Stop the Guessing Game: Implementing a Criterion and Evidence-Based Functional Performance Testing Algorithm in Foot and Ankle Injuries

Stanford HEALTH CARE

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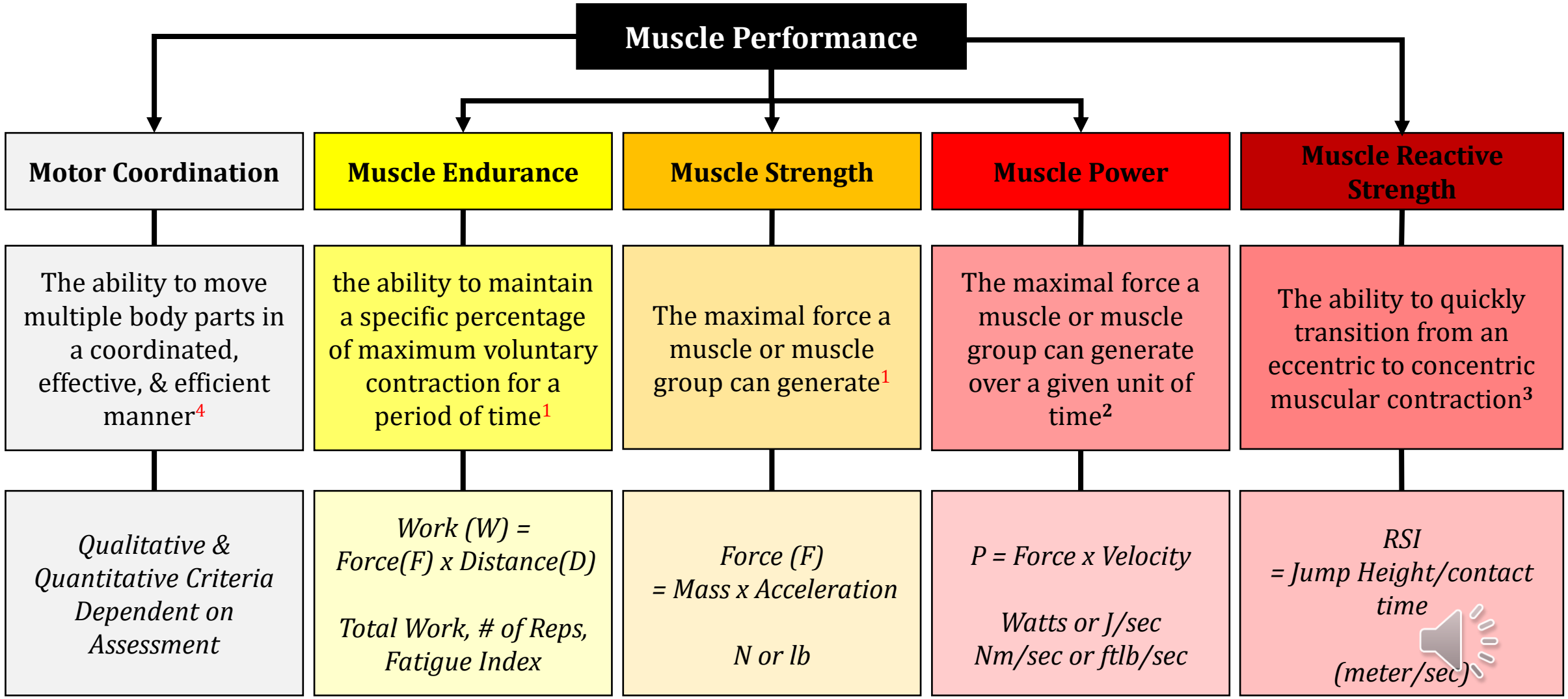
Muscle Performance

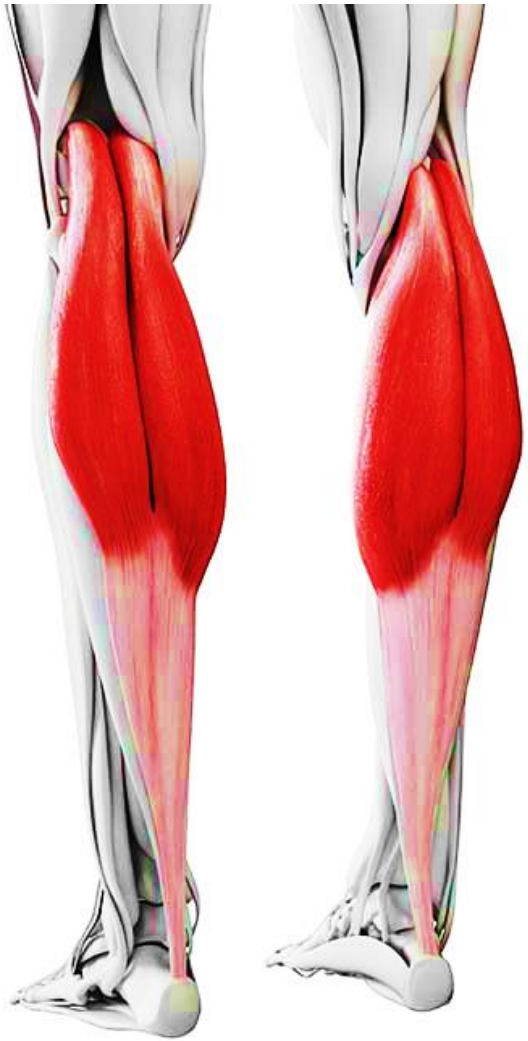
Muscle Performance: Constructs



Kell 2001[1], Sapega 1983[2], Rebelo 2022[3], Hathaway 2024[4]

Isolated Muscle Performance Testing

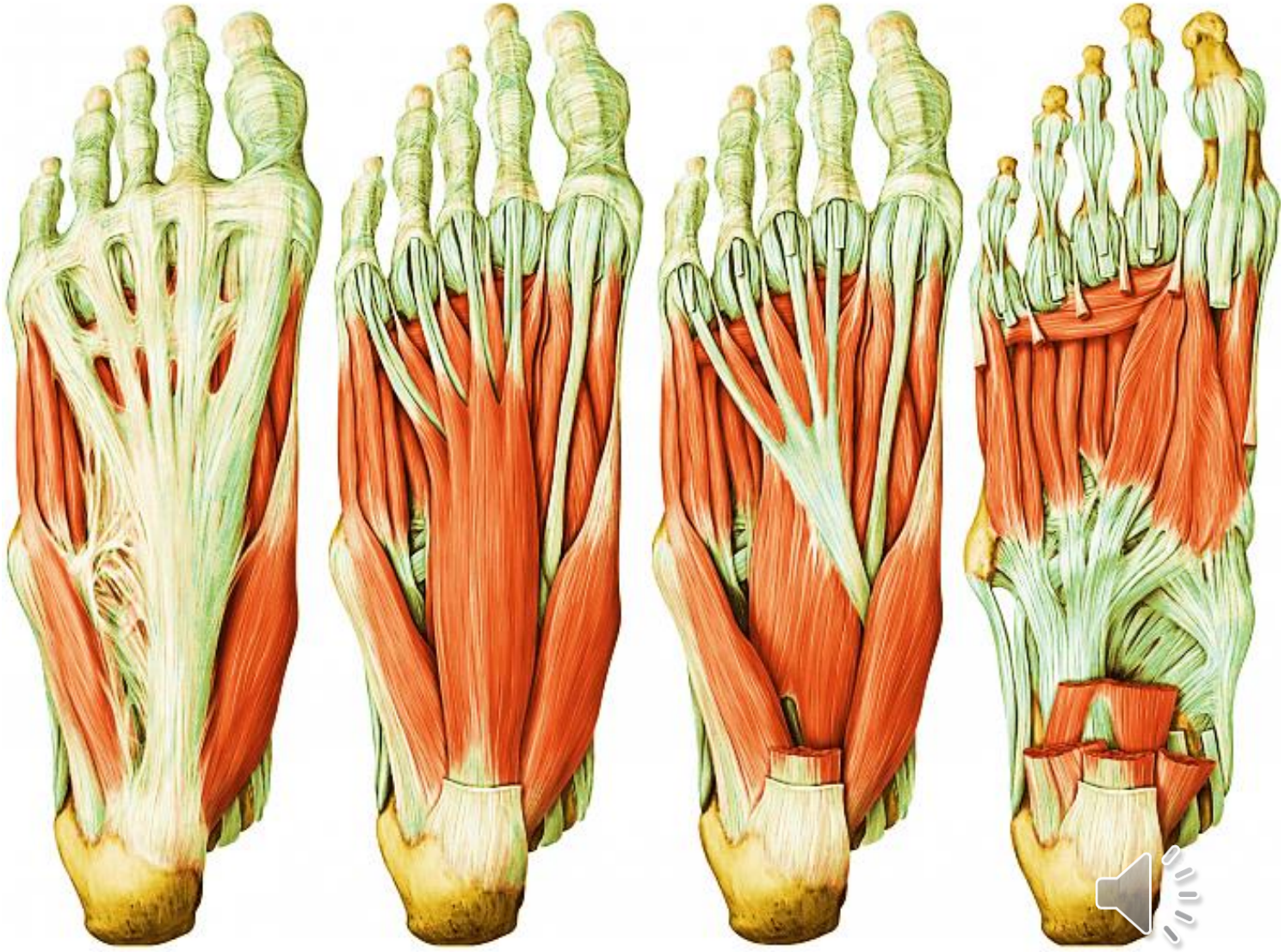
Gold Standard	Isokinetic Dynamometer
Good	Fixated Dynamometer (With Time Force Curves)
	Force Plate (Plantar Flexion Only)
Acceptable	Fixated Dynamometer (Without Time Force Curves)
	Pull Gauge OR Crane Scale
Sufficient	Field Test
	Manual Fixated Dynamometer
Insufficient	Manual Muscle Testing



Foot Intrinsics

Muscular Performance

- Motor Coordination
- Muscle Endurance
- Strength



Foot Demands of Locomotion[6]

The **ankle muscles** (especially the plantar flexors) are **key contributors** to **sport performance** and play a critical role in **accelerating the body rapidly** during **sprinting**,[1,2] **cutting**,[3] or **jumping**[4]

These ASSUMPTIONS are based on an **oversimplified rigid foot model**, i.e., **no deformation of the foot**.[6]

This leads to **overestimating ankle power** while simultaneously **underestimating the power generated** by the structures within the foot[5]

Pandy 2021[1], Schache 2019[2], Marshall 2014[3], Vanezis 2005[4], Zelik 2018[5], Tourillon 2024[6]

Muscle Performance: Foot

Whatever the hip, knee, and ankle power generation capability, if your foot system “deforms” under tension and is *not* able to transfer that power into the ground, your technique, mechanical effectiveness, and, ultimately, acceleration performance degrade.

Important contributors for **(1) lower limb power transfer & (2) push-off**:

1. Ankle Plantar Flexion Power
2. Foot Structures to resist deformation

The power of the ankle plantar flexors is **equally as important as the capacity of the foot structures to resist deformation** for efficiently promoting power transfer during push-off

Muscle Performance: Foot Motor Coordination

Vertical Navicular Drop Height is associated with ⬆ **risk of lower extremity injuries**, **BUT** the relationship is complex and *NOT* necessarily causal.

Navicular Drop & Injury Risk

- A **significant association** exists between **navicular drop >5 mm** & **various lower extremity injuries** (i.e., patellar tendinitis, iliotibial band syndrome, and plantar fasciitis)[1]
- ⬆**navicular drop** is a predictor of **medial tibial stress syndrome (MTSS)** in high school runners[2]
- ⬆**navicular drop** (and anterior pelvic tilt) are **significant predictors** of prior ACL injury[3]
- The function & structure of the **medial longitudinal arch (MLA) of the foot** (surrogate measure of navicular height) has been proposed as a risk factor for developing injuries.[7]
- **Navicular drop** is also associated with a ⬆ **risk of lateral ankle sprains** in adolescent athletes[4]

However…

- **NO clear link** between **foot posture** and **injury likelihood exists**[8,9]
- **NO correlation between sit to stand NDT & dynamic navicular drop during gait**, suggesting that static measures of NH change may **NOT** predict **dynamic navicular motion in gait**[11]
- Evidence shows that the **navicular drop** is a **poor predictor of the dynamic navicular drop**[10-13] and that it is therefore **necessary to measure the navicular drop dynamically** in order to **be representative for foot function.**[14,15]

Carvalho 2011[1], Bennett 2001[2], Hertel 2004[3], Saki 2020[4], Esmali 2014[5], Nakhaee 2008[6], Spörndly-Nees 2011[7], Wen 1997 & 1998[8], Hreljac 2005[9], Hoffman 2015[10], Deng 2010[11], Rathleff 2012[12], Dichary 2004[13], Eichelberger 2018[14], Dietz 20[15]

Muscle Performance: Foot Motor Coordination

Modified Spring Ankle Test (Navicular Drop Test)

Motor Coordination | Sufficient | Field Test

Phase of Test	Description	Criteria
SL Sit to Stand	*Client goes from a sit to stand on 1 leg w/ toes extended*	• *3-5 mm drop from NWB to WB*
SL Squat	*Client squats to knee over 2nd 3rd met by 2”*	• *3-5 mm drop from NWB to WB* • *Unable to achieve knee 2” over toe*
SL Calf Raise	*Client performs a SL calf raise with max heel height*	• *Able to achieve >45˚ foot relative to floor*

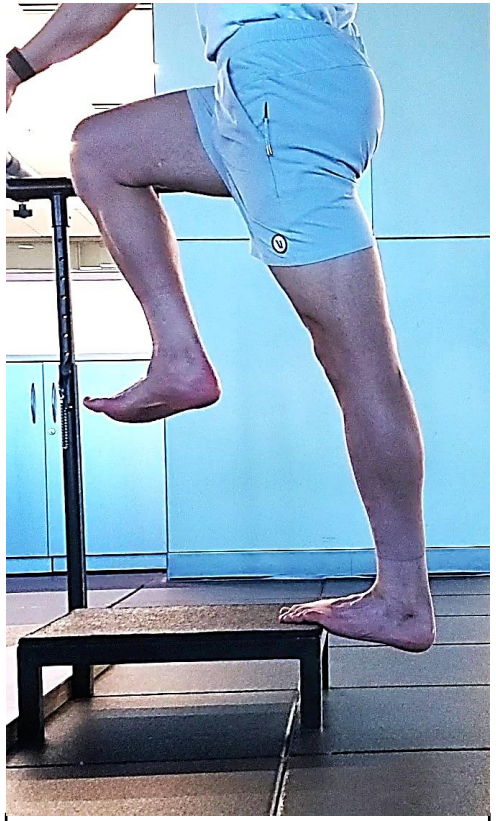
Note. Met, metatarsal, mm, millimeter; NWB, non-weight bearing; WB, weight bearing; SL, single leg

Dietz 2016

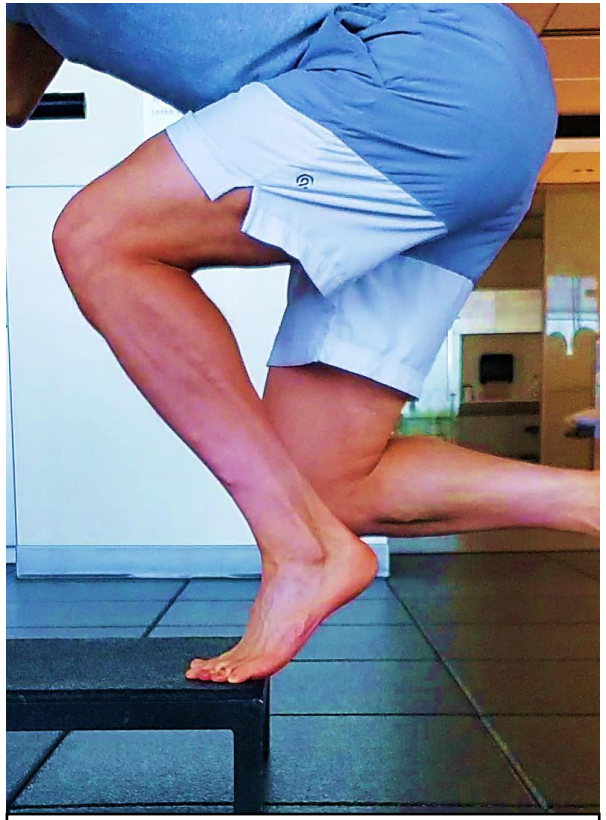
Muscle Performance: Foot Intrinsic Endurance

Muscle Endurance | **Sufficient** | Field Test

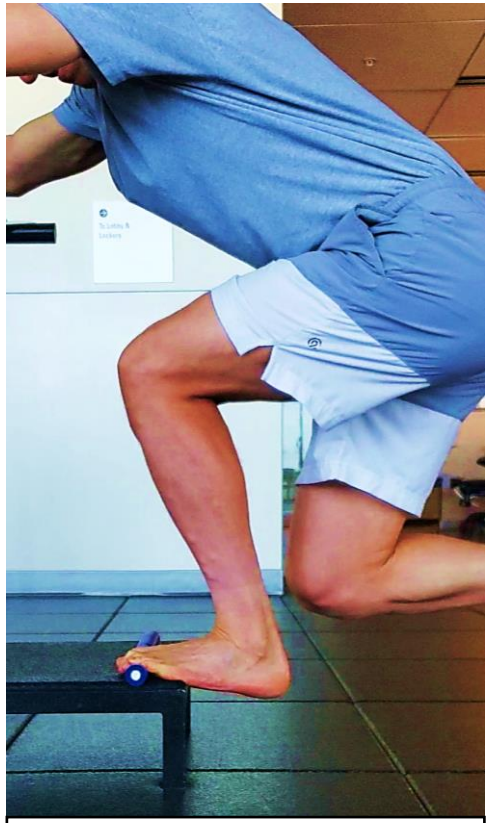
Condition 1



Condition 2



Condition 3



Condition 4

Recommended Criteria
• ≥ 60 sec holds, full body weight all conditions w/ single leg
• Limb symmetry index >90%
• Higher level athlete: ≥60 sec hold, body weight + 20% BW all conditions w/ single leg

Muscle Performance: Foot Intrinsic Endurance

Midfoot Endurance Battery

☐ **Equipment:**

- Step & Timer

☐ **Conditions:**

1. Straight Knee + Max PF
2. Straight Knee + Max DF
3. Knee Flexion 75˚ + Max PF
4. Knee Flexion 75˚ + Max DF

☐ **Modifications:**

- Double legs instead of single leg
- Less knee flexion
- Hallux Grip

☐ **Outcome:**

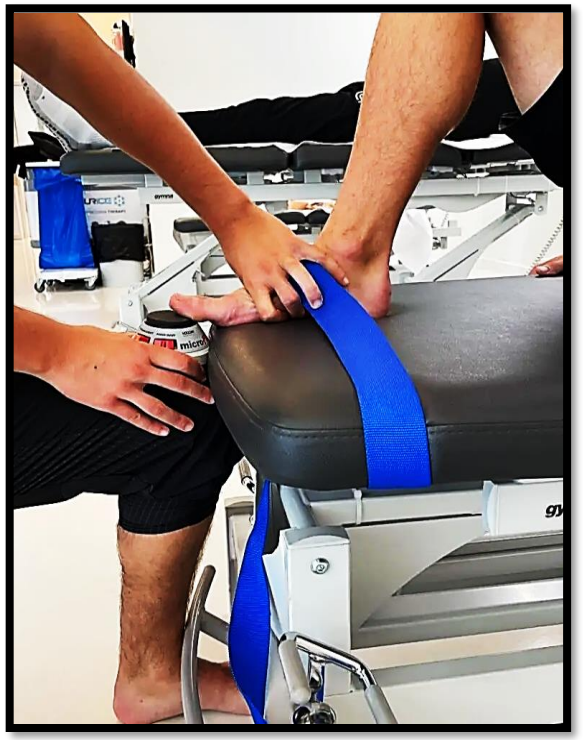
- Time (sec) to heel drop by 20% of max
- Goal: 60 sec on single leg per condition

Max Dorsiflexion	Max Dorsiflexion w/ Hallux Grip	Max Plantar Flexion
		
		

Muscle Performance: Foot Strength

Muscle Strength | **Acceptable** | Fixed Dynamometer

Toe Condition	Average Strength[2]	Normative Data[2]	Athlete Norm Data[1]	Pass Criteria	Ratio[1]
Hallux	**132 N (30 lb)**	**1.97 N/kg 20% BW**	**2.7 N/kg 27% BW**	**>90% LSI ≥ 20% BW**	Hallux / Lesser Toes
Lesser Toes	**121 N (27 lb)**	**1.80 N/kg 18% BW**	**2.2 N/kg 22% BW**	**>90% LSI ≥ 18% BW**	1.2-1.3



Group Means (SD)

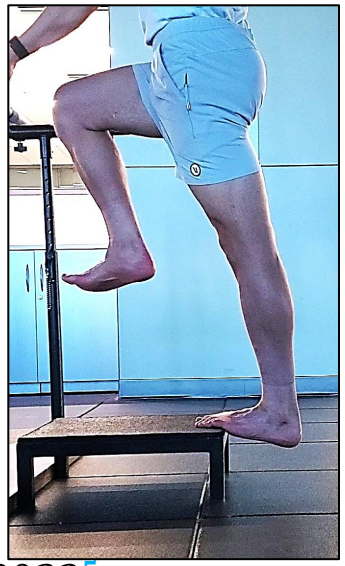
	Baseline				Reassessment						Inter-rater Reliability				Test-Retest Reliability			
	Tester 1		Tester 2		Tester 1		Tester 2				Baseline		Reassessment		Tester 1		Tester 2	
	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	SEM	MDC	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt
Hallux Flexion (N)	112.3 (38.5)	111.8 (41.0)	142.7 (44.9)	144.7 (48.0)	117.1 (38.0)	119.8 (43.3)	154.6 (52.3)	155.2 (42.7)	18.5	51.4	.75	.87	.82	.87	.68	.76	.85	.92
Lesser Toe Flexion (N)	103.9 (35.0)	110.4 (36.8)	121.5 (35.0)	135.5 (45.1)	117.1 (38.0)	108.4 (29.8)	129.1 (36.4)	144.1 (34.6)	18.0	49.8	.66	.77	.87	.82	.67	.74	.77	.77

Poor | Fair | Good | Excellent

Tourillon 2024[1], Fraser 2017[2], Xu 2023[3]

Muscle Performance Criteria: Foot

Construct	Assessment	Criteria



Dietz 2016[1], Guillén-Rogel 2022[2], Shrader 2005[3], Tourillon 2024[4], Xu 2023[5]

Ankle Sagittal Plane
(Plantar Flexion/Dorsiflexion)

Muscular Performance

- Endurance
- Strength
- Power

Muscle Performance: Injury Implications

- **1.6 cm³** ⬇ mm volume[2]
- 17.7% (Op) vs 24.8%(Non-op) soleus vol[2]
- 59% shorter fascicle length[5]

- **13%** ⬇ mm volume[2]
- **14.9%** ⬇ ankle work during isokinetic testing[7]
- **12%** ⬇ countermovement jump hgt[4]
- **8-9%** ⬇ angular velocity w/ jump[6]

1-2 years | **3-5 years** | **6-10 years** | **13 years**

Initial Injury

- **47%** ⬇ plantar flexion iso strength[5]
- **20%** ⬇ isokinetic CON & ECC strg[6]
- +8.1° AT Resting Angle[1]
- **12-20% shorter** fascicle length[3]
- Post AT Rupture, ⬆**176x** contralateral AT pathology (3.1 years)[7]
- **Heel height is 25%** (3.0 vs 11.9 cm) of opposite leg (AT rupture)[5]

- 11-13% ⬇ mm volume[2]
- 12-18% ⬇ plantar flexion strength[2]
- 12 mm (6%) ⬆ tendon length (vs uninjured limb)[2]

Pečjak 2023[1], Heikkinen 2017[2] , Fulton 2014[3], Nicholson 2020[4], Baxter 2018[5], Willy 2018[6] , Aroen 2018[7], Peˇcjak 2018[8]

Isolated Muscle Performance Testing

Gold Standard	Isokinetic Dynamometer
Good	Fixated Dynamometer (With Time Force Curves)
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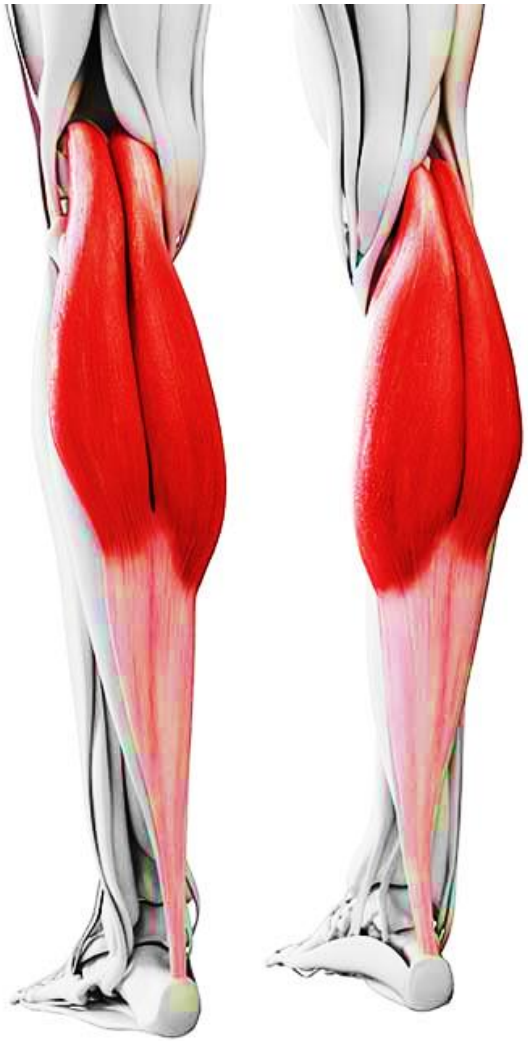
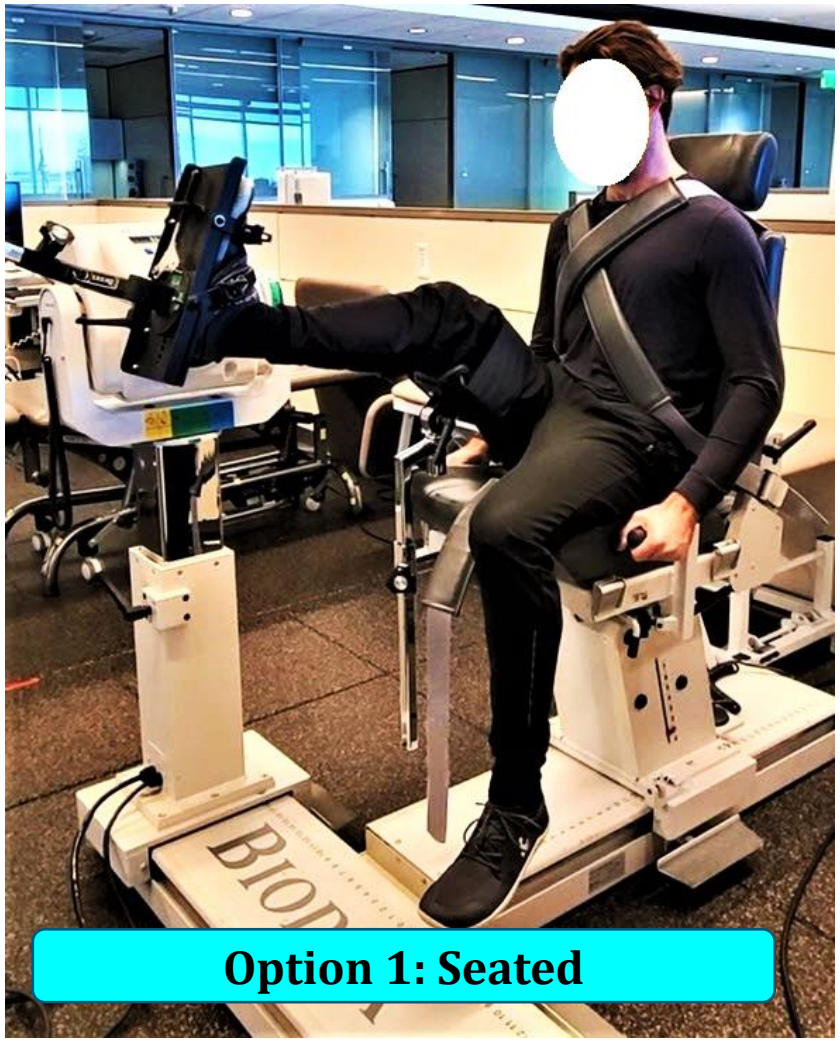
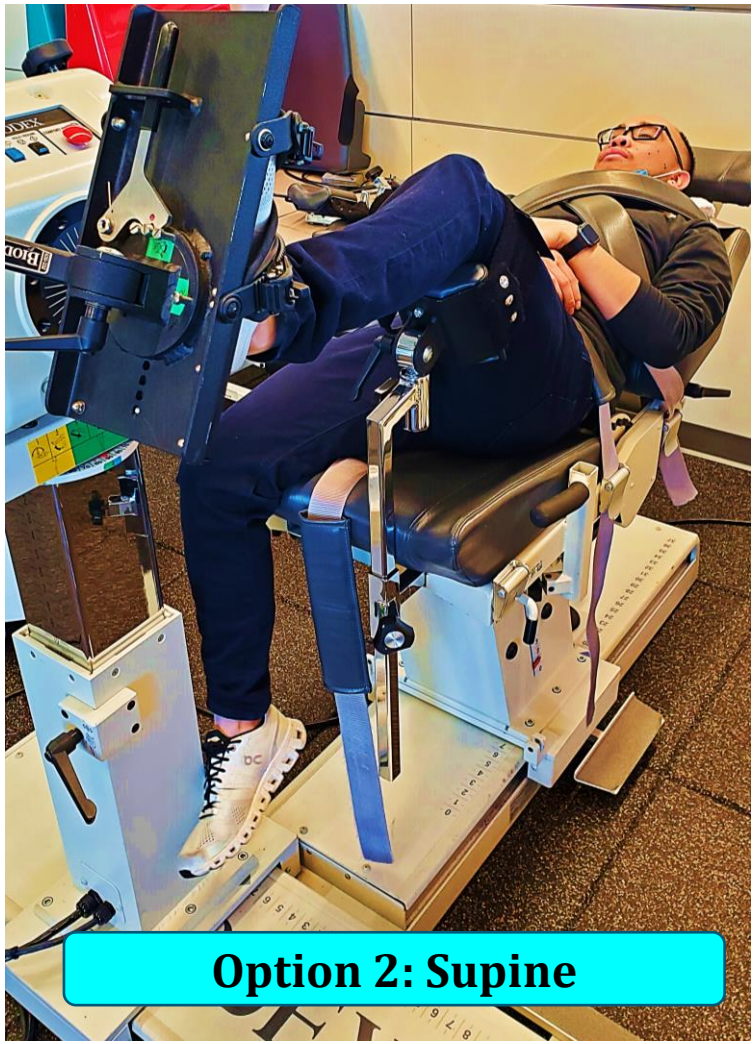


Ankle: Plantar Flexion Isokinetic Testing Positions



Option 1: Seated



Option 2: Supine

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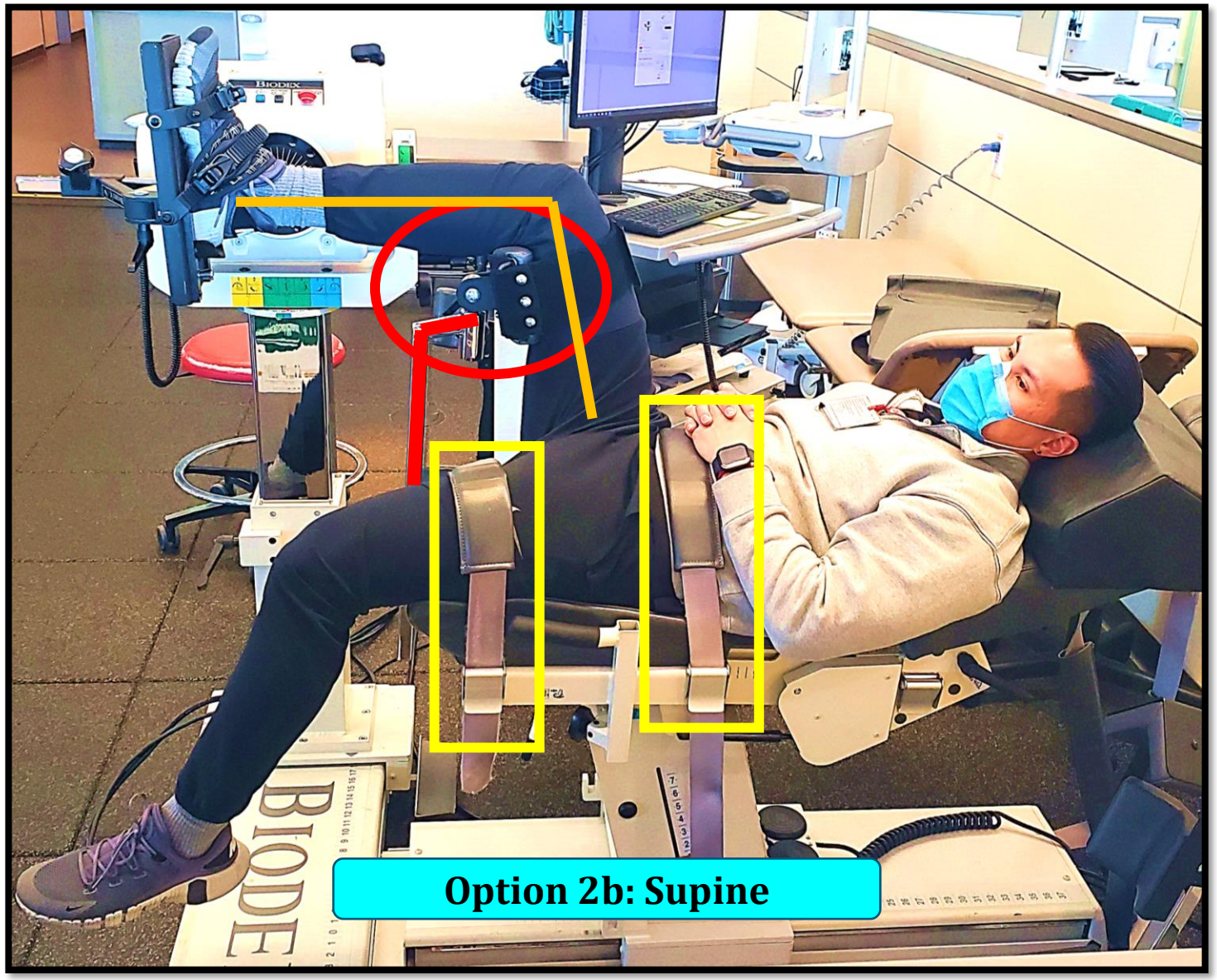
Ankle: Plantar Flexion Isokinetic Testing Positions

Thigh Support
Behind Distal Femur

Dual Belt
Stabilization

Parallel Tibia
Knee Angle ~90°



Option 2b: Supine

Gold Standard
Isokinetic Dynamometer

Motor Coordination

Muscle Endurance

Muscle Strength

Muscle Power

Jeanfavre 2024

Ankle: Plantar Flexion Isokinetic Testing Positions

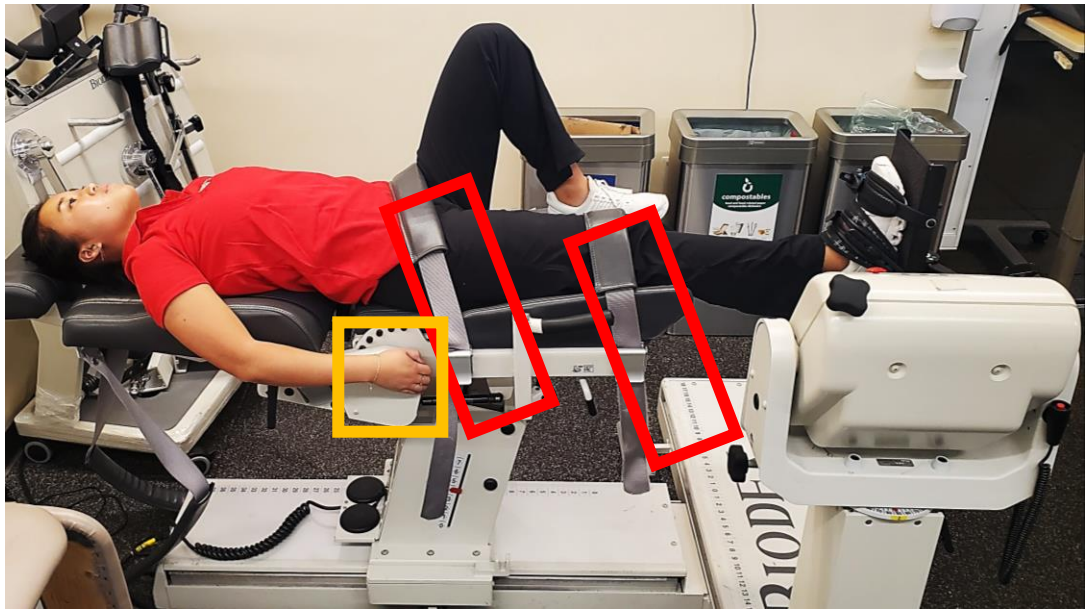
Gold Standard
Isokinetic Dynamometer

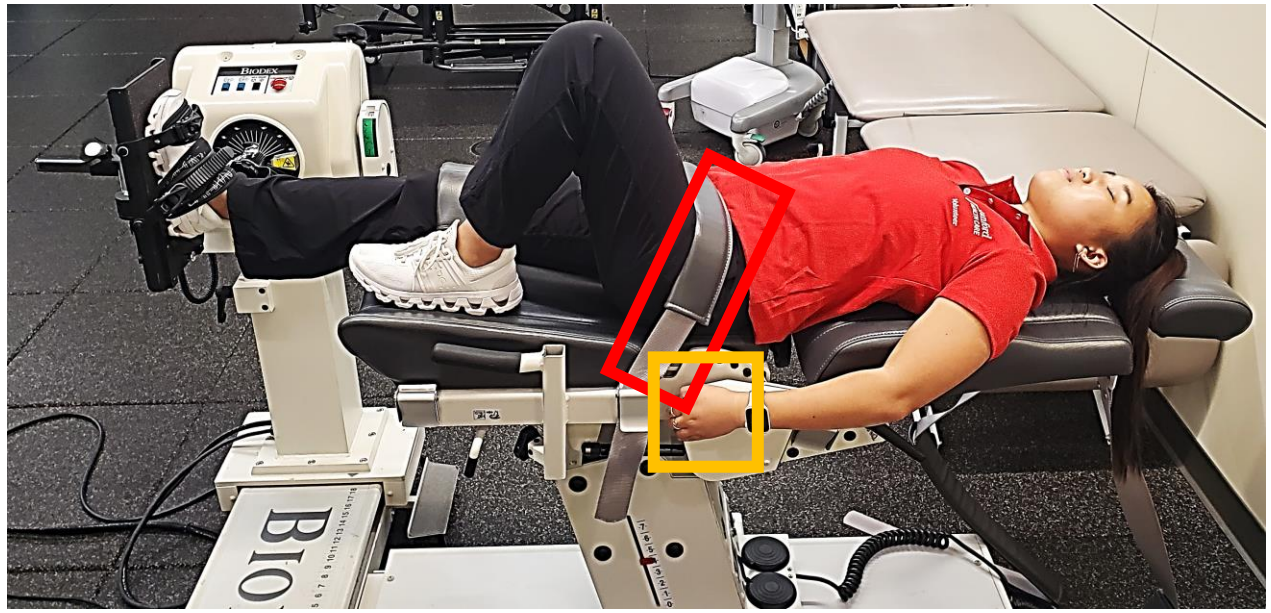
Patient Position
Supine, Knee & Hip @ 0°

Pelvis Support
Waist Belt ASIS

Thigh Support
Distal Femur

Stabilization
Contralateral Leg & Hand Hold





Option 3: Supine Knee Extended

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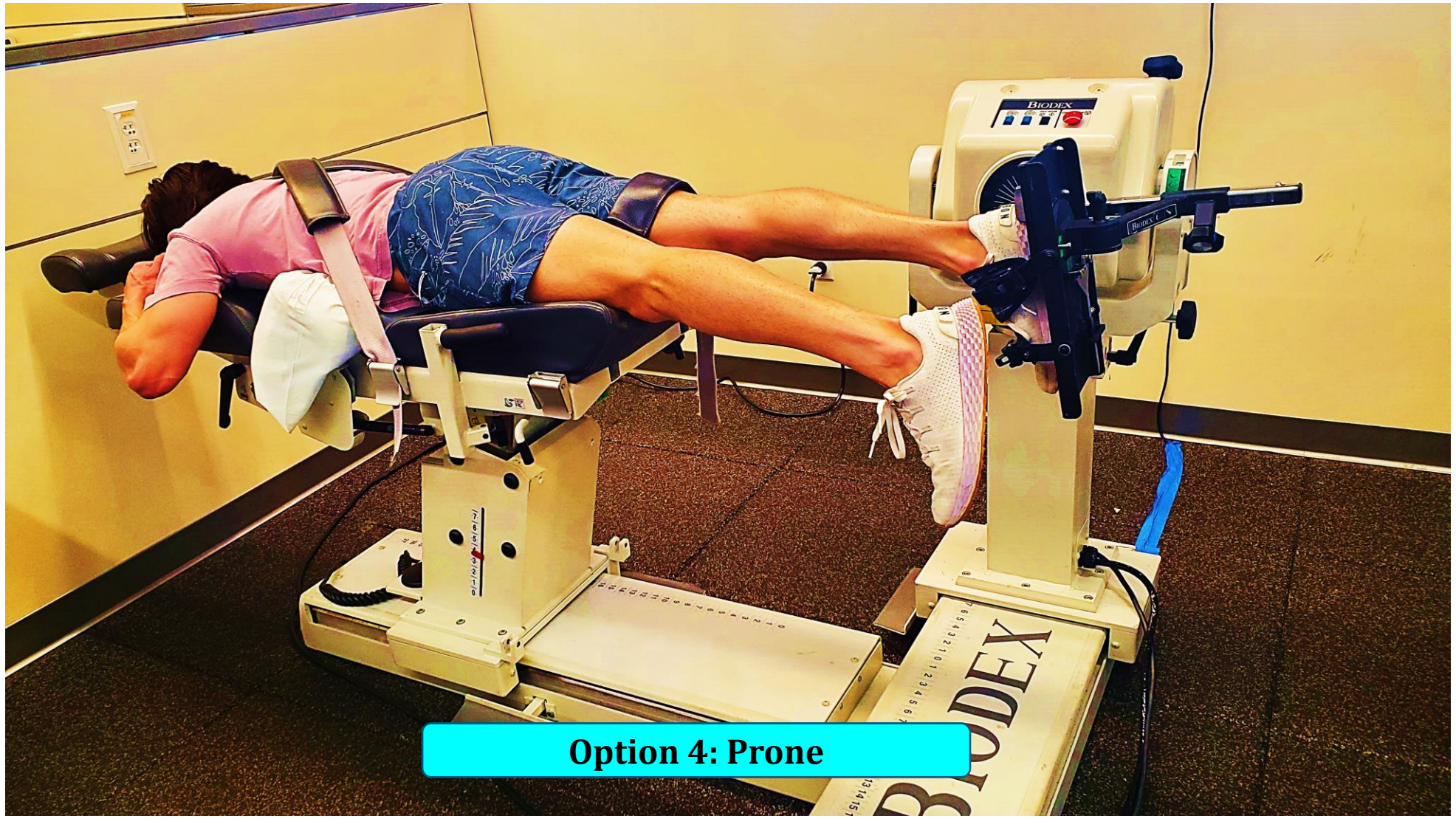
Ankle: Plantar Flexion Isokinetic Testing Positions

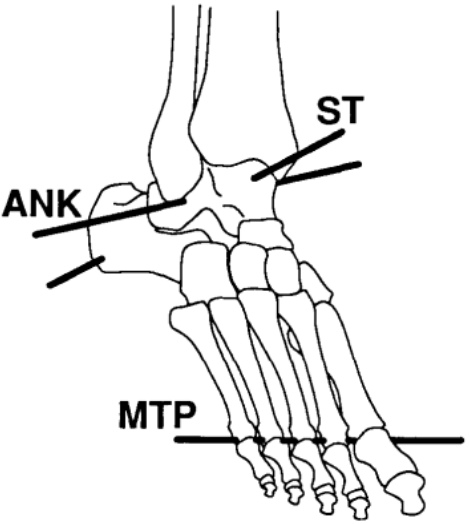


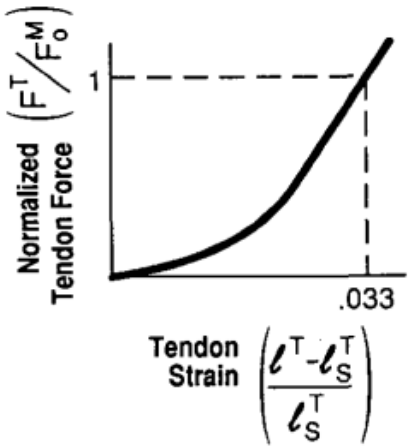
Jeanfavre 2024

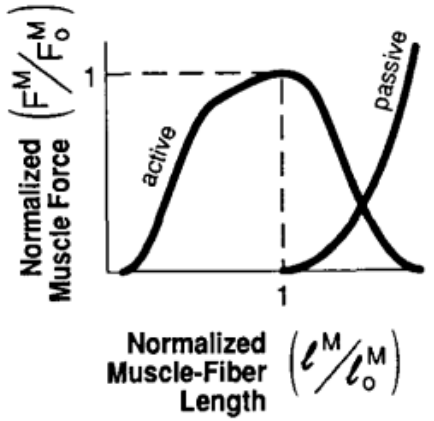
Muscle Performance: Plantar Flexion & Dorsiflexion

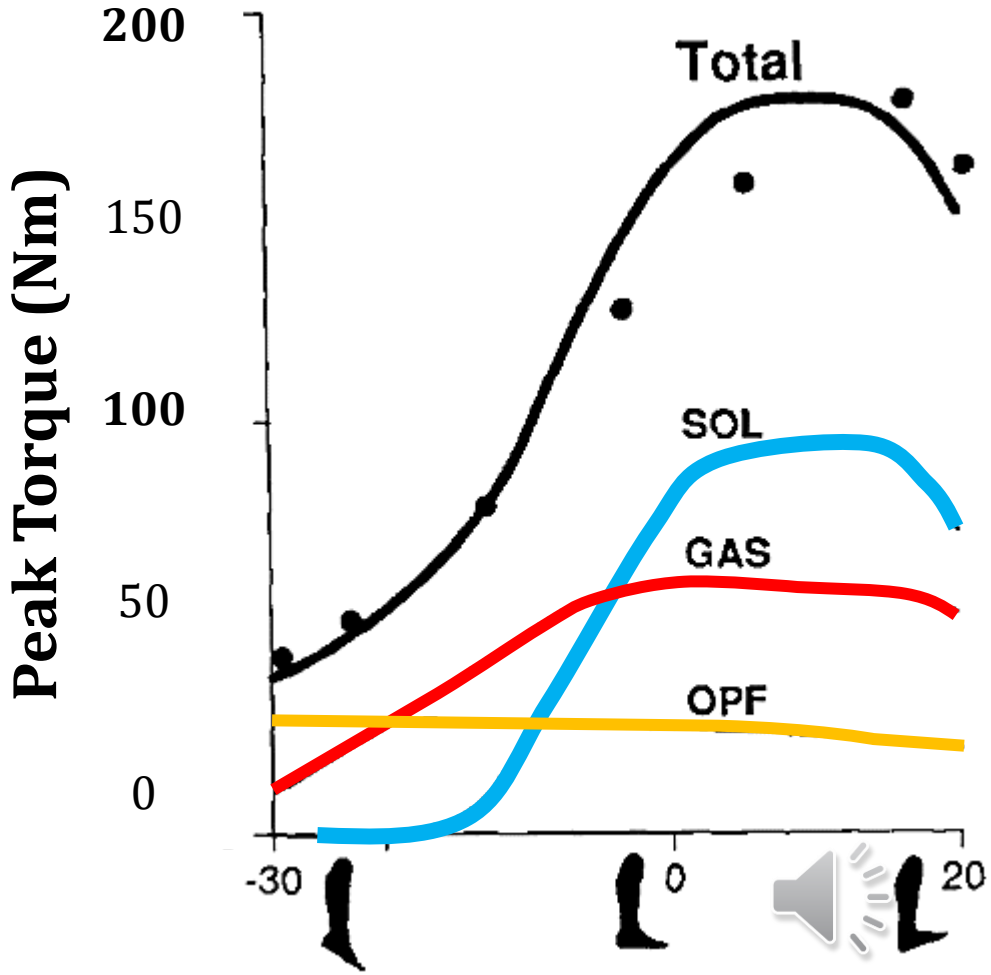
An Interactive Graphics-Based Model of the Lower Extremity to Study Orthopaedic Surgical Procedures

SCOTT L. DELP, J. PETER LOAN, MELISSA G. HOY, FELIX E. ZAJAC, MEMBER, IEEE, ERIC L. TOPP, AND JOSEPH M. ROSEN





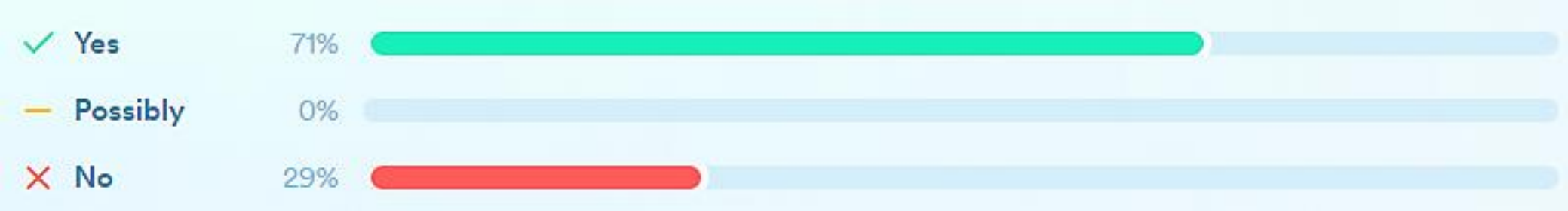




Muscle Performance: Plantar Flexion & Dorsiflexion

Knee Flexion vs Knee Extended

Do knee angles affect plantar flexion strength testing outcomes?

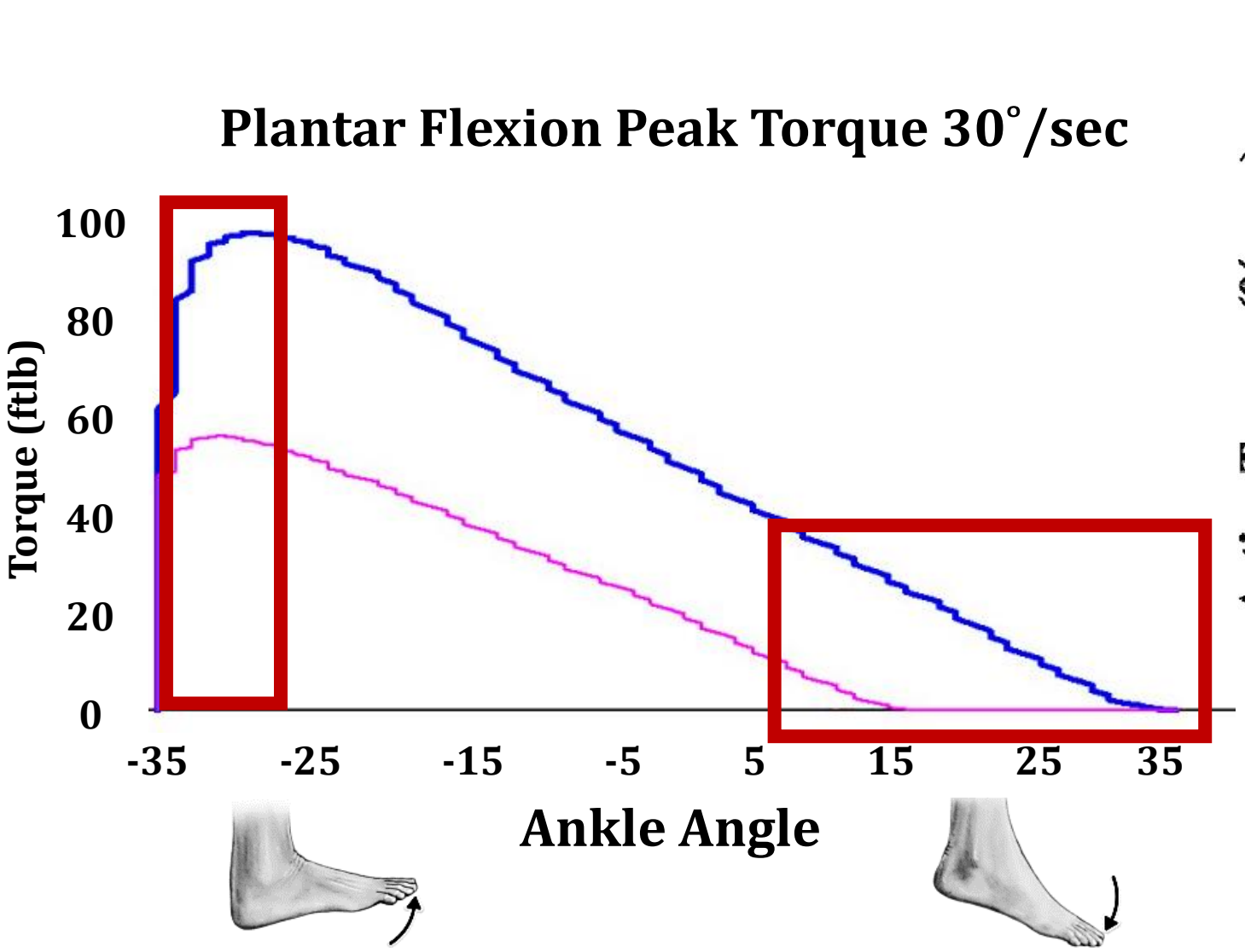


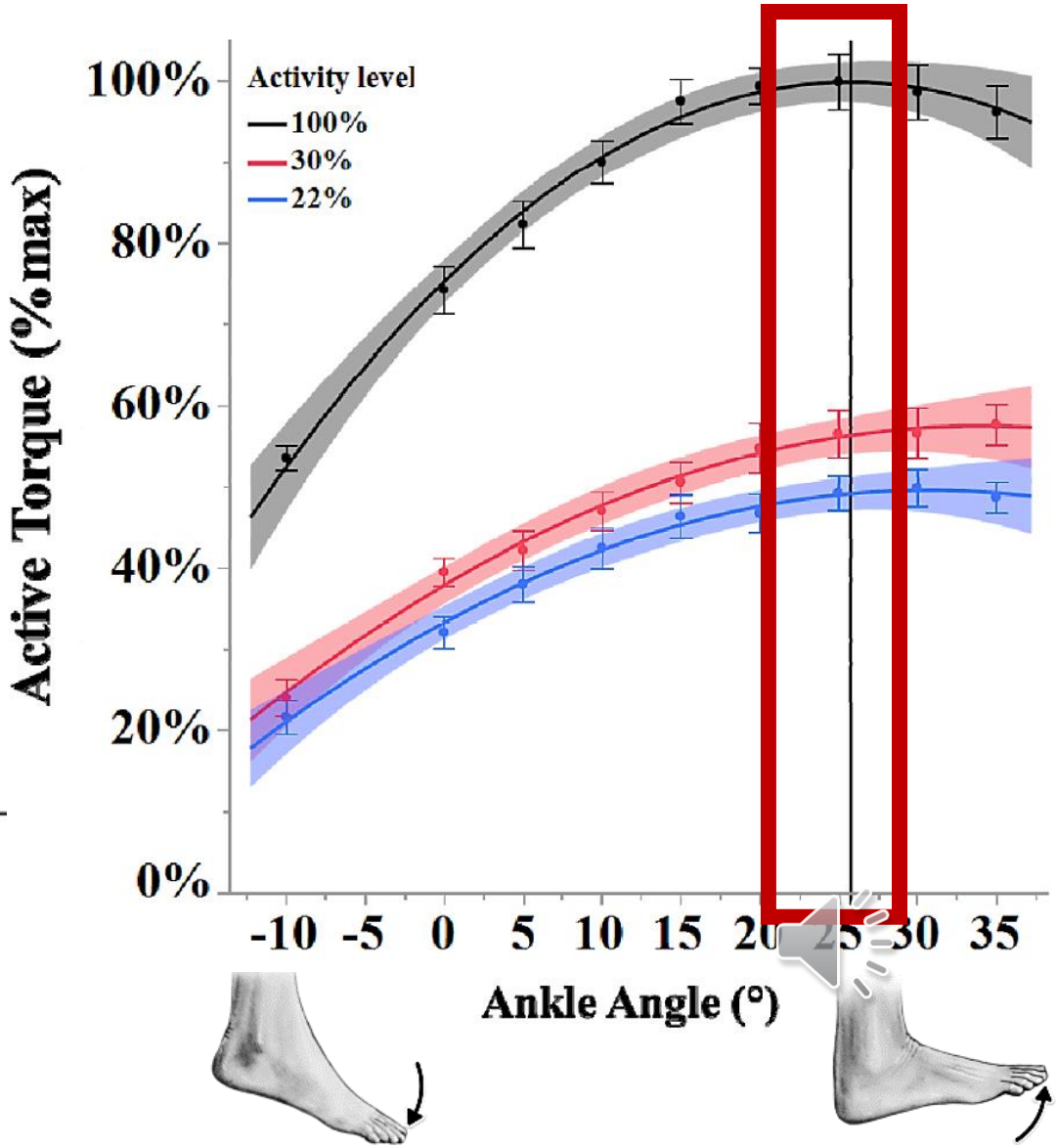
Knee angles **DO** affect **plantar flexor strength testing outcomes**, **BUT** the extent and nature of this effect can vary based on the specific parameters being measured.

Variable	Influence
Peak Torque & Power	Knee Flexion Angle 15°, 45°, 90°: ⬆ Knee Flexion Angle ➔ ⬇ power and torque[1,2]
Fatigue Indicators	Knee Flexion Angle had **NO significant** affect on **fatigue indicators** of plantar flexors[1]
Force Steadiness	Knee Flexion Angle do **NOT significant** affect on **force steadiness** of plantar flexors[1]
Post Achilles Repair	Knee angle does **NOT significantly** affect **isometric plantar flexion moments**, the **position of the ankle joint** is more critical in determining PF strength post-repair[8]

Hebert-Losier 2014[1], Gago 2017[2], Dargel 2009[3]

Muscle Performance: Plantar Flexion & Dorsiflexion

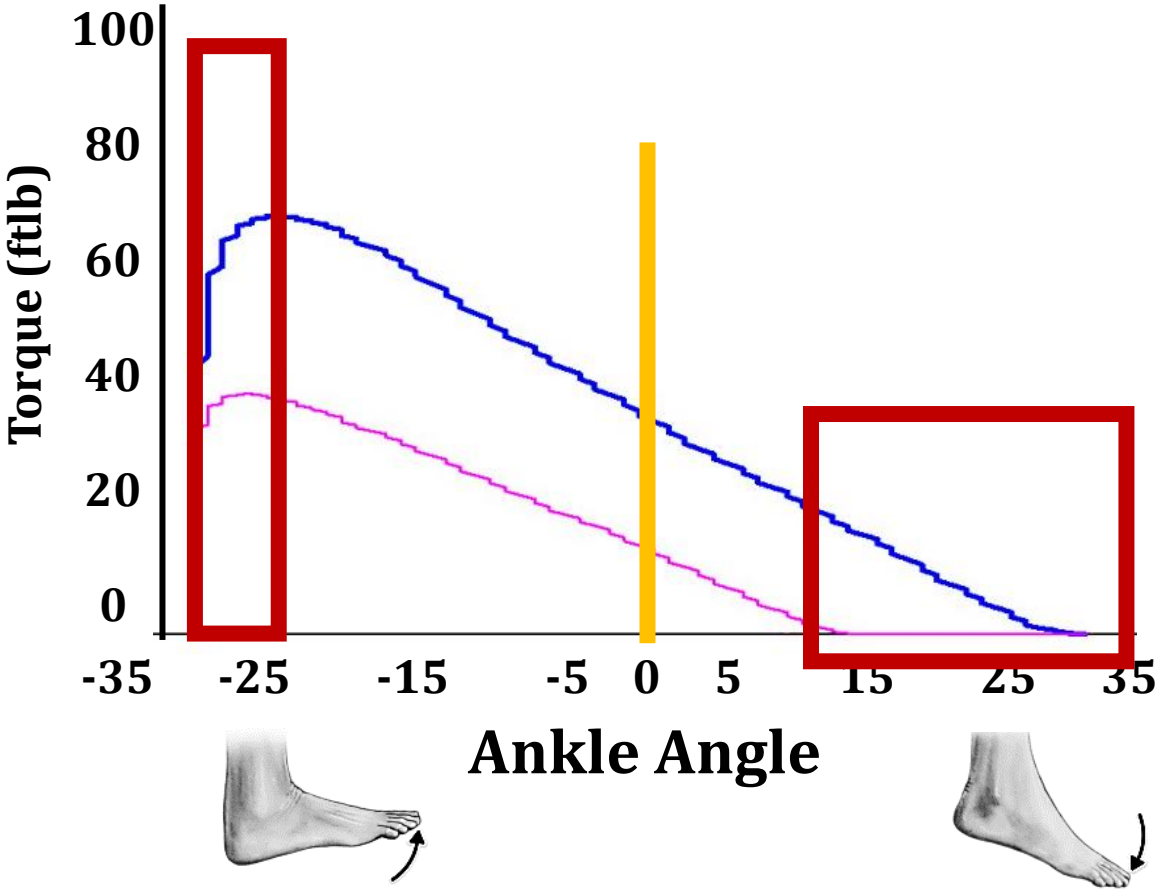




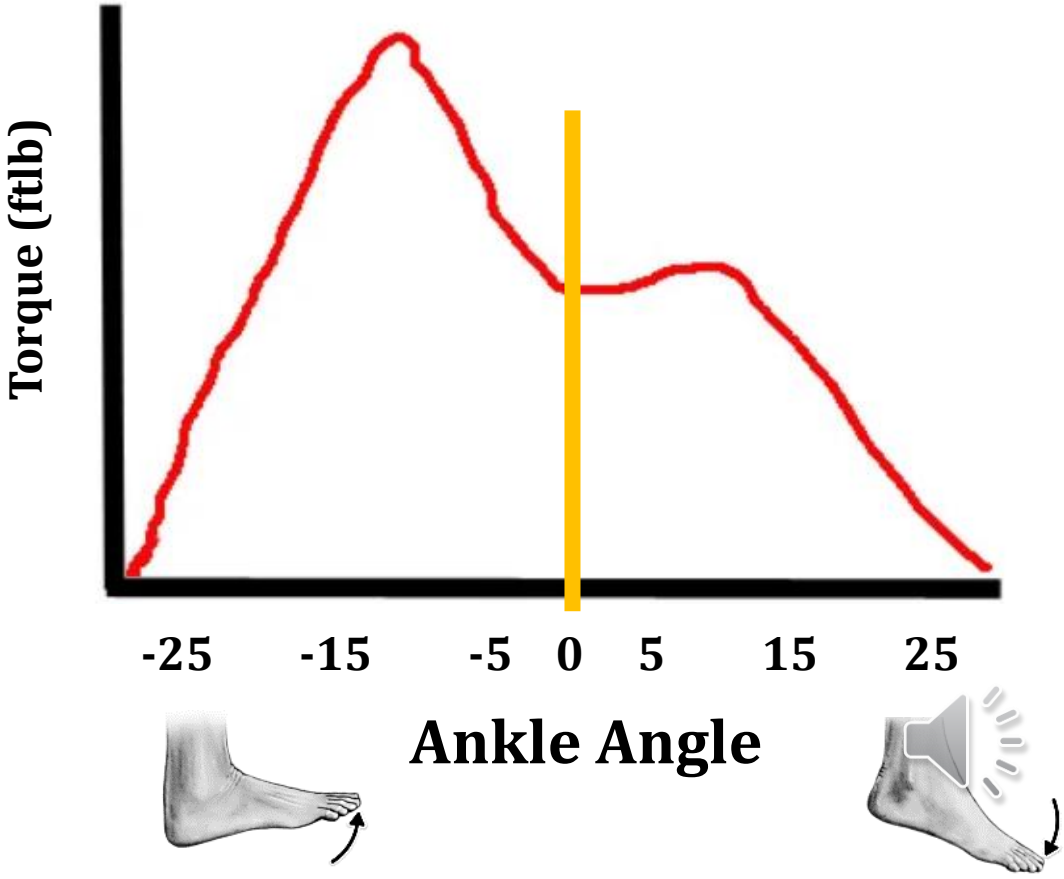
Hessel 2019

Muscle Performance: Curve Analysis

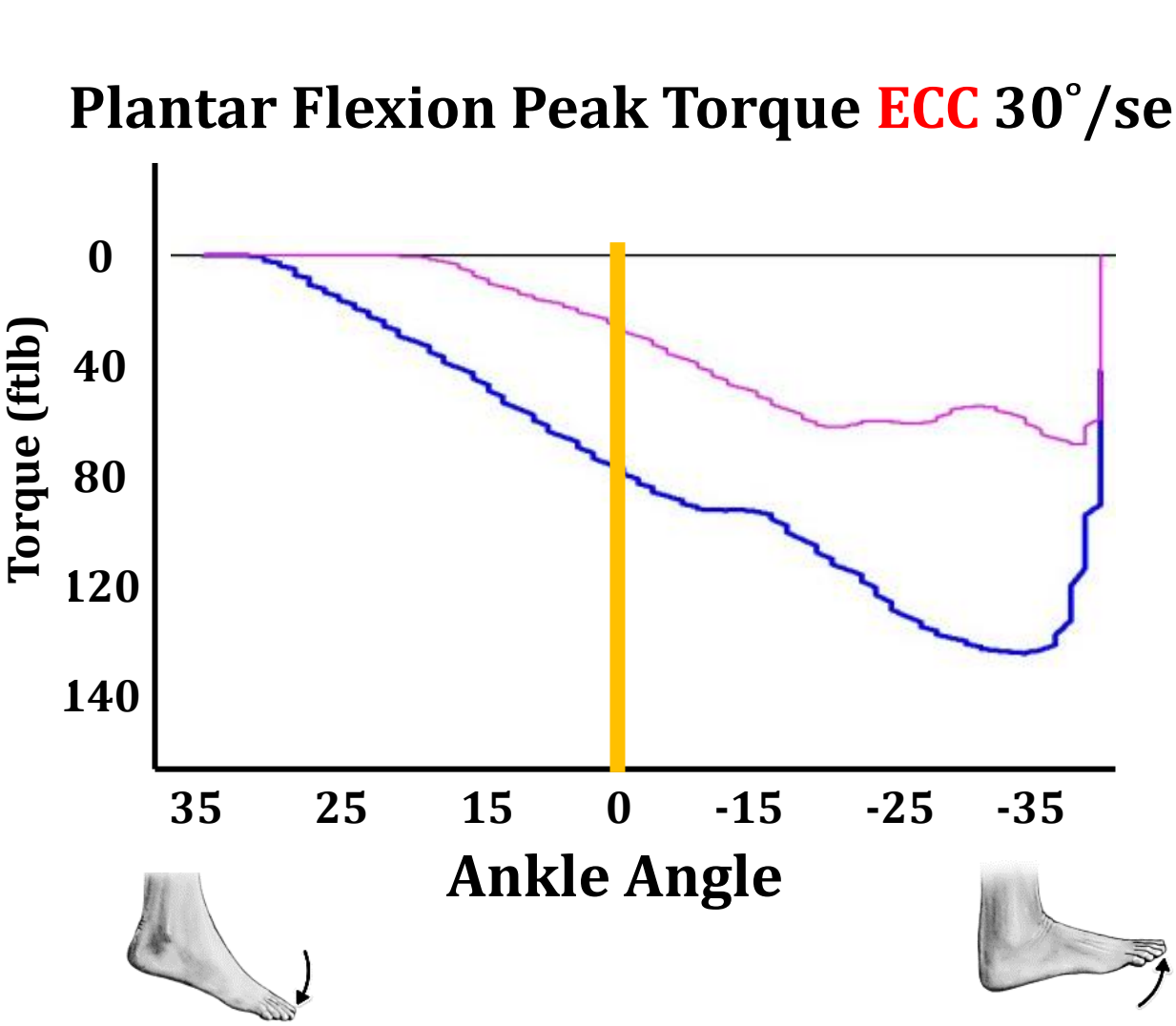
Plantar Flexion Peak Torque 30˚/sec

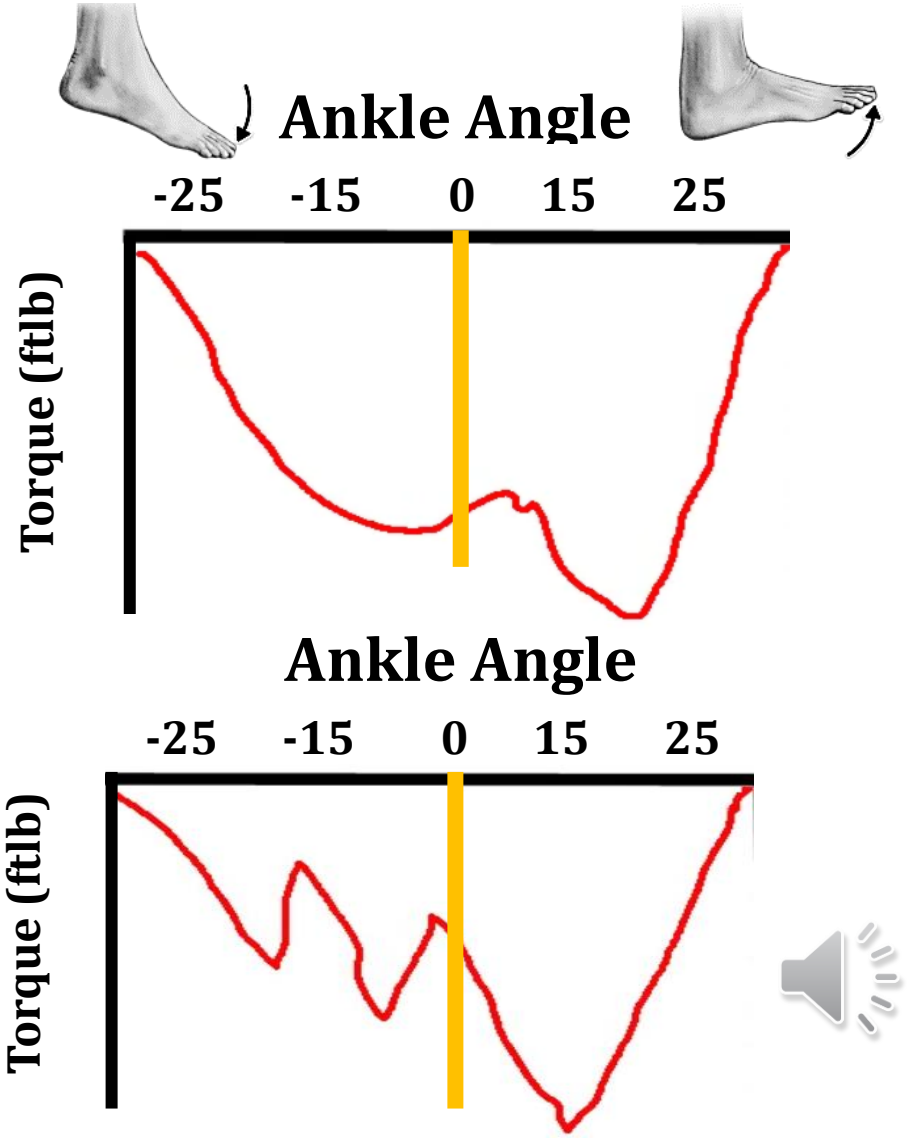


Achilles Tendinopathy



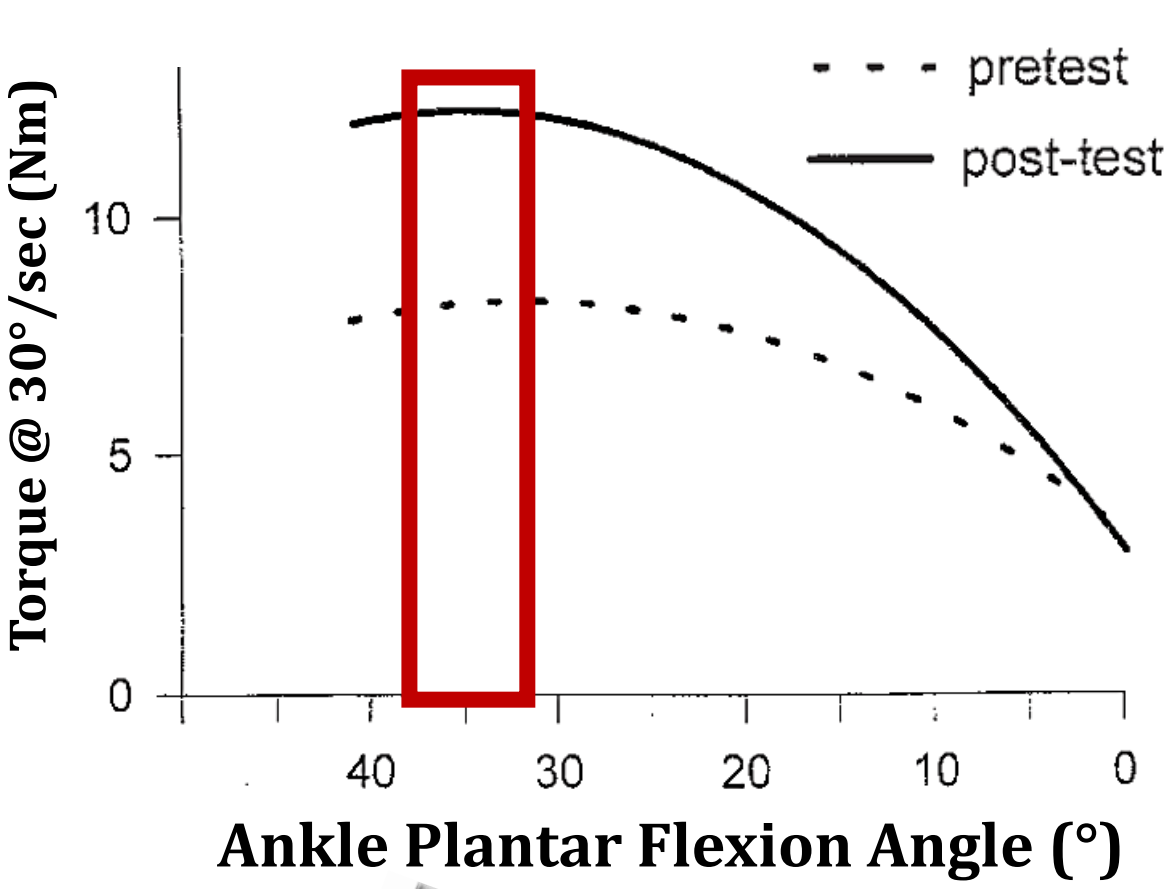
Muscle Performance: Curve Analysis



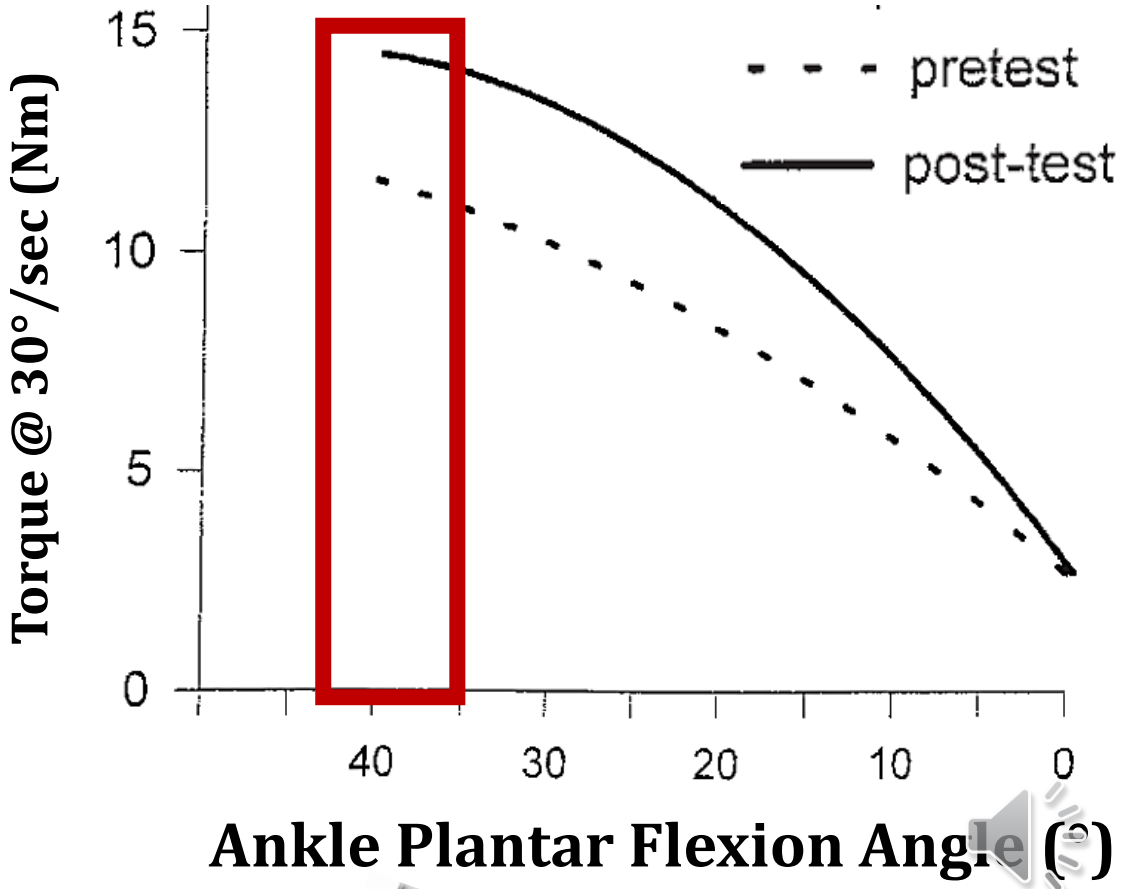


Muscle Performance: Plantar Flexion & Dorsiflexion

Concentric Dorsiflexion Strength



Eccentric Dorsiflexion Strength



Hessel 2019

Clinically Significant

Isokinetic Criteria: Plantar Flexion & Dorsiflexion

KEY POINTS

Construct	Assessment	Outcome & Criteria

Note. CON & ECC, indicated muscle actions tested non-consecutive repetitions; CON-ECC, indicate muscle actions tested independent of one another

O'Neil 2019[1], So 1994[2], Biodex Inc.[3] Mentiplay 2015[4]

Construct	Level 1 Return to Strength & Conditioning	Level 2 Return to Participation	Level 3 Return to Sport	Level 4 Return to Performance
Motor Coordination				
Muscle Endurance				
Muscle Strength				
Muscle Power				

Isolated Muscle Performance Testing

Gold Standard	Isokinetic Dynamometer
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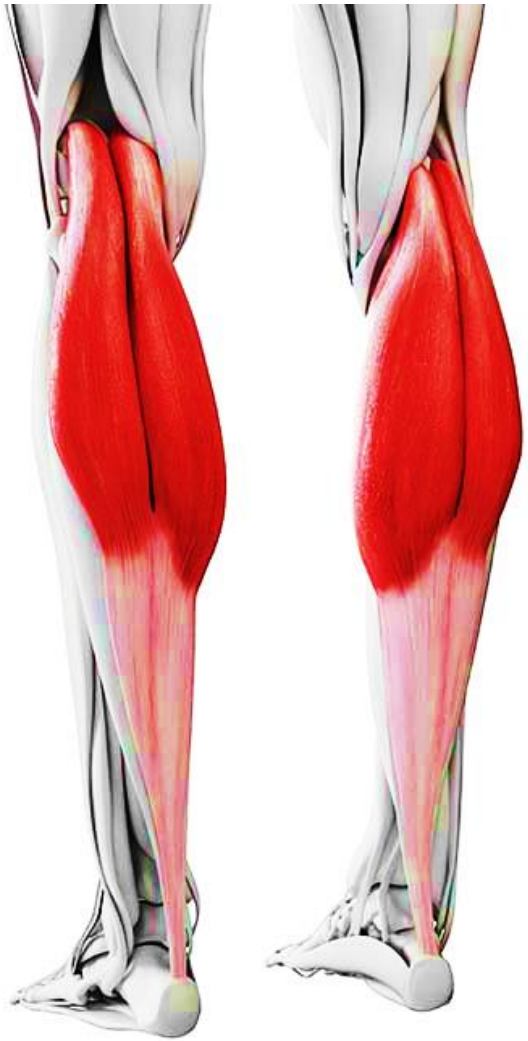


Muscle Performance: Plantar Flexion

Muscle Endurance | **Sufficient** | Field Test

Single Leg Heel Raise Test

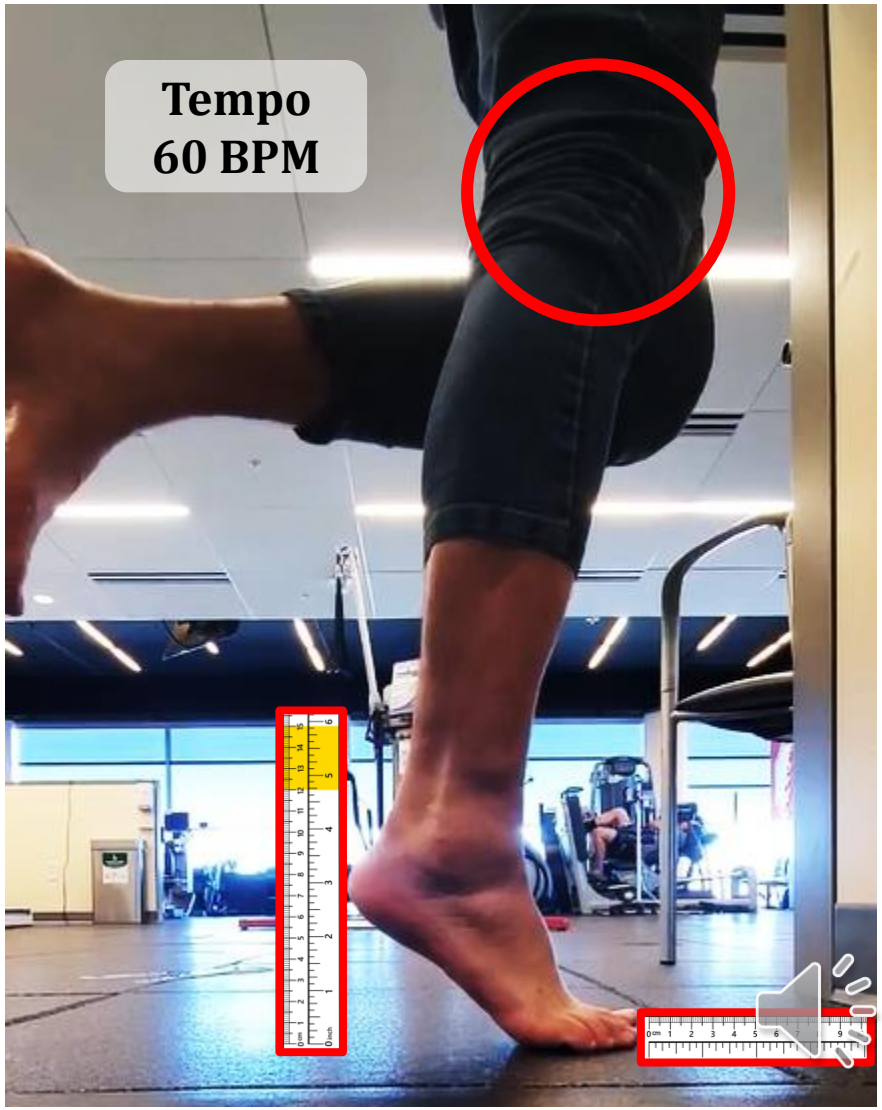
☐ Patient Position

- *1 leg stance, knee & hip 0°*
- *Ankle 0° OR 10°[2,5,6] DF Slant Board*
- *Forearm length away from wall*

☐ Equipment

- *Tape Measure (heel height)*
- *Calf Raise App*
- *Metronome App*
- *Wall/stable object*

☐ Start Ankle @ 0° OR 10°[2,5,6] DF



Heel Height Statistics

Reliability ICC: **0.91-0.94**[8]
SEM: **0.16 cm**[8]
MDC (% of Heel Height): **2.22-4.62**[8]
Meaningful Asymmetry: **>10% LSI**

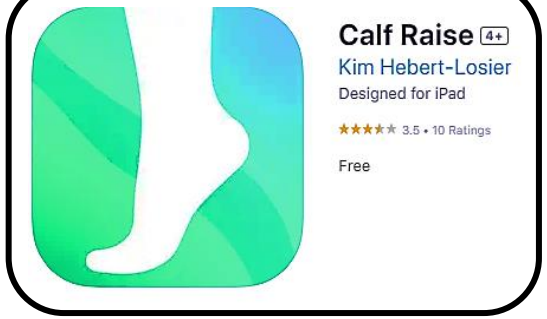
# of reps is NOT Correlated w/ PF PT (r =**-0.005**[3])
Reliability ICC: **0.57**[1]**-1.00**[2]
SEM: Young: **1.1°**[7] | Older: **2.4°**[7]
MDC (# of reps): **3.7-5.2**[4]
Meaningful Asymmetry: **>10% LSI**

Hébert-Losier 2009[1], Hébert-Losier 2017[2], Sara 2021[3], Segura-Ortí, 2011[4], Österberg 2022[5], Byrne 2017[6], Bohannon 2022[7], Schrefl 2024[7]

Muscle Performance: Plantar Flexion

Single Leg Heel Raise Test

- ☐ **Heel Height**
  - *Peak Height & Total Height*
  - *% Height Loss (Fatigue Index)*
- ☐ **Total Work**
- ☐ **Total Power**

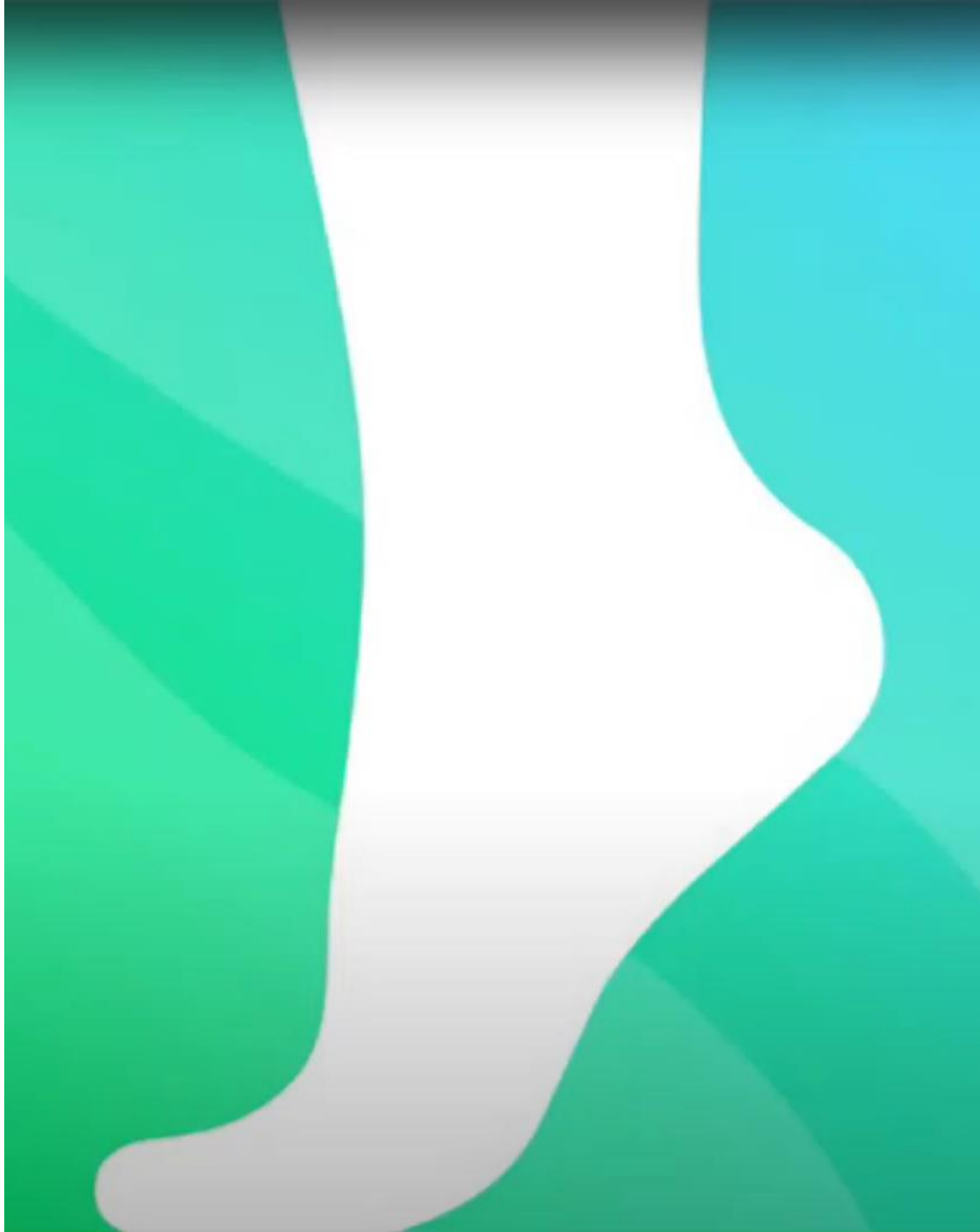


Calf Raise App vs Linear Encoder
Concurrent Validity
Total Work: ICC= **0.89[1]-0.963[3]**
Number of Reps **100%** consistency
Avg Heel Height (cm): ICC= **0.62[1]**

Note. *using the heel as a surrogate for center of body mass* ***overestimates the total work with 21.0-24.7%*** *compared to a gold standard (3D motion capture) BUT it was able to precisely detect the* ***relative difference between the limbs.***[2]

Using the heel-rise work test is ***valid*** *when using the* ***relative difference*** *between the limbs.* [2]

Ashnai 2024[1], Andreason 2021[2], Fernandez 2023[3]

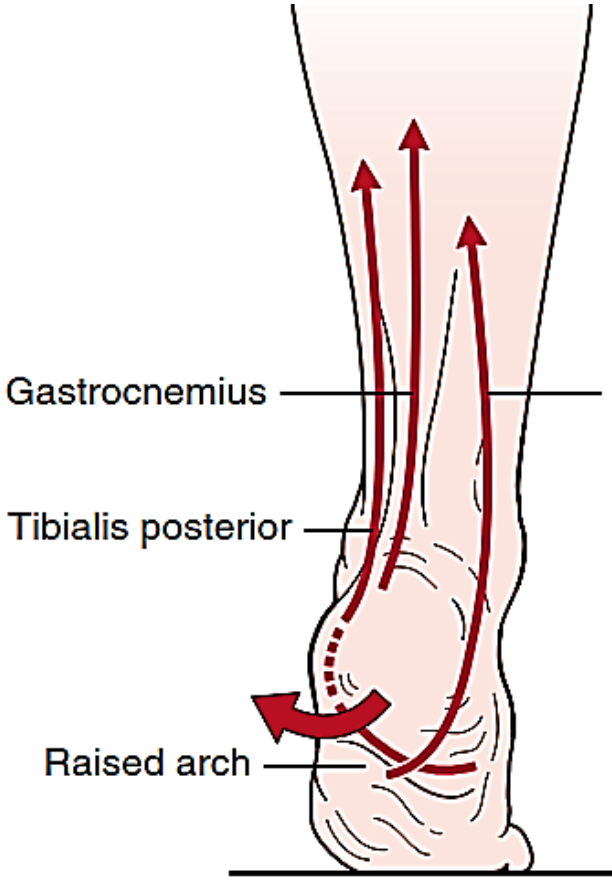


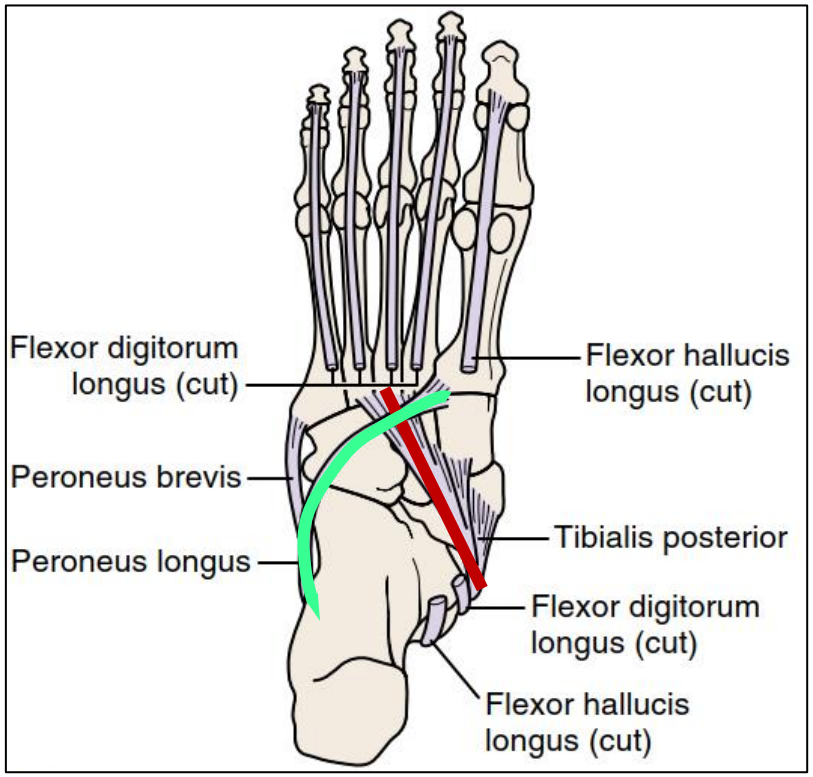
Muscle Performance: Plantar Flexion

Single Leg Heel Raise Test

Qualitative Assessment

- ☐ **Maintain Original Footprint**
- ☐ **Foot & Ankle Mechanics**[1]
  - *Plantar Flexion at the Ankle*
  - *Plantar Flexion at the Foot*
- ☐ **Test Stops When**[2]
  - *Metronome Pace could not be maintained*
  - *Heel height drops by 20% of original height*
  - *Knee Flexion Occurred*
  - *Hip propulsive Strategy was used*
  - *Forward lean into wall (rather than vertical)*
  - *Ensure force through 1st ray*[3]
  - *Ankle maintains alignment w/ the 2nd toe*[3]



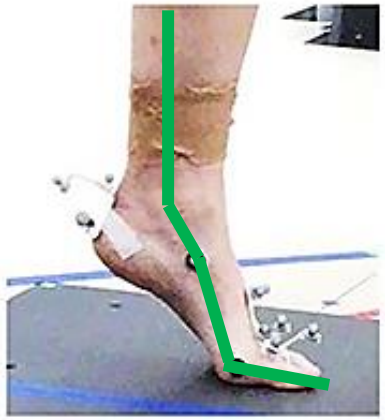


*Though **inversion** of the rearfoot (compliments of the tibialis posterior) is normal during single leg heel raise, **excessive inversion** (i.e., unbalanced via the peroneus mm.) can be compensation for weak plantar flexion.*

Jeong 2021[1], Green 2024[2], Tourillon 2023[3], M 2023[4]

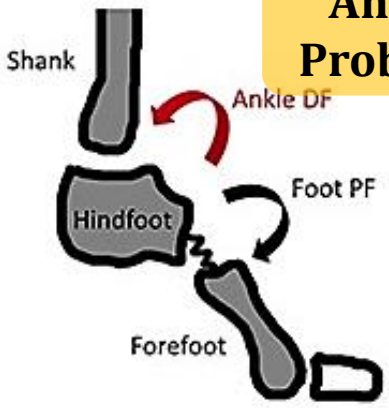
Muscle Performance: Plantar Flexion

Train On!



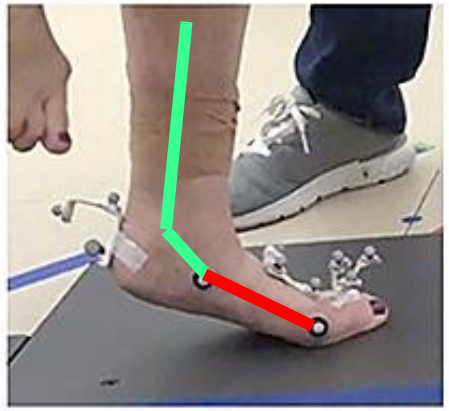
(A) Foot PF and Ankle PF

Ankle Problem



(B) Foot PF and Ankle DF

Foot Problem



(C) Foot DF and Ankle PF

Foot & Ankle Problem

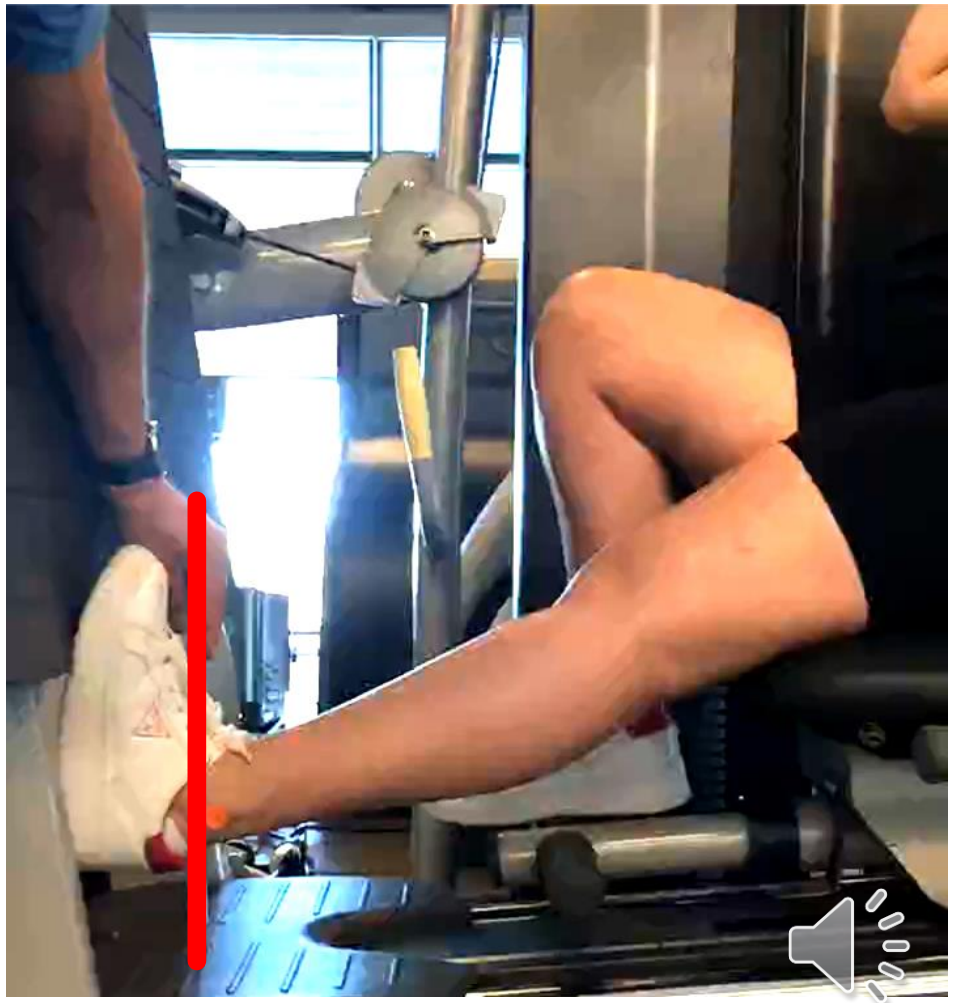
(D) Foot DF and Ankle DF

Hébert-Losier 2009[1], Hébert-Losier 2017[2], Sara 2021[3], Segura-Ortí, 2011[4], Österberg 2022[5], Byrne 2017[6], Bohannon 2022[7], Schrefl 2024[7]

Muscle Performance: Plantar Flexion

Seated Calf Raise PF Test

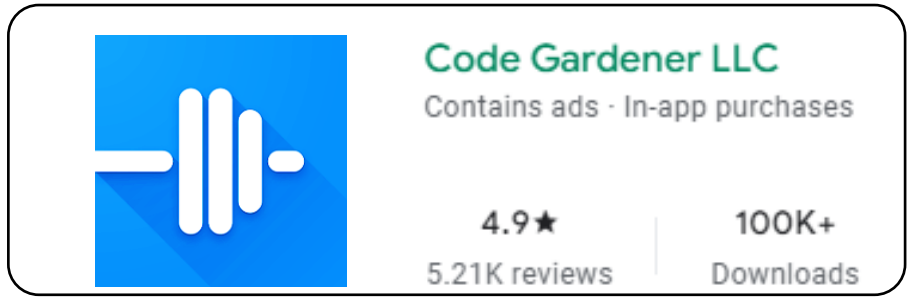
Single Leg Leg Press PF Test

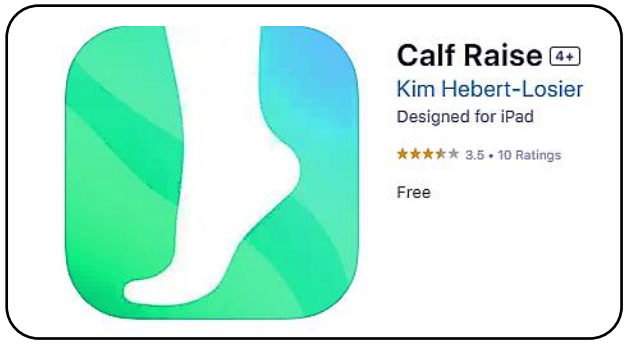


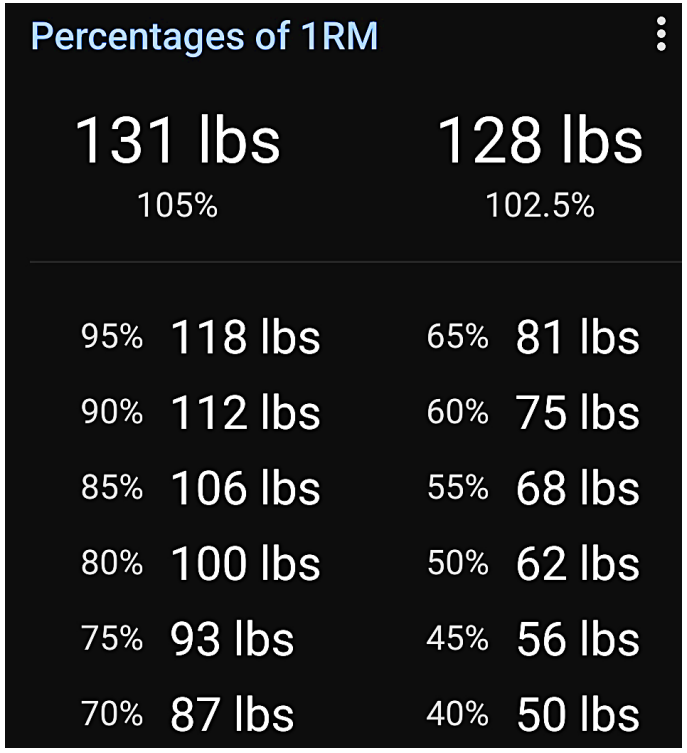
Hébert-Losier 2009[1], Hébert-Losier 2017[2], Sara 2021[3], Segura-Ortí, 2011[4], Österberg 2022[5], Byrne 2017[6], Bohannon 2022[7], Schrefl 2024[7]

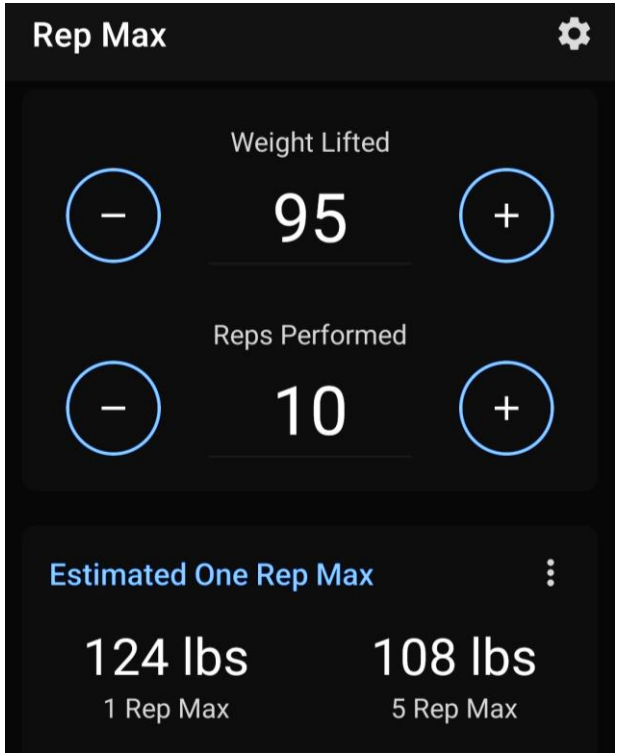
Muscle Performance: Plantar Flexion

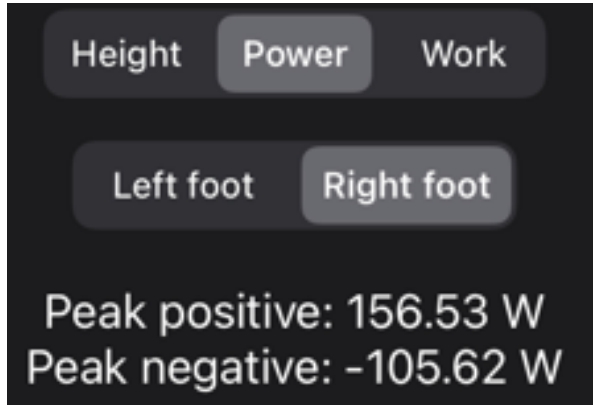
Single Leg Leg Press PF Test

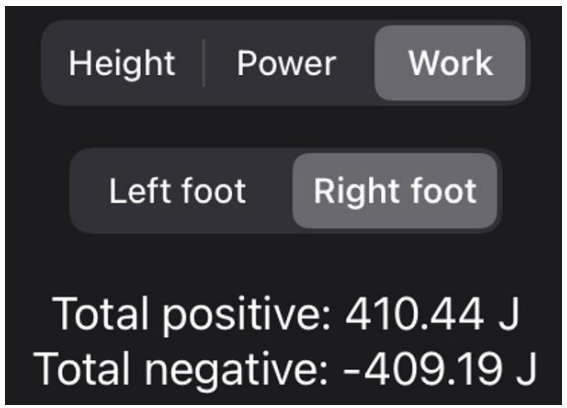


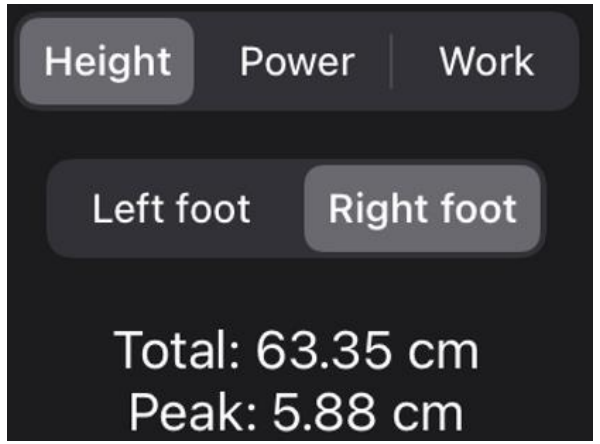






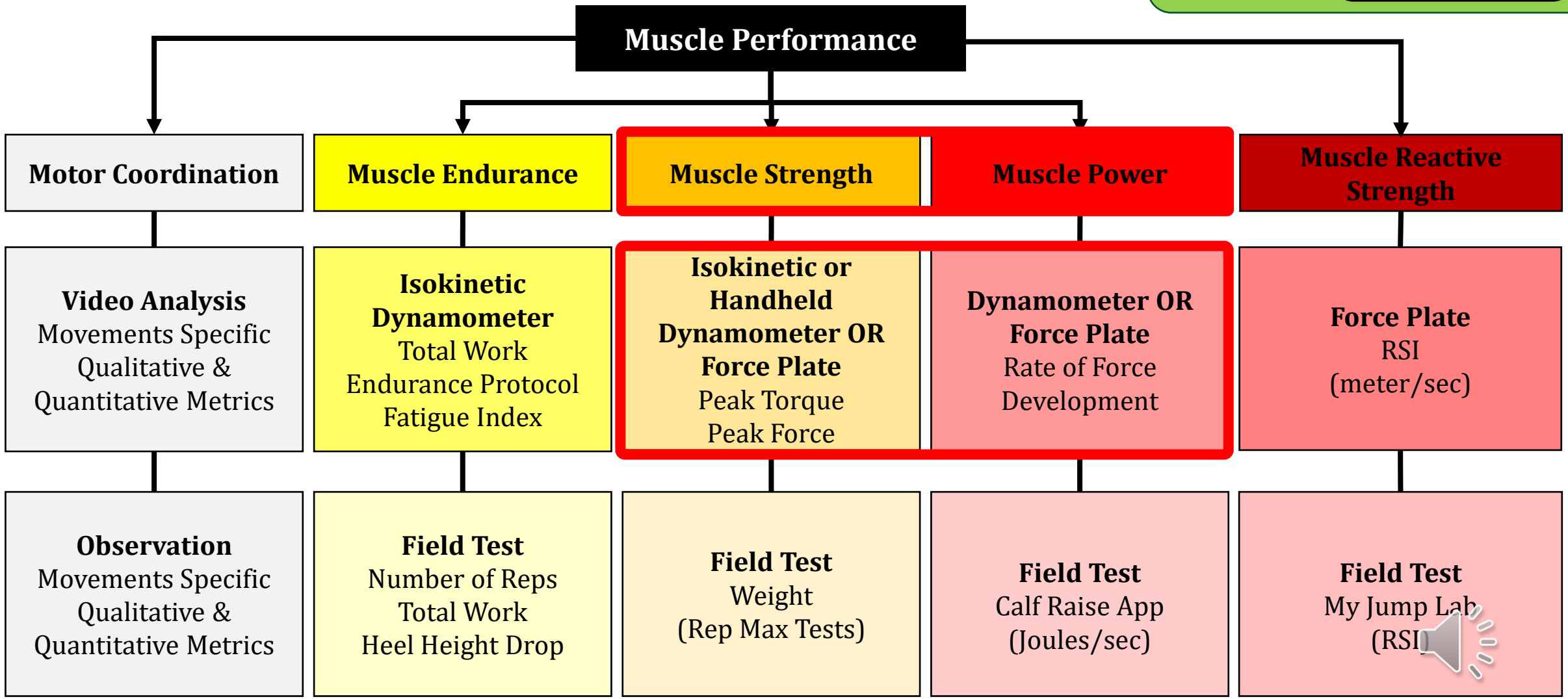






Muscle Performance: Constructs

Good — Force Plate, Ext Fixated Dynamometer



Kell 2001[1], Sapega 1983[2], Rebelo 2022[3], Hathaway 2024[4]

Muscle Performance: Plantarflexion Isometric Strength

Standing Ankle Iso PF Test[1]

Muscle Strength

Muscle Power

Good

Force Plate

☐ Patient Position

- *Standing with Hip 0°, Knee 0°, Ankle ~5° PF*
- *Shoulders supporting on Barbell*
- *Position: the ball of the foot of the tested leg is placed under the bar to facilitate a slight forward lean*

☐ Equipment

- *Barbell or Isometric Rack*
- *Force Plate (or comparable system)*

☐ Warm Up

- *General Warm Up: 3 min, stationary cycle, 1 W/kg BW*
- *Specific Warm Up: 3 x 3 sec efforts at 70%, 80%, 90% effort with 10 second recovery between efforts.*

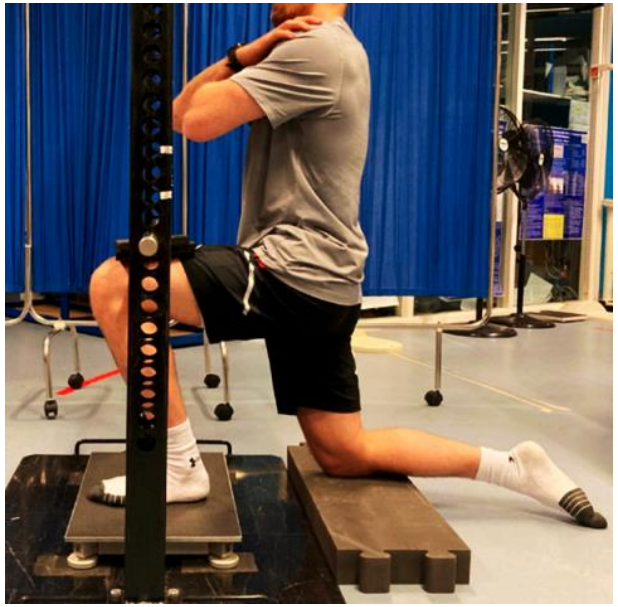
☐ Test Specifics

- *Tempo: Isometric*
- *Repetitions: 3-5 max efforts/leg*
- *Rep Duration: Rest: 60 seconds between sets*
- *Max Force Test: 3-5 x 5 sec (2 sec build-up, 3 sec max)*
- *Rapid Force Test: 5 x 1 sec (10 sec recovery) (repeat 2-3x)*
  - *Rapid Force Test Outcome: Force at 100 ms*

Coefficient of Variance: **<3-10%**[2-3] MDC or SEM: ***TBD***

VALD Performance 2023[1] Sportsmith 2024[2], Natera Performance Solution 2023[3]

Force Plate ½ Kneeling



Force Frame Seated

Fysiometer Seated

HHD Seated

Testing Recommendations[2]

- ☐ **Be consistent** w/ set up & execution
- ☐ Minimal effective padding to achieve **'comfortable' testing**
  - *Too much padding can effect RFD & instability*
- ☐ Apply **more tension than you expect** to strap or bar
  - *go 90% of the way & allow the athlete to do warm-up reps.*
  - *then add another 10% for their testing reps (ensure no heel lift)*
- ☐ Ensure **proper seated height** to avoid hip flexor cramping & achieve best results

McMahon 2023[1], Bean 2024[2]

Ankle: Plantar Flexion Isometric Strength

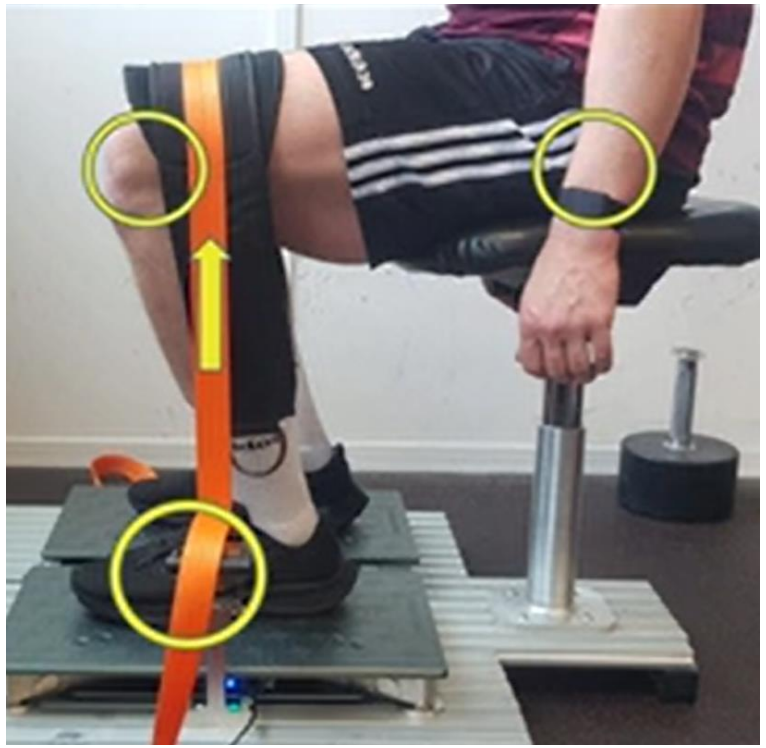
Muscle Strength

Muscle Power

Good

Force Plate | Fixed Dynamometer

- **2 x BW** (Seth O'niell)
  - Premier Football
- **2.6 x BW** (Rhodes 2022)
  - Everton FC Academy
- **1.8 x BW**
  - Munster Rugby
- **2.0 x BW** (Seth O'neill)
  - English Premier Rugby
- **1.8 – 2.0x BW** (C Griffin)
  - Recreational Runner



Test-Retest Reliability[2]	SEM (N)[2]	SEM%[2]	MDC (N)[2]
0-79 - 0.89	161.4-216.2	9.09-12.47	25.2-34.6

Test-Retest Reliability[1]	ICC: **0.915-0.938**
BW Ratio (%)[1]	**Female: 127.3%** (± 37.8) **Male 136.9%** (± 27.2)
MDC (kg)[1]	**25.2-34.6 kg**

Griffin 2024[1], Rhodes 2022[2], Sara 2021[3]

Clinically Significant

KEY POINTS

Muscle Performance Criteria: Plantar Flexion Field Tests

Construct	Assessment	Criteria

O'Neil 2019[1], Ashnai 2024[2], Hébert-Losier 2017[3], Jeong 2021[4], Silbernagel 2017[5], Schrefl 2024[6] Jeong 2021[7], Green 2024[8], Tourillon 2023[9], Strength Levels 2024[10], Griffin 2024[11], Lee 2023[12], McMahon 2023[13] , Glasgow 2021[14]

Ankle Frontal Plane
(Inversion/Eversion)

Muscular Performance

- Endurance
- Strength
- Power

Muscle Performance: Inversion & Eversion

Are there strength deficits in ankle inversion and eversion in functional ankle instability?

Consensus Meter

Results from 16 relevant papers

Yes 56% · Possibly 0% · Mixed 6% · No 38%

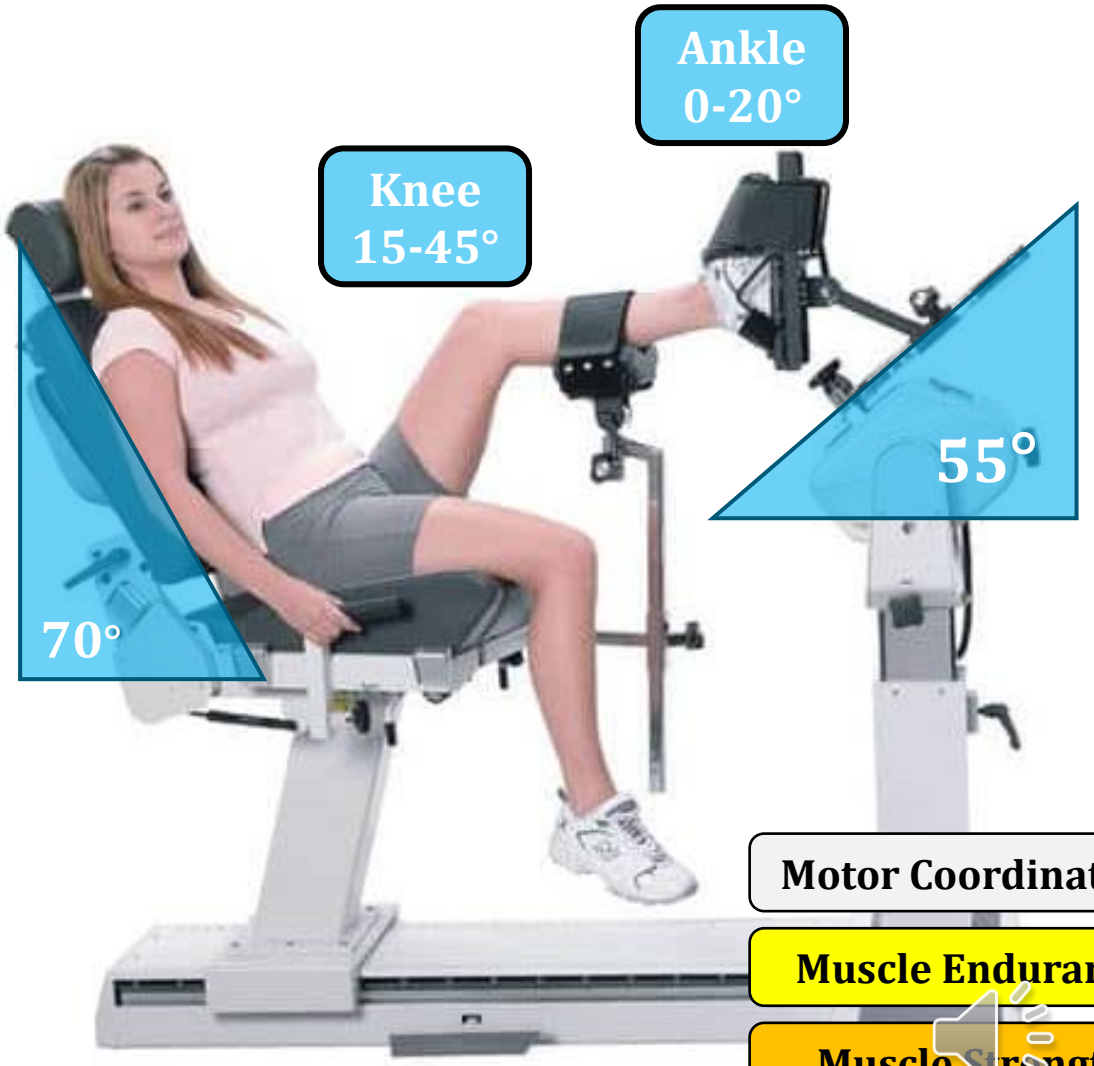
Results	Recency	Methods	Journals	Citations
Yes 56% 9 papers	2016 avg.	4 tier one studies	Q1 avg. =	409 total
Possibly 0%	—	—	—	—
Mixed 6% 1 paper	2003 avg.	0 tier one studies	Q1 avg. =	146 total
No 38% 6 papers	2002 avg.	1 tier one study	Q1.17 avg.	805 total

Muscle Performance: Inversion & Eversion

Gold Standard

Isokinetic Testing

- ☐ **Patient Position**
  - *Seated with Hip ~90°, Knee 15-45°[1], Ankle ~10°*
- ☐ **Speeds:** *30°, 60°, 90°/sec*
- ☐ **Range of Motion:** *30°-50° (INV: 30-50° | EVR: 15-25°)*[5-6]
- ☐ **Test Specifics**
  - *Speeds: 30°, 60°, 90°/sec*
  - *1 set per speed (unless testing CON & ECC)*
  - *Practice Reps: 3-7*
  - *Strength: 5-10*
  - *Endurance: 20*
  - *Rest between sets: 30 seconds*
- ☐ **Outcomes**
  - *Normality of force curve ("Strength Curve Profile")*
  - *Peak & Average Torque (Limb symmetry index)*
  - *Torque/Body Weight:*
  - *Total Work*
  - *Fatigue Index*
  - *Eversion to Inversion Ratio:* **:** ≥95%[2,4]



Intra-rater: ICC 0.92–0.96
Inter-rater: 0.95[4]

Motor Coordination
Muscle Endurance
Muscle Strength
Muscle Power

Porter 2004[1], McGirr 2014[2] ,Cho 2023[3], Aydoğ 2004[4], Wimpenny 2023[5], Biodex Multi-Joint System Manual 2015[6]

Clinically Significant

Isokinetic Criteria: Plantar Flexion & Dorsiflexion

KEY POINTS

Construct	Assessment	Outcome & Criteria	Limb Comparison
Muscle Endurance	INV-EVR CON-CON 60°/s[3] & 120°/s[4]	❑ **INV CON 60°/s Tot Work:** Normative Values Unknown ❑ **EVR CON 120°/s Tot Work:** Normative Values Unknown	**90% LSI** &/or **90% of Demographic Norm**
Muscle Strength	Concentric INV & EVR Peak & Avg Peak Torque (PT) 30°/s & 60°/s	**Concentric 30°/sec** ❑ INV CON PT/BW: **M: 12-16%** | **F: 14-19%**[1,3] ❑ EVR CON PT/BW: **M: 13-17%** | **F: 12-16%**[1,3] ❑ EVR:INV CON: **M: 87%** (65-108%) | **F: 81%**(58-103%)[1] **Concentric 60°/sec** ❑ INV CON PT/BW: **M: 11-14%** | **F: 12-15%**[3] ❑ EVR CON PT/BW: **M: 9-12%** | **F: 9-12%**[3] ❑ EVR:INV CON: **M: 90%** (64-115%) | **F: 80%**(60-100%)[1]	
	ECC & CON, EVR & INV 30°, 60° & 120°/s	**Eccentric 30°/sec** ❑ INV ECC PT/BW: **36%**[5] | EVR ECC PT/BW: **35%**[5] **Eccentric 60°/sec** ❑ INV ECC PT/BW: **36%** | EVR ECC PT/BW: **34.5±8.6**[6] **Eccentric EVR / Concentric INV 120°/sec** ❑ @ 15° INV: 3.9±1.7[2] | @ 20° INV: 4.9±2.5[2]	
Muscle Power	Isometric INV (15° EVR) | EVR (15° INV)	❑ RFD 20-80% MVC | ❑ RFD 100 ms	

Note. CON & ECC, indicated muscle actions tested non-consecutive repetitions.

Wong 1984[1], Yildiz 2019[2], Biodex Inc.[3] Wimpenny 2023[4], David 2013[5], Sierra-Guzmán 2018[6]

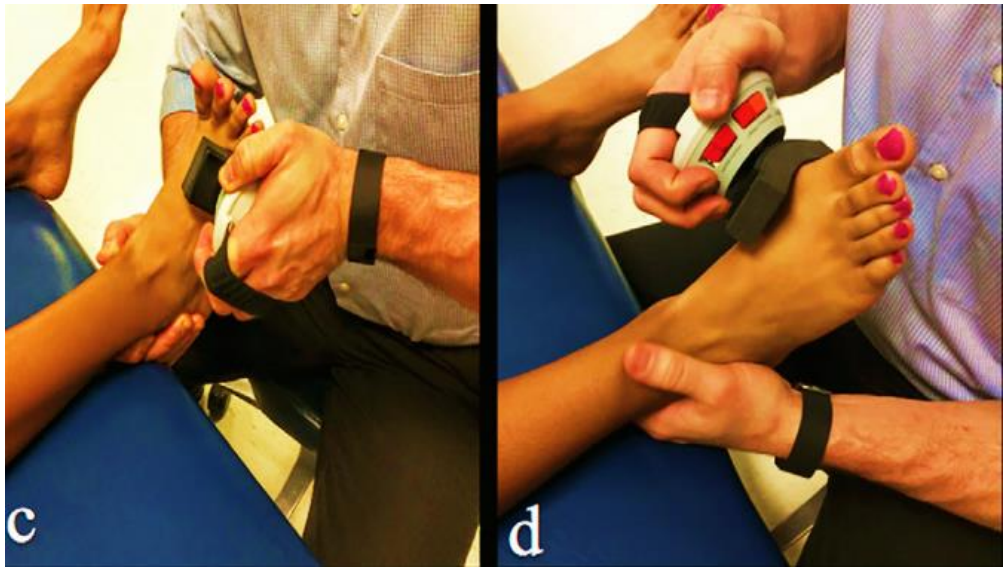
Muscle Performance: Handheld Dynamometry

Muscle Strength | **Muscle Power** | **Acceptable** Fixed Dynamometer | **Sufficient** Manually Fixed HHD

	Inter-Rater Reliability				Test-Retest			
	Baseline		Reassessment		Tester1		Tester2	
	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt
Ankle Dorsiflexion	.60	.61	.76	.67	.82	.88	.83	.88
Ankle Plantar Flexion	.77	.88	.83	.89	.68	.86	.84	.92
Ankle Inversion	.69	.90	.53	.85	.73	.87	.83	.83
Ankle Eversion	.74	.79	.71	.65	.85	.79	.78	.74
Hallux Flexion	.75	.87	.82	.87	.68	.76	.85	.92
Less Toe Flexion	.66	.77	.87	.82	.67	.74	.77	.77

Poor — Fair — Good — Excellent

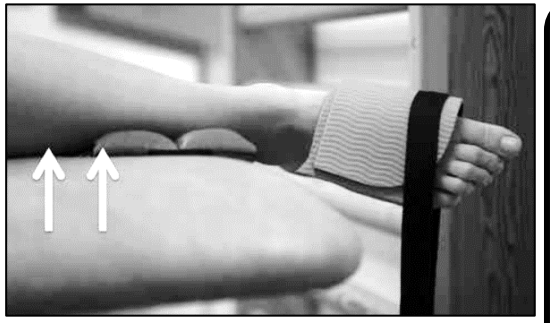
Fraser 2017



Muscle Performance: HHD Plantar Flexion

Avg **92-108 lb**[3] | Force/BW **55%**[3]
MDC **25 lb**[2] | SEM **9.3 lb**[2]

Avg Force **58-63 lb**[3]| Force/BW **40%**[3]
MDC **12.7 lb**[2]| SEM **4.5 lb**[2] **(2.2-14.9%)**[5]



Ankle Inversion Strap Fixed Dynamometer

Break Test
AVG Force: **72 lb (±13.6)**[1]

Make Test
Avg Force: **51lb (±20.5)**[1]
Force/BW: **30% BW**[3]

Ankle Eversion Strap Fixed Dynamometer

Break Test
Mean Force: **66.0 lb (±12.5)**[1]

Make Test
Avg Force: **51lb (±12.5)**[1]
Force/BW: **29% BW)**[3]

Avg Force: **132 lb (±59 lb)**[2]
MDC **15%**[2] | SEM **5.4%**[2]

Fixed HHD setups tend to produce **higher force outputs** and **are more accurate** for individuals with greater strength, while **HHD alone** may be **more consistent** for those with **lower strength.**[5]

Shimizu 2023[1] Cho 2023[2], Fraser 2017[3] , Mentiplay 2015[4], Davis 2017[5], Chamorro 2017[6]

Clinically Significant

KEY POINTS

Muscle Performance Criteria: Handheld Dynamometry & 1 RM

Construct	Assessment	Criteria

Note. RFD, 200 ms has the best reliability, yet good reliability is also noted with the other RFD metrics

Predicted PF Strength = 3.735+(0.00618×[**Height (cm)**])−(0.003320×**[Age(yr)]**)+(0.1121× **[Sex*]**)[1]

Predicted DF Strength = 0.637+(0.01573×[**Height (cm)**])−(0.001958×**[Age(yr)]**)+(0.2659×**[Sex*]**)[1]

***Sex:** Male: 1, Female: 0

Moraux 2013[1], McGirr 2014[2] ,Cho 2023[3], Fraser 2017[4], Aguilaniu 2024[5], Mentiplay 2015[6]

Muscle Performance: The Kinetic Chain

Foot & Ankle Injuries Implications of the Hip Joint & Muscles:

Hip Extension Strength:

- ⬇ **hip extension muscle strength** is identified as an **independent risk factor** for **lateral ankle sprains** in youth soccer players[1]
- An ⬆ **hip muscle extension** force significantly ⬇ **the hazard of injury**[1]

Hip Abductor Strength:

- ⬇ **isometric hip-abductor strength** is associated with a ⬆risk of **noncontact lateral ankle sprains** in male soccer players, predisposes athletes to ankle injuries.[2,3]
- In females, **asymmetry in hip abduction strength** was a **risk factor** for **non-contact ankle injuries**.[4]

Chronic Ankle Instability (CAI):

- CAI cohorts often exhibit ⬇ in **hip flexor, abductor, and external rotator strength** compared to controls, suggesting that **hip strength** is a **critical component in managing and rehabilitating CAI**.[5,6]

Impact of Fatigue:

- **Hip-abductor fatigue** can **negatively influence ankle kinematics** & muscle activity, potentially ⬆ the **risk of ankle sprains** during activities like single-leg jumps.[7]

De Ridder 2017[1], Powers 2017[2], Kawaguchi 2021[3], Hietamo 2017[4], Khalaj 2024[5], Brighenti 2023[6], Gafner 2018[6]

Muscle Performance: The Kinetic Chain

Foot & Ankle Injuries Implications of the Knee Joint & Muscles:

Hamstring Strength & Ankle Instability:

- Individuals with CAI often exhibit ⬇ **maximal & submaximal isometric strength** in the **knee flexor muscles;** weakness is observed in **BOTH** the injured and non-injured limbs, suggesting **a systemic issue** rather than a localized one[1]
- **Strengthening** the **quadriceps & hamstring muscles** may help ⬆**overall lower limb stability & ⬇ risk of further ankle injuries**[2,3]

Quadriceps Strength & Ankle Instability:

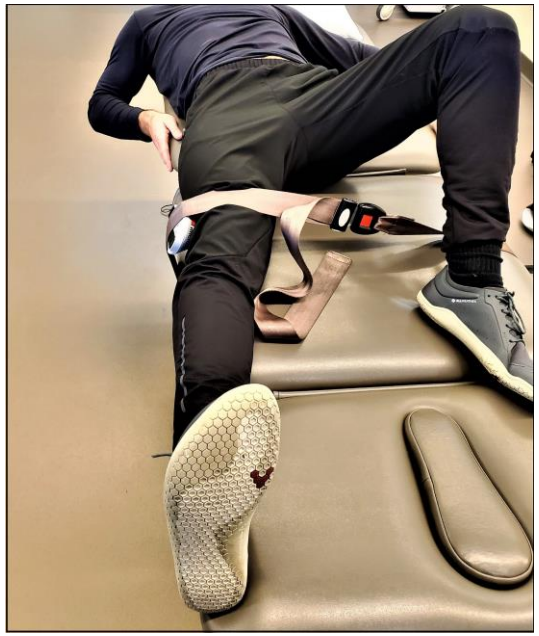
- Systematic review & meta-analysis of 16 studies demonstrated **moderate ⬇ concentric knee extension torque** normalized to body weight at **60°/s** (SMD=−0.64, 95% CI −0.07 to −1.22)[4]

Quadriceps Strength & Achilles Tendon Pathology:

- Post Achilles tendon rupture ➡ ⬇plantar flexion strength due lingering deficits & subsequent elongation of the tendon ➡ ⬆ **reliance of knee extensor muscle** to compensate for the ⬇ function of the ankle, resulting in **greater knee joint loads** during activities such as **walking, jogging, and running.**[5]

Labanca 2024[1], Jacopo Brighenti 2023[2], Abbey 2021[3], Khalaj 2020[4], Sun 2020[5], Brighenti 2023[6], Gafner 2018[6]

Muscle Performance: The Kinetic Chain



Muscle Performance: Hip[1]

Movement	Dynamometer Position	Patient Position	Normative Value (% BW ± SD)
Flexion	5 cm above the upper border of the patella	Sitting	**38.54% ± 7.61%**
Extension	5 cm above the medial malleolus, at the triceps surae	Prone	**27.04% ± 6.46%**
Abduction	5 cm above the proximal border of the lateral malleolus	Supine	**16.85% ± 4.17%**
Adduction	5 cm above the proximal border of the medial malleolus	Supine	**16.89% ± 4.05%**
Internal Rotation	5 cm above the proximal border of the lateral malleolus	Sitting	**23.82% ± 8.48%**
External Rotation	5 cm above the proximal border of the medial malleolus	Sitting	**17.09% ± 5.03%**

Alvarenga 2019[1], Jeanfavre 2024[2]

Goal #1: LSI ≥90%
Goal #2: ≥90% (±1SD) of Demographic Norm

Muscle Performance: The Kinetic Chain

Muscle Performance: Knee

Movement	Hand-Held Dynamometer Position	Patient Position	Normative Value (% BW) [1]
Flexion	Knee flexed to 15˚ (or 45˚)	Prone	Male: **52-69%*** Female: **48-57%***
Extension	Against the back of the plinth	Sitting	Male: **86-115%** Female: **80-95%**

Note. *based upon 60% of knee extension normative range

Hamstring Measurement Position[3]	Uninjured-Leg Strength (lbs)[3]
HHD15 (15°)	52.8 (45.6-62.0)
HHD90 (90°)	44.3 (37.1-49.0)

Goal #1: LSI ≥90%
Goal #2: ≥90% (±1SD) of Demographic Norm

Biodex Manual 2011[1], Jeanfavre 2024[2] , Reurink 2016[3]

Muscle Performance: Summary

Muscle Performance

Motor Coordination	Muscle Endurance	Muscle Strength	Muscle Power
Movements Specific Qualitative & Quantitative Metrics	Total Work Fatigue Index # of Reps, Heel height	Peak Torque, Peak Force, RM Tests	Rate of Force Development
• Foot Coordination • Force Curve Normality	• Foot Intrinsics • Plantar/Dorsi Flexion • Inversion / Eversion	• Foot Intrinsics •Plantar/Dorsi Flexion • Inversion / Eversion	•Plantar/Dorsi Flexion •Inversion / Eversion

Gold Standard	Isokinetic Dynamometer
Good	Fixated Dynamometer (With Time Force Curves) Force Plate (Plantar Flexion Only)
Acceptable	Fixated Dynamometer (Without Time Force Curves) Pull Gauge OR Crane Scale
Sufficient	Field Test Manual Fixated Dynamometer
Unacceptable	Manual Muscle Testing

Foot & Ankle Muscle Performance

Goal #1: LSI ≥90%

Goal #2: ≥90% (±1SD) of Demographic Norm

Hip & Knee Muscle Performance

Goal #1: LSI ≥90%

Goal #2: ≥90% (±1SD) of Demographic Norm