

Intralimb Compensation Due to Ankle Motion Constraints During Human Hopping

Megan E. Krause, BSBSE, Young-Hui Chang, Ph.D.
Comparative Neuromechanics Laboratory
School of Applied Physiology
Georgia Institute of Technology



Everyday Constraints

- Variety of ankle constraints during locomotion:
 - Fashion – high heel shoes or ski boots
 - Orthotically – Using an ankle foot orthosis
 - Pathologically – stroke



<http://www.dillards.com>



<http://www.shumakers.com>



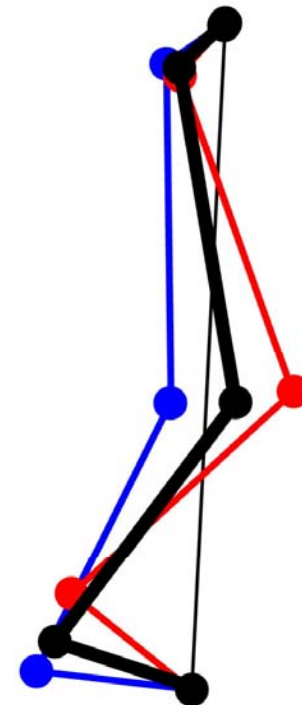
<http://orthomedics.us/pediatrics.aspx>



<http://www.talkingpointsmemo.com>

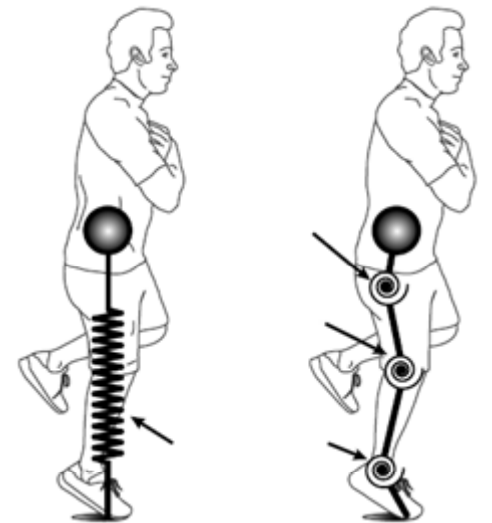
How do we overcome these ankle constraints?

- **Compensatory strategies** of the lower limb conserve whole limb variables rather than conserving the kinematics and kinetics of individual joints
- **Limb Level Goals:**
 - Leg length (Auyang, 2009; Chang, 2009)
 - Leg orientation (Auyang, 2009; Chang, 2009)
 - Leg stiffness (Chang, 2008)
 - Vertical force (Yen, 2009)



Experimental model

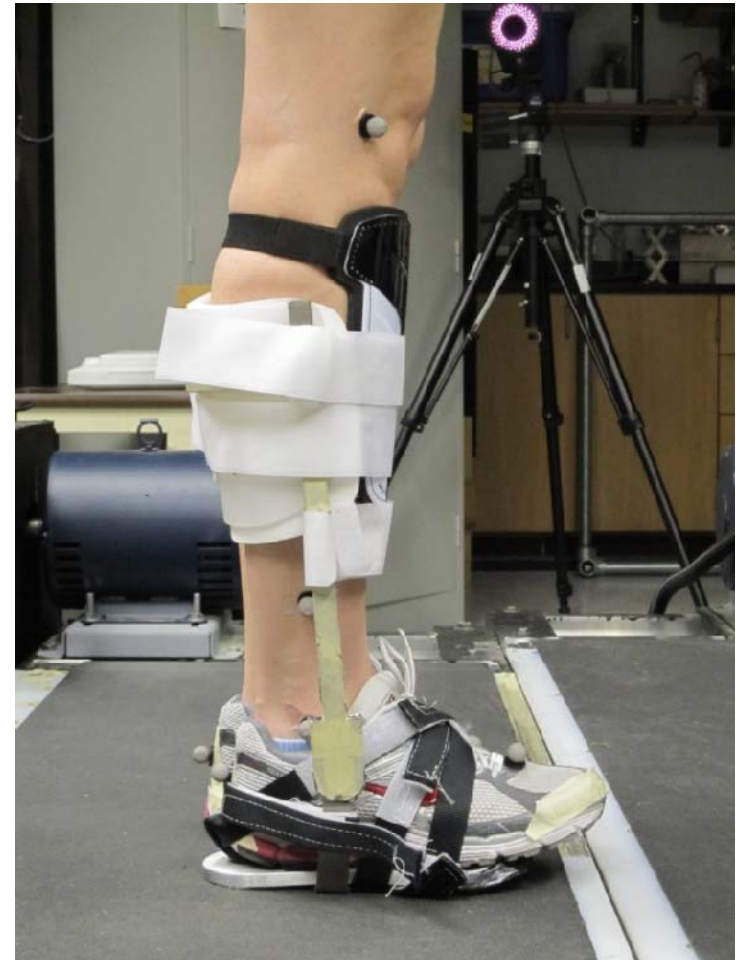
- **Hopping** = experimental model for locomotion
- The **spring-mass model** predicts hopping and running dynamics of the leg (Blickhan, 1989; Farley, 1991)



(Chang, 2008)

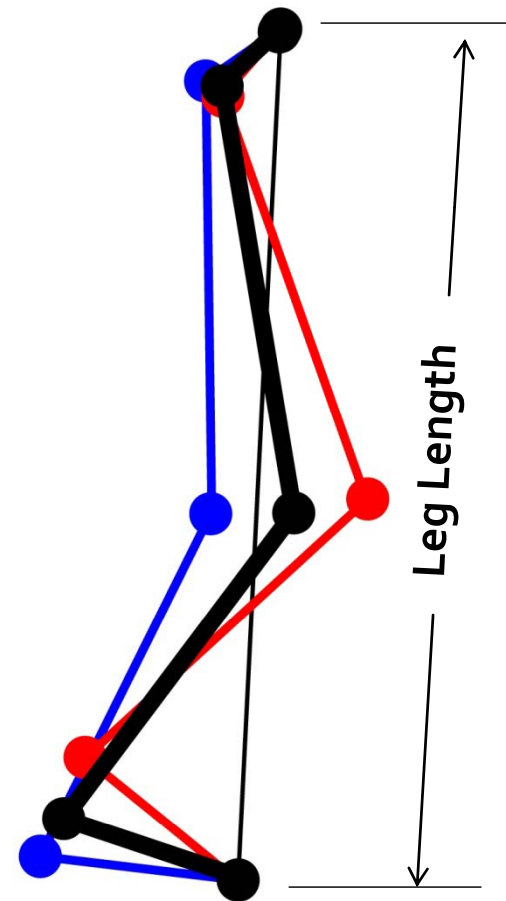
Purpose

- To study how the joints compensate when a kinematic constraint is applied to the ankle



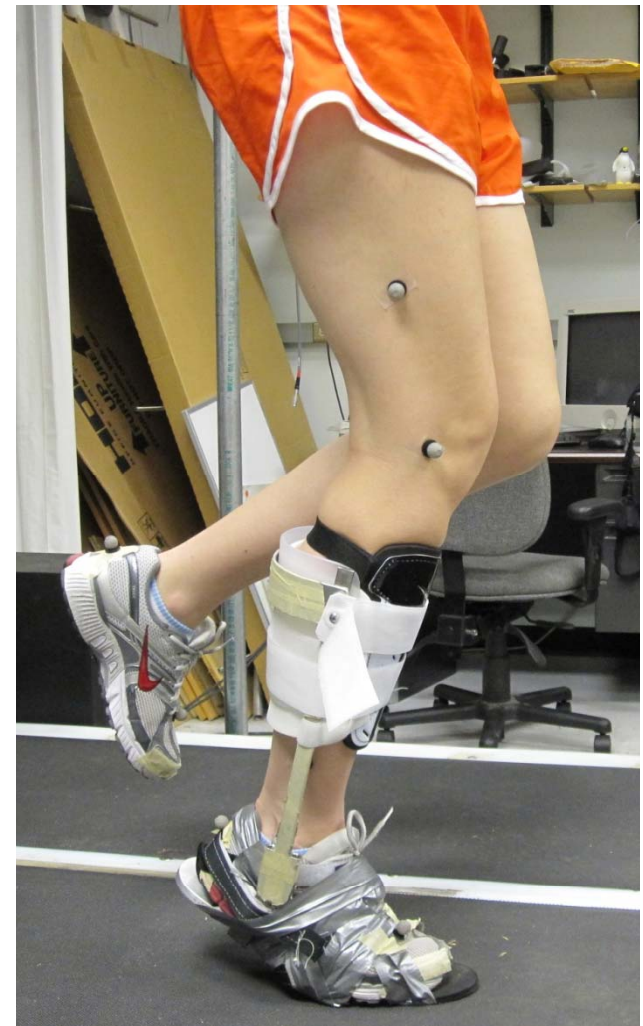
Hypothesis

- **Joints are coordinated to conserve leg length (LL)**
- **Predictions:**
 1. LL will be conserved across conditions
 2. Intercycle joint angle variance will be coordinated to conserve LL across cycles



Methods - Procedure

- N=10
- Hopped at 2.2 Hz
- 3 trials (20 seconds each) per condition
- 4 conditions:
 - Free
 - PF Blocked
 - DF Blocked
 - DFPF Blocked



Conditions

Free



PF Blocked



ROM Blocked:
48% ($\pm 10\%$)

DF Blocked



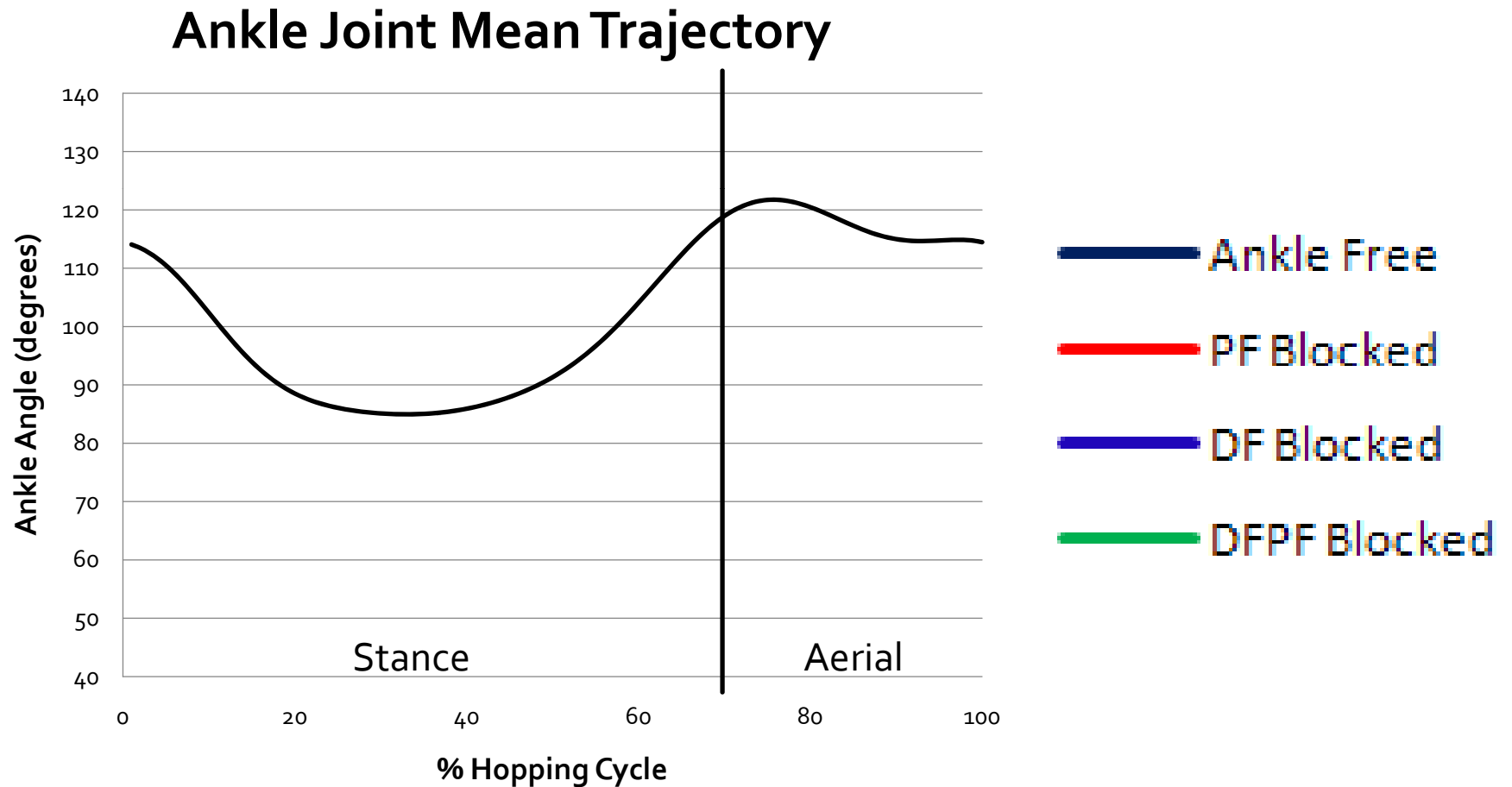
ROM Blocked:
39% ($\pm 11\%$)

DFPF Blocked

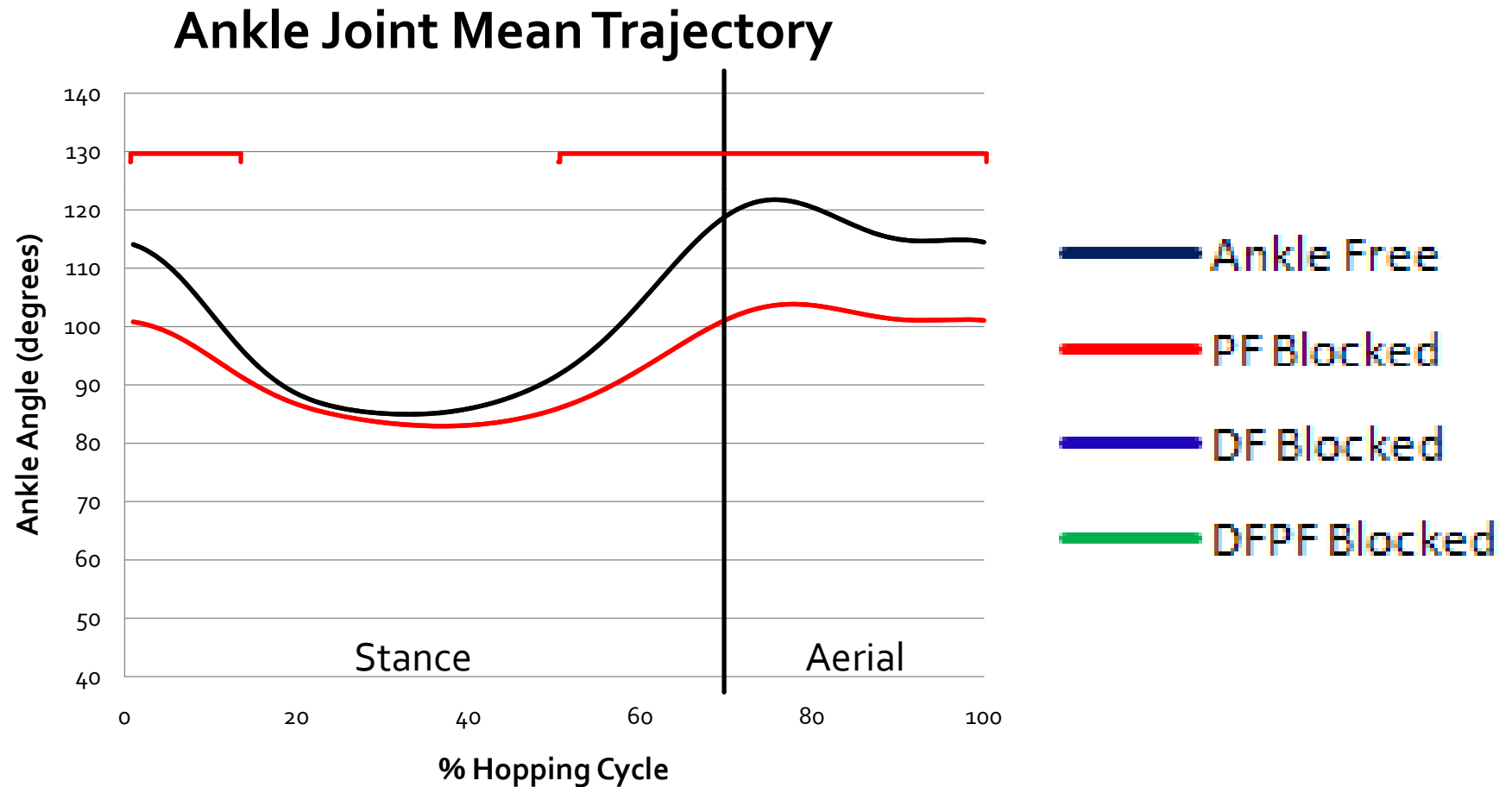


ROM Blocked:
PF: 18% ($\pm 13\%$)
DF: 18% ($\pm 10\%$)

Ankle Joint Limitations

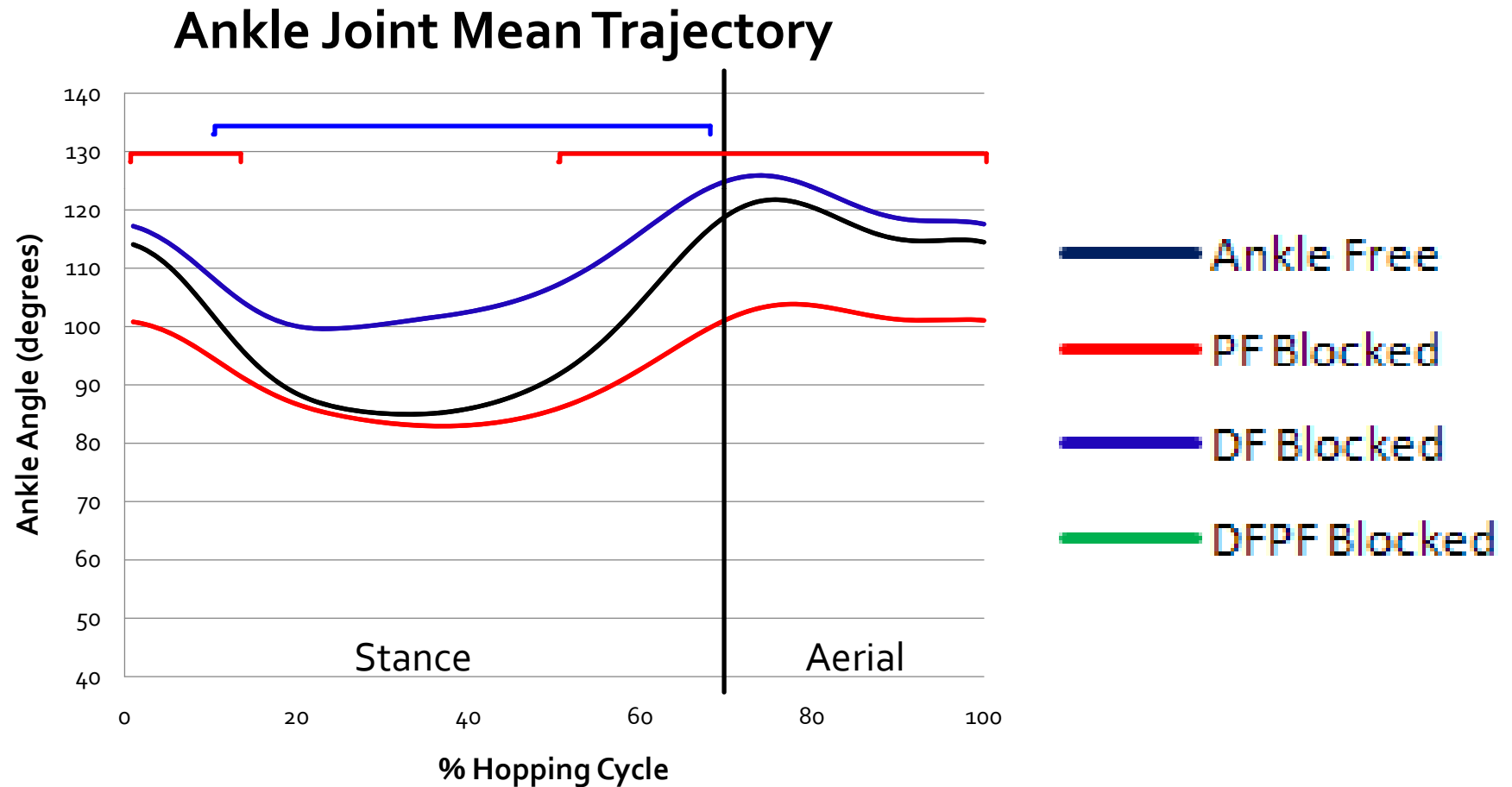


Ankle Joint Limitations



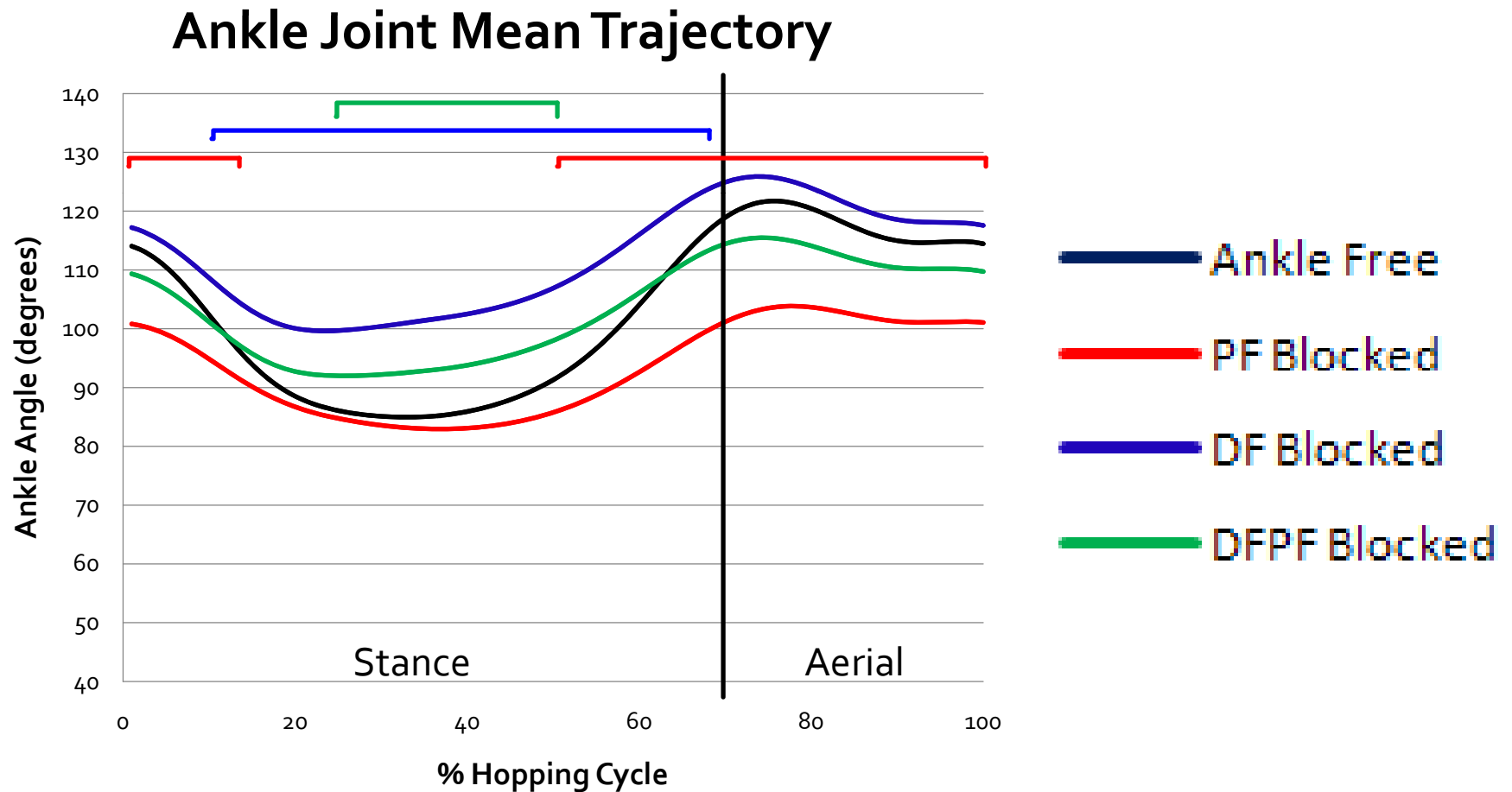
⌋ = $p < 0.05$

Ankle Joint Limitations



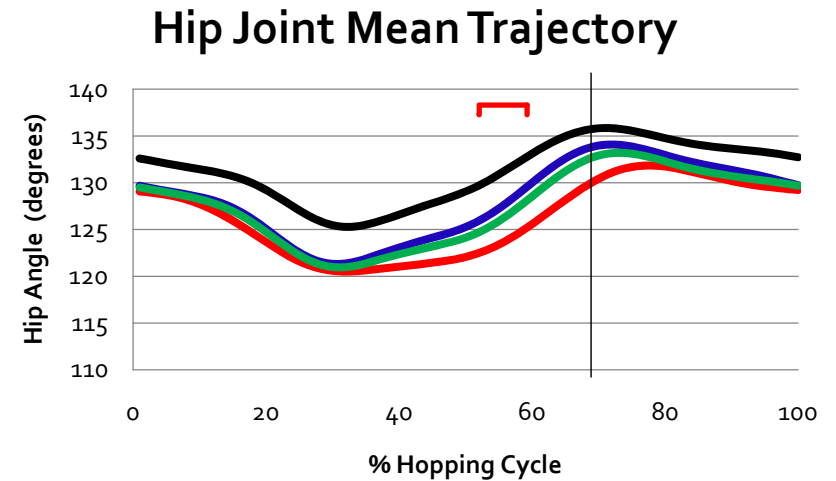
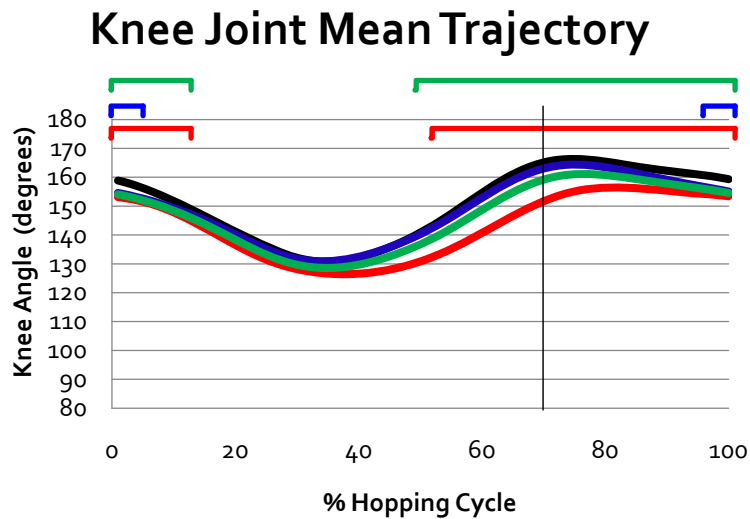
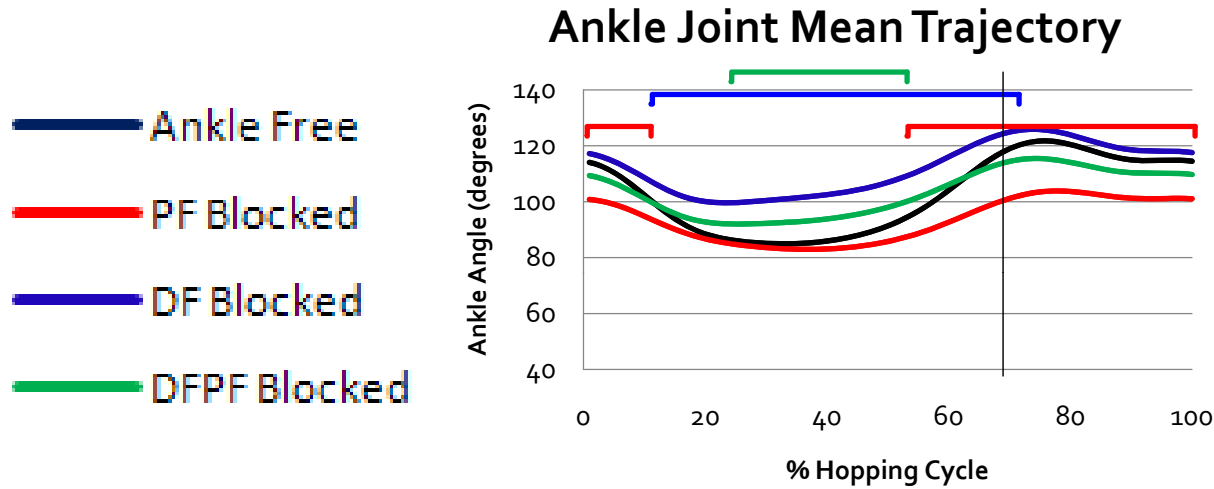
⌋ = $p < 0.05$

Ankle Joint Limitations



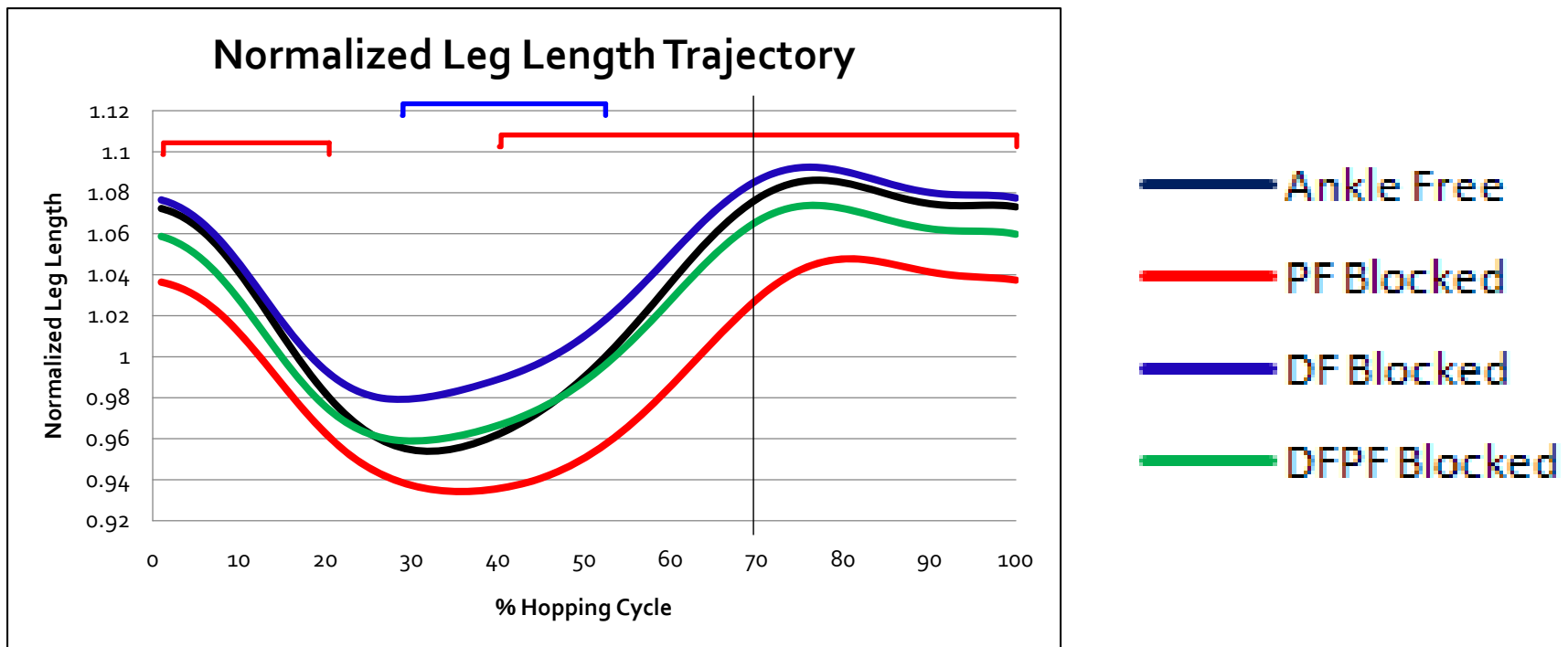
⌋ = $p < 0.05$

Joint Angle Differences



Leg Length Not Conserved

- Leg Length is not conserved for DF Blocked and PF Blocked conditions at the portions of hopping cycle affected by the constraints



□ = $p < 0.05$

Uncontrolled Manifold (UCM) Analysis

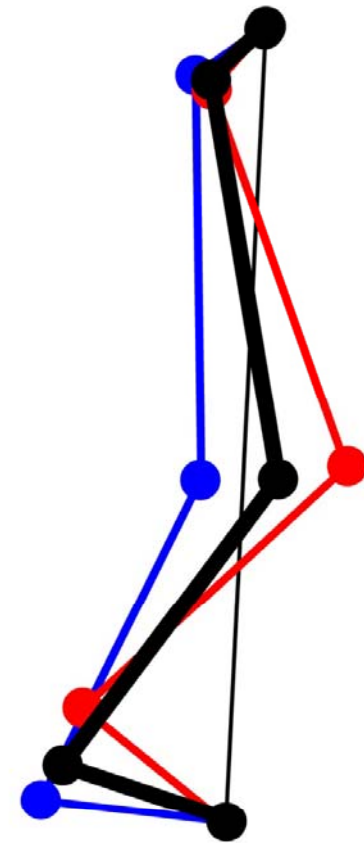
- Method used to test the 2nd prediction of the hypothesis
- UCM Analysis was used to quantify joint coordination across hopping cycles

IMA: Index of Motor Abundance

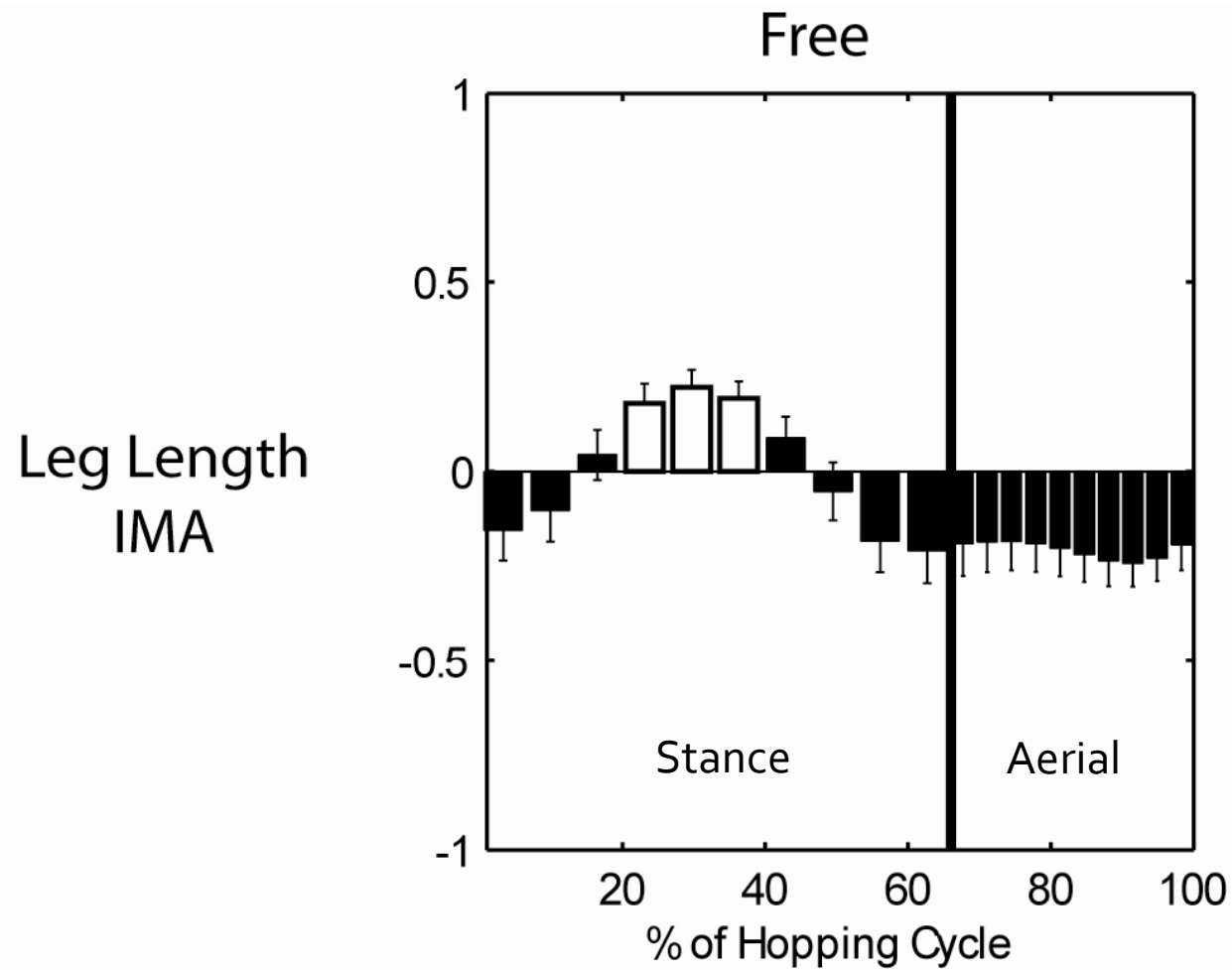
- Metric to determine if joint coordination occurred

$$IMA = \frac{Var_{UCM} - Var_{ORT}}{Var_{UCM} + Var_{ORT}}$$

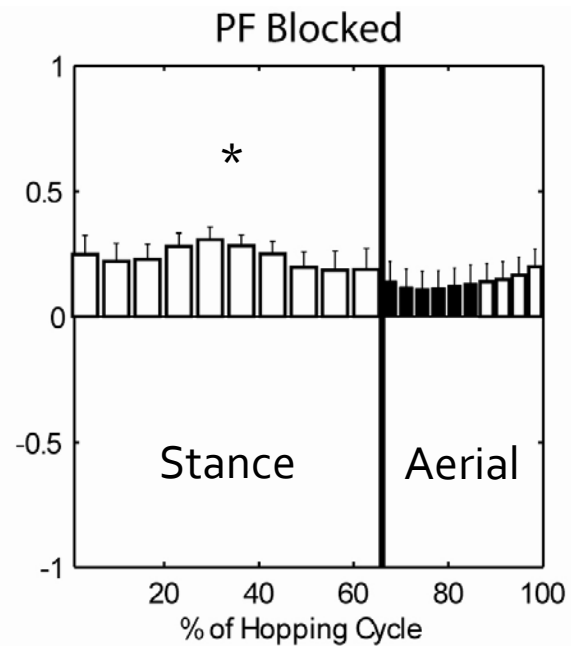
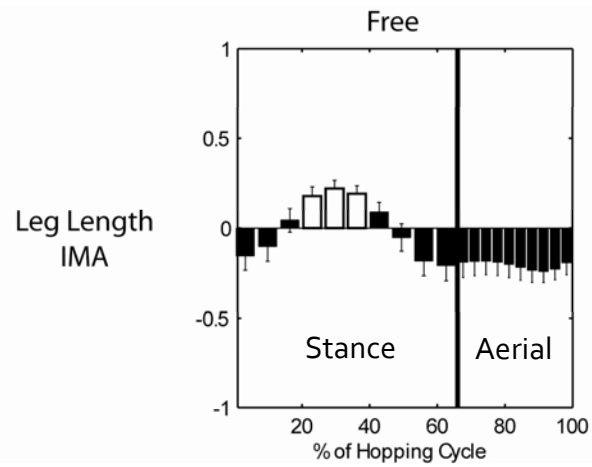
- **IMA > 0**: Hypothesis accepted (Joints are coordinated to conserve LL)
- **IMA ≤ 0**: Hypothesis rejected



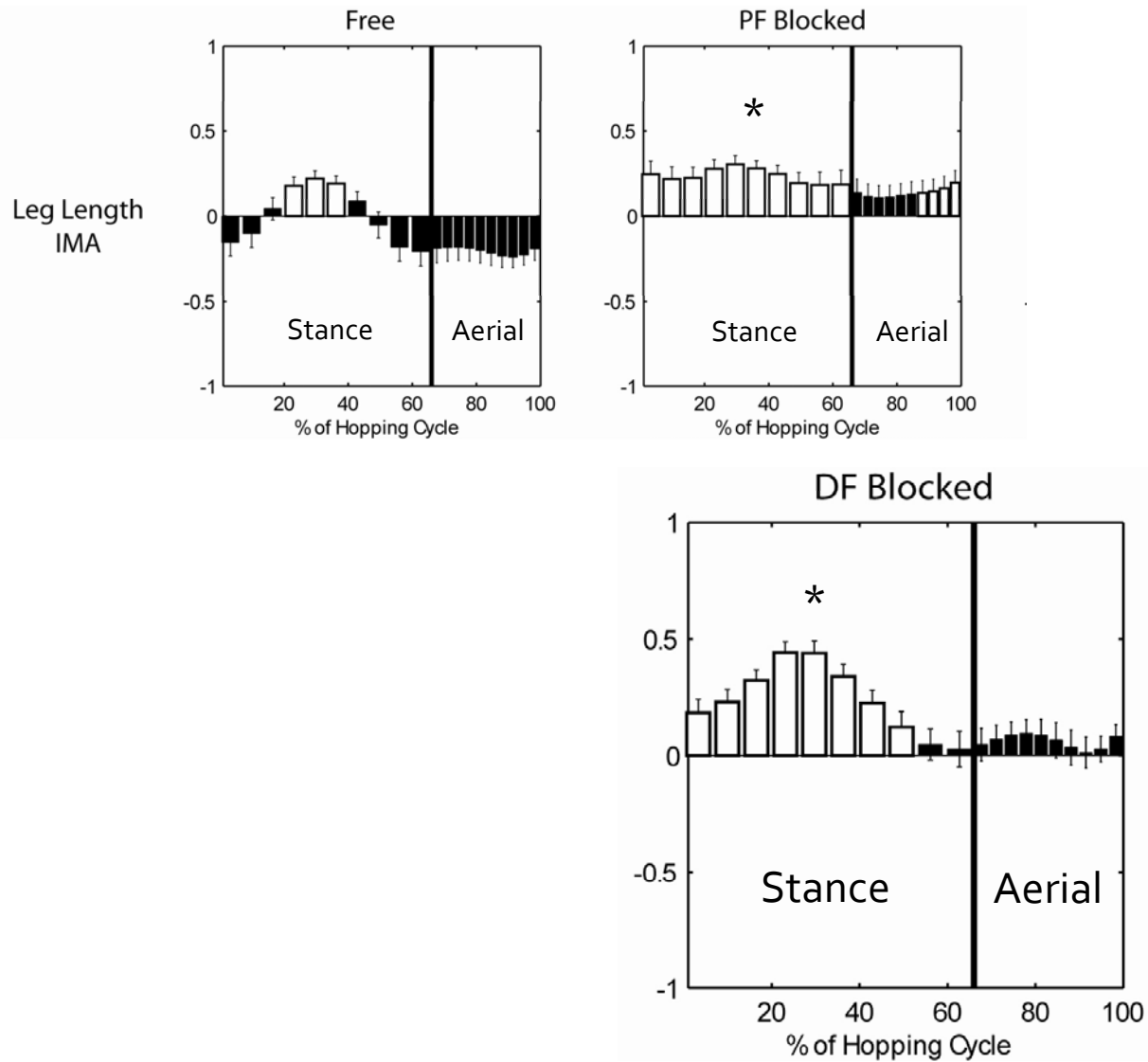
Leg Length IMA



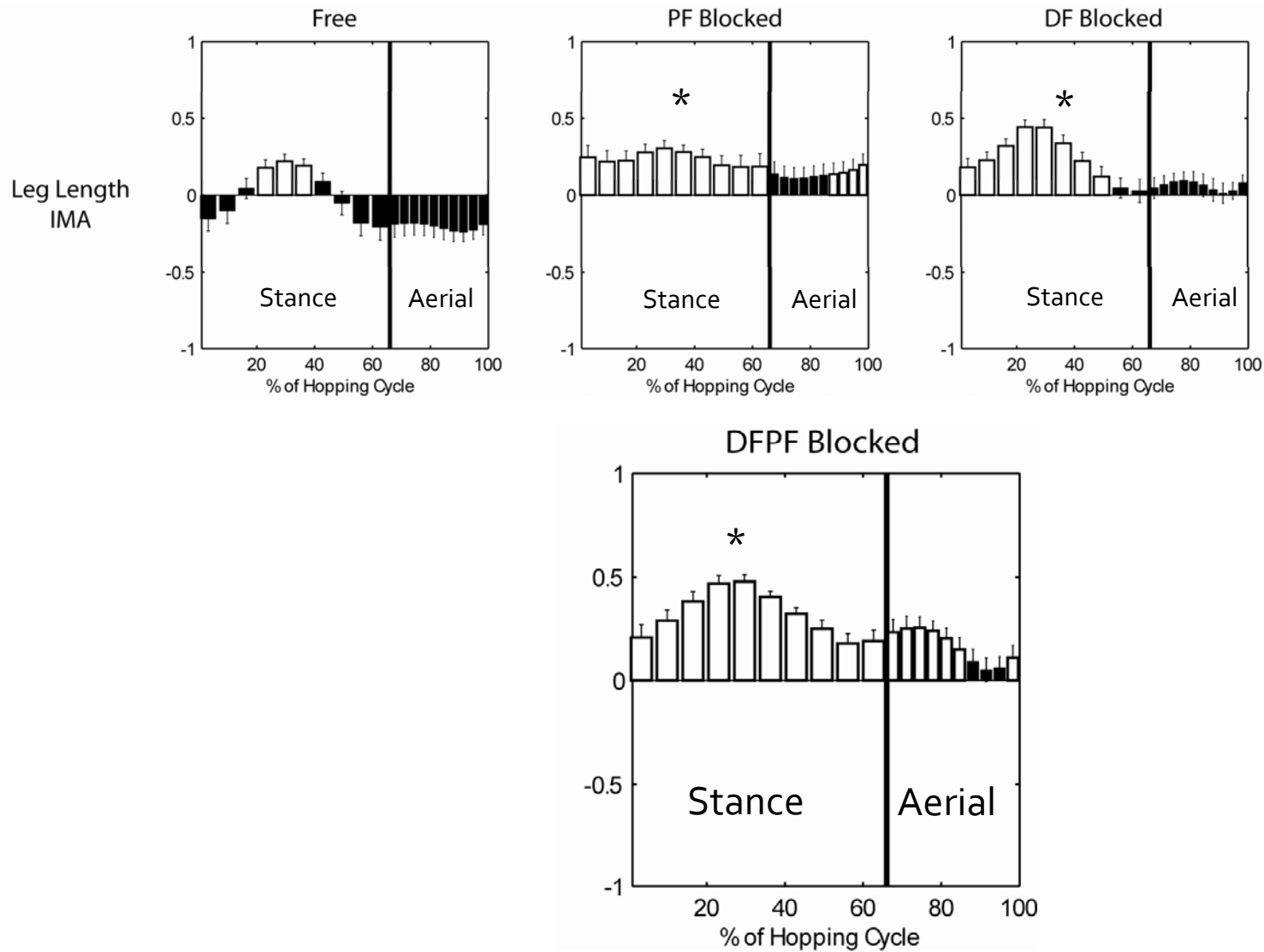
Leg Length IMA



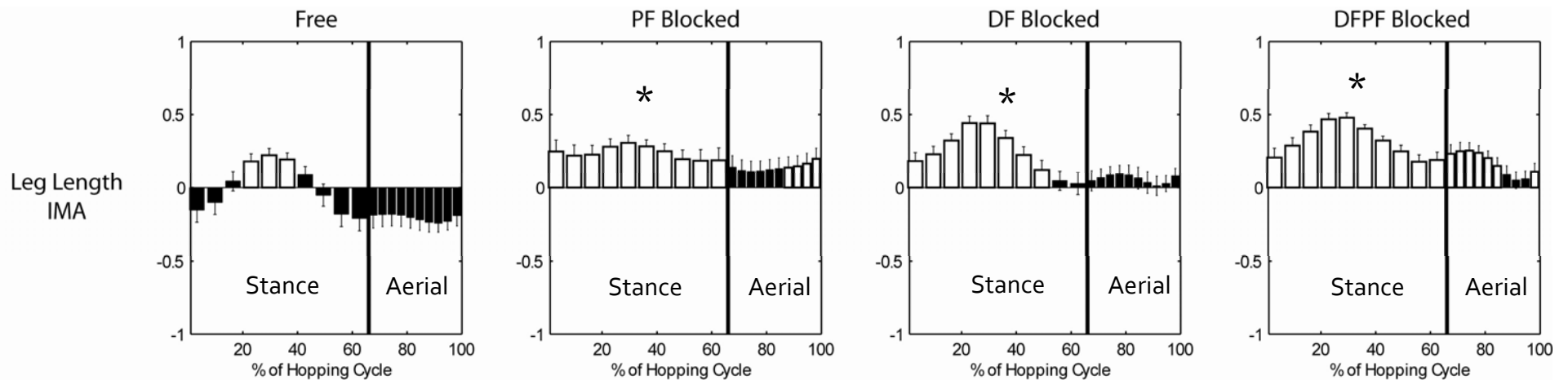
Leg Length IMA



Leg Length IMA



Leg Length IMA



- Increase in average IMA during stance occurs for constrained conditions
- Timing of IMA increase corresponds to the time when the constraints affect the hopping cycle

Discussion: Prediction 1

- Prediction 1: LL will be conserved across conditions
 - Rejected for PF Blocked & DF Blocked
 - LL conserved for DFPF Blocked

Discussion: Prediction 2

- Prediction 2: Intercycle joint angle variance will be coordinated to conserve LL across cycles
 - LL was conserved from hop to hop
 - Joint coordination is occurring to conserve LL

New Goal for Leg Length

- According to mean trajectory results:
 - When ankle motion is extremely limited (PF Blocked & DF Blocked), LL is not conserved
 - The system cannot overcome the limitation of the constraint
- According to the UCM analysis:
 - Across hops, an increase in joint coordination occurs to conserve LL
 - Compensation strategy = different LL goal

Limitations & Future Studies

- Limitation:
 - AFO did not behave the same for all subjects
- Future Studies:
 - Repeat with a more robust AFO
 - Constraining other joints
 - Constraining multiple joints

Conclusion

- System cannot always compensate
- The DF Blocked and PF Blocked constraints were too great for the leg to compensate across conditions
- However, the system conserves LL across hopping cycles
- Even when the LL trajectory changes, the joints still coordinate to conserve a new LL goal

Research Applications

- **Patient Rehabilitation:** Focus on whole limb training rather than on individual joints
- **Orthotics:** Associated compensatory strategies occur at the other joints
- **Prosthetics:** Even if amputees adopt trajectories different from the norm, they may coordinate their joints to stabilize LL

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References

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Questions



Methods – Experimental AFO

- An adjustable plastic and metal hybrid AFO was used as an experimental tool to limit ROM at the ankle joint

