Ankle Muscle Strength Affects Muscle Forces During Double Leg Hopping

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Objective: Evaluate the effect of ankle muscle weakness on muscle control and coordination of double leg hopping.

Introduction

Falls and fall related injuries are the primary cause of morbidity and mortality in older adults [1].

Declining lower limb strength and altered muscle activity often precede a fall in older adults [2].

Muscle strength declines 2-4% each year after age 60, affecting ankle strength and mobility [3, 4].

Double leg hopping requires precise muscle activity, adequate muscle strength, and dynamic balance control.

Experimental measurements combined with musculoskeletal modeling and simulation facilitate the investigation of hopping biomechanics with and without ankle muscle weakness to evaluate dynamic balance ability.

Methods

Participant Demographics

Total	Gender	Age (years)	Height (m)	Weight (kg)
N = 3	Female	21.3 ± 1.9	1.67 ± 0.05	67.4 ± 10.3

Instrumentation

- 66 reflective markers
- 7-camera motion capture system (Qualisys, 200 Hz)
- In ground force plates (AMTI, 2000 Hz)
- Lower limb electromyography (Delsys, 2000 Hz)

Modeled Ankle Plantarflexor Maximum Isometric Forces

	MG F_{iso}^{Max} [N]	LG F_{iso}^{Max} [N]	SOL F_{iso}^{Max} [N]
Baseline	3115.50	1575.06	6194.84
Weakened	2541.21	1415.09	5250.67

- Maximum isometric force of each medial gastrocnemius (MG), lateral gastrocnemius (LG), and soleus (SOL) were defined from an existing musculoskeletal model [7].
- A weakened model was developed to represent aging [8].

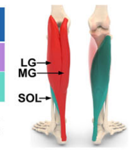


Image made from content of a BodyParts3D web site.

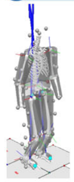
1 Protocol

3 healthy adults each performed 10 continuous double leg hops with their hands on their hips or to their sides.

2 Qualisys

Reflective markers were tracked using Qualisys.

3 Visual3D



An 8-segment model was developed in Visual3D. Inverse kinematics (IK) of 3 hops were found [5].

4 OpenSim Models

Baseline: IK solutions and GRFs were applied to a scaled model with 23 degrees of freedom and 92 musculotendon actuators [6].

Weakened: Maximum isometric forces of MG, LG, and SOL reduced.

5 Residual Reduction

RRA improved dynamic consistency.

6 Computed Muscle Control

CMC determined the needed muscle excitation patterns.

Outcome Metrics: Averaged peak muscle forces and ankle reserve actuator torques of 3 hops per participant from each model.

Results

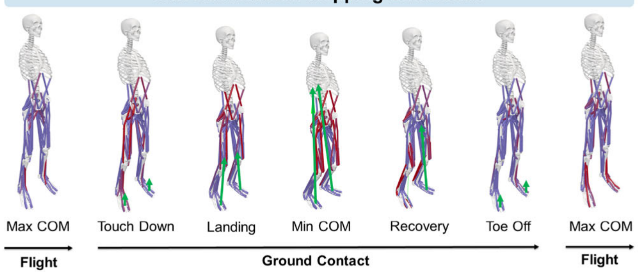
Average CMC Residuals

Condition	Residual	Mean	Peak	RMS
Baseline	FX [N]	5.9	21	9.3
	FY [N]	-27	106	50
	FZ [N]	-0.58	9.9	3.8
	MX [Nm]	-0.39	14	6.2
	MY [Nm]	1.7	10	4.1
	MZ [Nm]	0.47	31	11
Weakened	FX [N]	6.0	21	9.3
	FY [N]	-27	106	50
	FZ [N]	-0.22	9.1	3.6
	MX [Nm]	-0.03	13	5.7
	MY [Nm]	1.7	10	4.1
	MZ [Nm]	0.85	27	9.9

Values averaged across 9 trials (3 trials per participant). 92% of the residuals from each hop passed existing criteria [9].

Criteria:
Force: Peak & RMS < 5% of net external force
Moment: Peak & RMS < 1% of COM * net external force

Muscle Actuated Hopping Simulation

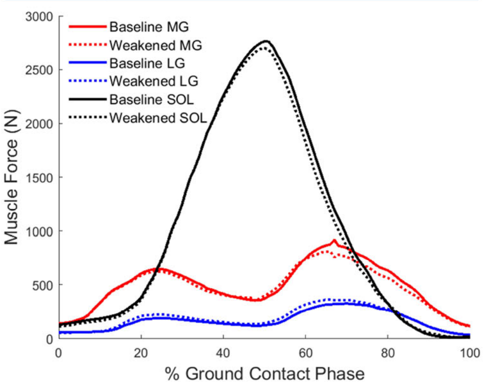


Peak Muscle Forces During Ground Contact

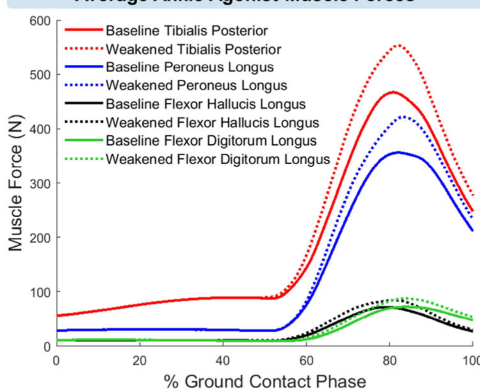
Muscle	Baseline [N]	Weakened [N]	% Difference [%]
Medial Gastrocnemius	918	812	-12
Lateral Gastrocnemius	327	363	11
Soleus	2,766	2,702	-2.3
Tibialis Posterior	467	554	17
Flexor Digitorum Longus	72	88	20
Flexor Hallucis Longus	72	85	17
Peroneus Longus	357	422	17

Peak muscle forces from CMC muscle recruitment solutions. Values averaged across 9 trials (3 trials per participant). Weakened muscles had smaller peak forces, except for the lateral gastrocnemius. Agonist muscles had higher peak forces in the weakened model.

Average Ankle Plantarflexor Muscle Forces



Average Ankle Agonist Muscle Forces



Peak Ankle Reserve Actuator Torques

Trial	Baseline [N*m]	Weakened [N*m]	Trial % Difference [%]	Participant % Difference [%]	Overall % Difference [%]
P1 Hop 1	6.59	18.1	93.2	76.1	53.1
P1 Hop 2	2.44	6.78	94.1		
P1 Hop 3	15.9	24.1	41.0		
P2 Hop 1	16.6	26.6	46.2	29.5	
P2 Hop 2	25.4	25.2	-0.79		
P2 Hop 3	17.9	27.7	43.0		
P3 Hop 1	1.27	1.32	3.86	53.8	
P3 Hop 2	0.43	1.28	99.6		
P3 Hop 3	1.26	2.29	58.0		

Peak ankle reserve actuator torques from CMC muscle recruitment solutions for all participants and trials. All results are plantarflexion moments and occurred in the recovery phase of the hop. The weakened model required larger ankle reserve plantarflexion torque.

Conclusions

Ankle muscle weakness associated with aging affects hopping strategy and muscle recruitment.

The weakened ankle muscles produced smaller peak forces with higher activations to produce the same hopping motion.

Ankle plantarflexion torque from the reserve actuator and agonist muscles was needed to compensate for weakened ankle plantarflexor muscles.

An older adult would likely select a different hopping strategy.

Ankle strength should be preserved to maintain movement and prevent dynamic balance decline.

References

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