Deutsche Sporthochschule Köln
German Sport University Cologne

momentum
Das Deutsche Forschungszentrum für Leistungssport Köln

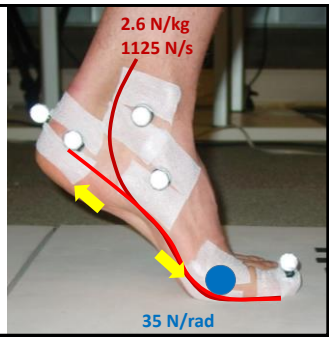
Die Funktion des menschlichen Fußes: Innovative Diagnostik- und Trainingsmethoden für Sport und Klinik

Dr. Jan-Peter Goldmann

Institut für Biomechanik und Orthopädie

Content

1. Muscle Force
   + Passive Stiffness
   + Activation
   = Dynamic Stiffness
2. Demonstration of diagnostic and training tools



Dynamic Stiffness

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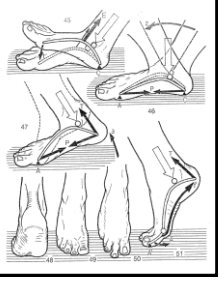
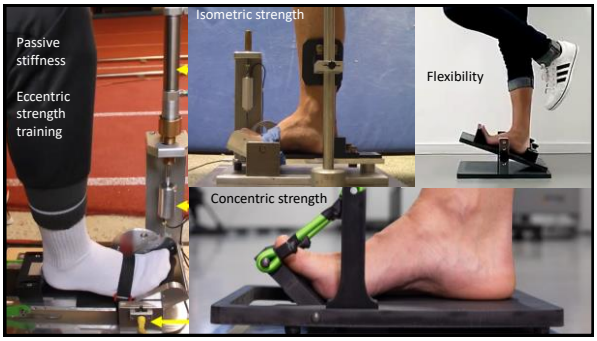
Flexible spring (Ker 1987) vs stiff lever (Hicks 1954)

Energy absorption (TD) vs force transfer (PO)

Interaction of active and passive structures

(Holowka et al. 2022, Kessler 2020, Farris et al. 2019, Kelly et al. 2018, 2019)





Morphologische Anpassungen

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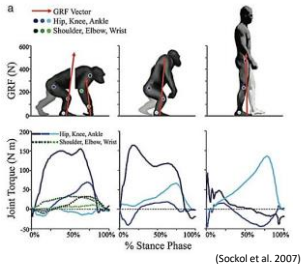
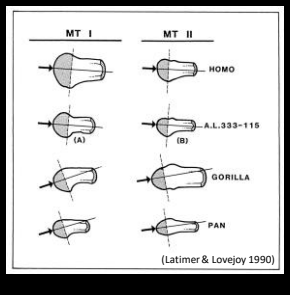


Schimpanse Mensch

(Sockol et al. 2007)

Dorsalflexion Zehengrundgelenk



(Latimer & Lovejoy 1990)

NOTE *Anatomy*

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Dimensions of the Foot Muscles in the Lowland Gorilla

Motoharu OISHI[1]*, Naomichi OGIHARA[2], Hideki ENDO[3], Teruyuki KOMIYA[4], Shin-ichiro KAWADA[5], Tae TOMIYAMA[1], Yosuke SUGIURA[1], Nobutsune ICHIHARA[1] and Masao ASARI[1]

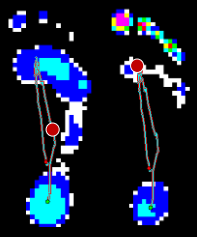
Table 2. Comparisons of mass ratios and PCSA ratios in shank muscles with those of published gorilla (Gm and Gj) and human data

	Mass ratios				PCSA ratios			
	This study	Gm	Gj	Human (SD)	This study	Gm	Gj	Human (SD)
Triceps surae	43.2	42.5	40.9	54.3 (3.55)	49.8	39.7	39.6	61.7 (6.84)
Extrinsic pedal digital flexors	18.2	19.2	17.0	7.7 (1.47)	14.9	18.9	15.8	8.5 (1.89)
Dorsiflexors	22.6	23.7	21.4	17.5 (2.74)	16.9	27.9	17.2	10.4 (1.88)
Other muscles	16.1	14.6	20.7	20.4 (1.16)	18.4	13.6	27.4	19.4 (4.11)

(Oishi et al. 2009)

Druckverteilung unter dem Fuß

(Ferris et al. 1995; Hamel et al. 2001)



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Foot stiffening during the push-off phase of human walking is linked to active muscle contraction, and not the windlass mechanism

Dominic James Farris[1], Jonathon Birch[1,2] and Luke Kelly[2]

plantar aspect of the foot. We conclude that active muscular contraction, not the passive windlass mechanism, is the foot's primary source of rigidity for push-off against the ground during bipedal walking.

(Farris et al. 2020)

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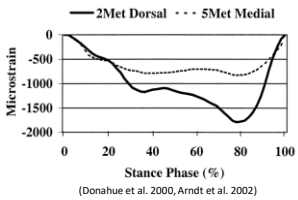
The foot is more than a spring: human foot muscles perform work to adapt to the energetic requirements of locomotion

Ryan Riddick[1], Dominic J. Farris[2] and Luke A. Kelly[1]

Cite this article: Riddick R, Farris DJ, Kelly LA. 2019 The foot is more than a spring: human foot muscles perform work to adapt to the energetic requirements of locomotion. *J. R. Soc. Interface* **16**: 20180680. http://dx.doi.org/10.1098/rsif.2018.0680

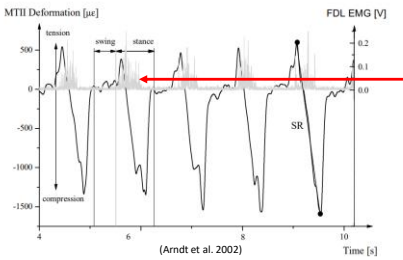
between 69 and 410% compared to level steps (all $p < 0.001$). These findings suggest that the energetic function of the foot is actively modulated by the intrinsic foot muscles and may play a significant role in movements requiring large changes in net energy such as stepping on stairs or inclines, accelerating, decelerating and jumping.

Die knöcherne Beanspruchung...



(Donahue et al. 2000, Arndt et al. 2002)

Biegemomente und Kompressionsspannungen an den Metatarsalia
(Stokes et al. 1979; Ferris et al. 1995; Sharkey et al. 1995; Donahue & Sharkey 1999; Arndt et al. 2002)



(Arndt et al. 2002)

Regulierung von Kompressionsspannungen durch Muskelaktivität
(Pauwels et al. 1965; Lu et al. 1997; Arndt et al. 2002; Sverdlova et al. 2010)

WIRE EMG OF FLEXOR HALLUCIS LONGUS DURING BAREFOOT AND SHOD RUNNING ON A TREADMILL: A PILOT STUDY

J-P Goldmann*, C Lersch*, W Potthast*, B Segesser**, G-P Brüggemann*

*Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Germany
**Praxisklinik Rennbahn, Muttenz, Switzerland

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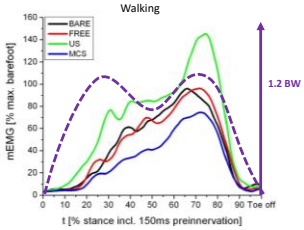
(Goldmann et al. 2006)



Regulierung von Biegemomenten und Zugspannung...

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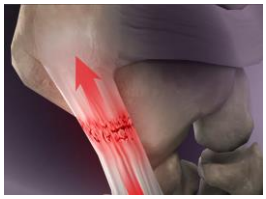

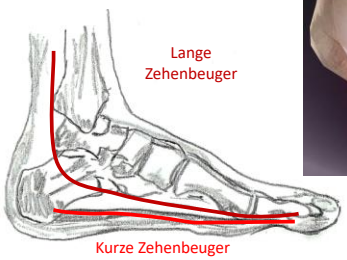

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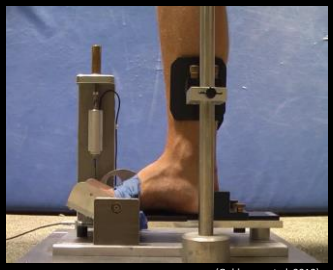
Isometrische Maximalkrafttests und Training



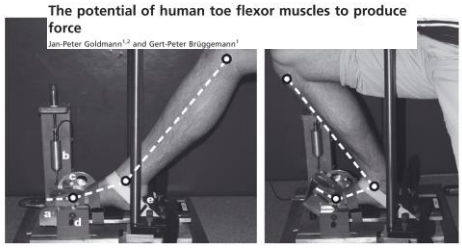
(Goldmann et al. 2012)

Journal of Anatomy

J. Anat. (2012) 221, pp187–194 doi: 10.1111/j.1469-7580.2012.01524.x

The potential of human toe flexor muscles to produce force

Jan-Peter Goldmann[1,2] and Gert-Peter Brüggemann[1]



PJ dorsal flexion	0 25 35 45	0 25 35 45	0 25 35 45	0 25 35 45	0 25 35 45
Ankle angle	20° dorsal	10° dorsal	neutral	20° plantar	35° plantar

Journal of Sports Sciences, 2013
Vol. 31, No. 4, 424–433, http://dx.doi.org/10.1080/02640414.2012.736627

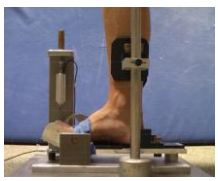
The potential of toe flexor muscles to enhance performance

JAN-PETER GOLDMANN[1,2], MAXIMILIAN SANNO[1,2], STEFFEN WILLWACHER[1], KAI HEINRICH[1], & GERT-PETER BRÜGGEMANN[1]

Experimental group: strength training of toe flexor muscles (n = 15; 24 ± 4 J, 77 ± 9 kg, 185 ± 7 cm)

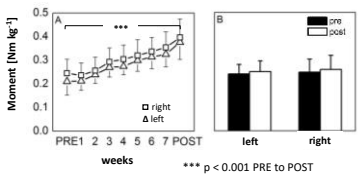
Training: 90% - 7 weeks - 28 sessions - 5 rep - 4 sets - 3 s contraction - 3 s rest period (total 560 contractions)

Control group: no training (n = 12; 26 ± 2 J, 77 ± 5 kg, 181 ± 6 cm)



Isometric Strength Training

+ 60-70% strength after 7 weeks training



*** p < 0.001 PRE to POST

(Goldmann et al. 2013)

PERFORMANCE ENHANCEMENT

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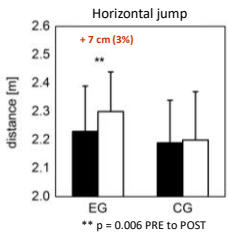


** p = 0.006 PRE to POST

(Goldmann et al. 2013)

2014

Original Article

Strength Training for the Intrinsic Flexor Muscles of the Foot: Effects on Muscle Strength, the Foot Arch, and Dynamic Parameters Before and After the Training

J. Phys. Ther. Sci.
26: 373–376, 2014

TAKAYUKI HASHIMOTO, PT, MS[1, 2)*], KEISHOKU SAKURABA, MD, PhD[1)]

jumping, and 50-m dash time. [Conclusion] This muscle strength training method significantly improved muscle strength scores, foot arch shape, and movement performance.

2024

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2024.2367365

Routledge
Taylor & Francis Group

SPORTS PERFORMANCE

Human foot muscle strength and its association with sprint acceleration, cutting and jumping performance, and kinetics in high-level athletes

Romain Tourillon[a,b], Antoine Michel[a], François Fourchet[b,c], Pascal Edouard[a,d] and Jean-Benoit Morin[a,e]

of cutting and jumping performance. In conclusion, MTPj flexion torque was more strongly associated with sprinting performance kinetics especially at high-speed.

2025

RESEARCH ARTICLE

Effects of a forefoot strengthening protocol on explosive tasks performance and propulsion kinetics in athletes: a single-blind randomized controlled trial

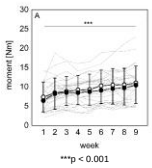
Romain Tourillon[1,2,*], François Fourchet[2,3], Pascal Edouard[1,4], Jean-Benoît Morin[1,5]

Conclusion

An 8-week "periodized high-load" forefoot strengthening protocol allowed to improve MTPj maximal torque and MTPj flexors volume. This strength gains led also to cutting, horizontal jump overall performance and kinetics improvement as well as greater maximal speed propulsion kinetics. MTPj strength capacity may exert a more substantial impact on performance and kinetics on horizontally and medio-lateral-oriented explosive movements than on vertically-oriented ones.

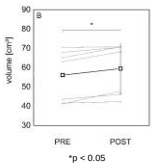
Strength training of toe flexor muscles in the diabetic foot significantly…

…increases strength by 49-62%...



***p < 0.001

…and volume by 6.4% and...

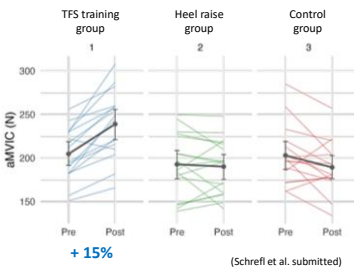


*p < 0.05

(Höhne et al 2013)

…reduces plantar peak pressure by 11% (p < 0.05) during walking.

TFM STRENGTH TRAINING IN ELITE BALLET DANCERS



+ 15%

(Schrefl et al. submitted)

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EINZELFALLSTUDIE

Schwere, austherapierte Sprunggelenksfraktur
(mehrfragmentäre distale Tibiafraktur und Spiralfraktur der Fibula)

Kraftdefizit von 30% am verletzten Fuß
Gesund 2.45 N/kg
Verletzt 1.71 N/kg

Gezieltes Krafttraining der Zehenbeuger führt bereits nach vier Trainingswochen zu 20% Kraftzuwachs
PRE: 1.71 N/kg;
POST: 2.10 N/kg

(Goldmann unpublished)

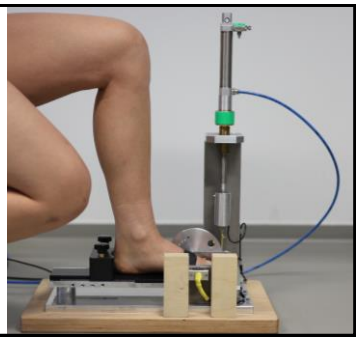
Joe Nimble®

BIG TOE POWERPRO

https://www.joe-nimble.com/int/p/big-toe-power-pro-training-device-009029-001-os

CONTENT

1. MUSCLE FORCE
   + PASSIVE STIFFNESS
   + ACTIVATION
   = DYNAMIC STIFFNESS
2. DEMONSTRATION OF DIAGNOSTIC AND TRAINING TOOLS



PASSIVE MPJ STIFFNESS

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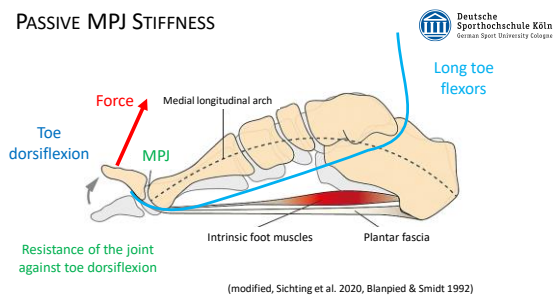

(modified, Sichting et al. 2020, Blanpied & Smidt 1992)

Passive Stiffness

Pneumatic actuator
(Festo, Esslingen, Germany)

1 bar = 41 N

Load cell
(DMS, HBM, Darmstadt; accuracy 99%)

Potentiometer
(MCP05, linearity 1%, Megatron, Putzbrunn, Germany)

(Goldmann et al. 2025, Wenzel et al. 2025)

Mechanical Linkage

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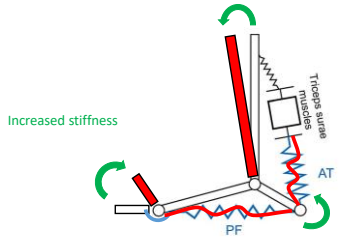

(modified, Shiotani et al. 2022, Sichting et al. 2020, Cheung et al. 2006, Erdemir et al. 2004)

Results

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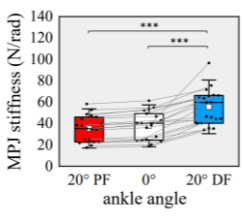
Reliability: between-day and within-day ICC = 0.99, p < 0.001
(Wenzel et al. 2025)



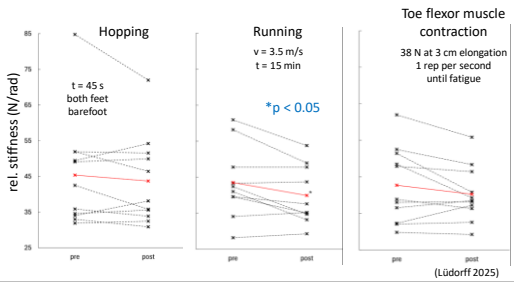
19 subjects
(13 m, 6 f, 24 ± 6 yrs, 75.4 ± 9.6 kg, 1.79 ± 0.08 m, forefoot length 8.01 ± 0.6 cm)

***p < 0.001

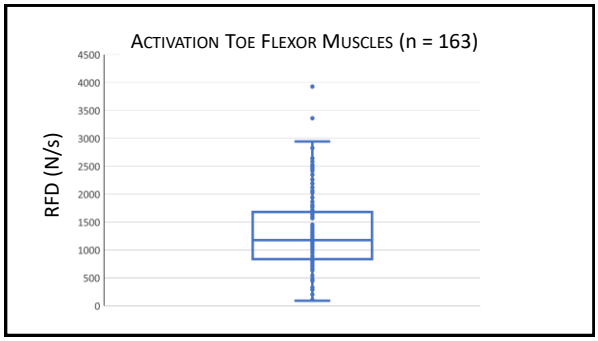
(Goldmann et al. 2025)

Effects of short-term loading

n = 13 men



(Lüdorff 2025)


ACTIVATION TOE FLEXOR MUSCLES (n = 163)
RFD (N/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0


Passive stiffness
Isometric strength
Flexibility
Eccentric strength
Lösungen für Diagnostik, Training und Therapie


Human Foot Function
DIAGNOSTICS ‖ MONITORING ‖ TRAINING
https://www.linkedin.com/in/dr-jan-peter-goldmann