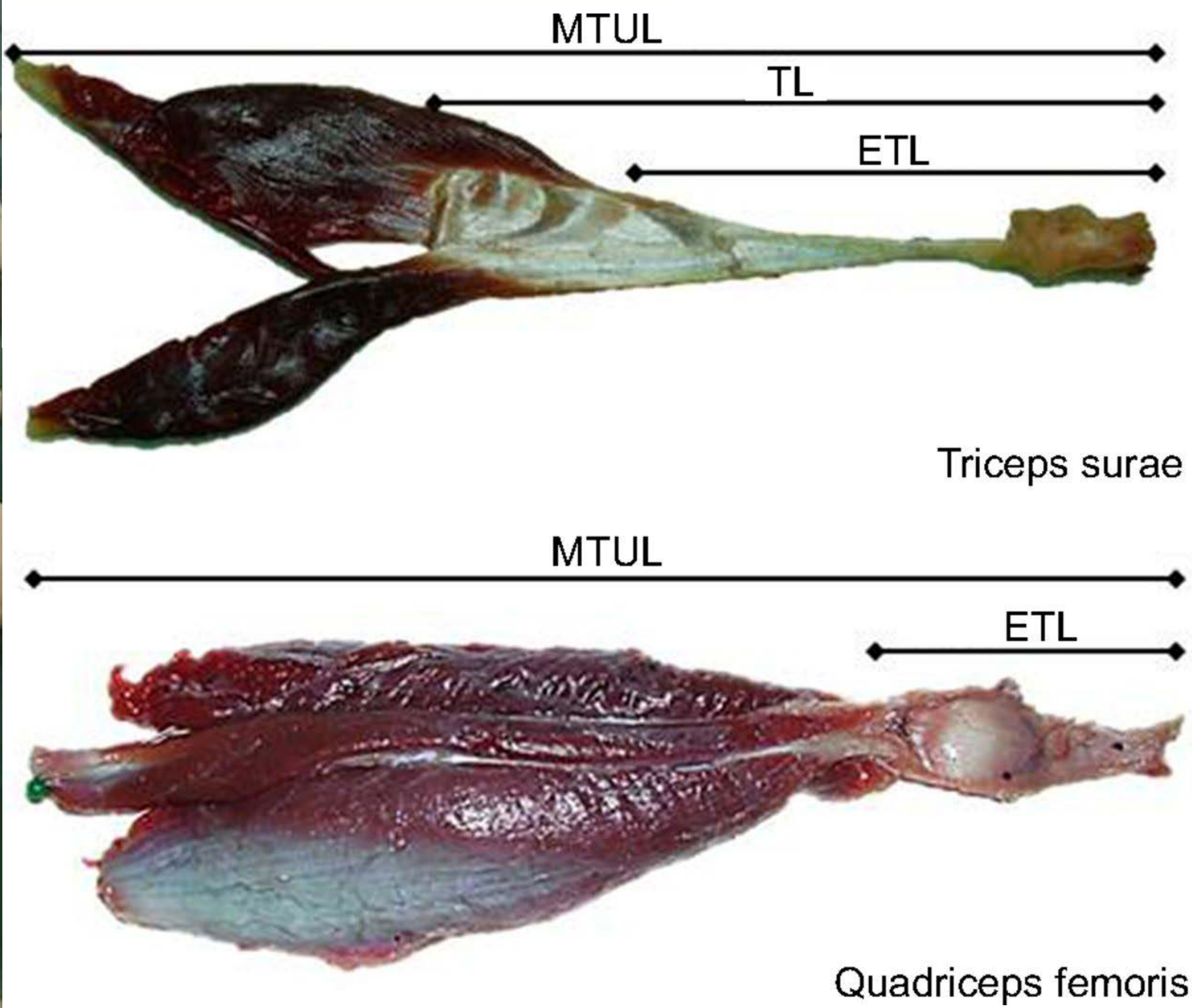


Bramble & Lieberman 2004

RESEARCH ARTICLE

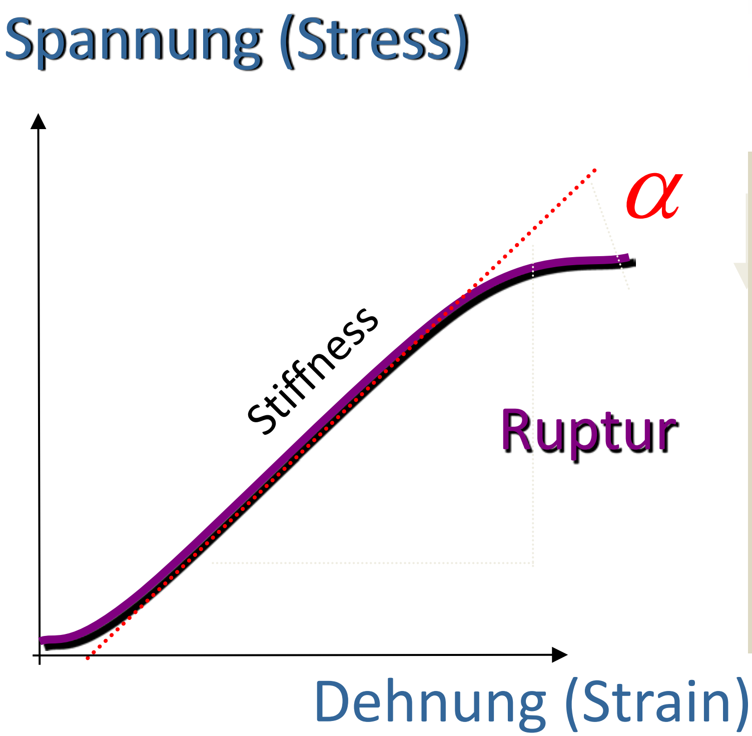
dons in gibbon locomotion: springs or strings?

ereecke[1,*] and Anthony J. Channon[2]
@ Kulak, KU Leuven, 3000 Leuven, Belgium and [2]Structure and Motion Laboratory,
ary College, Hatfield, Hertfordshire AL9 7TA, UK
rrespondence (Evie.Vereecke@kuleuven-kulak.be)



Dämpfungs-System

A bisserl
Physik, bitt´ schön!



Spannung (Stress): Kraft pro Flächeneinheit

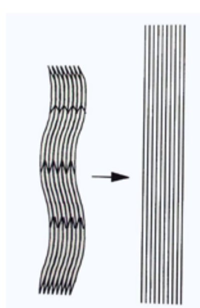
Dehnung (Strain): relative Längenänderung unter Krafteinwirkung

Steifigkeit (Stiffness): Kraft pro Längenänderung

E-Modul: Spannung pro Dehnung

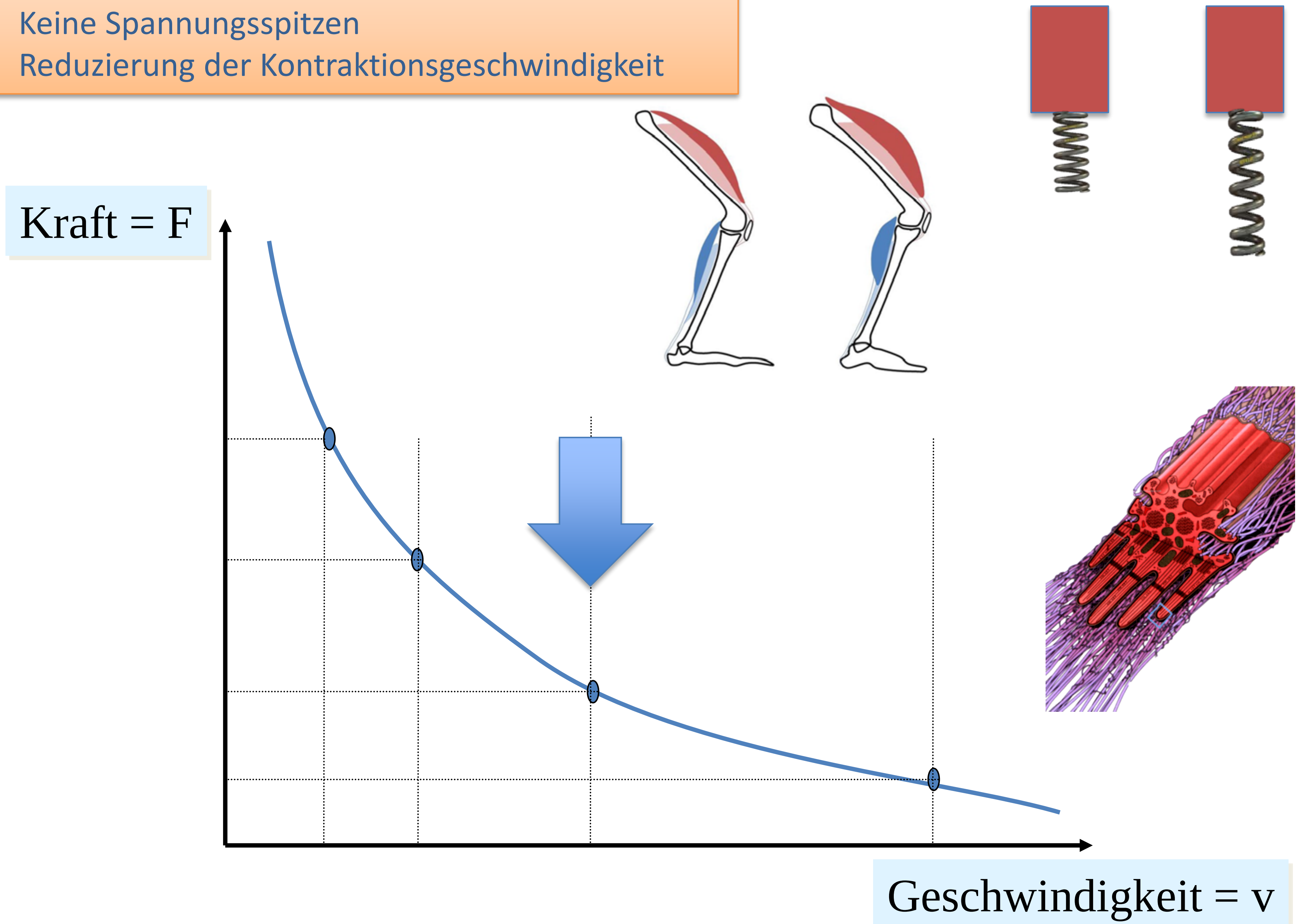
E = Elastizitätsmodul

Young´s Modulus

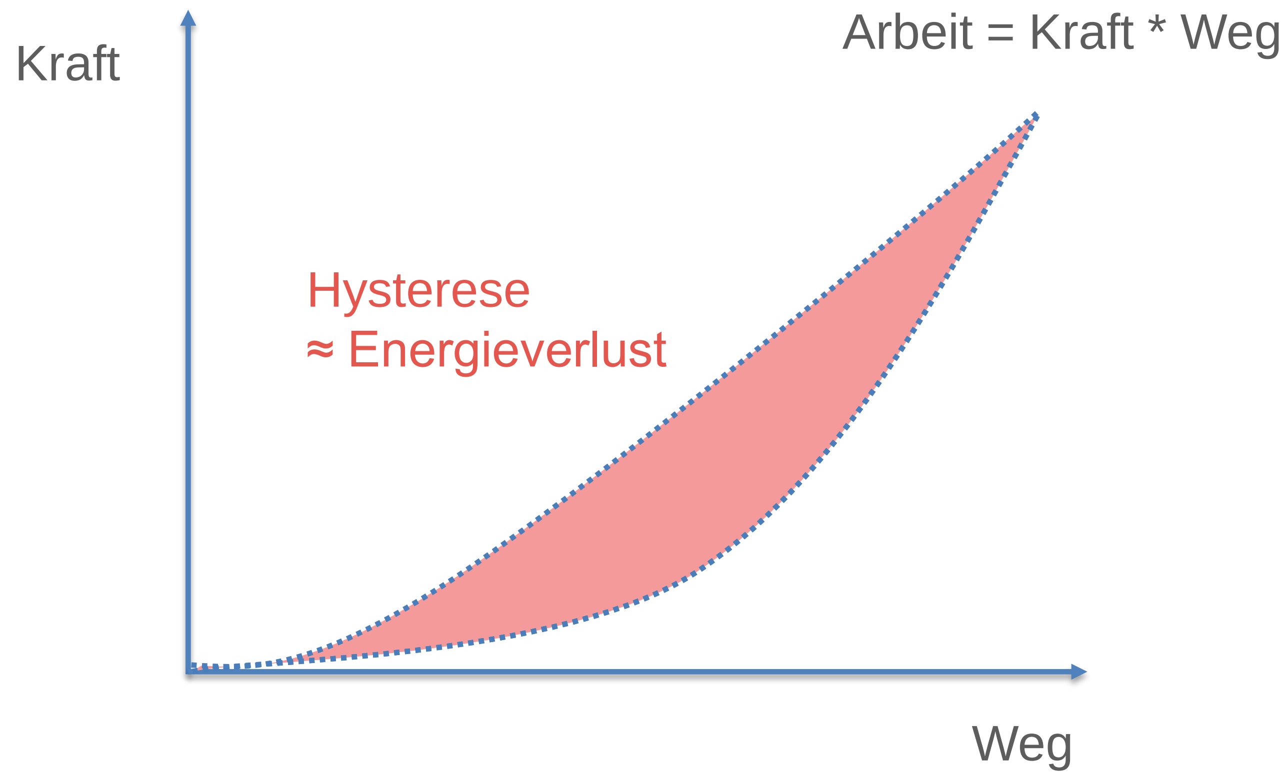


Spannungsverhalten:

- Limitierung dF/dt
- Keine Spannungsspitzen
- Reduzierung der Kontraktionsgeschwindigkeit

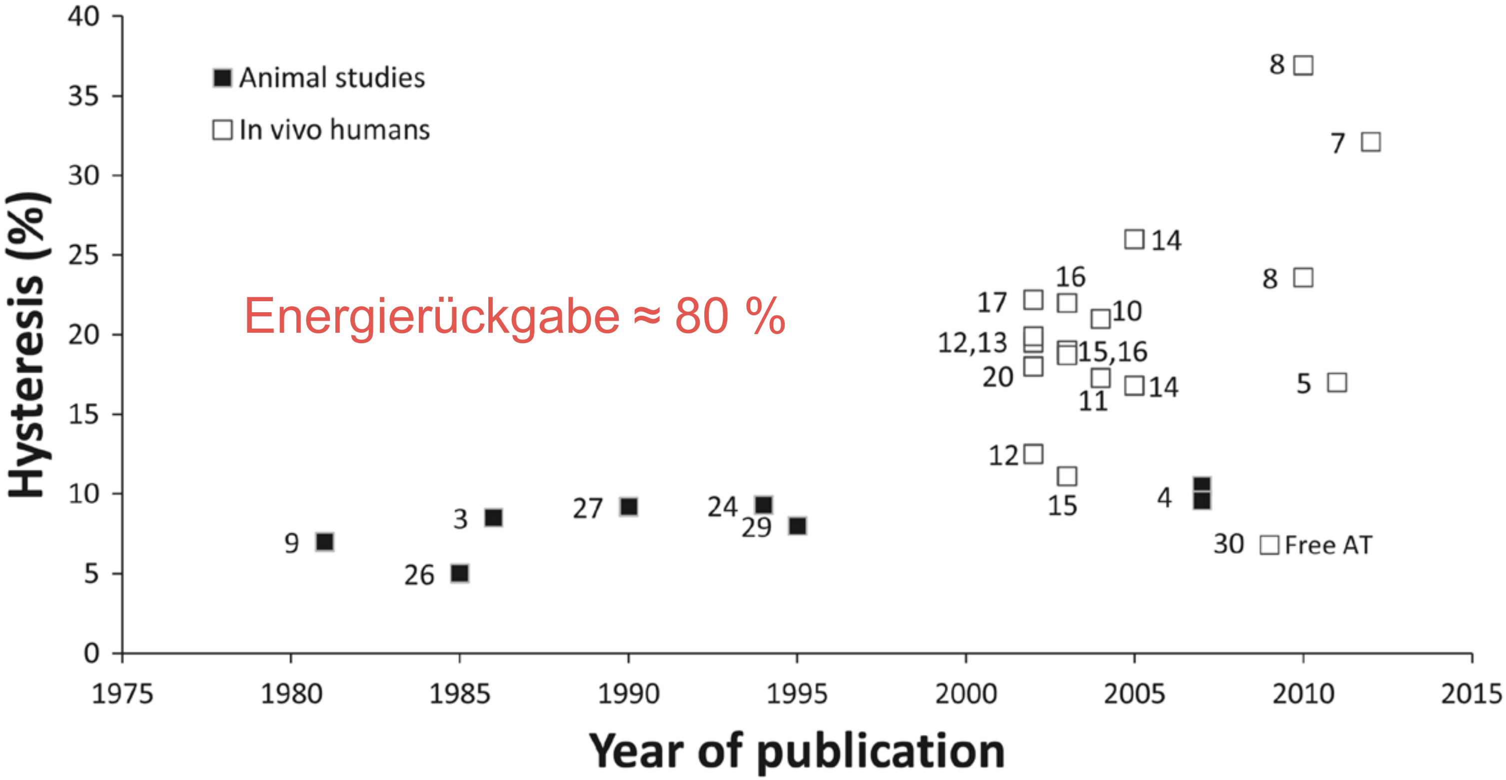


Power-System
Energie-Speicher



Sehne als potentieller Energiespeicher

in vivo / Studien am Menschen

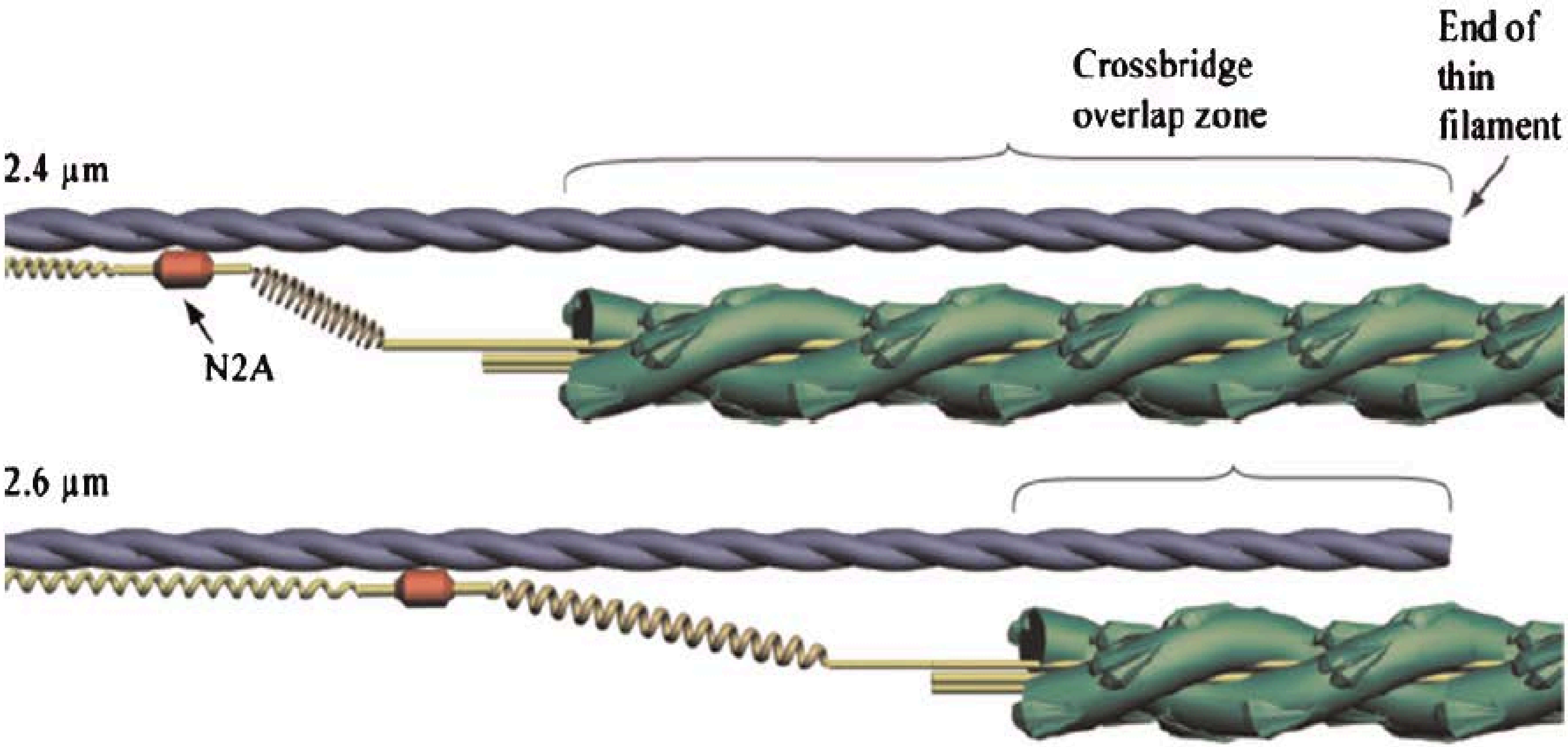


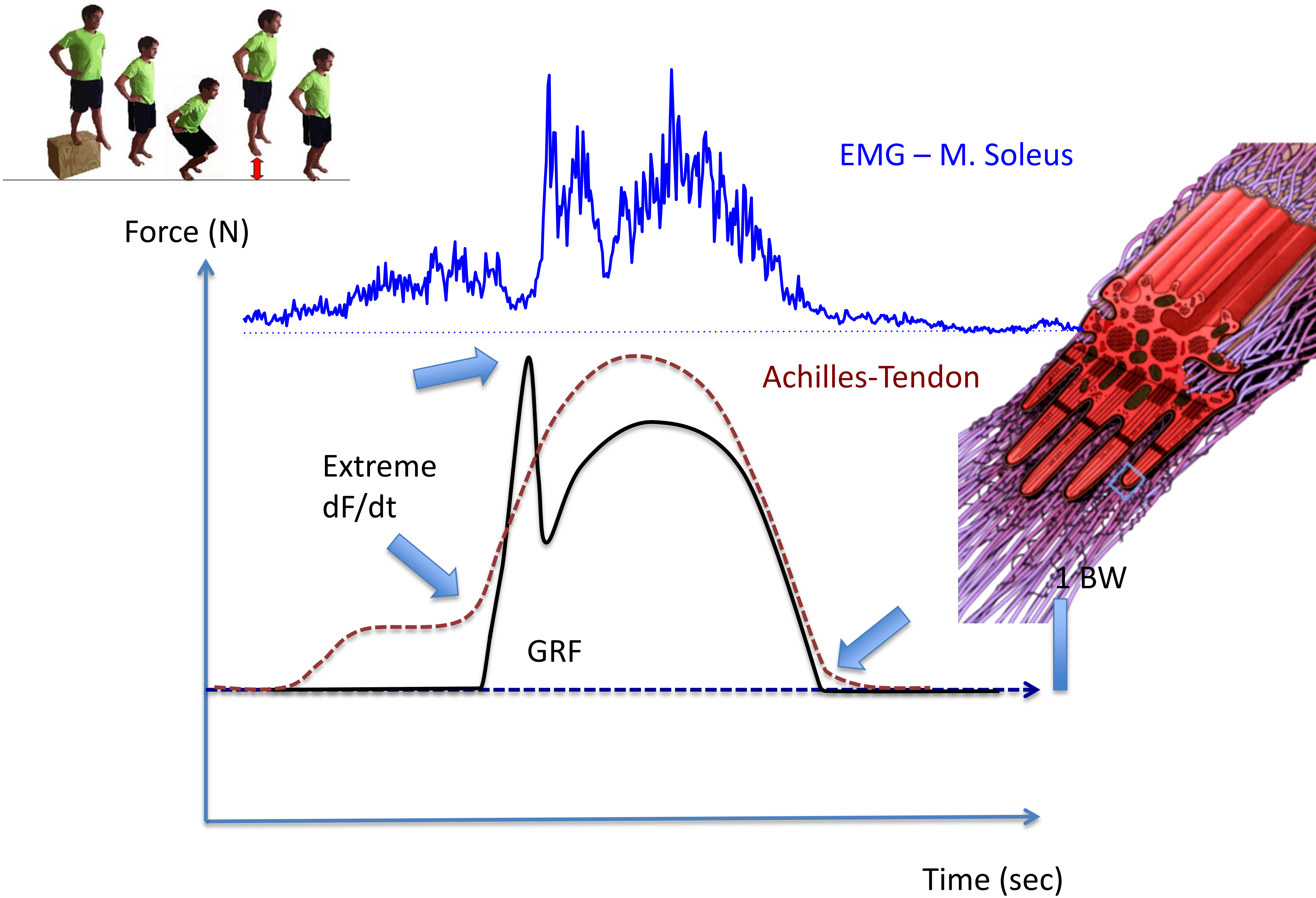
Finni et al. 2012

Muskel_Titin: Neue Hypothesen......

What Is the Role of Titin in Active Muscle?

Jenna A. Monroy1, Krysta L. Powers1, Leslie A. Gilmore1, Theodore A. Uyeno2, Stan L. Lindstedt1, and Kiisa C. Nishikawa1, Exercise and Sport Sciences Reviews, 2012



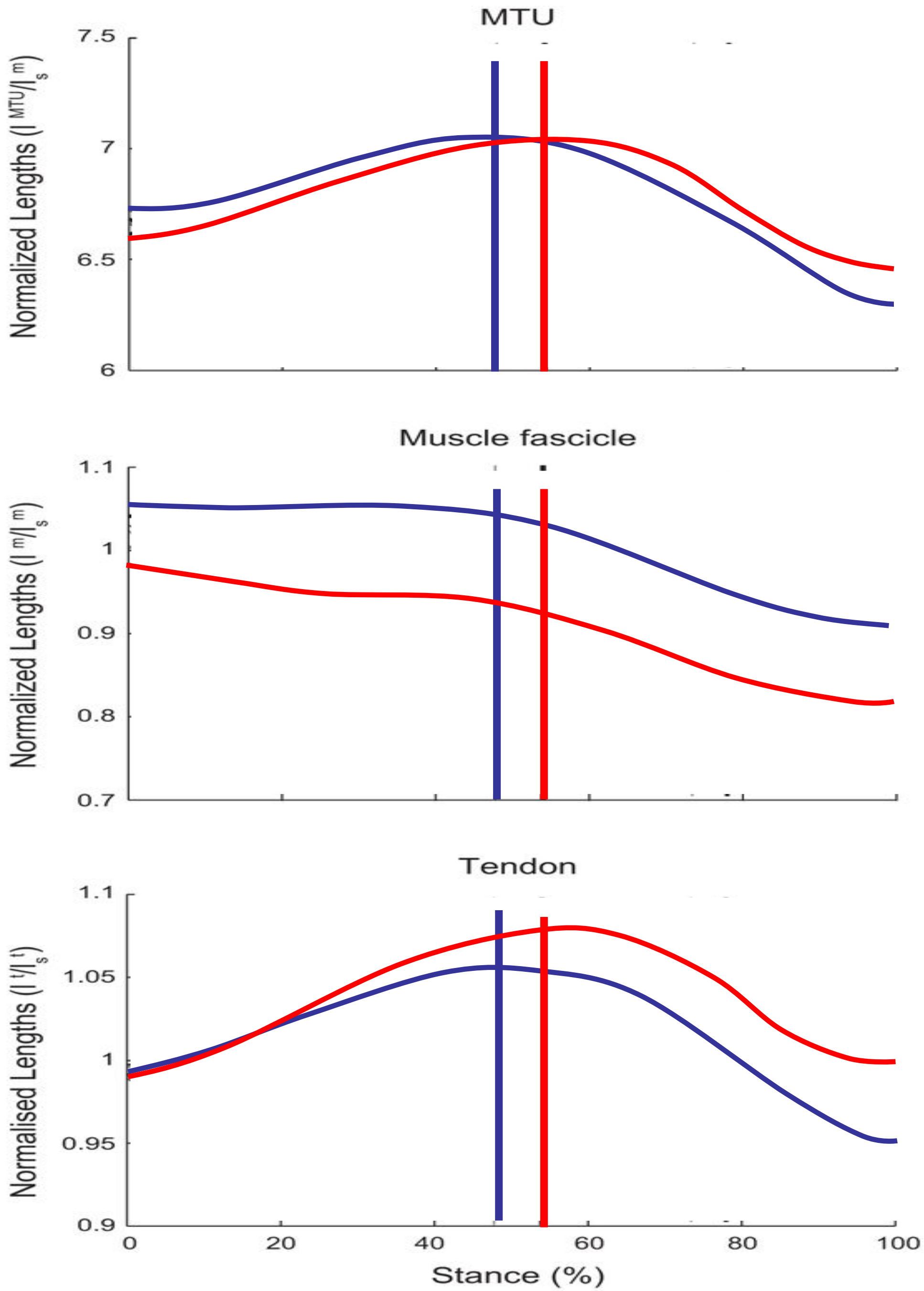


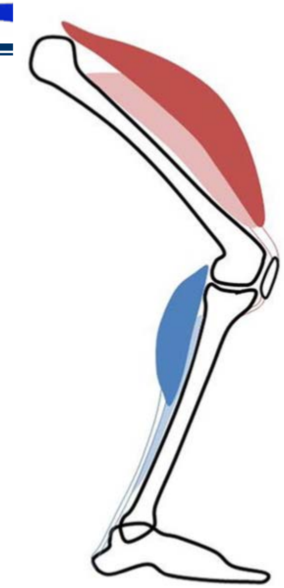
EMG – M. Soleus
Force (N)
Achilles-Tendon
Extreme
dF/dt
GRF
1 BW
Time (sec)

Muskel-Sehne

Muskelfaser

Sehne





Running:

2 m/sec
5 m/sec

Lai et al.
2015 JAP

Mod. Lai et al. 2015

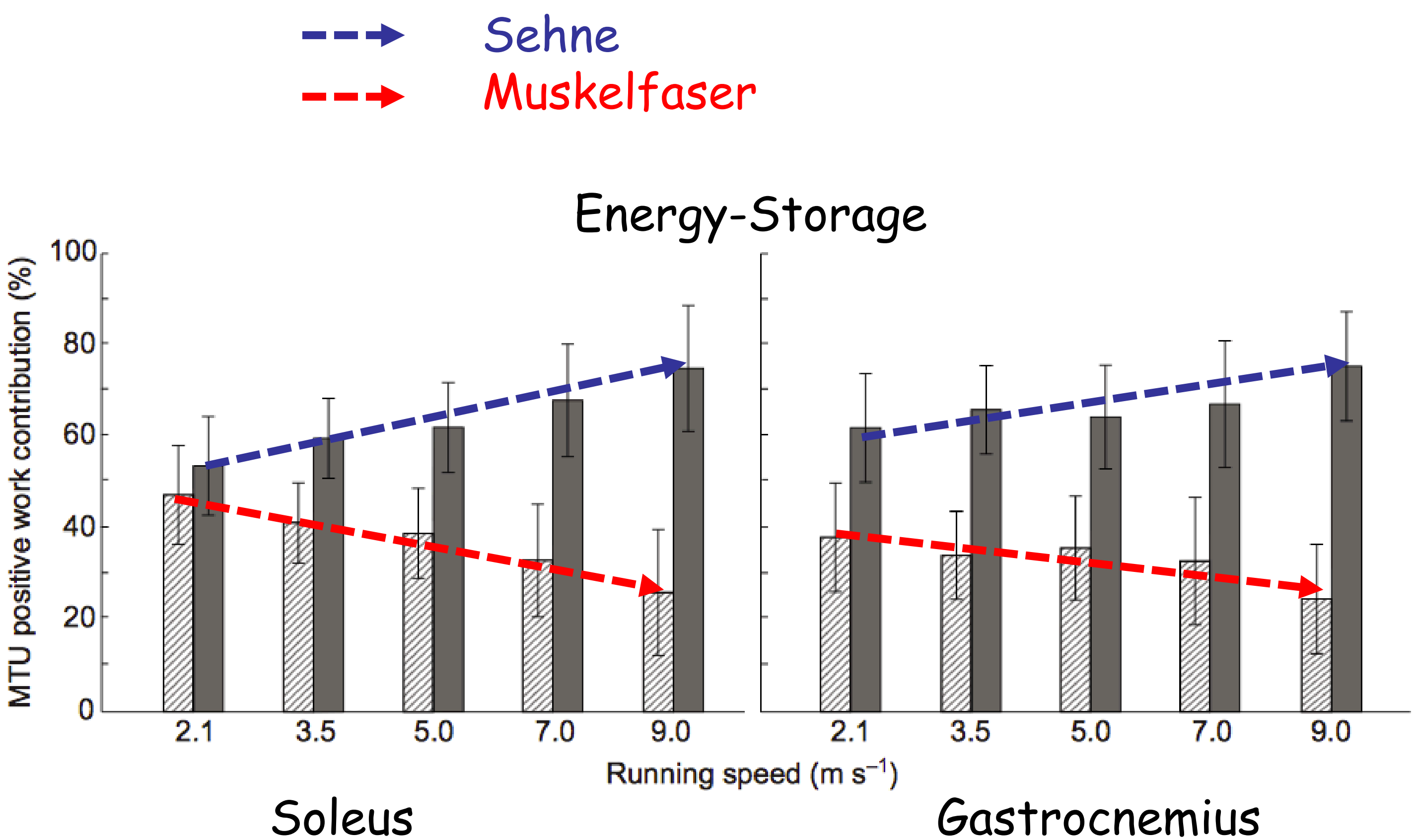
Running Velocity and Energy_Return

© 2014. Published by The Company of Biologists Ltd | The Journal of Experimental Biology (2014) 217, 3159-3168 doi:10.1242/jeb.100826

RESEARCH ARTICLE

Tendon elastic strain energy in the human ankle plantar-flexors and its role with increased running speed

Adrian Lai, Anthony G. Schache, Yi-Chung Lin and Marcus G. Pandy*

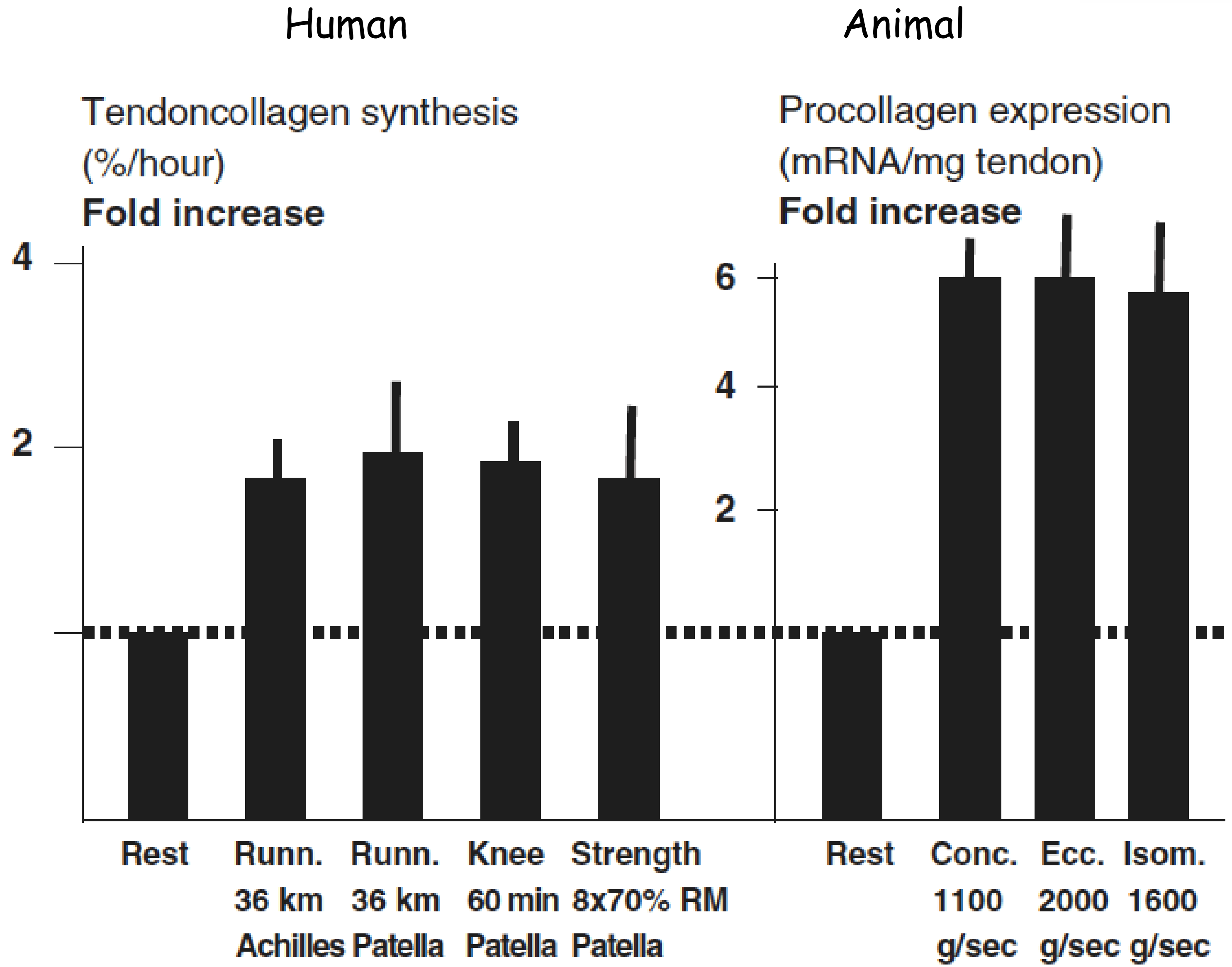


Mod. Lai et al. 2014

Anwendungsforschung

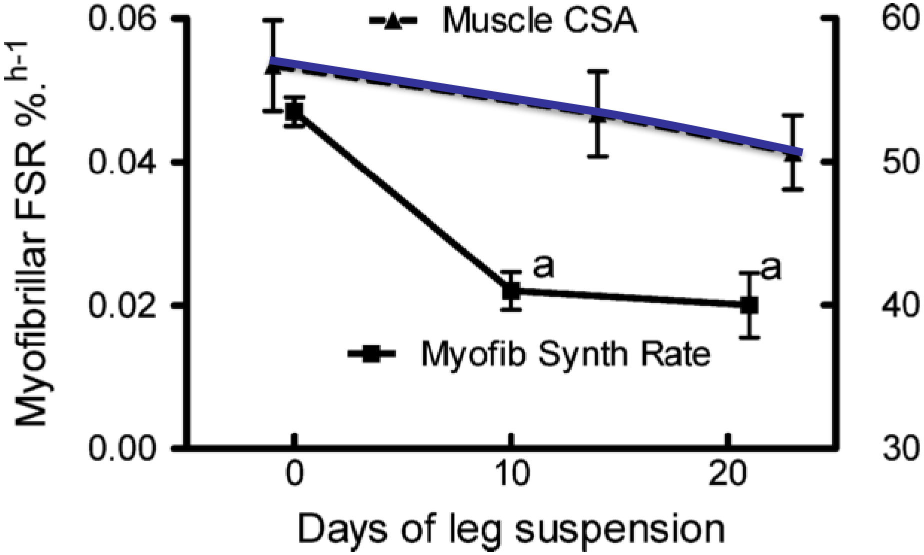
Was ist da trainierbar??

Wie ist das trainierbar??

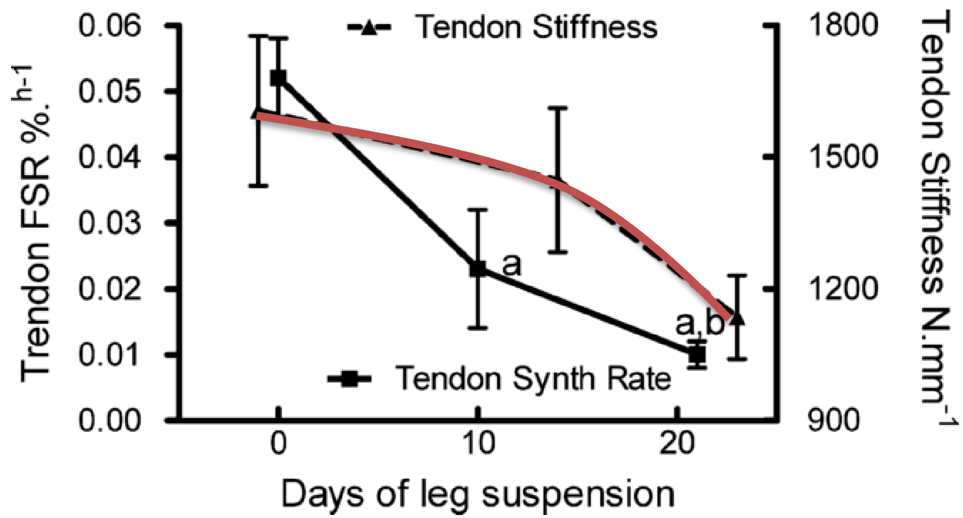


24 h after acute bout of exercise

Kjaer et al 2009



de Boer J Physiol 585.1 (2007) pp 241-251



Effects of unilateral lower limb suspension on human quadriceps cross-sectional area and myofibrillar and tendon fractional synthesis (FSR)

Tendon in Athletic Areas

PLOS ONE 2016

RESEARCH ARTICLE

Are Sport-Specific Profiles of Tendon Stiffness and Cross-Sectional Area Determined by Structural or Functional Integrity?

Hans-Peter Wiesinger[1]*, Florian Rieder[1], Alexander Kösters[1], Erich Müller[1], Olivier R. Seynnes[2]

1 Department of Sport Science and Kinesiology, University of Salzburg, Salzburg, Austria, 2 Department of Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway

Table 1. Anthropometric characteristics of subjects.

	Ski Jumper	Runner	Water Polo	Control	$F_{(3;35)}$	P-Value
Sample size	10	10	9	10		
Age (yrs)	22.2 ± 2.9†††***	31.5 ± 4.6	24.2 ± 3.2†††***	31.0 ± 5.1	13.08	<0.001
Body height (cm)	176.3 ± 4.5	180.9 ± 8.2	182.4 ± 6.5	182.9 ± 7.2	1.96	0.140
Body mass (kg)	64.3 ± 3.9†§§§***	72.8 ± 7.6§	84.3 ± 10.8	83.9 ± 12.3	10.72	<0.001
BMI (kg/m^2)	20.7 ± 1.0§§§***	22.2 ± 1.7§*	25.3 ± 2.8	25.0 ± 2.8	10.33	<0.001

Values are expressed as mean ± SD. BMI, body mass index;

† P < 0.05;

††† P < 0.001 compared with runners;

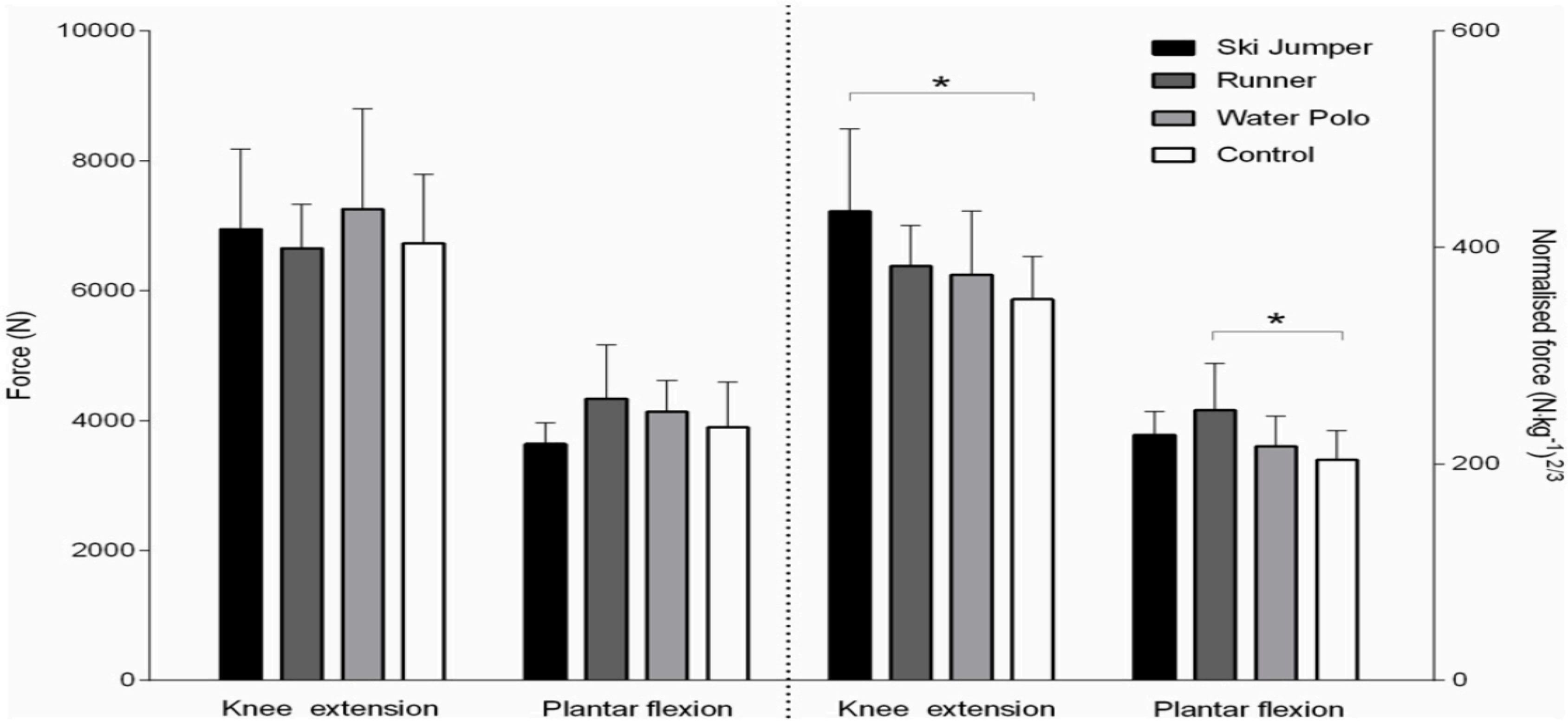
§ P < 0.05;

§§§ P < 0.001 compared with water polo players;

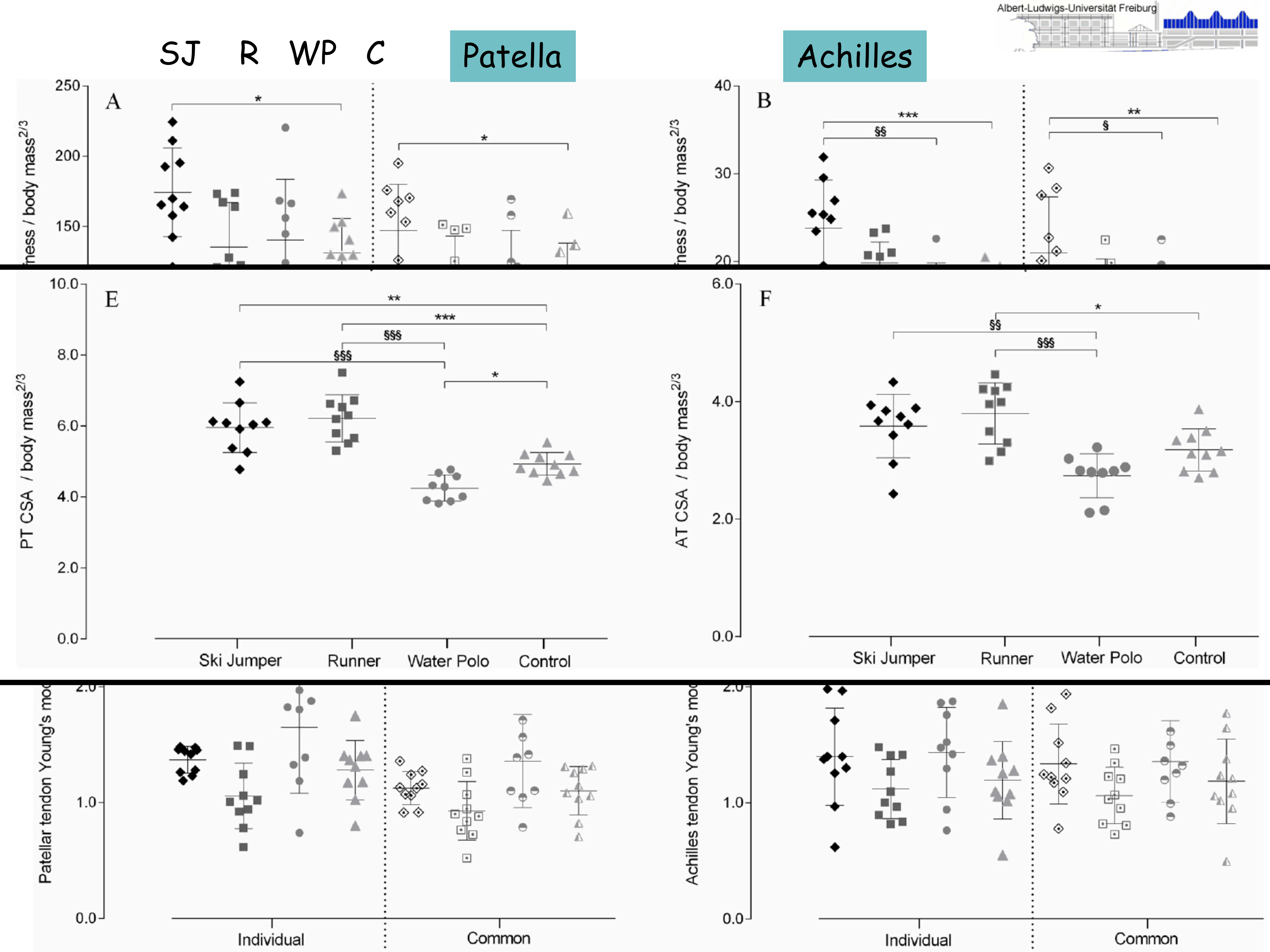
* P < 0.05;

*** P < 0.001 compared with controls.

Absolute Kraft (N)   Relative Kraft (N/kg)



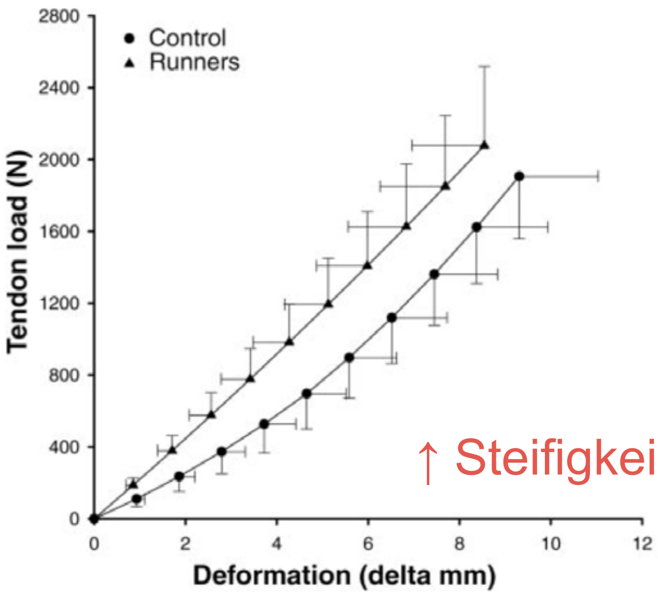
Wiesinger et al. 2016



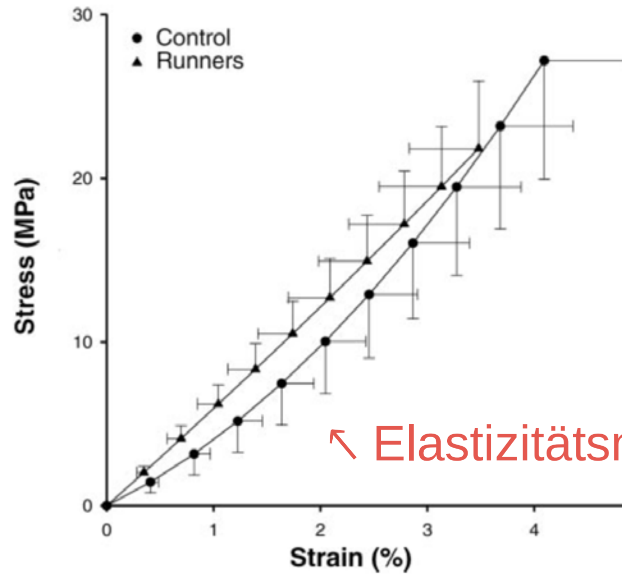
Albert-Ludwigs-Universität Freiburg
SJ R WP C
Patella
Achilles
A
B
ness / body mass2/3
250
200
150
40
30
20
*
***
§§
**
§
E
F
PT CSA / body mass2/3
AT CSA / body mass2/3
10.0
8.0
6.0
4.0
2.0
0.0
**
***
§§§
§§§
*
§§
§§§
Ski Jumper
Runner
Water Polo
Control
Patellar tendon Young's mod
Achilles tendon Young's mod
2.0
1.0
0.0
Individual
Common

Chronische Anpassung an Belastung

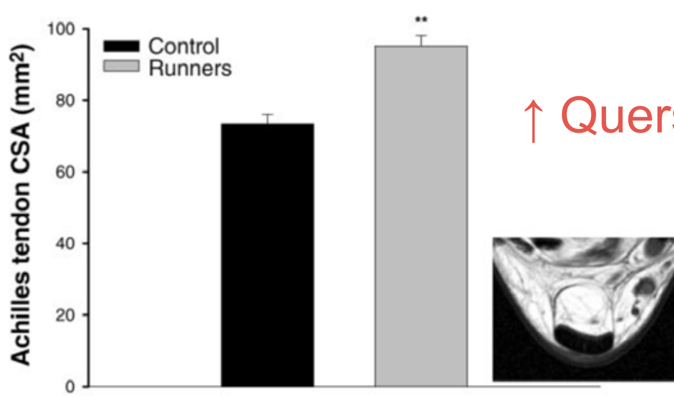
Läufer vs. Nicht-Läufer



↑ Steifigkeit



↖ Elastizitätsmodul

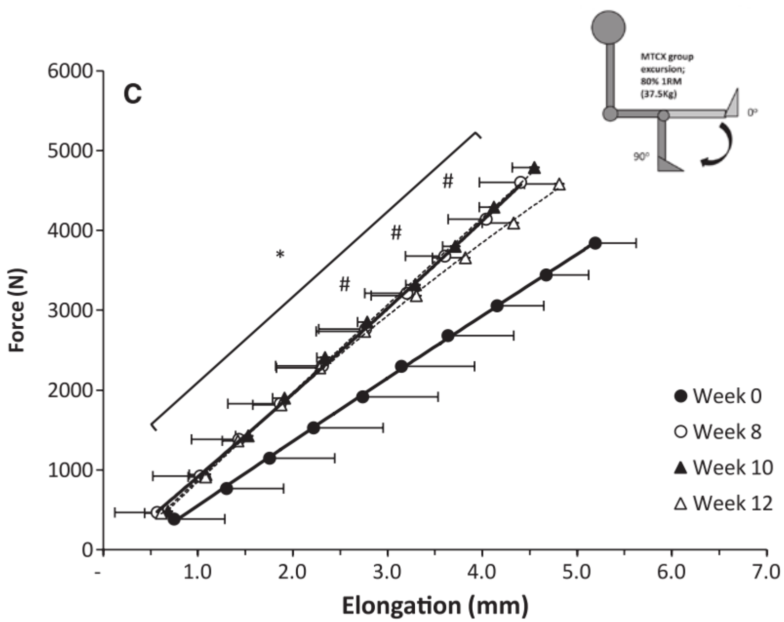


↑ Querschnitt

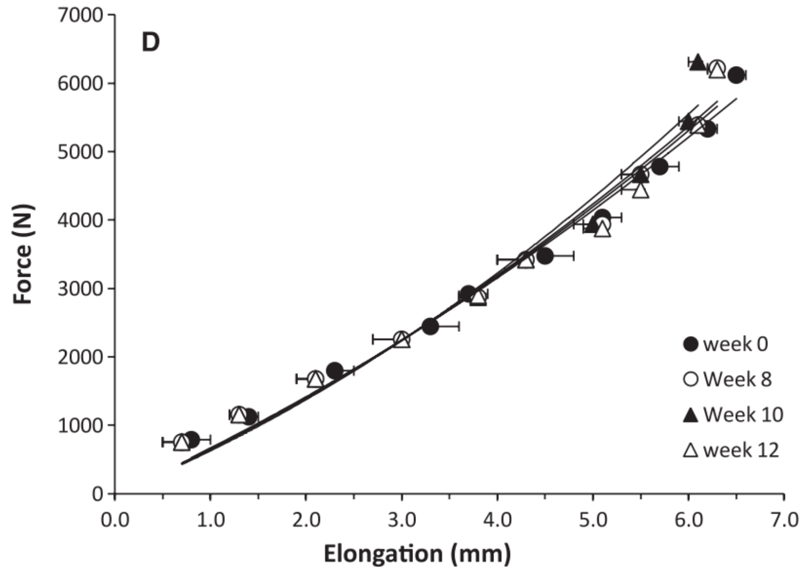
Kjaer 2004 (mod. nach Rosager et al. 2002)

Mehrwöchiges Krafttraining
Veränderung der Sehnen-Steifigkeit

Trainingsgruppe



Kontrollgruppe



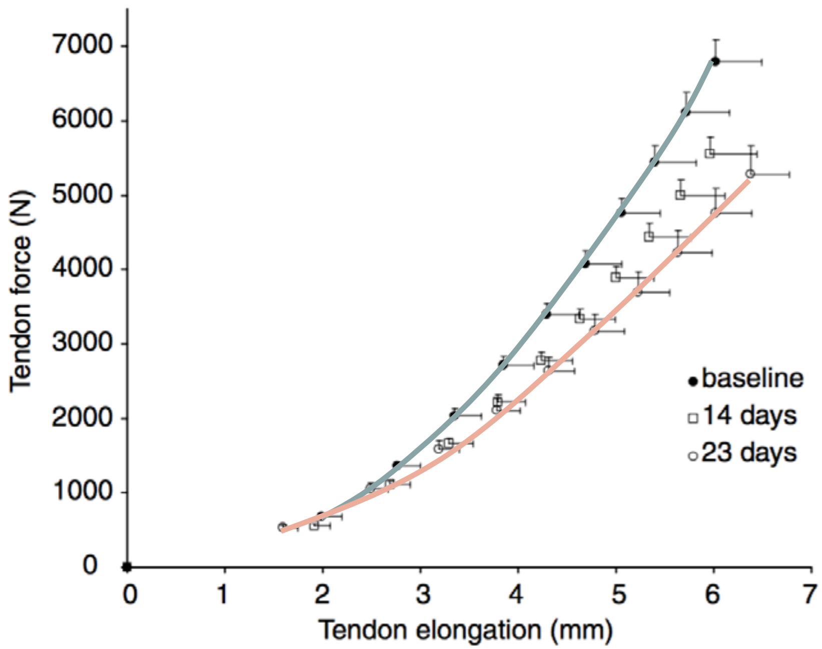
8 Wochen Krafttraining

McMahon et al. 2013

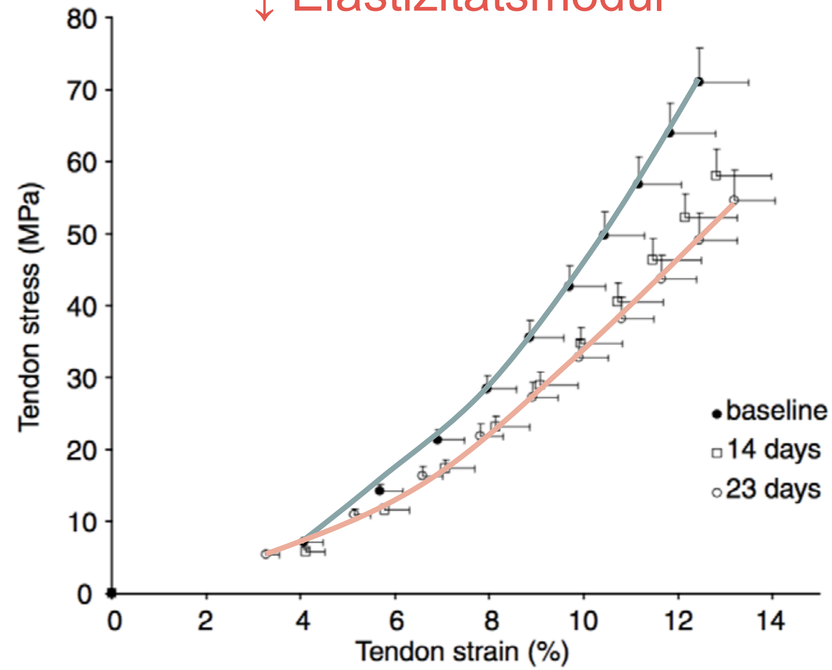
Anpassung bei Inaktivität

23 Tage Bed-Rest

↓ Steifigkeit



↓ Elastizitätsmodul



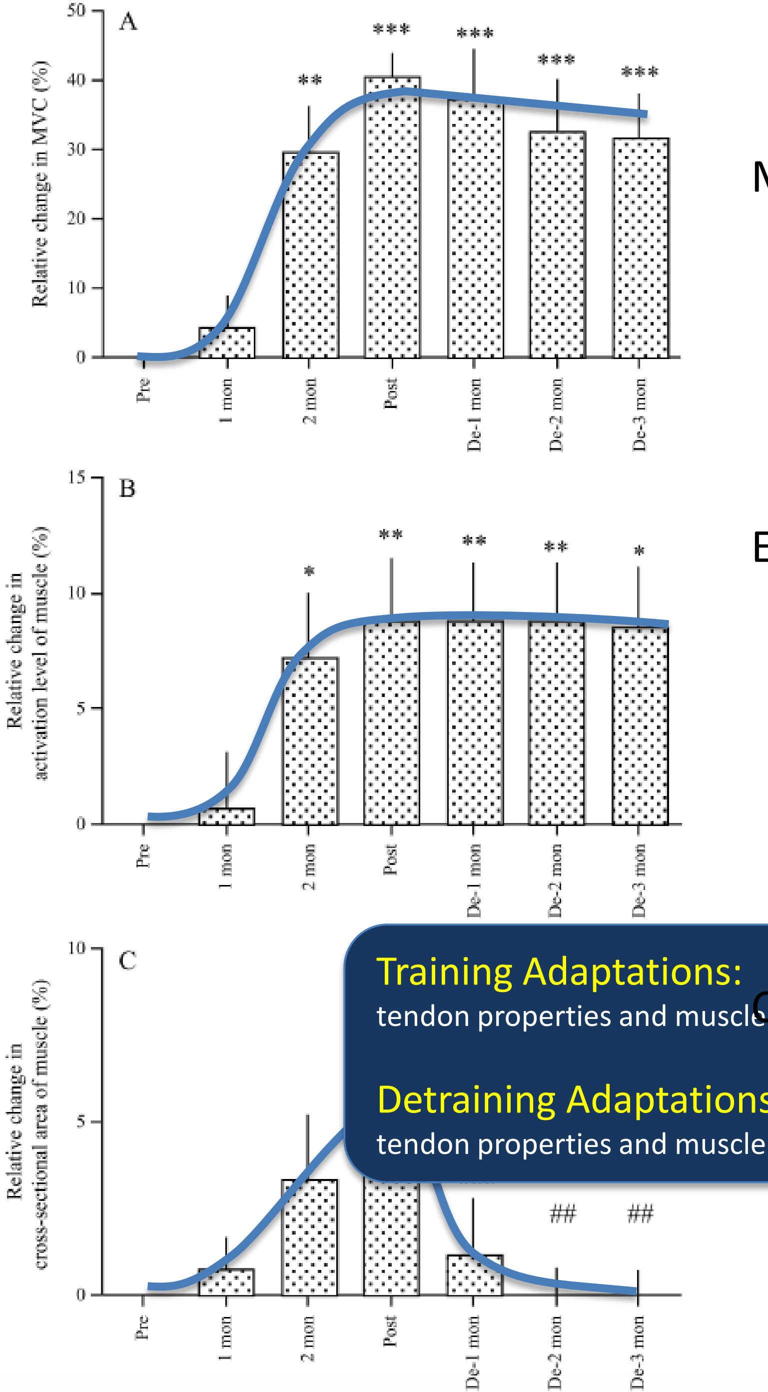
$100 \pm 12\ mm^2 \rightarrow 101 \pm 11\ mm^2$

Boer et al. 2007

TIME COURSE OF CHANGES IN MUSCLE AND TENDON PROPERTIES DURING STRENGTH TRAINING AND DETRAINING

KUBO et al. 2010

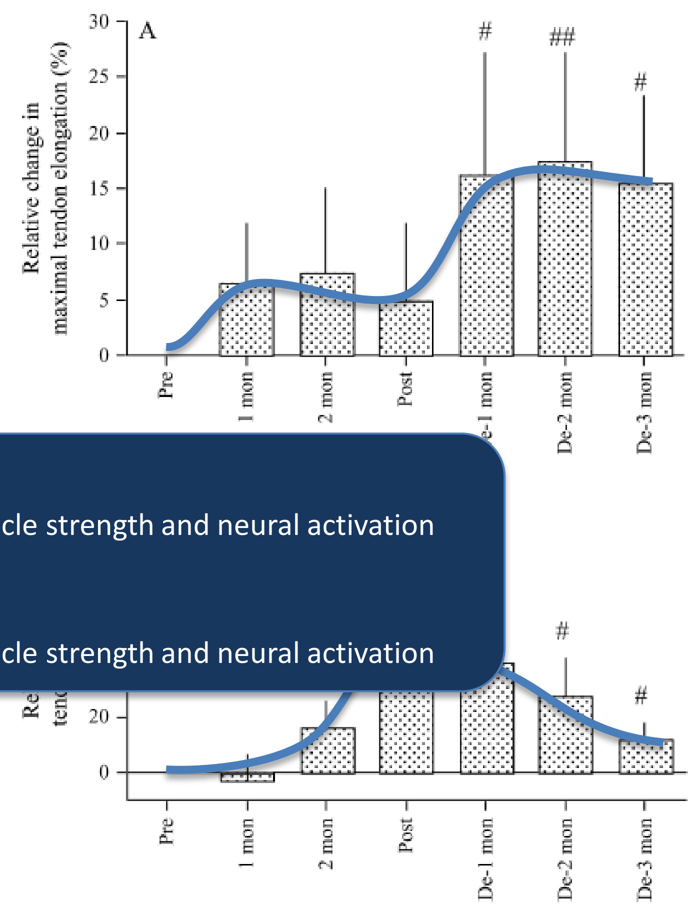
N = 8 Training; 6 Detraining: 22y; 175 cm



MVC

EMG

CSA



Length %

Stiff %

Training Adaptations:

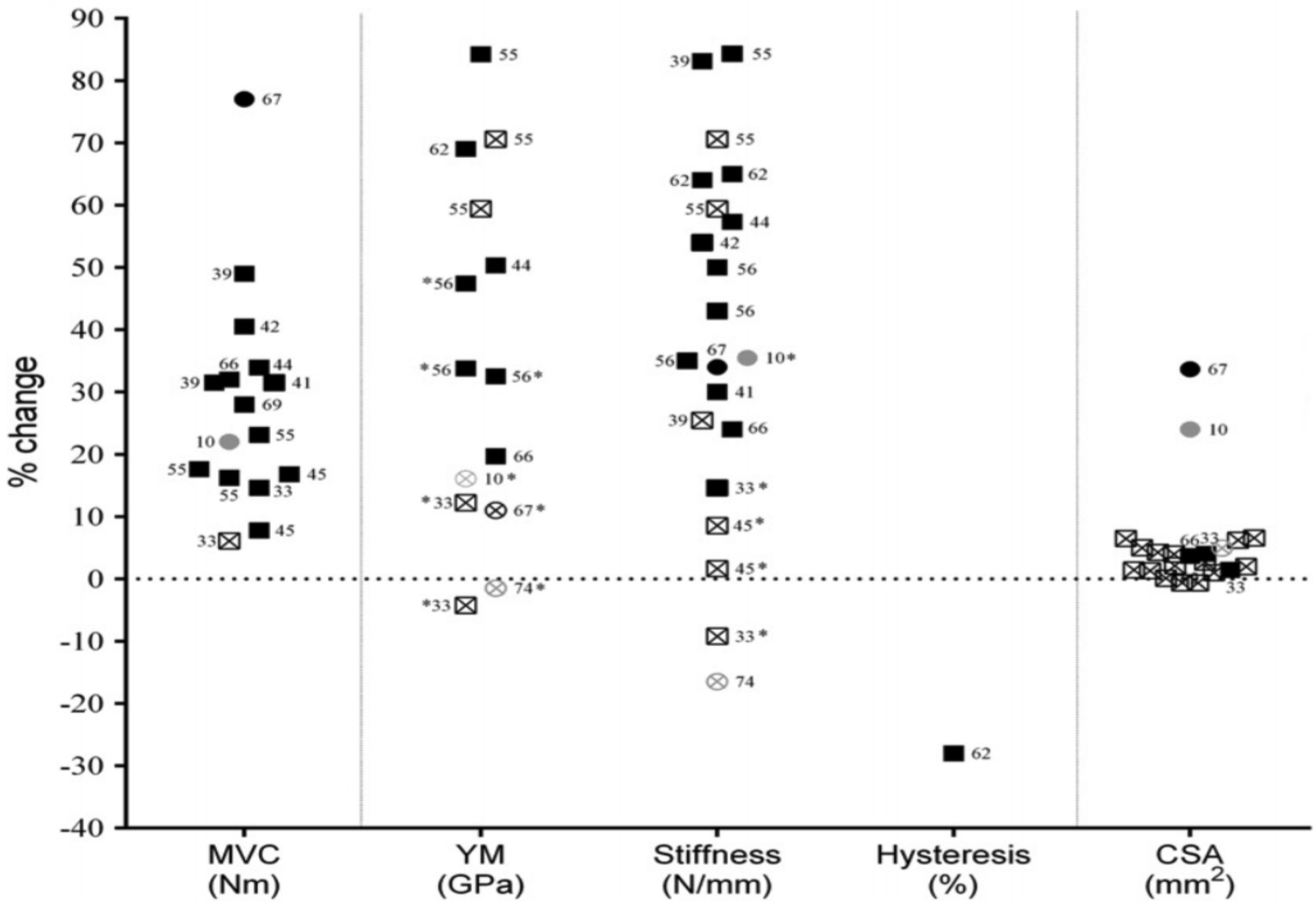
tendon properties and muscle CSA << muscle strength and neural activation

Detraining Adaptations:

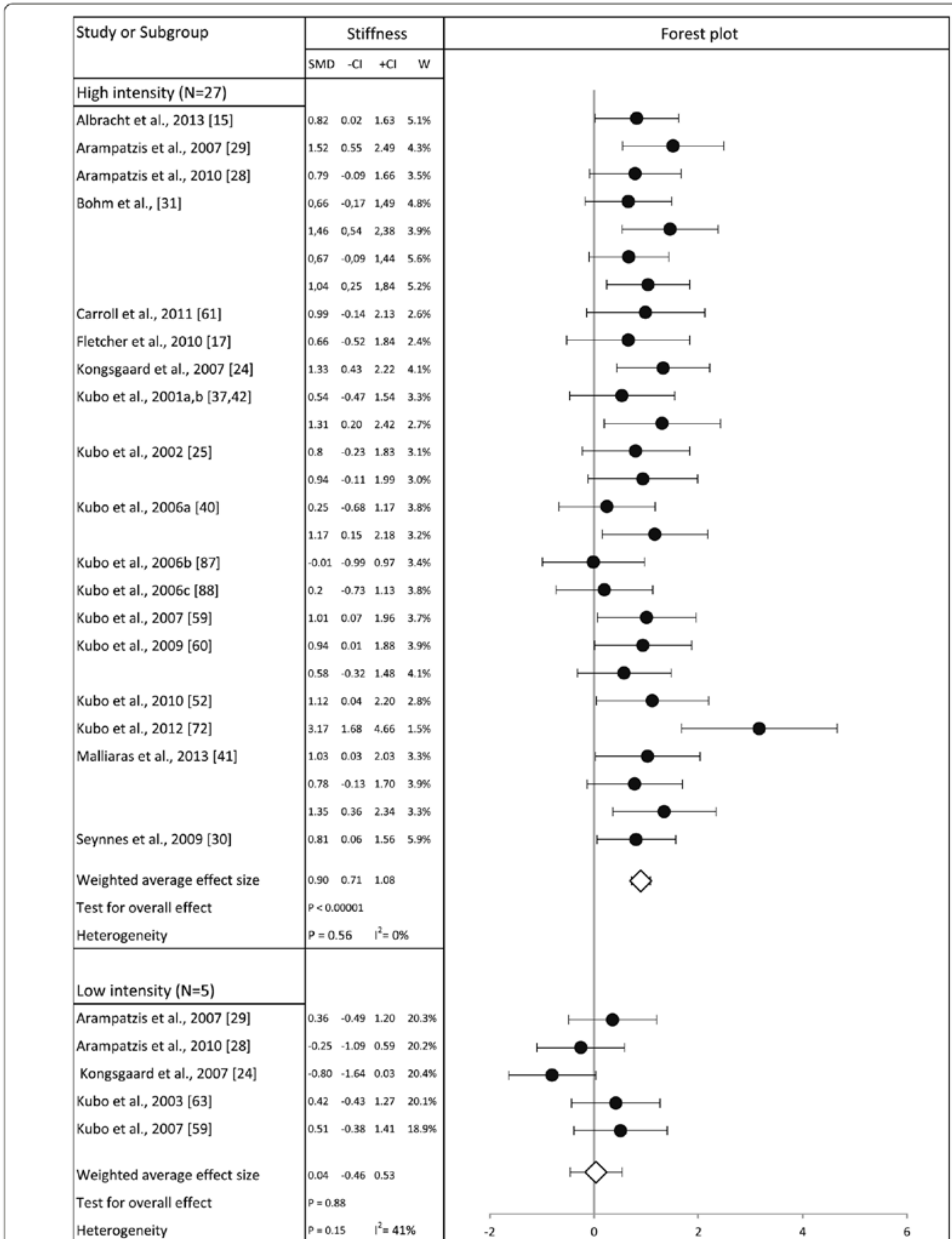
tendon properties and muscle CSA >> muscle strength and neural activation

Muskel-Sehnen Anpassung an Training

im Überblick



Wiesinger 2015



Study or Subgroup	Stiffness SMD	-CI	+CI	W
High intensity (N=27)				
Albracht et al., 2013 [15]	0.82	0.02	1.63	5.1%
Arampatzis et al., 2007 [29]	1.52	0.55	2.49	4.3%
Arampatzis et al., 2010 [28]	0.79	-0.09	1.66	3.5%
Bohm et al., [31]	0,66	-0,17	1,49	4.8%
	1,46	0,54	2,38	3.9%
	0,67	-0,09	1,44	5.6%
	1,04	0,25	1,84	5.2%
Carroll et al., 2011 [61]	0.99	-0.14	2.13	2.6%
Fletcher et al., 2010 [17]	0.66	-0.52	1.84	2.4%
Kongsgaard et al., 2007 [24]	1.33	0.43	2.22	4.1%
Kubo et al., 2001a,b [37,42]	0.54	-0.47	1.54	3.3%
	1.31	0.20	2.42	2.7%
Kubo et al., 2002 [25]	0.8	-0.23	1.83	3.1%
	0.94	-0.11	1.99	3.0%
Kubo et al., 2006a [40]	0.25	-0.68	1.17	3.8%
	1.17	0.15	2.18	3.2%
Kubo et al., 2006b [87]	-0.01	-0.99	0.97	3.4%
Kubo et al., 2006c [88]	0.2	-0.73	1.13	3.8%
Kubo et al., 2007 [59]	1.01	0.07	1.96	3.7%
Kubo et al., 2009 [60]	0.94	0.01	1.88	3.9%
	0.58	-0.32	1.48	4.1%
Kubo et al., 2010 [52]	1.12	0.04	2.20	2.8%
Kubo et al., 2012 [72]	3.17	1.68	4.66	1.5%
Malliaras et al., 2013 [41]	1.03	0.03	2.03	3.3%
	0.78	-0.13	1.70	3.9%
	1.35	0.36	2.34	3.3%
Seynnes et al., 2009 [30]	0.81	0.06	1.56	5.9%
Weighted average effect size	0.90	0.71	1.08	
Test for overall effect	P < 0.00001			
Heterogeneity	P = 0.56	I^2 = 0%		
Low intensity (N=5)				
Arampatzis et al., 2007 [29]	0.36	-0.49	1.20	20.3%
Arampatzis et al., 2010 [28]	-0.25	-1.09	0.59	20.2%
Kongsgaard et al., 2007 [24]	-0.80	-1.64	0.03	20.4%
Kubo et al., 2003 [63]	0.42	-0.43	1.27	20.1%
Kubo et al., 2007 [59]	0.51	-0.38	1.41	18.9%
Weighted average effect size	0.04	-0.46	0.53	
Test for overall effect	P = 0.88			
Heterogeneity	P = 0.15	I^2 = 41%		

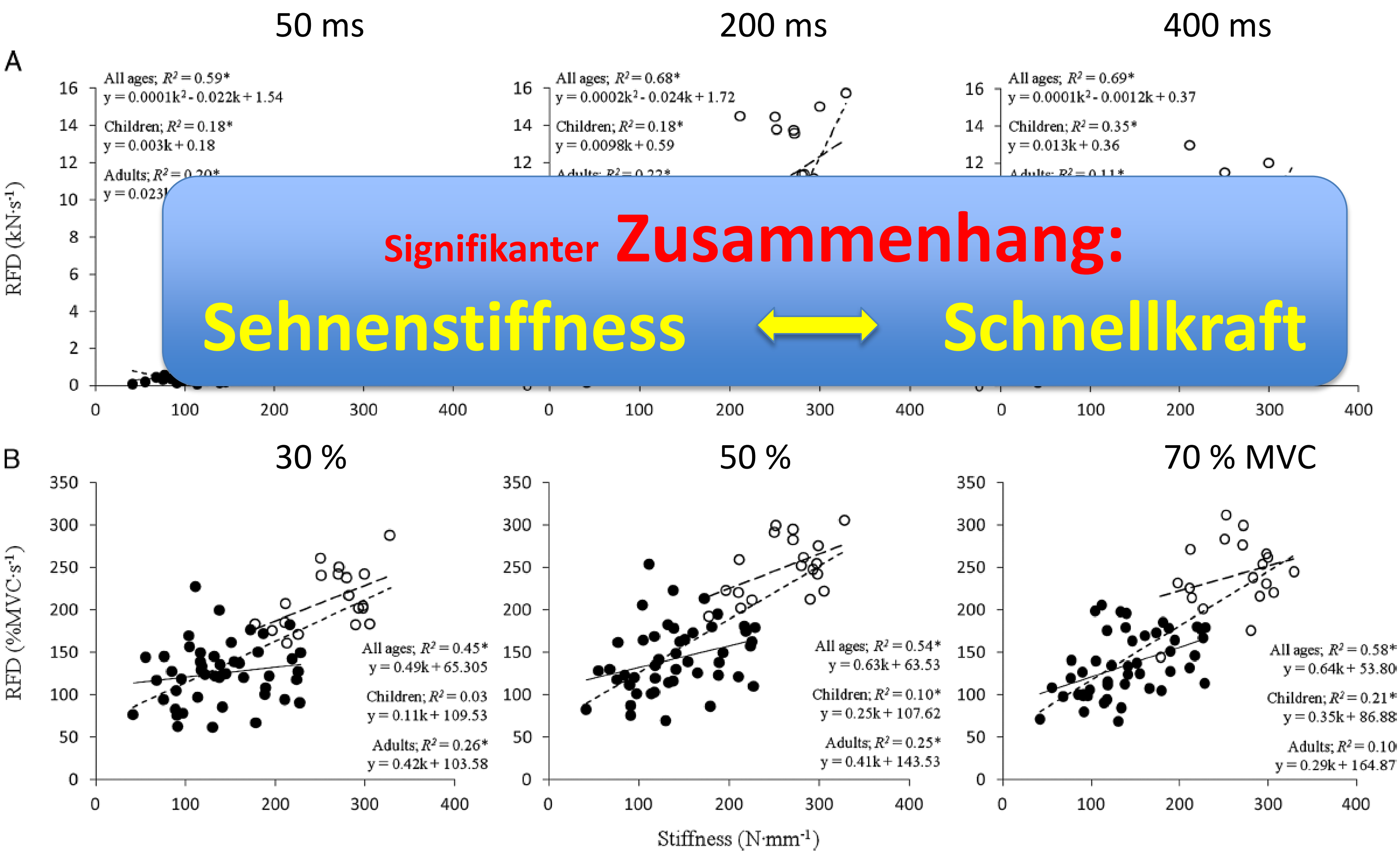
Figure 4 Forest plot for the meta-analysis of the effect of mechanical loading on tendon properties. Illustrated are the exercise intervention-induced changes on tendon stiffness (black), Young's modulus (white), and cross-sectional area (CSA, gray), respectively, featuri single-study effect sizes (SMD, circles), the corresponding confidence intervals (CIs, error bars), and study weight in the overall comparison (well as the respective weighted average effect sizes (random-effects model, diamonds) with the overall effect test and heterogeneity analys

Erhöhung der Sehnen-Steifigkeit

≥ 70 % MVC

≥ 12 Wochen

Bohm et al. 2015



Signifikanter Zusammenhang:

Sehnenstiffness ⟷ Schnellkraft

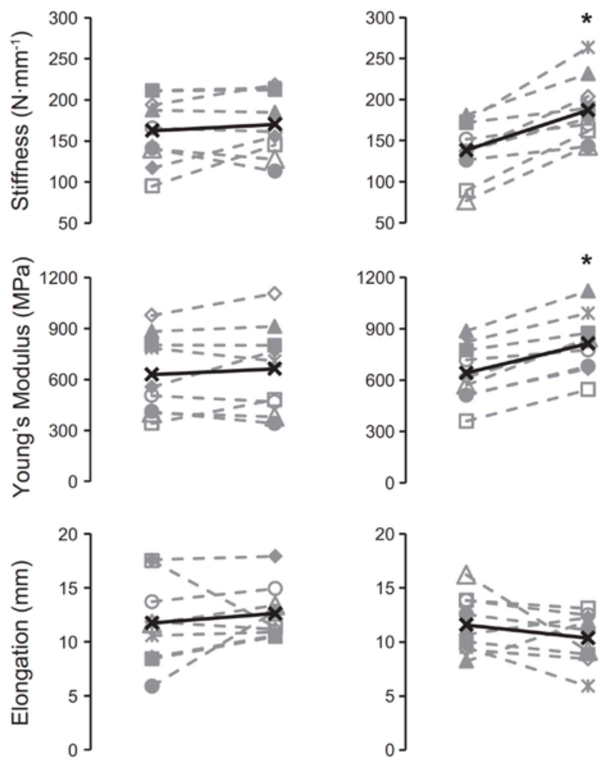
47 prepubertal children (5–12 yr) and 19 adults

Waugh et al. 2013

J Appl Physiol 117: 257–266, 2014.
First published June 5, 2014; doi:10.1152/japplphysiol.00325.2014.

Effects of resistance training on tendon mechanical properties and rapid force production in prepubertal children

C. M. Waugh,[1] T. Korff,[1] F. Fath,[1] and A. J. Blazevich[1,2]
[1]*Centre for Sports Medicine and Human Performance, Brunel University, London, United Kingdom; and* [2]*Centre for Exercise and Sports Science Research, Edith Cowan University, Joondalup, Western Australia, Australia*



Con Exp

N = 10 Jungs + 10 Mädchen
(8,9 +/- 0,3 Jahre)

Training:
10 Wochen

Progressiv: 3 * 15 reps
- Ankle ergometer

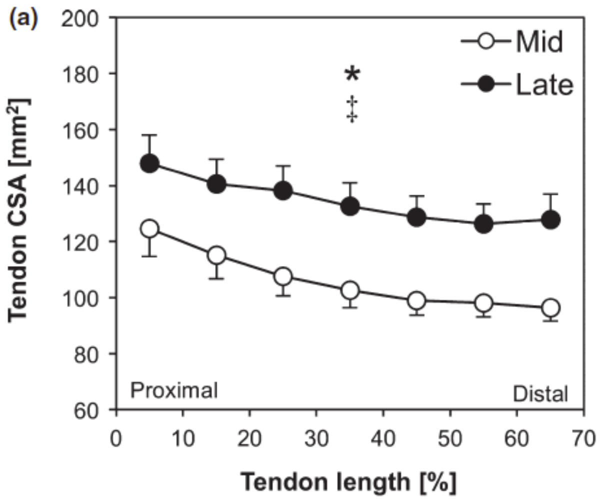
Key points

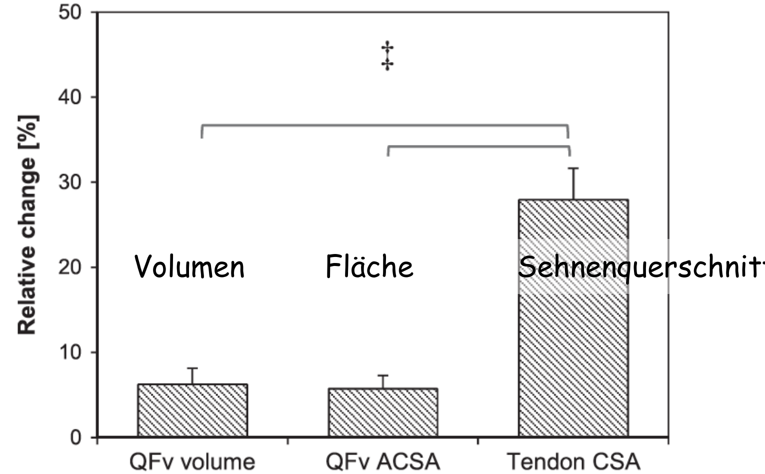
- Tendons are highly responsive to increased mechanical loading and adapt through changes of their mechanical, material, and morphological properties.
- Changes in tendon stiffness seem to be more attributed to adaptations of the material rather than morphological properties.
- An effective training intervention for the tendon should apply a high loading intensity over a longer intervention duration (>12 weeks).

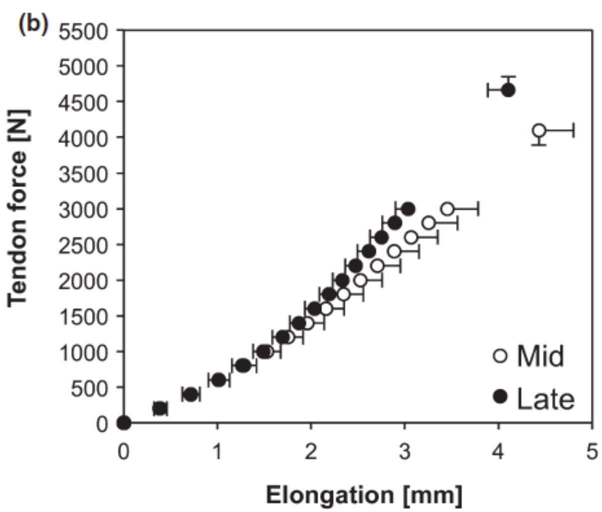
Böhm et al. Sports Medicine - Open (2015)

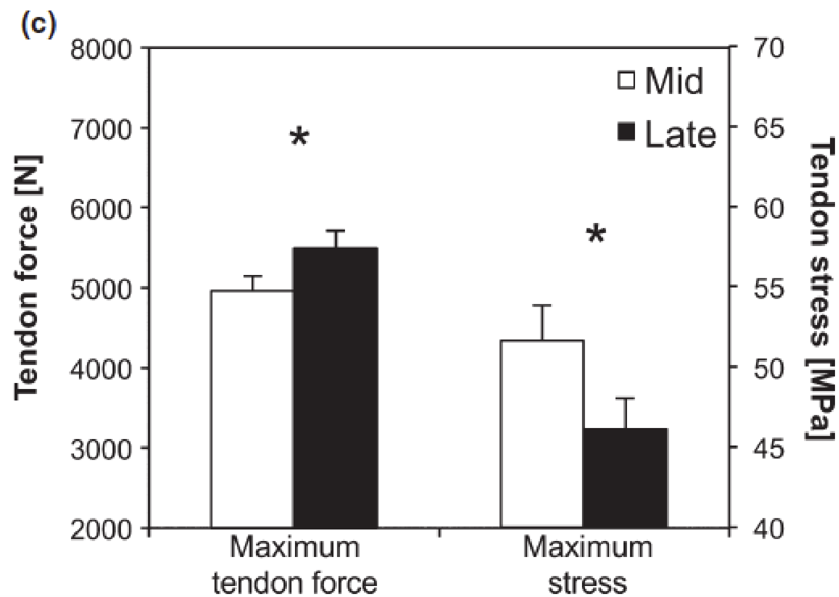
mid (16 +/- 1 years) **late** (18 +/- 1 years).

N = 9 male; 9 female volleyball player
2 year follow-up: 6 men/6 women









Scand J Med Sci Sports 2014: 24: e283–e289
doi: 10.1111/sms.12166

Published by John Wiley & Sons Ltd
SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

Evidence of imbalanced adaptation between muscle and tendon in adolescent athletes

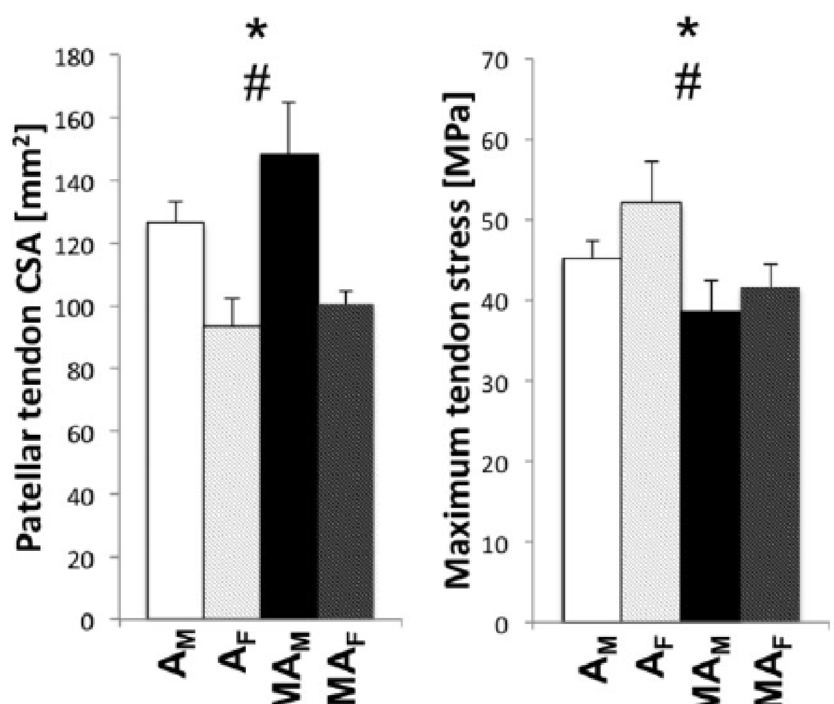
F. Mersmann[1,2], S. Bohm[1,2], A. Schroll[1,2], H. Boeth[2,3], G. Duda[2,3], A. Arampatzis[1,2]

A = 10 ♂; 9♀: adolecent (15,9 y) (Volleyball)
MA = 8 ♂; 10 ♀: middle-age (46,9 y) (Volleyball)

no significant age effect on the physiological cross-sectional area of the VL and knee extension moment

patellar tendon PCSA was significantly smaller and the tendon stress was significantly higher in adolescent

➔ Imbalanced development:
Adolescence
Muscle – Tendon



In vivo measurements of muscle specific tension in adults and children

Thomas D. O'Brien, Neil D. Reeves, Vasilios Baltzopoulos, David A. Jones
and Constantinos N. Maganaris **Exp Physiol 95 pp 202–210**

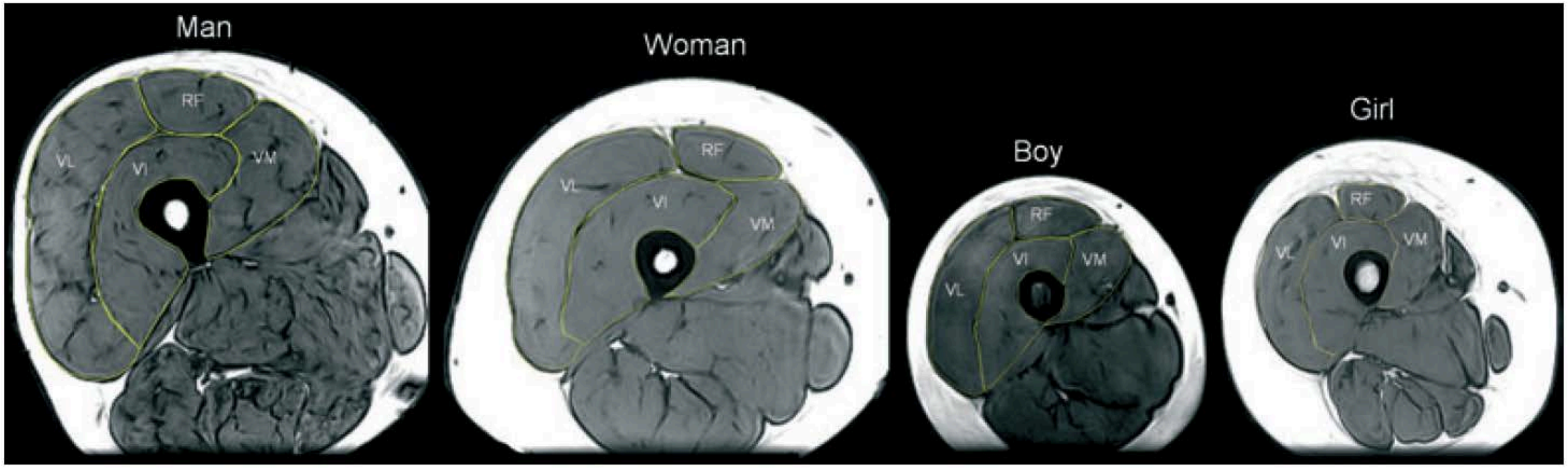
Table 4. The volume, PCSA and specific tension of the entire quadriceps muscle

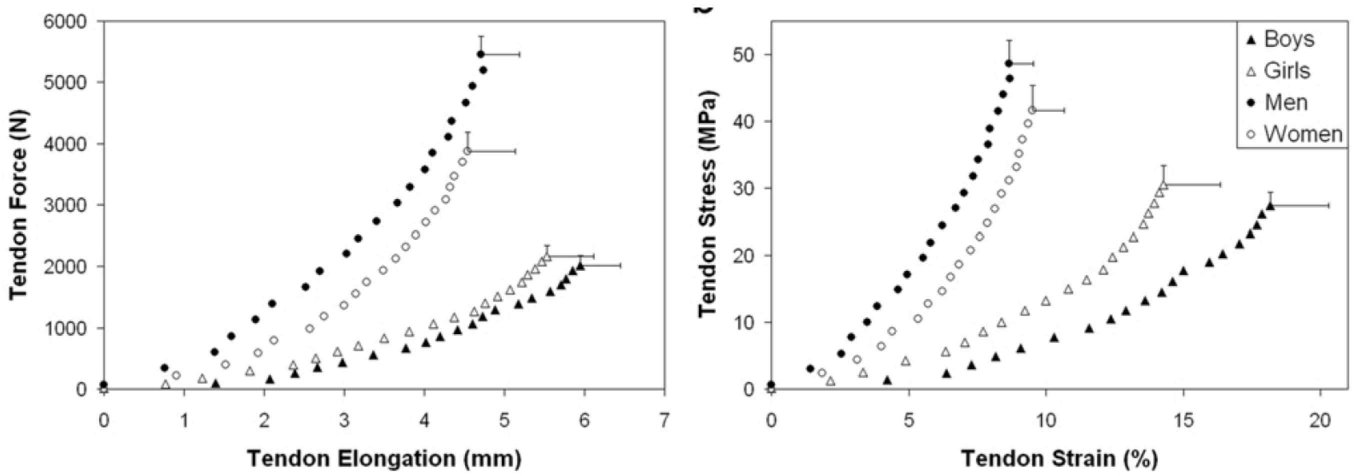
Group	Volume (cm^3)	PCSA (cm^2)	Specific tension ($N\ cm^{-2}$)
Men	2052.7 ± 453.1	231.8 ± 55.5	55.02 ± 11
Women	1359.2 ± 267.8	162.8 ± 29.8	57.3 ± 12.6
Boys	708.6 ± 136.3	104.6 ± 20	54.06 ± 14.2
Girls	793.8 ± 145	108.2 ± 18.5	59.77 ± 15.3
Post hoc significant differences	M > W, B, G*	M > W, B, G*	—
	W > B, G*	W > B, G*	—

Significant differences between men (M), women (W), boys (B) and girls (G), *$P < 0.01$.

Each:	N = 10
Men	28 y
Women	27 y
Boys	9 y
Girls	9 y

Prepuberal (Tanner)





	Fascicle length (mm)	Muscle length (mm)	Fascicle : muscle length	Tendon length (mm)	Fascicle : tendon length
Men	85.9[b,g] (2.5)	349.7[b,g] (10.6)	0.25 (0.01)	51.7 (3.4)	1.7 (0.1)
Women	77.7[b] (1.9)	326.9[b,g] (5.7)	0.24 (0.01)	49.7 (4.8)	1.7 (0.17)
Boys	62.6[m,w] (2)	258.4[m,w] (6.2)	0.24 (0.01)	42.2 (3)	1.6 (0.13)
Girls	66.4[m] (2.5)	274.7[m,w] (8.3)	0.24 (0.01)	42.2 (2.8)	1.6 (0.11)

„These findings indicate that the strength gains as a result of maturation are not due to an improved ‘muscle quality’.“

O` Brian et al. 2009

What does this mean ?

Muscle:

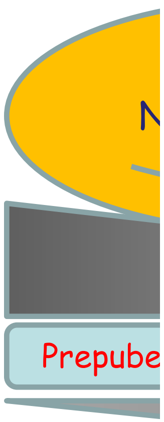
The proportional contribution of each muscle head to total quadriceps PCSA remained constant in each group.

→ *Thus, with respect to the cross-sectional size of the muscle, children can be considered as small-scale adults.*

O` Brian et al. 2009

Ist ein spezifisches Training im Nachwuchsleistungssport notwendig?

Ja, aber….



- Importance of general physical preparation and the multiple health, fitness and performance benefits of structured resistance training.
- Young athletes who engage in resistance training are more likely to sustain elite-level performance and less likely to suffer a sports-related injury.

Faigenbaum et al. BJSM 2015

Vielen Dank