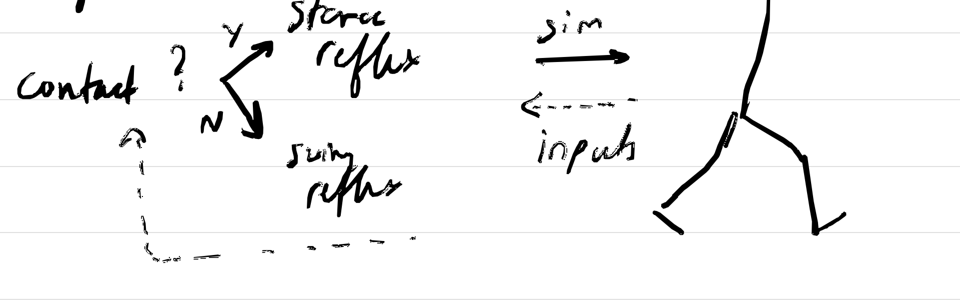
Predictive Simulations to Study Plantarflexors in Gait Pathologies

- Gastroc / Sol in walking
  - ↳ 2 joints ↳ 1 joint
- Acceleration in late gait stance
- pathologies come with muscle weakness
- isolation is difficult due to co-occurring problems
- Predictive sims generate without tracking data
- Controllers based on muscle reflexes for stable simulation
+ high level: stance vs swing
* contact model on foot determine state
+ low level muscle reflexes: length, velocity force, stabilize torso



- Could be used for a variety of gaits
+ also to see if adaptation occurs
+ actually create cause → effect.

Point: Study PF weakness and contracture
1. Pathologic gait often slower
2. Framework chooses self selected pattern
3. Introduce PF contracture

Optimization Framework

Obj func → CMA-ES optimizer → Controller params

Controller params → Gen Sims → Obj func

Gen Sims ↙ Gait Controller → MSK model → forward sim

Use simplified 9-DOF MSK model
- planar joints
- 9 muscles for sagittal plane motion
- 3 contacts per foot, 1 heel, 2 toes

4 Low-level control laws for excitation

Stance			Swing	
ES	MS	PS	S	LP
Early	Mid	Pre swing	swing	Landing prep

C	Constant
L+, V+	Stretch (length & velocity)
F+	Force
PD	Pelvis tilt stability

- 90 design vars in optimization problem

Objective Function

$$J = J_{CoT} + w_{speed} J_{speed} + w_{injury} J_{injury} + w_{head} J_{head}$$

Cost of Transport
- minimize energy per dist.

Speed (w_{speed} = 1000)
- step speed close to target speed
- large falling penalty

Injury (w_{injury} = 0.1)
- ligaments, modeled as rotational springs
- penalize lig. torques

Head (w = 0.25)
- stabilize head
- penalize excessive accelerations

Validation
1) realistic walking speed
- generate 7 sims between 0.5 - 2 m/s
- compared to cost of transport + kinematic measures
- optimization framework could reproduce speeds accurately
+ experimental vs simulated cost of transport
- also compare simulated spatio-temporal techniques

Second aim, self selected walking pattern & speed
- adjust step speed at no less than 0.75 m/s

Kinematic / Kinetic Validating
- Angles / Moments / GRFs in % gait cycle

Modeling Plantar Flexor Deficits

- modeled weakness due to contracture in one / both
+ mild / moderate / severe weakness & contracture

PF Weakness
- Increasing weakness → slower, heel gait

Does PF weakness impair push-off?
- late stance have reduced PF moment
- PF weakness due to overlengthening Achilles in surgery: heel walking gait (Hoang 24)
+ true, constantly dorsiflexed

Contribute to Crouch Gait?
- no, model did not create crouch gait

PF Contracture Results
- crouched, toe walking gait
- Cause excessive PF moment?
+ yes during early stance
- equinus (toe walking!)
+ yes, soleus or both instead of just gastroc
- crouch gait?
+ stance, ↑ knee flexion moment (Soleus)
+ hip angle in stance ↑, sol more influence

Conclusions
- Severe PF weakness → heel walking gait
- Severe PF contracture → toe walking
- PF weakness did not create crouch, contracture did (not hard conclusion)
- SOL contracture caused more crouch than GAS
+ GAS crosses knee, so interesting find
+ SCONE → simulation & optimization framework

Questions

Q: Why 2 contact spheres at toes?
A: Difficulty technically, better real world results.
Q: How long for computation?
A: 10-15 hours, optimization took 2 cycles, found tidy solution. Parallelized to search space
Q: Metabolic Cost for pathological study ideal?
A: Maybe not, but that would be more neurologically tough to measure. Keep all assumptions here to muscular
Q: Joint torque displacement proximally?
A: Yes, but more minorly than anticipated