Mechanical Engineering Seminar (U-Grad)
Special Topics in Mechano-Informatics II (Grad)
“Biomechanics of Human Movement”

May 9th, 2014

Dr. Emel Demircan

Announcements

- HW1 average score 82.7/100
- HW2 out today, due on 5/23, 5pm **(Only Questions of I-IV)**
- Project Teams/Topics:

Socially Assistive Robots I:
1) Tomoyuki Maekawa
2) Emiko Uchiyama
3) Tianwei Zhang

Exoskeleton Robots & Rehabilitation Robotics:
1) Haruyuki Sanuki
2) Shunsuke Sato
3) Tatsuya Ichikawa

Socially Assistive Robots II:
1) Veerachant Srisamosarn
2) Park Huijun

Animation and Simulation:
1) Taira Miyatake
2) Yumiko Furuhata
3) Itsuki Ichikawa

Human Motion Tracking I:
1) Wu Cheng
2) Liang Boshen

Human Motion Tracking II:
1) Rie Hitsuyu
2) Heewon Park

Schedule

4/18: Introduction
4/25: Spatial Descriptions, Kinematics, Introduction to Biomechanical Simulation
5/2: Skeletal Muscle Structure, Force Generation, Musculoskeletal Geometry
5/9: Production of Movement
5/23: Motion Tracking Techniques
6/6: Inverse Dynamics, Control, Operational Space Formulation
6/27: Human Articulated Body Model, Dynamics, and Motion Control
7/4: Advanced Topics in Human Motion Analysis, Student Presentations

Agenda

- Muscle Physiology
- Muscle-Tendon Unit
- Force-Velocity, Force-Length Relationship
- Muscle Jacobian
- Muscle/Task Relationship
- Production of Movement
- Gait Cycle
- Determinants of Gait
- Gait Analysis
- Gait Abnormalities: A Case Study

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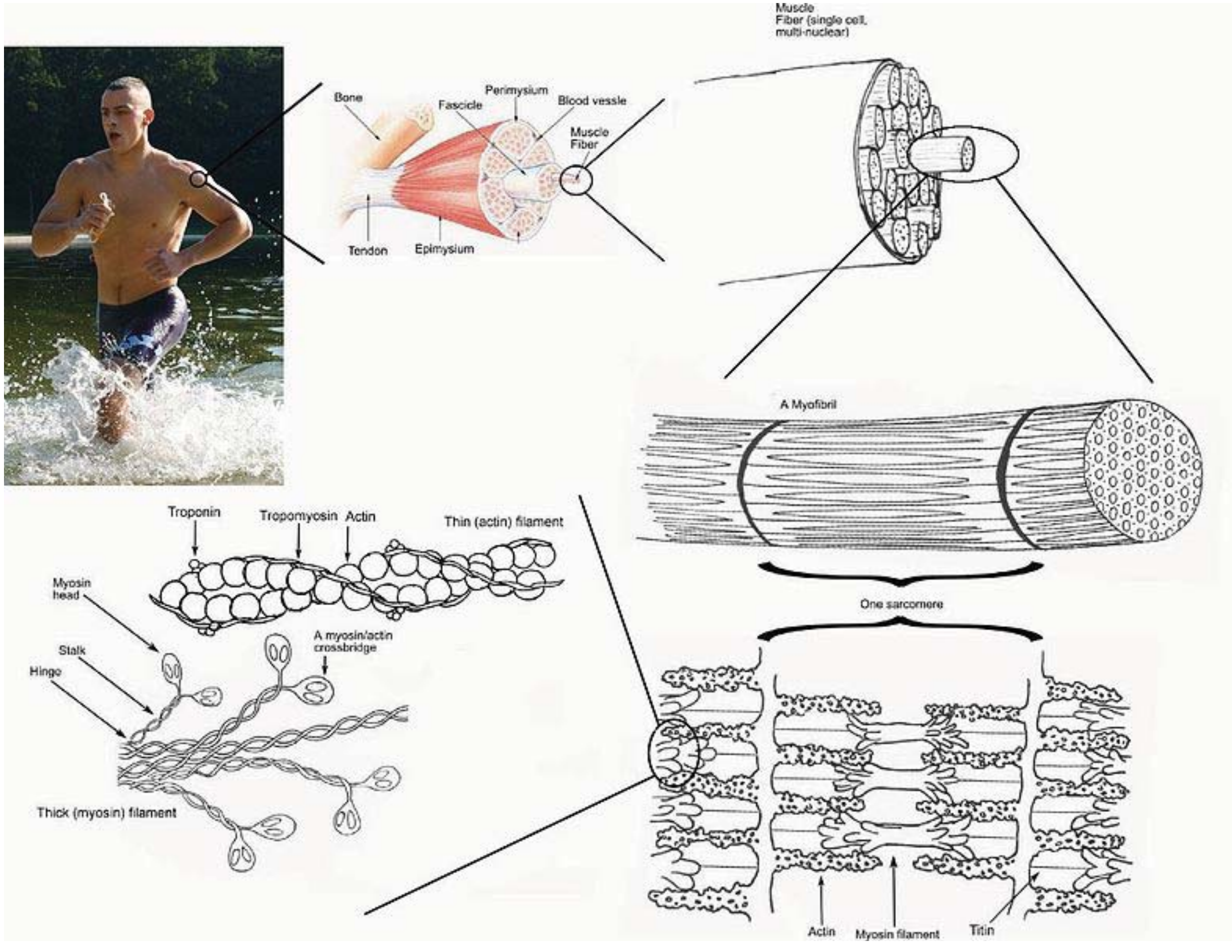
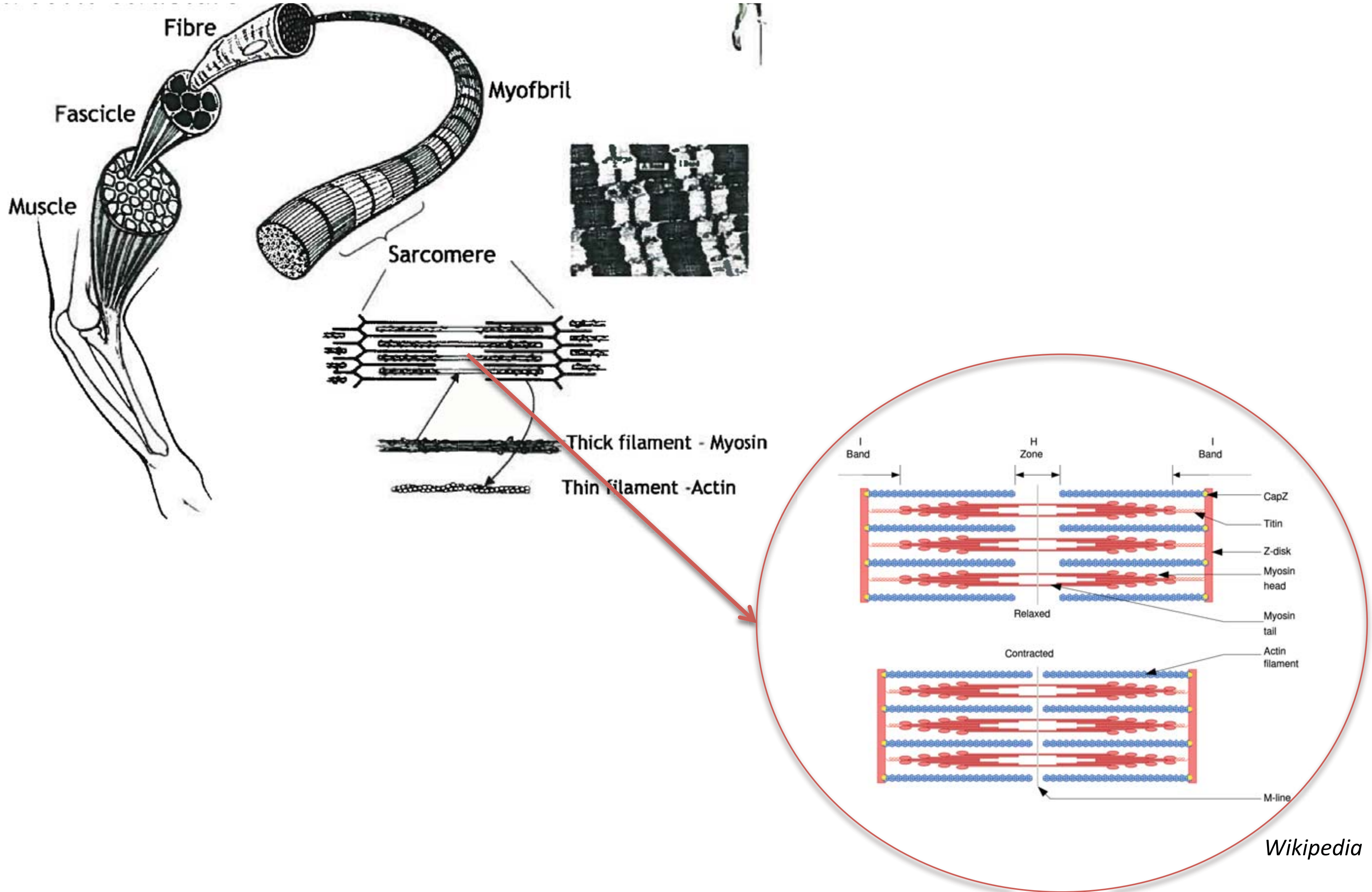
Muscle Physiology

- Muscles
  - Force Production
  - Support



wikipedia.org

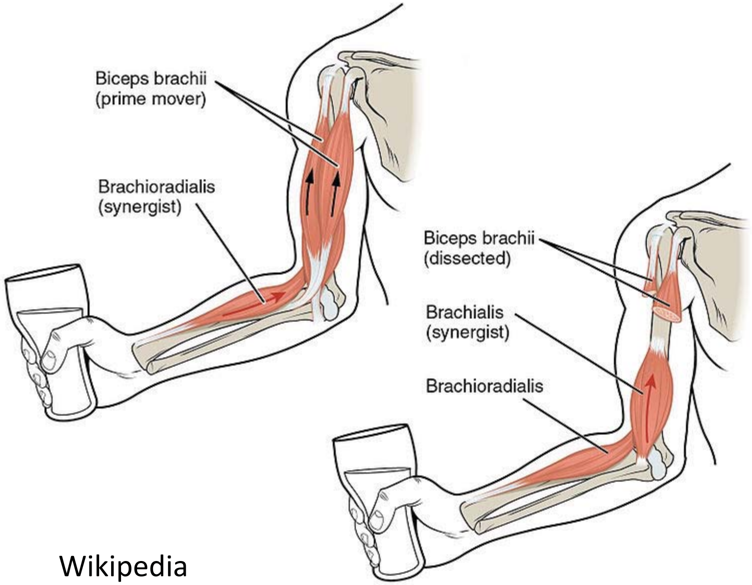
Muscle Structure



Wikipedia

Agonist/Antagonist Muscles

- Muscles pull, do not push!
- Muscles come in pairs:
- **Agonists** are referred to, interchangeably, as "prime movers" (skeletal muscles)
- **Antagonist** muscles oppose a specific movement
- **Antagonism is a role**, played depending or the motion. If the motion is reversed, agonist and antagonist switch roles. A flexor muscle is always flexor. But in flexion, it is always agonist and in extension, it is always antagonist. An extensor muscle is agonist in extension and antagonist in flexion.



Wikipedia

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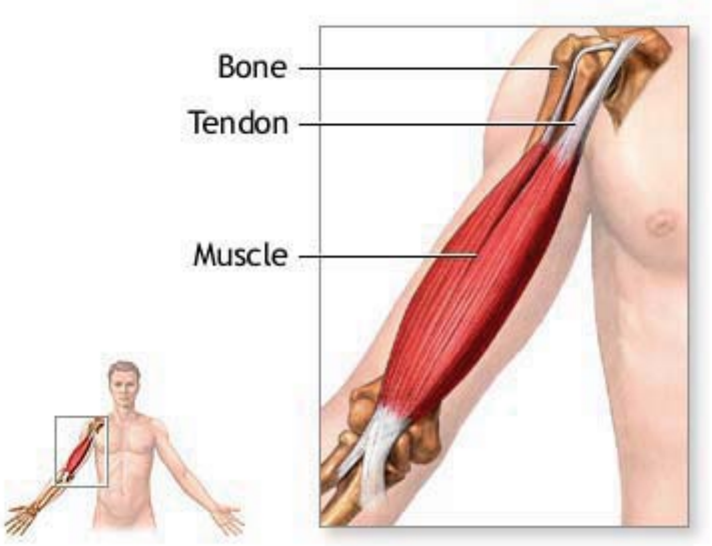
Muscle-Tendon Unit



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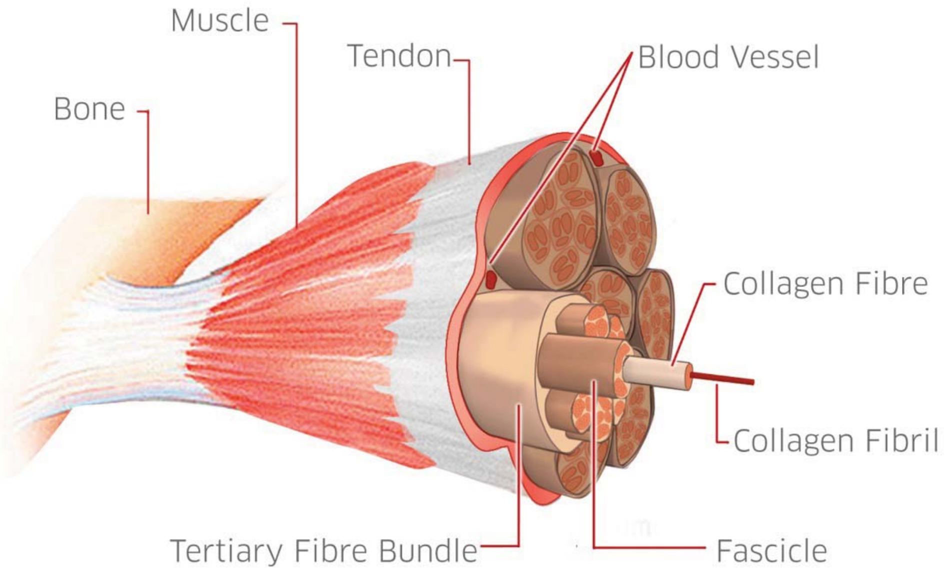
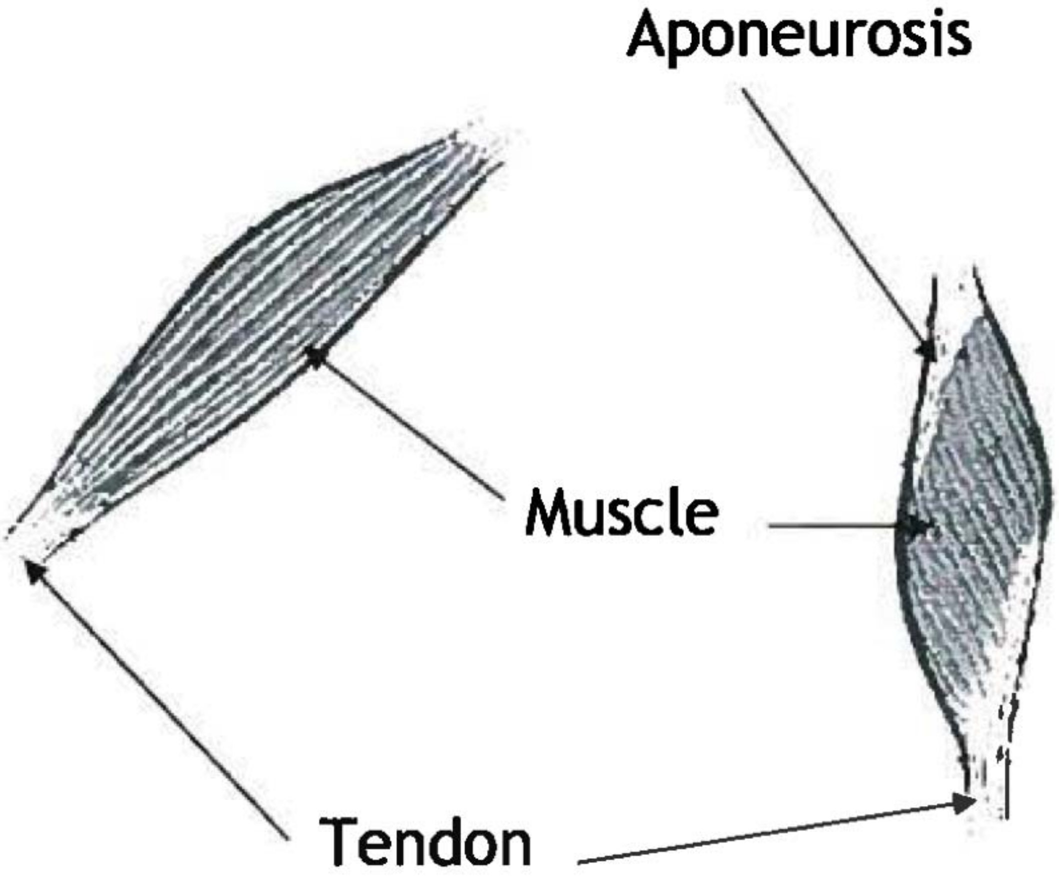
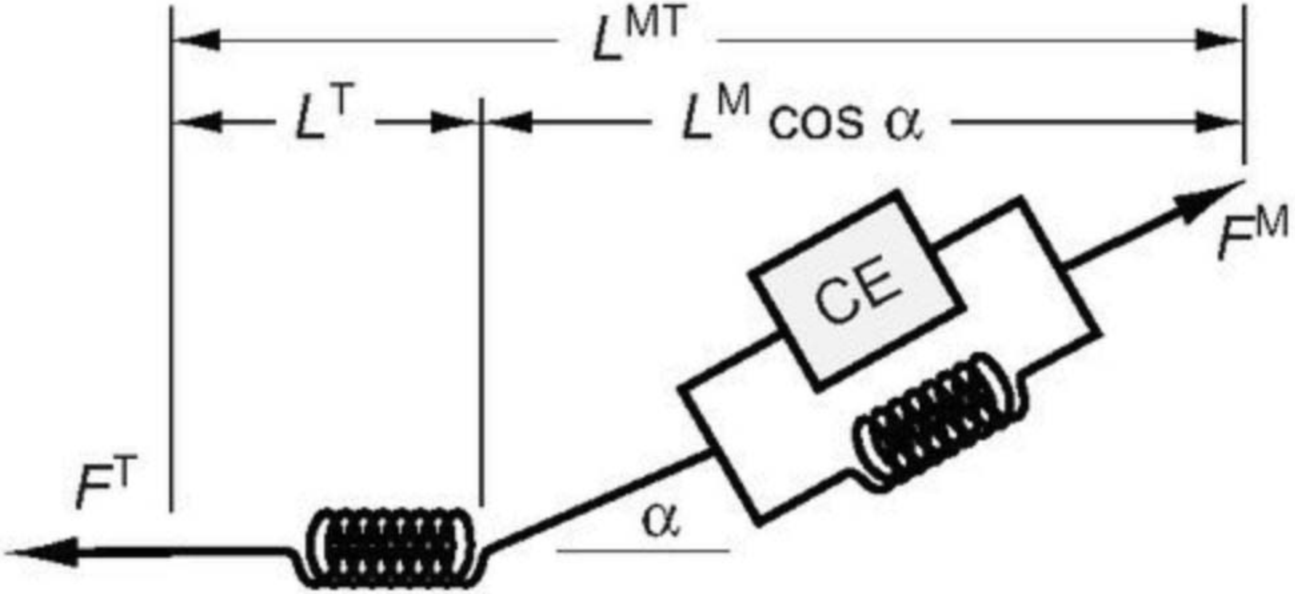


Muscle-Tendon Unit



Hill-Type Equilibrium Model (1938)

Mechanical Model of Musculotendon Unit

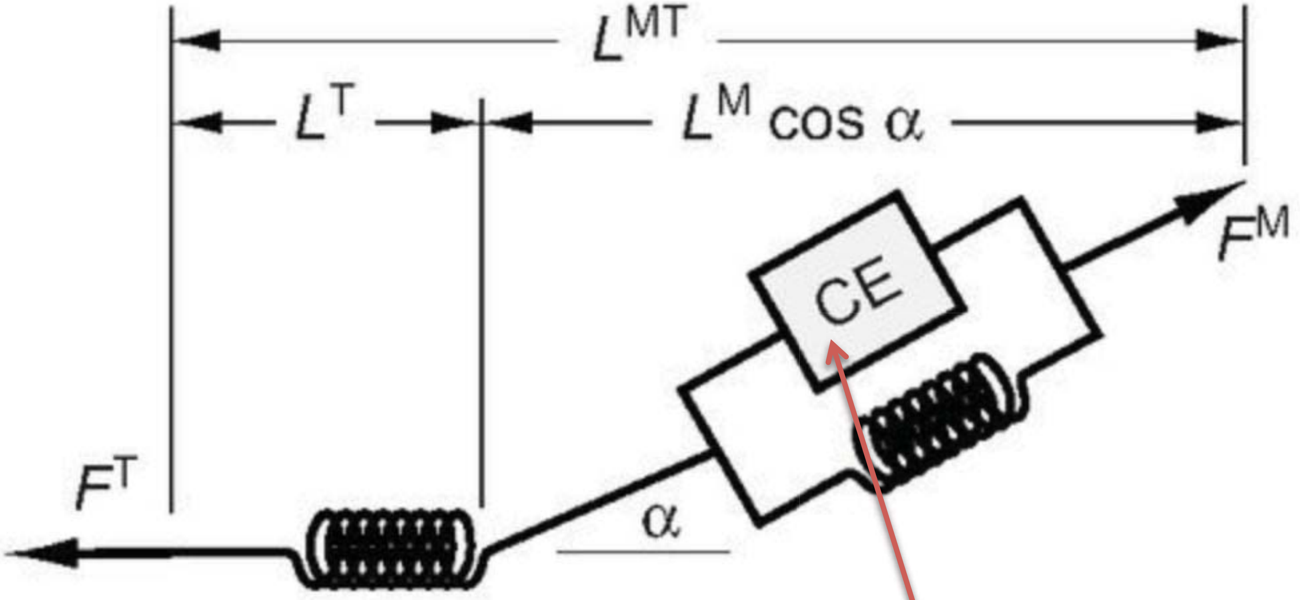


http://jeb.biologists.org/content/216/11/2150/F2.expansion.html

CE: contractile element
LMT: muscle-tendon length
LM: muscle fiber length
LT: tendon length
Alpha: pennation angle
Fm: muscle force
Ft: tendon force

Hill-Type Equilibrium Model (1938)

Mechanical Model of Musculotendon Unit



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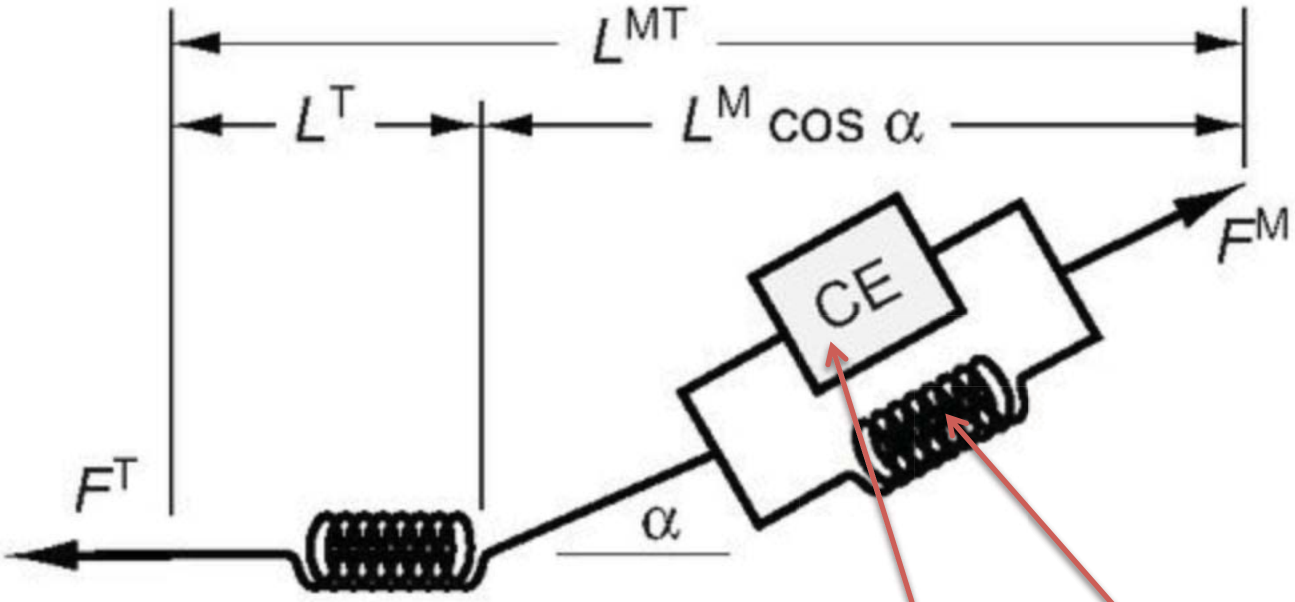
Represents the active force production in sarcomere

Hill-Type Equilibrium Model

Mechanical Model of Musculotendon Unit



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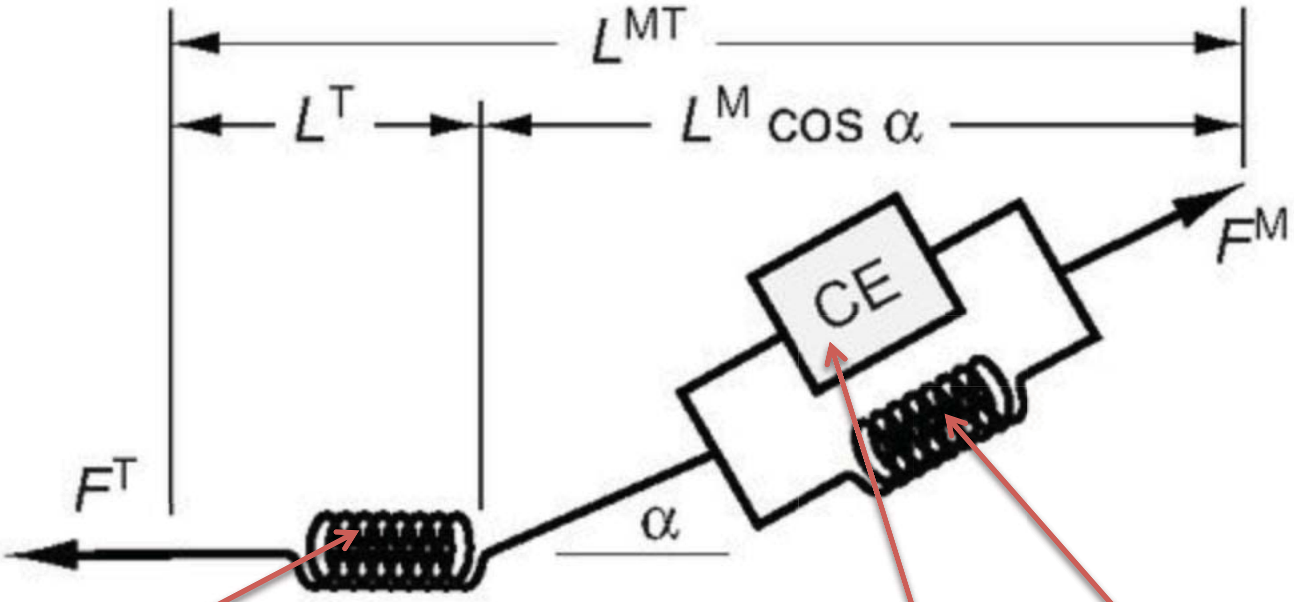
Represents the connective tissues / Soft Tissue Mechanical Behavior

Represents the active force production in sarcomere

Hill-Type Equilibrium Model

Mechanical Model of Musculotendon Unit



http://jeb.biologists.org/content/216/11/2150/F2.expansion.html

Represents the tendon
Soft tissue response
Energy Storing Mechanism

CE: contractile element
LMT: muscle-tendon length
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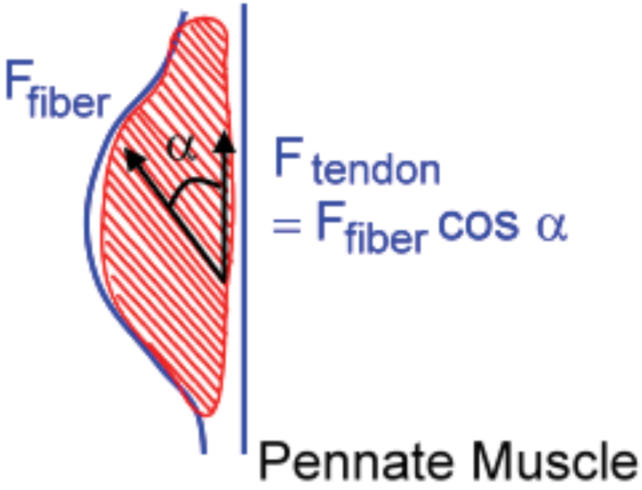
LT: tendon length
Alpha: pennation angle
Fm: muscle force
Ft: tendon force

Represents the connective tissues / Soft Tissue Mechanical Behavior

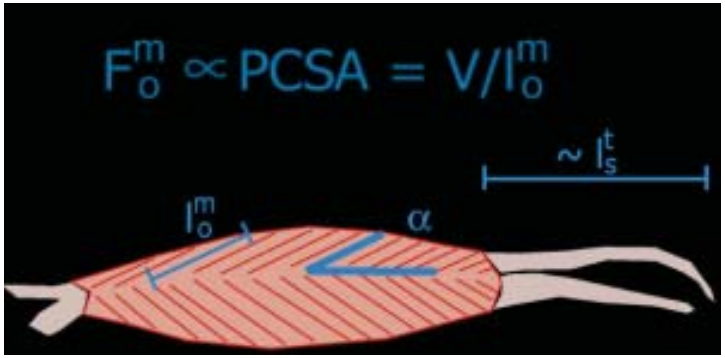
Represents the active force production in sarcomere

Muscle Architecture

Arrangement of Muscle Fibers Relative to the Axis of Force Generation



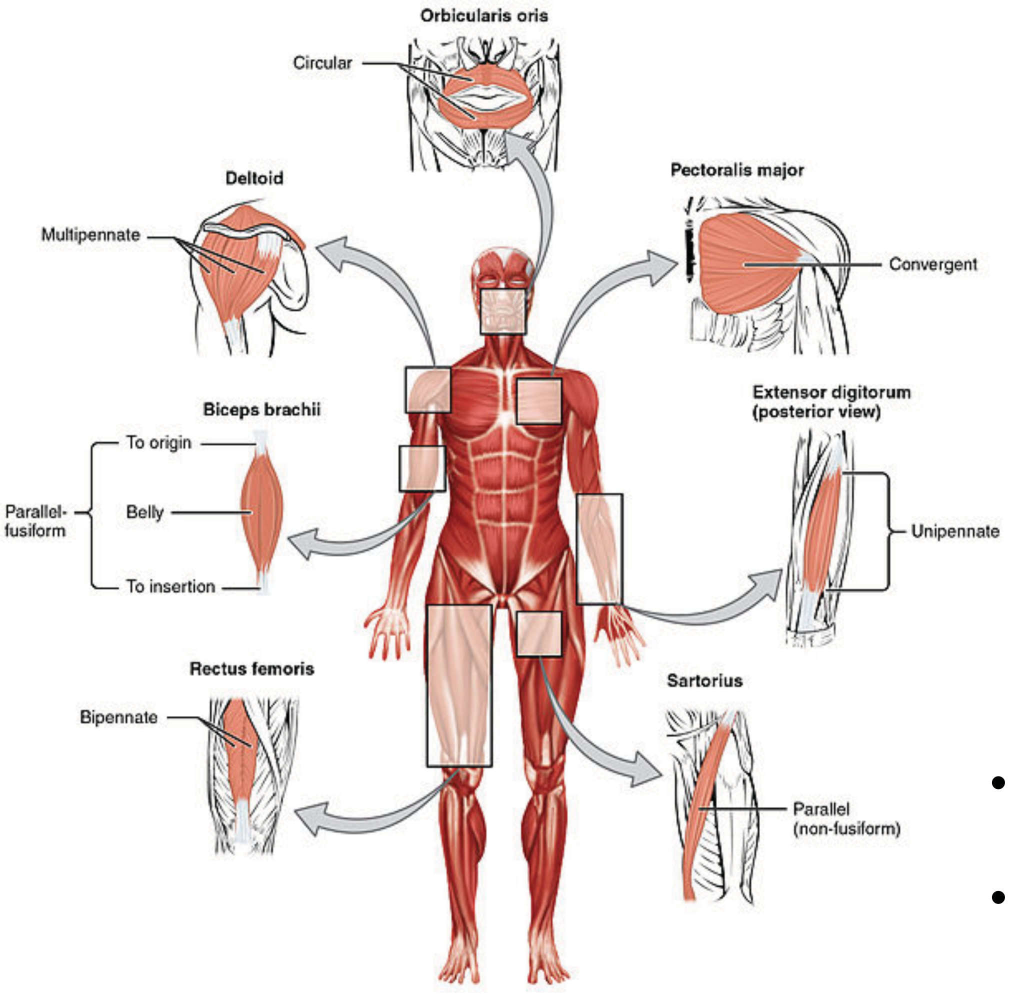
http://www.pt.ntu.edu.tw/



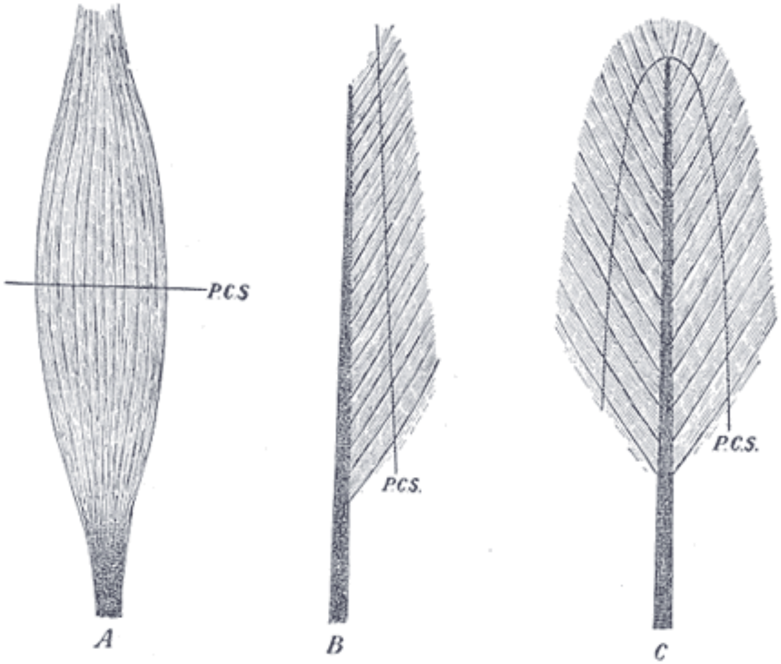
l = optimal fiber length
F = force produced at optimal fiber length
PCSA = physiological cross-sectional area
V = muscle volume
Alpha = pennation angle

- Physiologic cross-sectional area (PCSA) is the sum of the areas of each fiber in the muscle.
- Muscle force is proportional to physiologic cross-sectional area (PCSA), and muscle velocity is proportional to muscle fiber length.

Muscle Types



Wikipedia



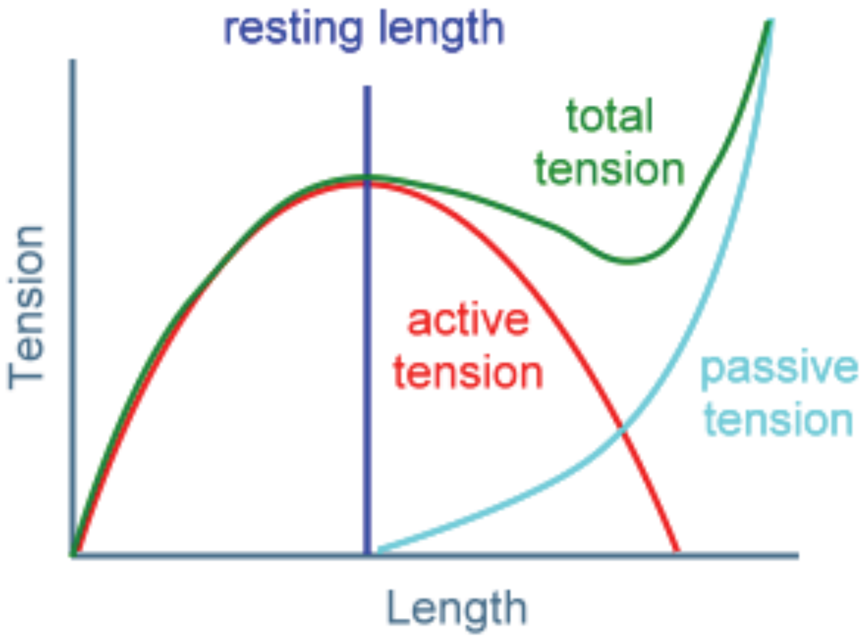
A: fusiform. B: unipennate. C: bipennate.

- Muscles can be described by the direction that the muscle fibers run in.
- Physiologic cross-sectional area (PCSA) is the sum of the areas of each fiber in the muscle.

Muscle Force Generation

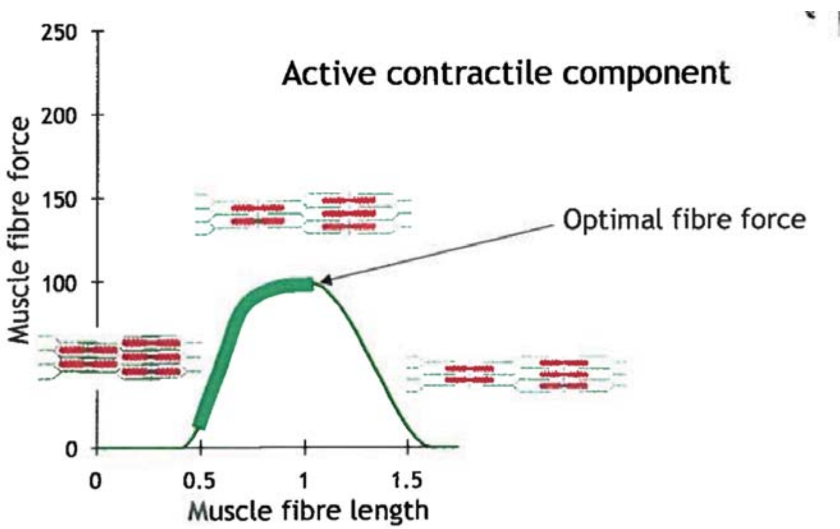
Force-Length Relationship

- Muscle force generation depends on **velocity** and **length**
- Muscle fibers have a small operating range where they produce maximal force. Skeletal muscle can produce approx. 30N of force per square cm of muscle.



Length-Tension Curve of a Muscle

worldfitness.com



Muscle fibres have a small operating range where they produce maximal force. Skeletal muscle can produce ~ 30 N of force per square cm of muscle

Muscle Force Generation

Force-Velocity Relationship

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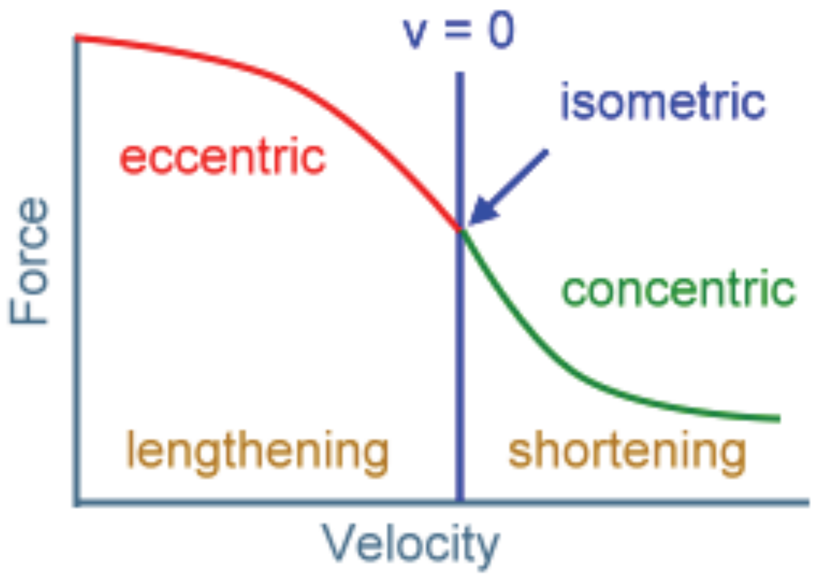

Force-Velocity Curve of a Muscle

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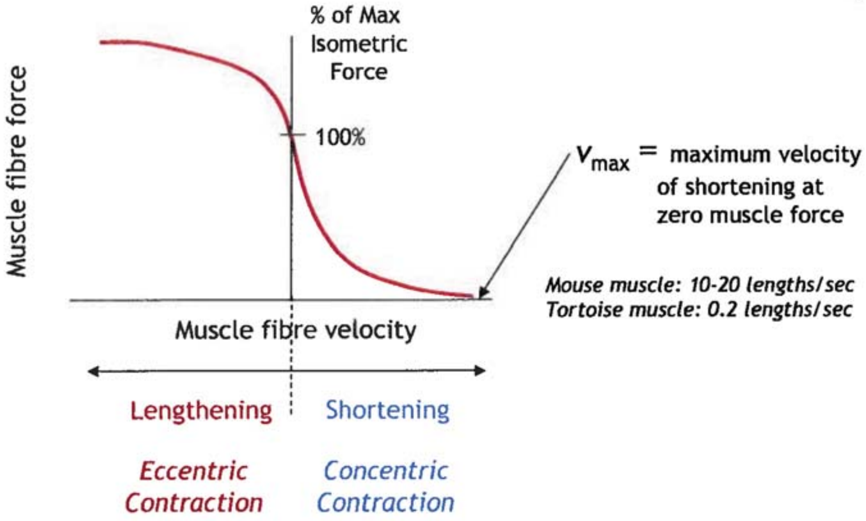
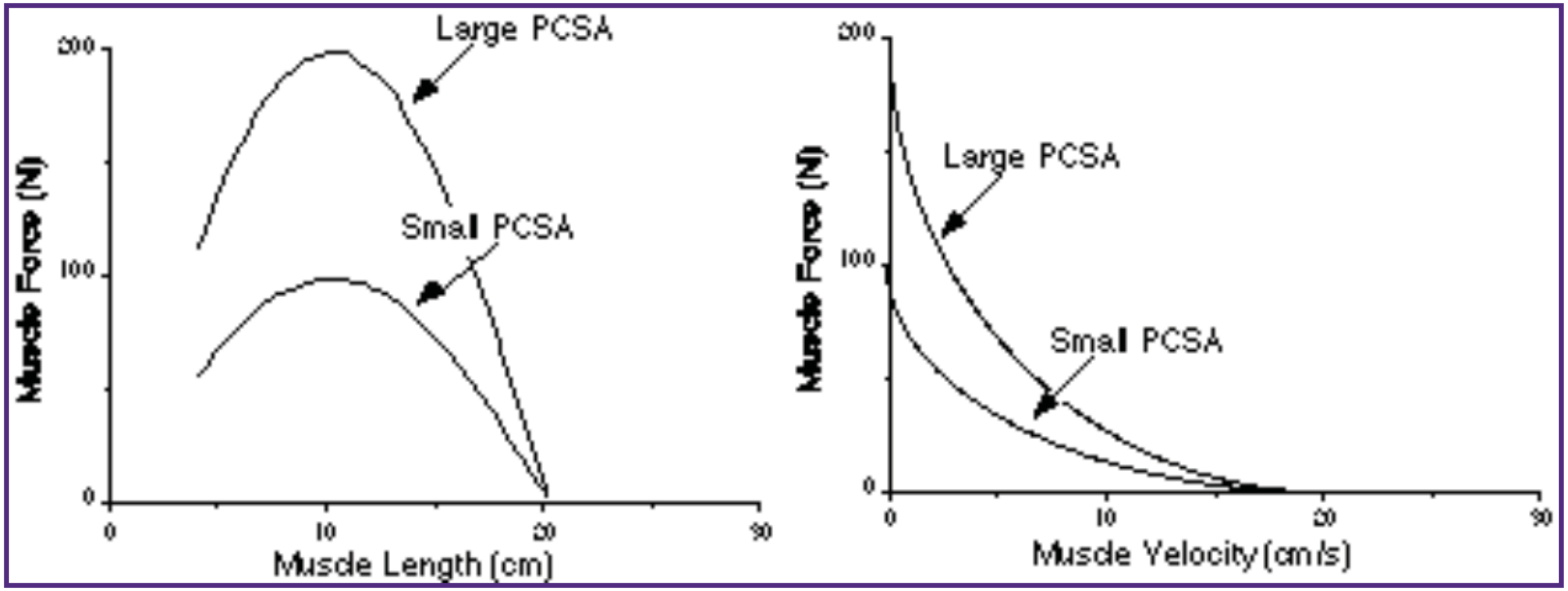


Effect of Muscle Architecture on Muscle Function

- Comparison of two muscles with same fiber lengths and pennation angles but different physiologic cross-sectional areas (and different mass):



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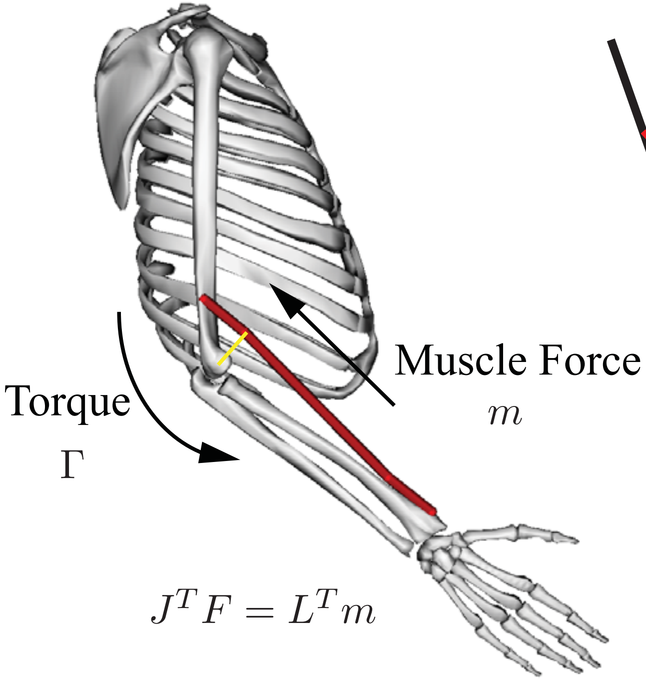
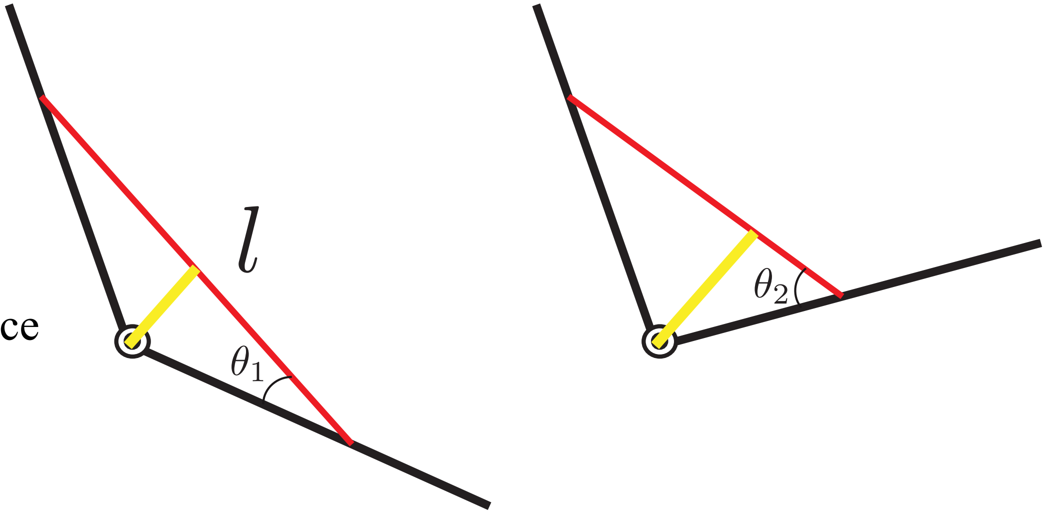
Musculoskeletal Geometry

Muscle Moment Arm

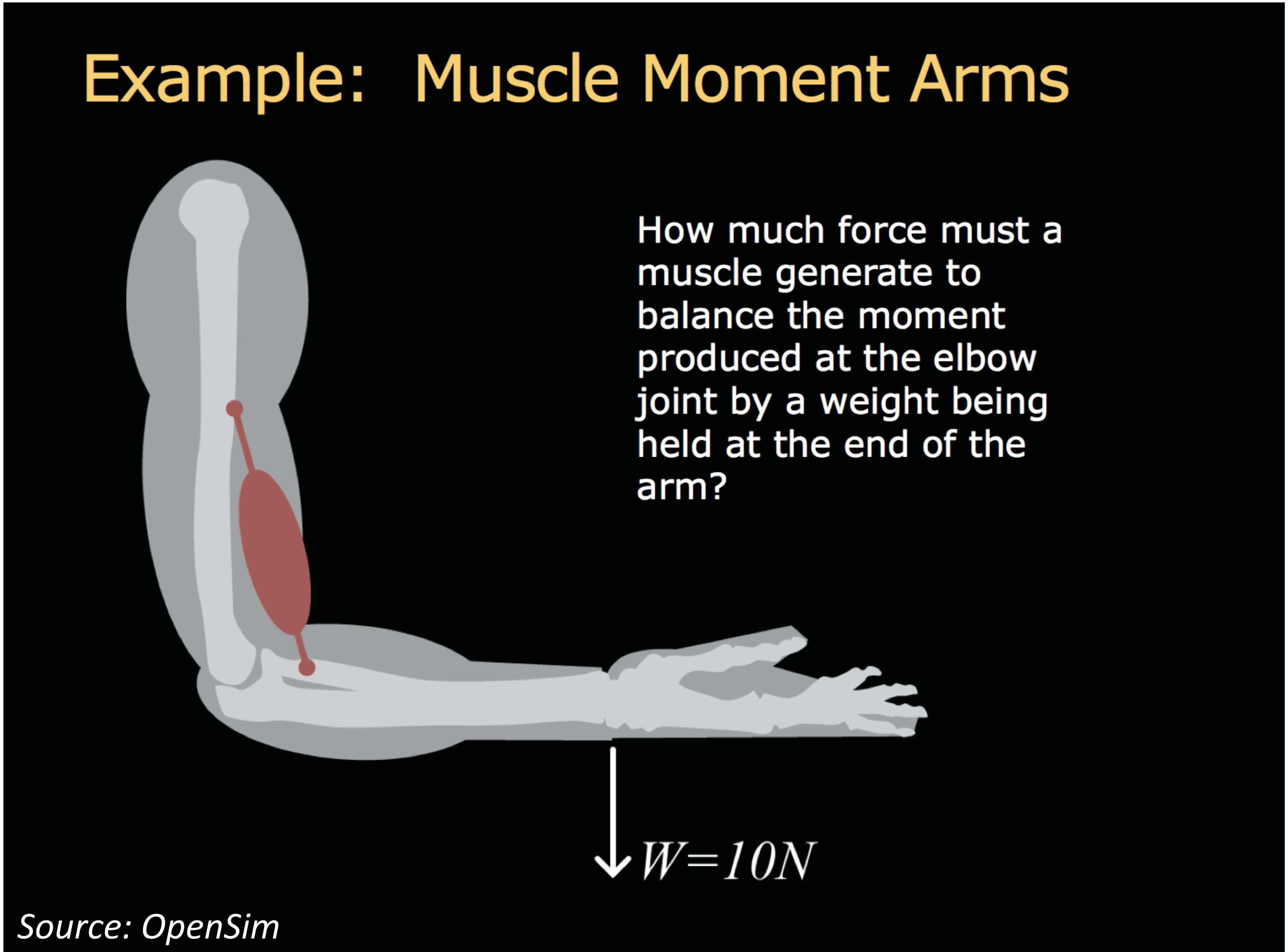




Definition: Muscle Jacobian, L. *In human musculoskeletal models all musculo-tendon lengths, l, can be uniquely determined from the joint angle, θ, and differential changes, dl, are given by:*

$$dl = L d\theta$$

Moment Arm Calculation

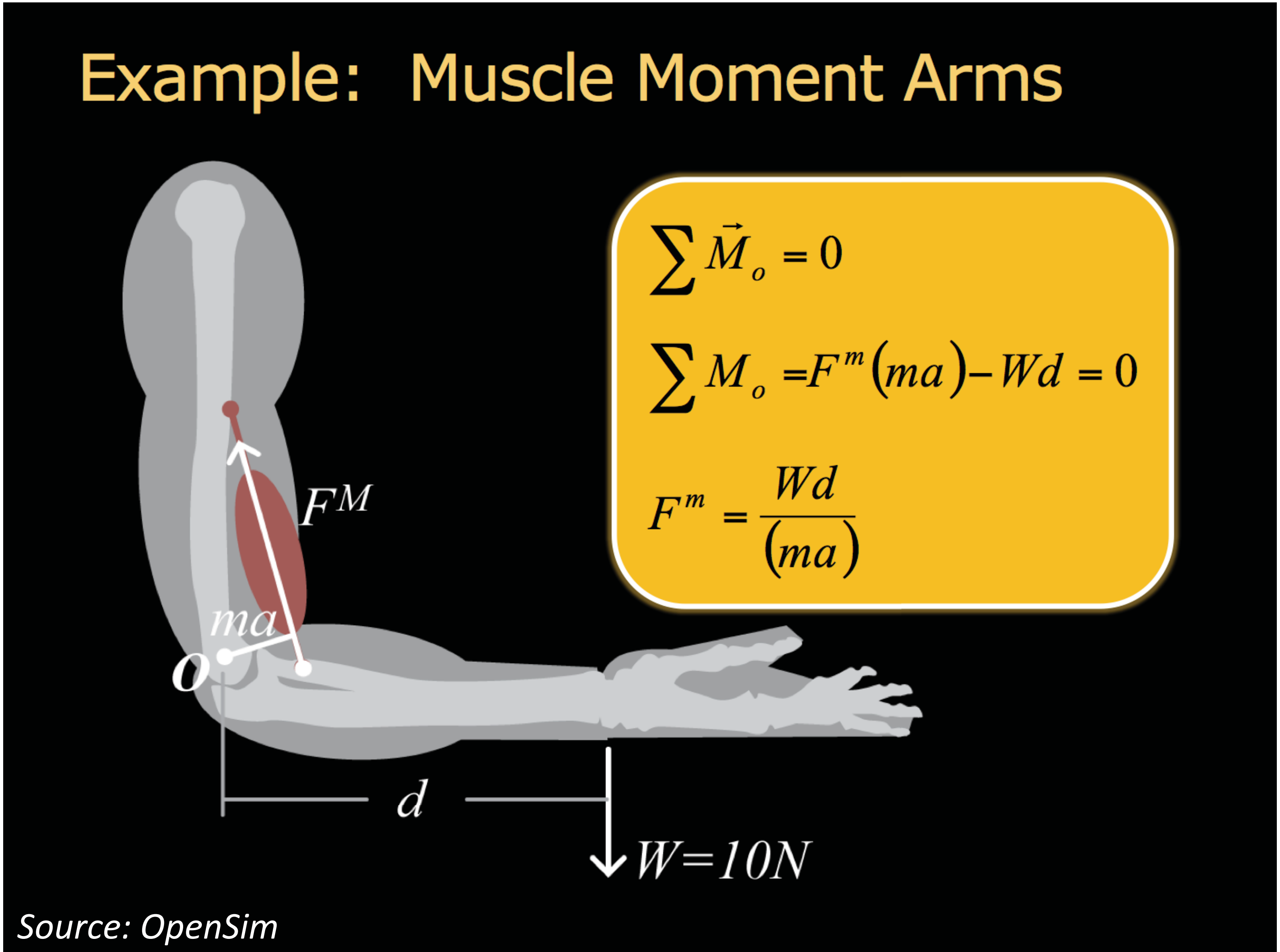


Example: Muscle Moment Arms

How much force must a muscle generate to balance the moment produced at the elbow joint by a weight being held at the end of the arm?

Source: OpenSim

Moment Arm Calculation



Example: Muscle Moment Arms

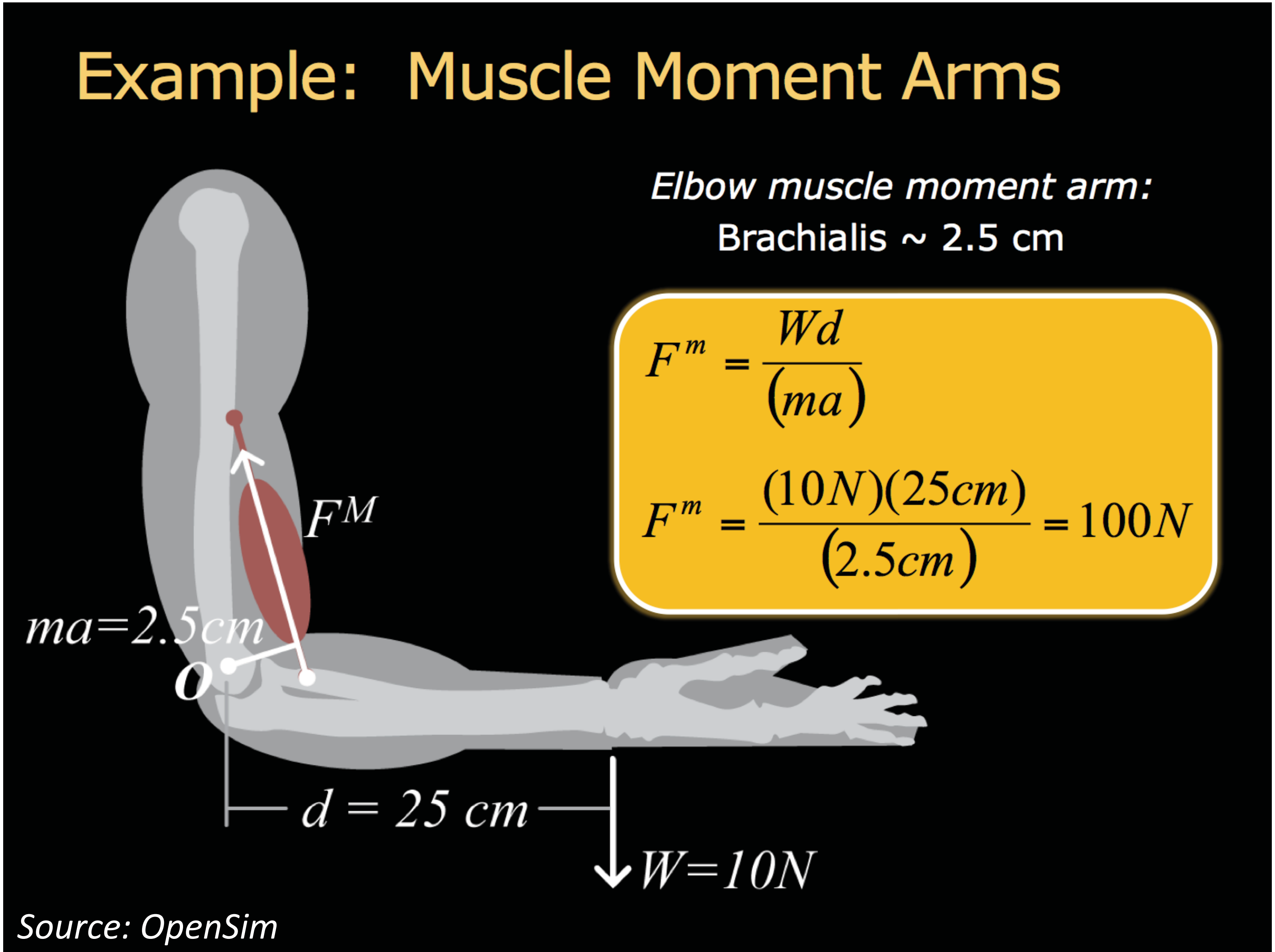
$$\sum \vec{M}_o = 0$$

$$\sum M_o = F^m(ma) - Wd = 0$$

$$F^m = \frac{Wd}{(ma)}$$

Source: OpenSim

Moment Arm Calculation



Example: Muscle Moment Arms

Elbow muscle moment arm:

Brachialis ~ 2.5 cm

$$F^m = \frac{Wd}{(ma)}$$

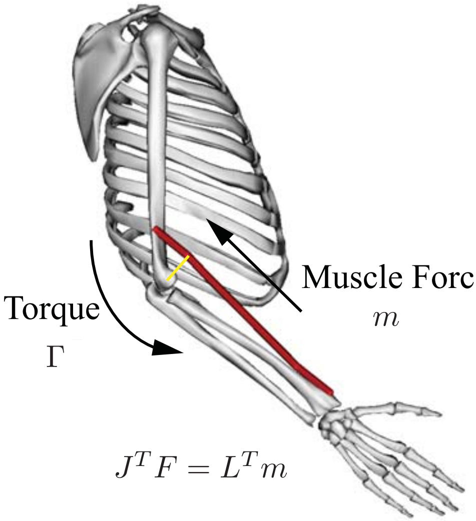
$$F^m = \frac{(10N)(25cm)}{(2.5cm)} = 100N$$

Source: OpenSim

Muscle/Task Relationship

Task Dynamics: $$\Gamma = J^T F$$

Muscle Dynamics: $$\Gamma = L^T m$$



Muscle-induced Joint Torques / Task:

$$J^T F = L^T m$$

where
J : skeleton Jacobian
F : task Forces
L : muscle Jacobian
m : muscle Forces

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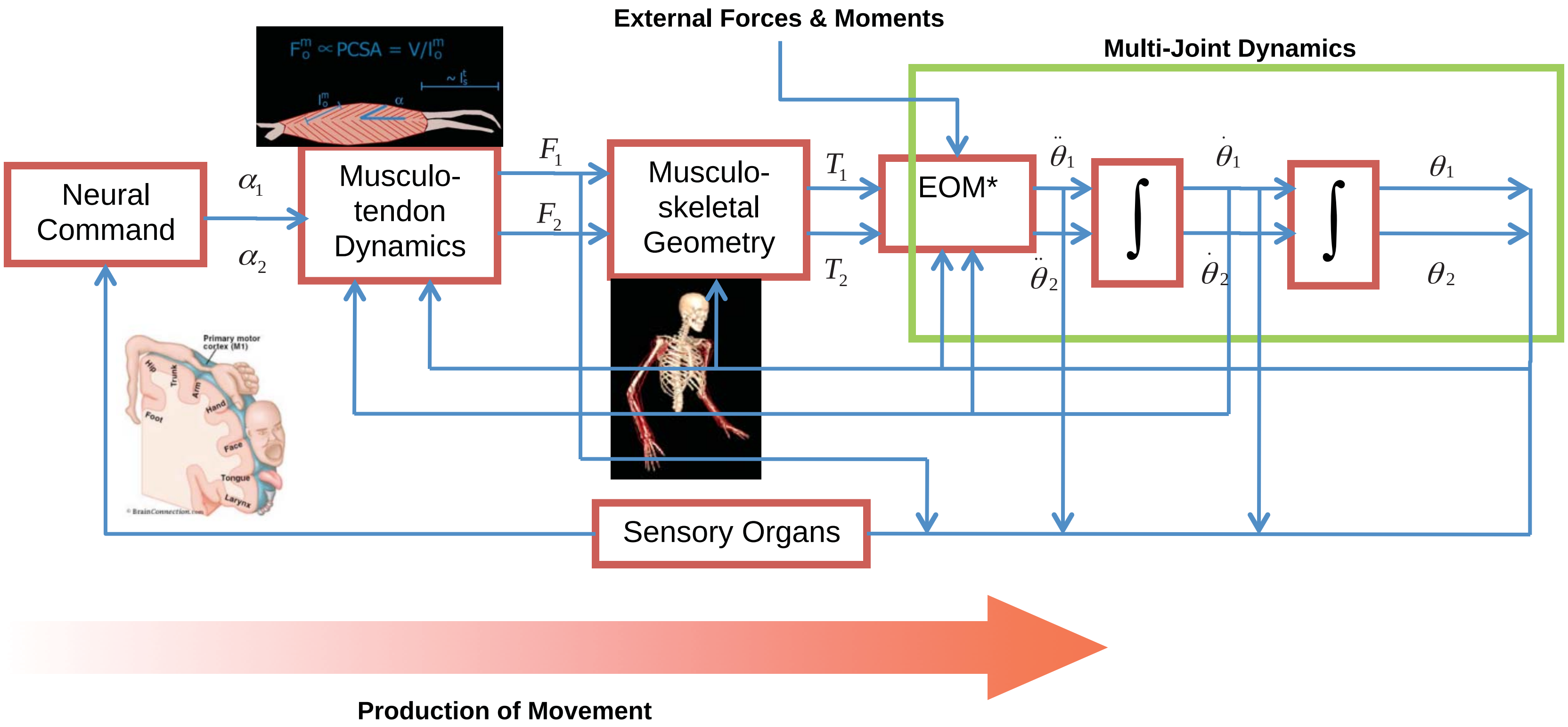
From Neural Command to Motion

Human Motion Production



External Forces & Moments

Multi-Joint Dynamics

Neural Command

α_1

α_2

Musculo-tendon Dynamics

F_1

F_2

Musculo-skeletal Geometry

T_1

T_2

EOM*

$\ddot{\theta}_1$

$\ddot{\theta}_2$

$\int$

$\dot{\theta}_1$

$\dot{\theta}_2$

$\int$

θ_1

θ_2

Sensory Organs

Production of Movement

(Adapted from: Buchanan et al. 2004. Neuromusculoskeletal modeling: estimation of muscle forces and joint moments and movements from measurements of neural command. Journal of Applied Biomechanics)

: equations of motions

Anatomical Planes

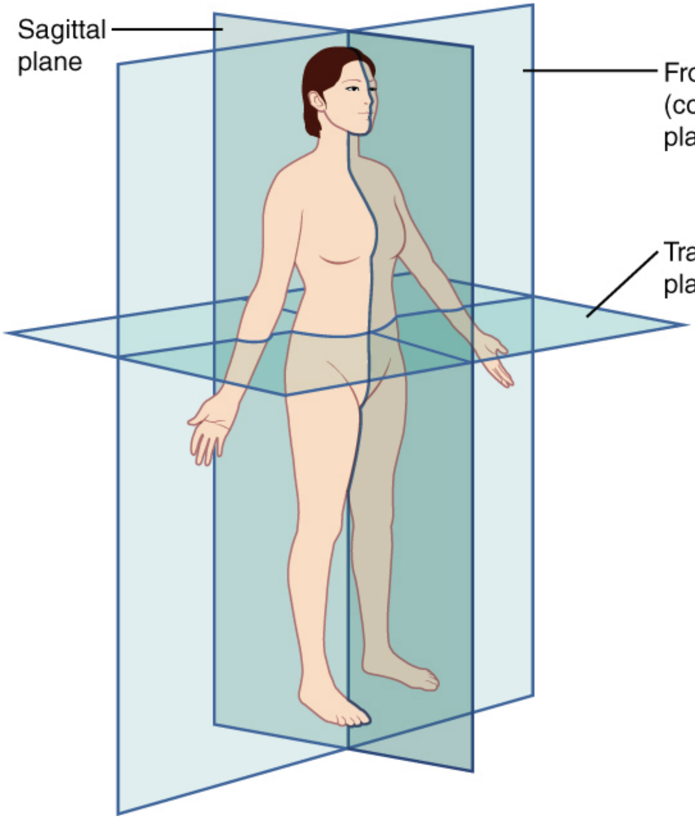
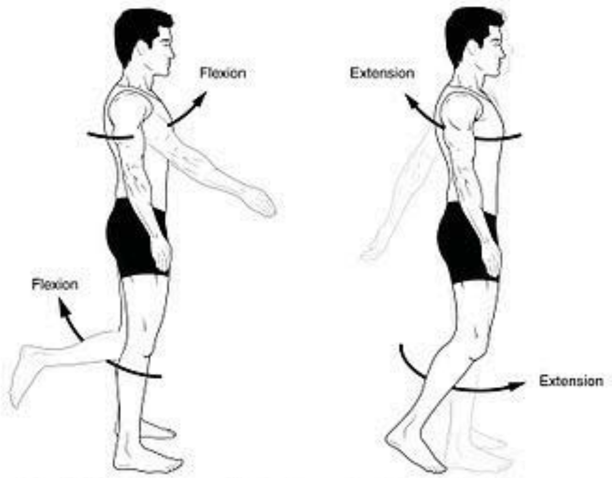
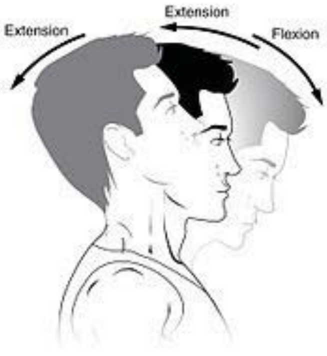


Image Courtesy: *http://commons.wikimedia.org/wiki/*

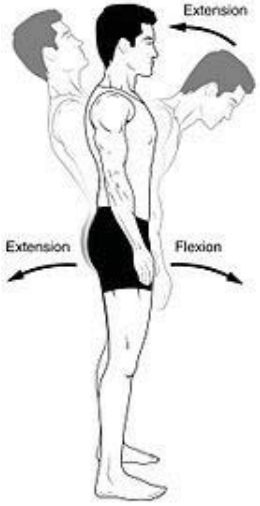
Body Movements



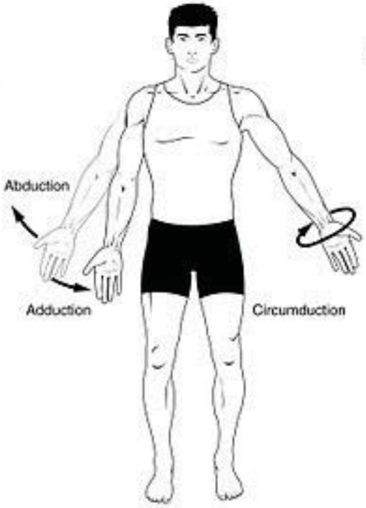
(a) and (b) Angular movements: flexion and extension at the shoulder and knees



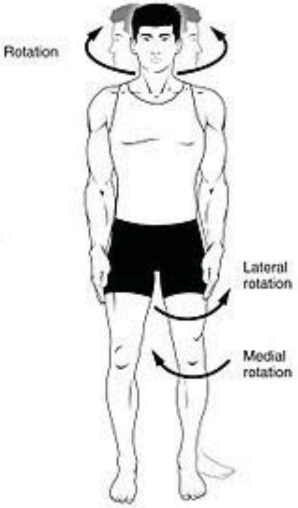
(c) Angular movements: flexion and extension of the neck



(d) Angular movements: flexion and extension of the vertebral column



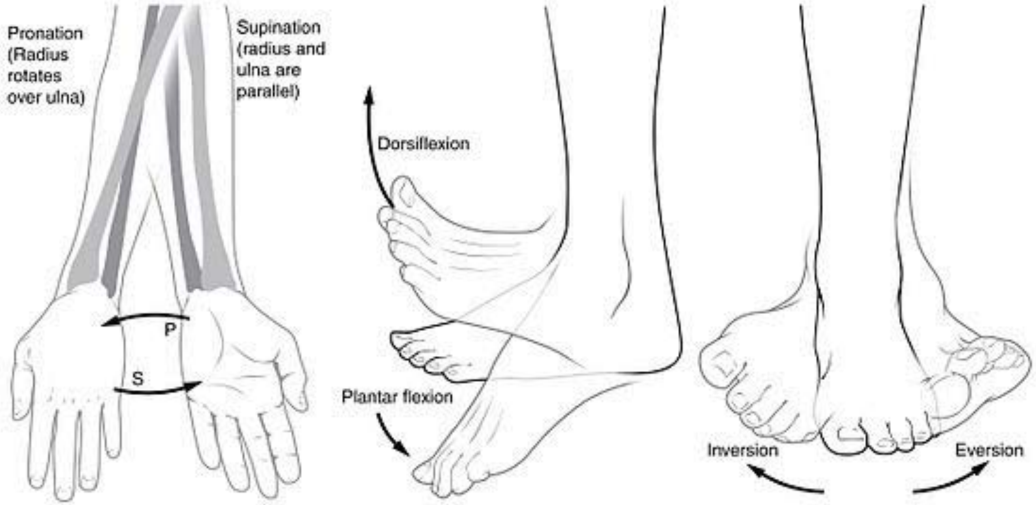
(e) Angular movements: abduction, adduction, and circumduction of the upper limb at the shoulder



(f) Rotation of the head, neck, and lower limb

Wikipedia

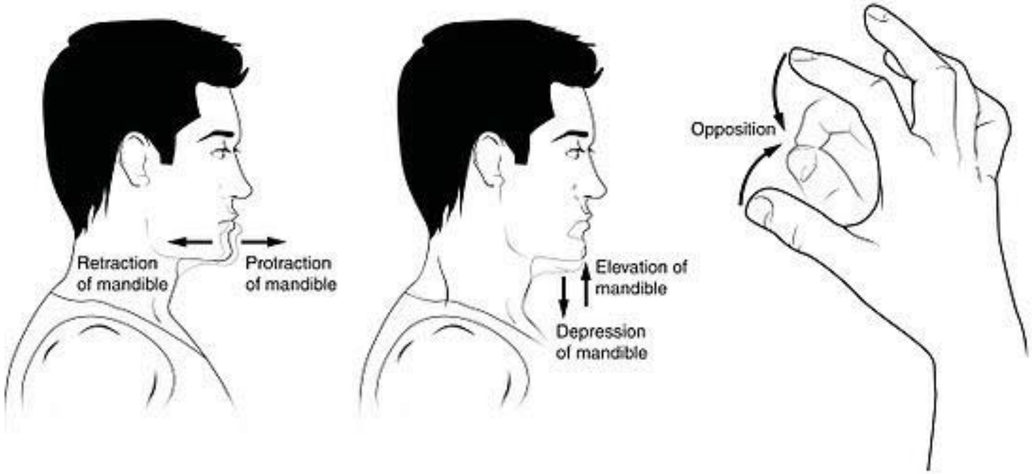
Body Movements



(g) Pronation (P) and supination (S)

(h) Dorsiflexion and plantar flexion

(i) Inversion and eversion



(j) Protraction and retraction

(k) Elevation and depression

(l) Opposition

Wikipedia

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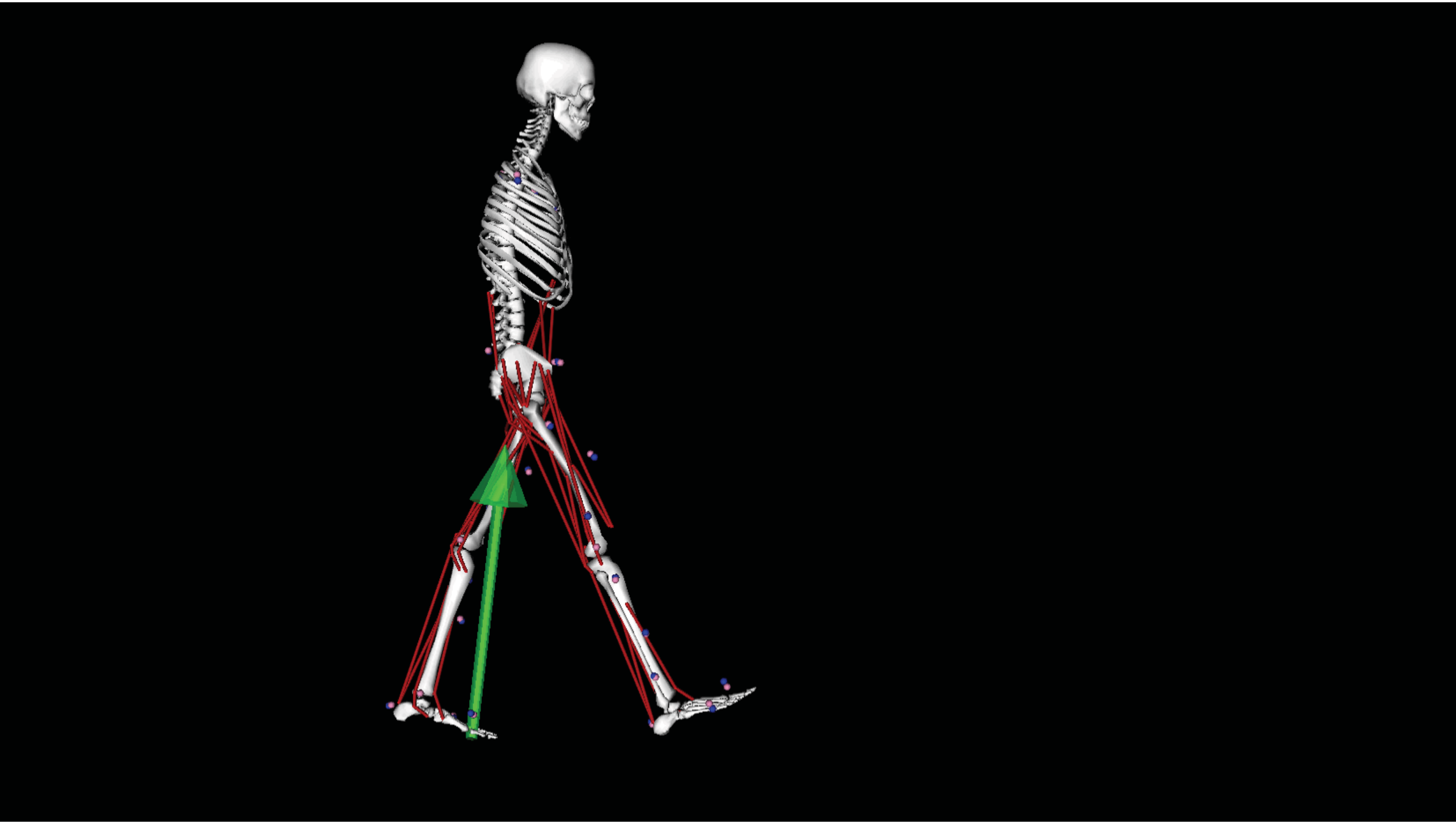
Human Gait

balance | weight bearing | forward propulsion



Gait Terminology

Stride: complete cycle of locomotory movement

- sequence of right plus left steps

Step Length : distance between R and L heel strikes

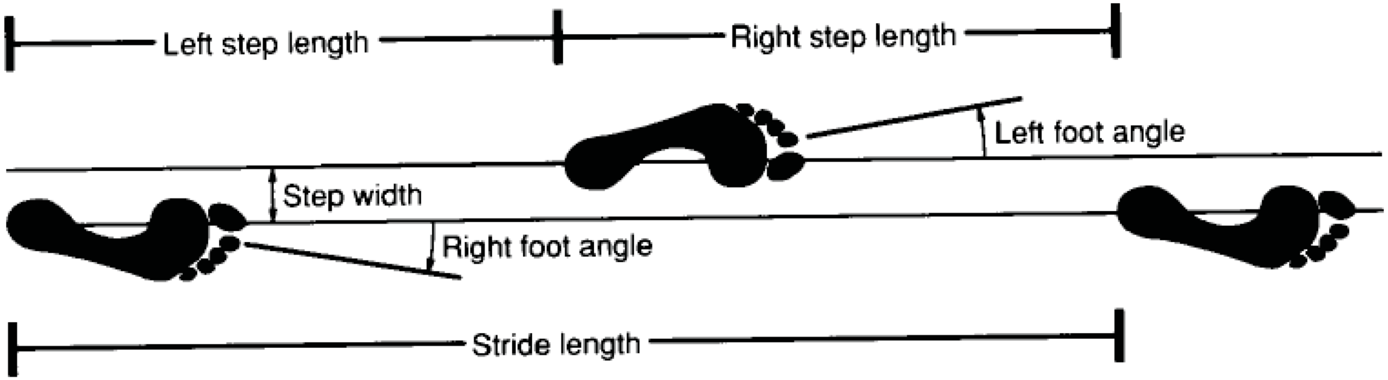
- normal adult step length : 80 cm

Cadence: rhythm of locomotion

- normal adult cadence: 101-120 steps/minute

Walking Velocity = cadence * step length

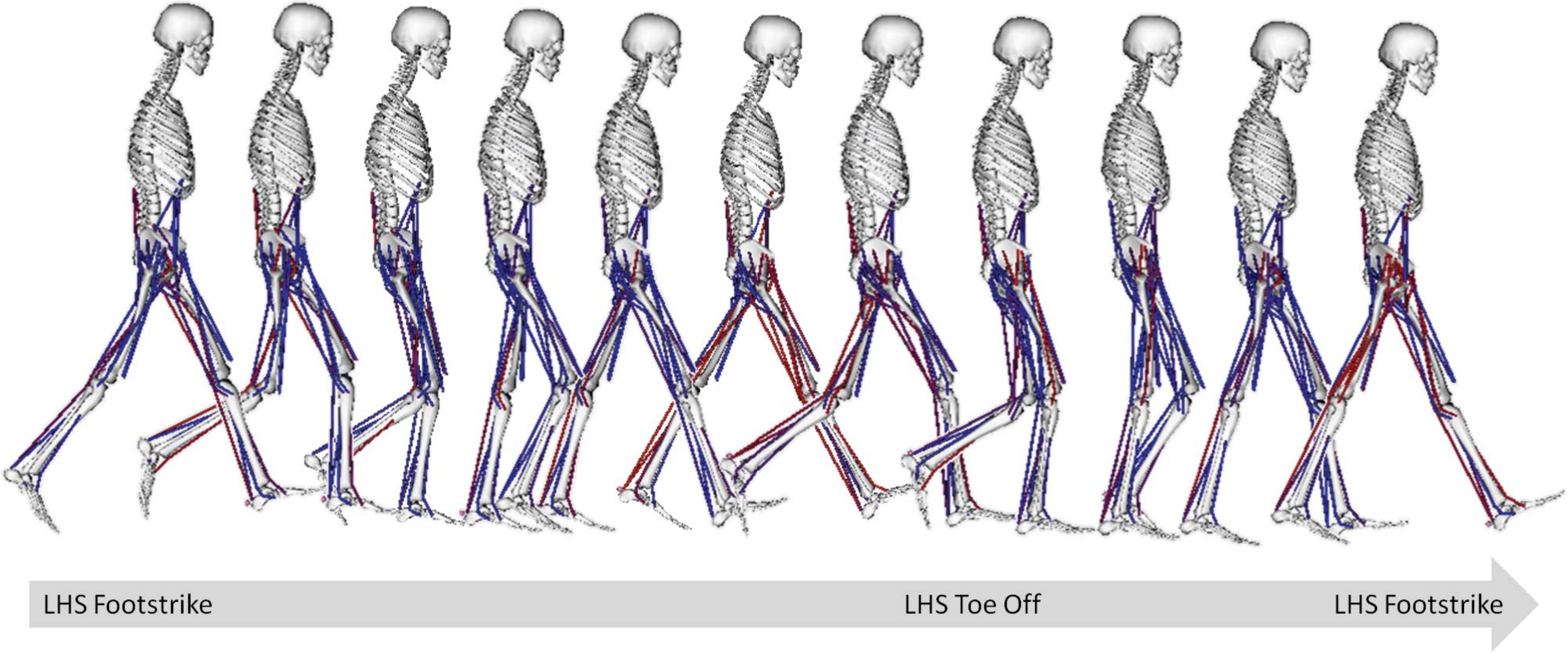
- normal adult walking velocity:1.5 m/s



Clinical biomechanics of gait, Stephen Robinovitch

Gait Cycle

The gait cycle is the basis for understanding normal and pathological human walking



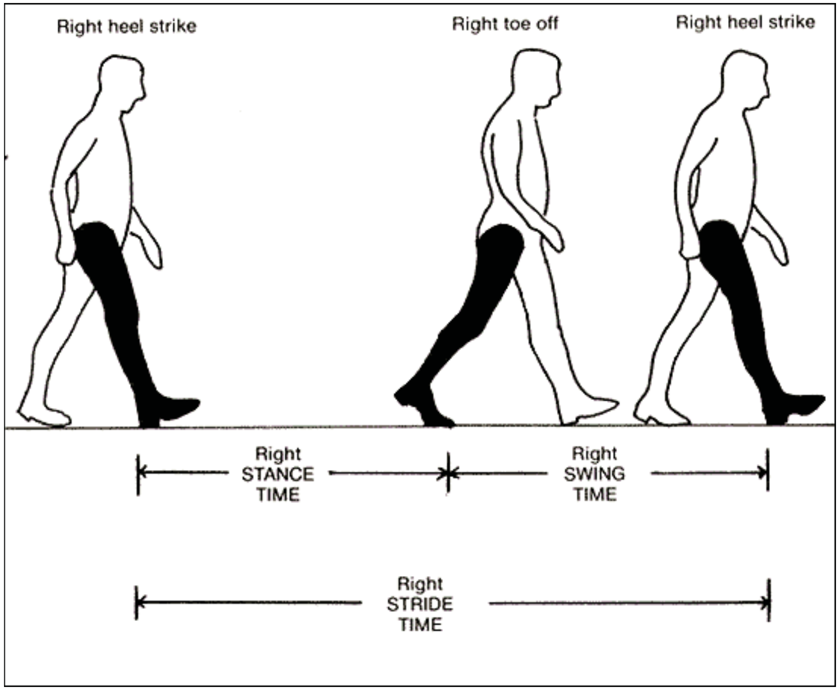
LHS Footstrike

LHS Toe Off

LHS Footstrike

Gait Cycle

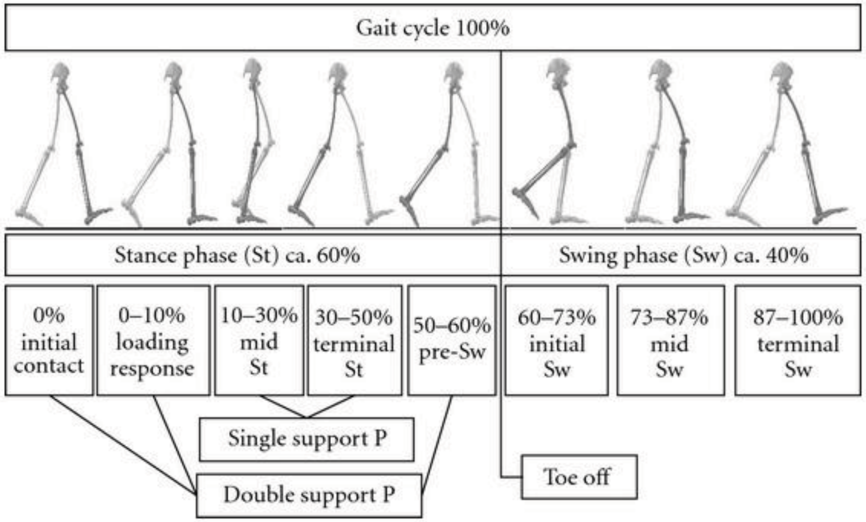
Stance phase takes up 60% of the stride
Swing phase takes up the remaining 40%



http://www.oandp.org/jpo/library/popup.asp?xmlpage=1991_02_059&type=image&id=f1

Gait Cycle

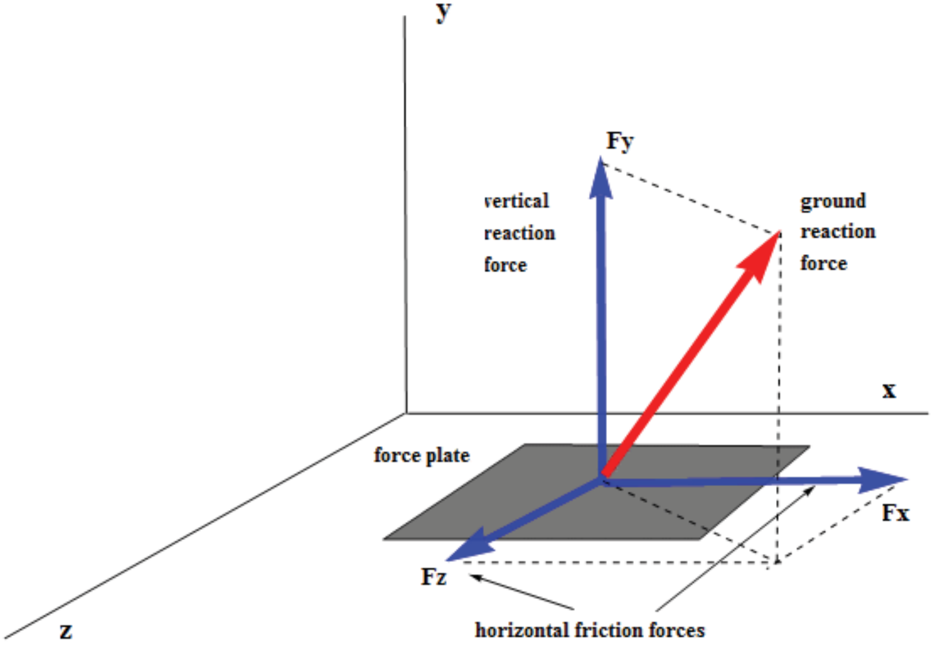
Stance begins and ends with periods of double support

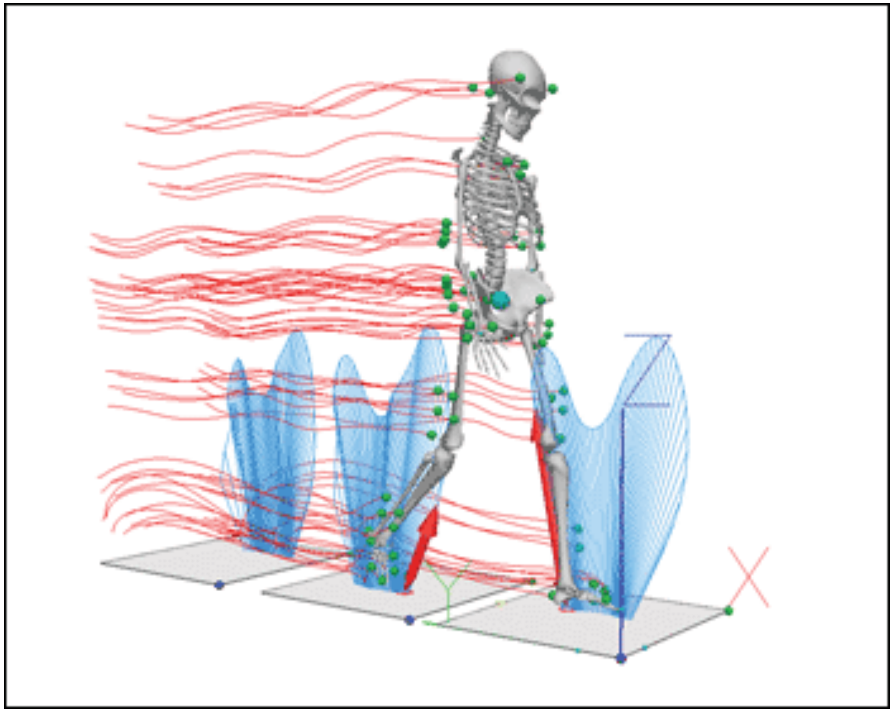


http://www.jeios.com/spler/wp-content/uploads/2014/01/Kinematics.jpg

Ground Reaction Forces during Normal Gait

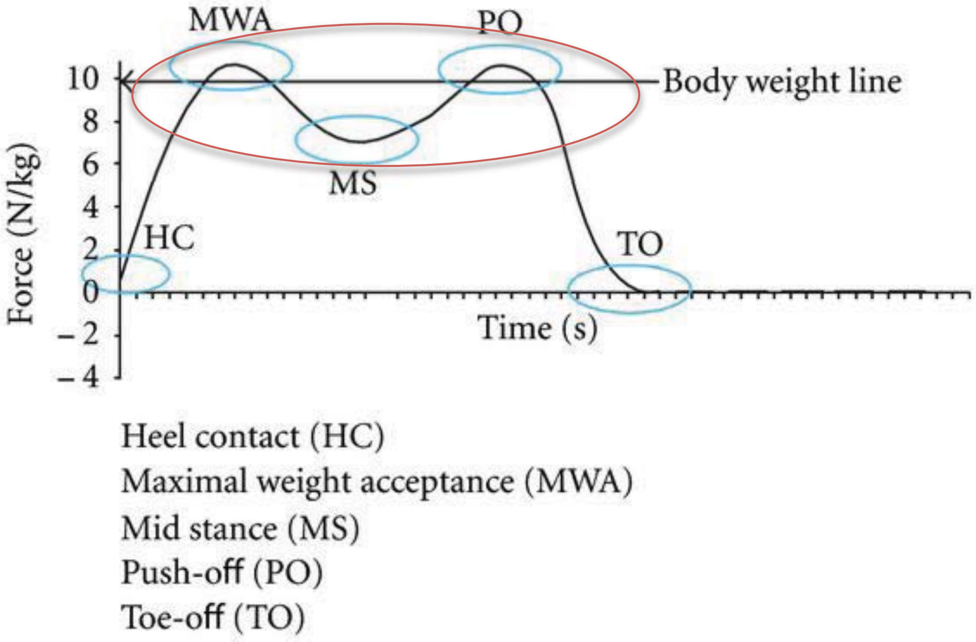
Information from the force plates
Fx, Fy, Fz & Mx, My, Mz





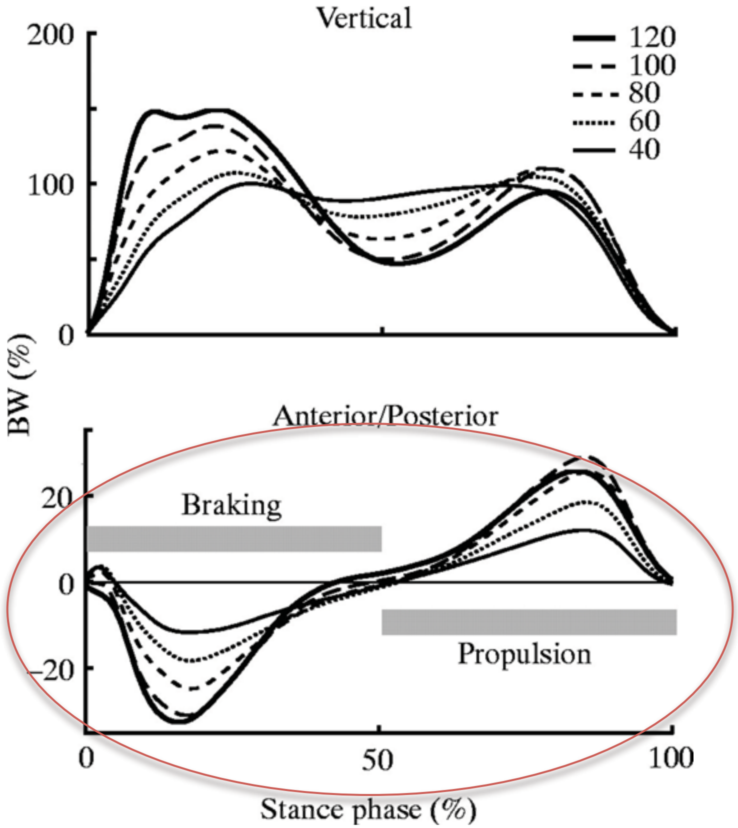
http://www.sheffield.ac.uk/research/impact/stories/fce/5

Ground Reaction Forces during Normal Gait



http://www.hindawi.com/journals/rerp/2011/586412/fig4/

Vertical GRF goes above and falls below body weight



Ankle plantar flexor force production is an important determinant of the preferred walk-to-run transition speed, J Exp Biol, March 2005

Horizontal GRF pushes back at initial contact and forward at the end of single stance.

Determinants of Gait

i. Displacement of center of gravity
ii. Factors responsible for minimizing the displacement of center of gravity

From Saunders, Inman, and Eberhart, The Journal of Bone and Joint Surgery

Determinants of Gait

i. Displacement of center of gravity

During normal pattern of gait within each gait cycle, the center of gravity is displaced:

- Twice in vertical direction, in sagittal Plane.
- Twice in lateral direction, in horizontal Plane.

From Saunders, Inman, and Eberhart, The Journal of Bone and Joint Surgery

Displacement of Center of Gravity

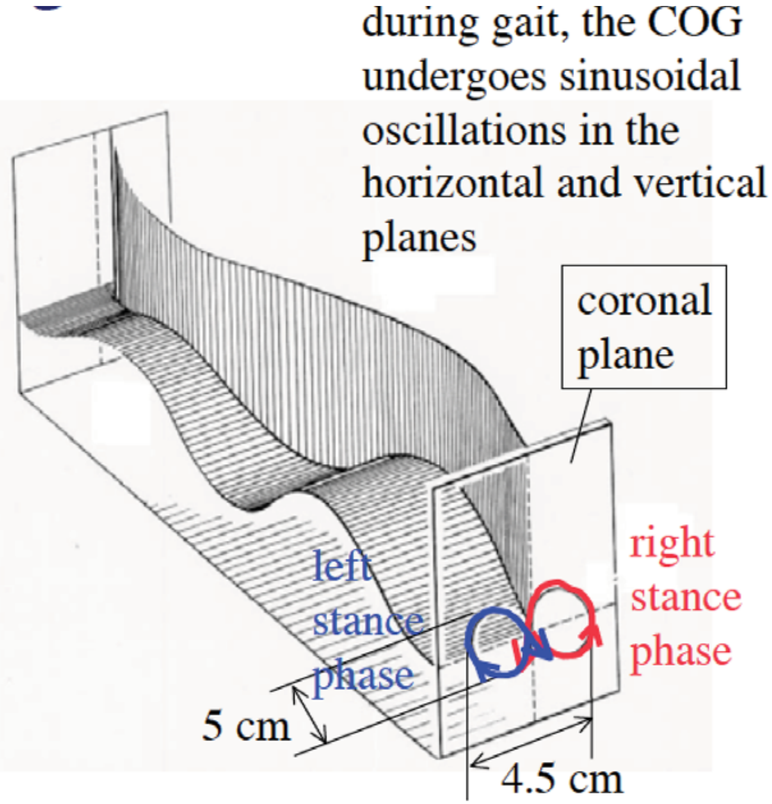
Vertical Displacement (Sagittal Plane)

Movement of the lowest displacement occurs at heel strike and double support.

Movement of the highest displacement occurs at mid-stance.

Average: 1.8 inch.

Pathway: sinusoidal curve.



during gait, the COG undergoes sinusoidal oscillations in the horizontal and vertical planes

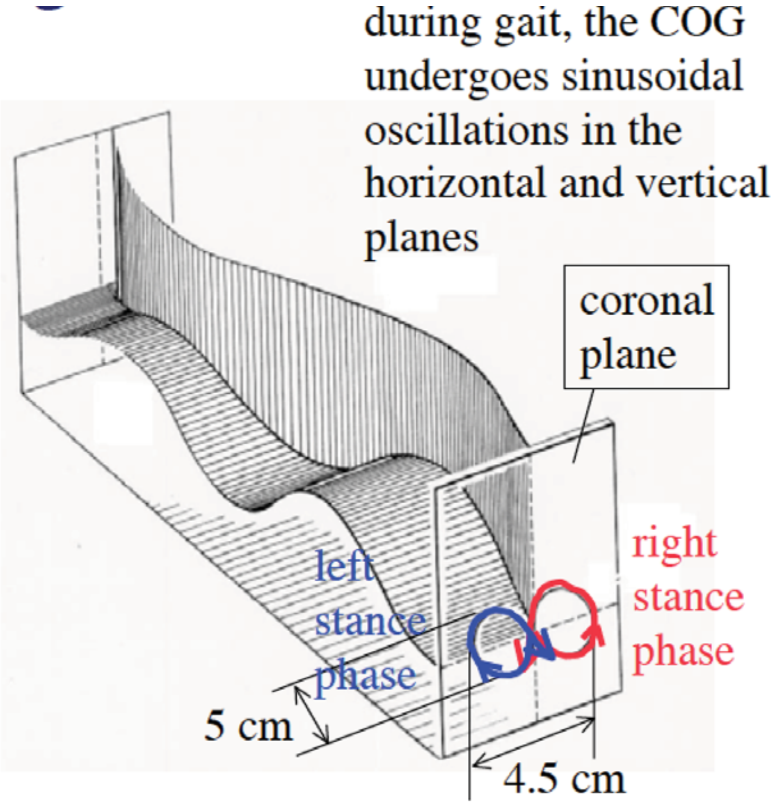
Displacement of Center of Gravity
Lateral Displacement (Horizontal Plane)

The displacement occurs over the right then over the left leg during walking.

The maximum displacement is at mid-stance

Average: one and 3/4 inches.

Pathway: sinusoidal curve.


during gait, the COG undergoes sinusoidal oscillations in the horizontal and vertical planes

Displacement of Center of Gravity

The Combination of Displacements

When the vertical and lateral displacement of center of gravity of body are combined and projected on the coronal plane:

- It occupies approximately "2" inches square.
- The amount of up-down and sideways motion during walking – uses up precious energy

Displacement of Center of Gravity
The Combination of Displacements

- At the maximum vertical displacement of center of gravity, it still lies slightly below the level of same center of gravity when the subject is standing. that means the person is slightly shorter when he is walking than in standing.

Determinants of Gait

i. Displacement of center of gravity

ii. Factors responsible for minimizing the displacement of center of gravity

From Saunders, Inman, and Eberhart, The Journal of Bone and Joint Surgery

Displacement of Center of Gravity

Determinants

Definition: *Determinant is a various movement that occurs in the body including pelvis, knee and ankle to maintain center of gravity of the body in a horizontal plane and ensure the smoothing pathway of gait.*

Determinants of gait:

1) Pelvic rotation
2) Pelvic tilting
3) Knee flexion in stance phase
4) & 5) Foot and knee mechanism
6) Lateral displacement of the body

Goals:

1. Decrease the max. height of the body COM during the mid-stance
2. Increase the min. height of the body COM during the heel strike and toe off.

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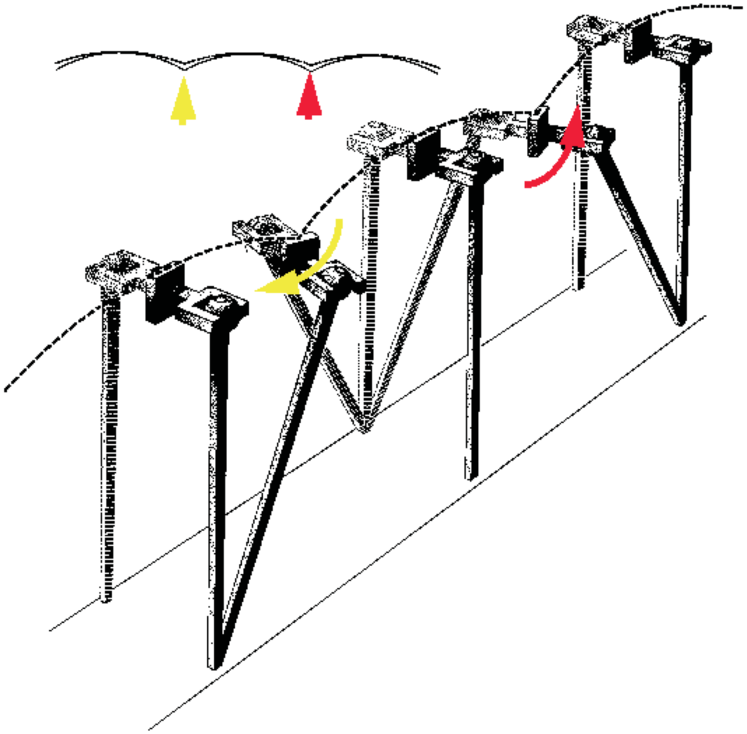
Determinants of Gait

1) Pelvic Rotation

In normal pattern of walking:

- The pelvis rotates alternatively to right and to left in relation to the line of progression in transverse plane about the vertical axis.
- **The average magnitude** of this rotation is approximately four degrees (4º) on either side of the central axis. The total equal "8" degrees.
- **Associated hip movement:** Internal and external rotation during stance phase.
- **Function:** Pelvic rotation during normal gait decreases the vertical displacement of COG 3/8 inches



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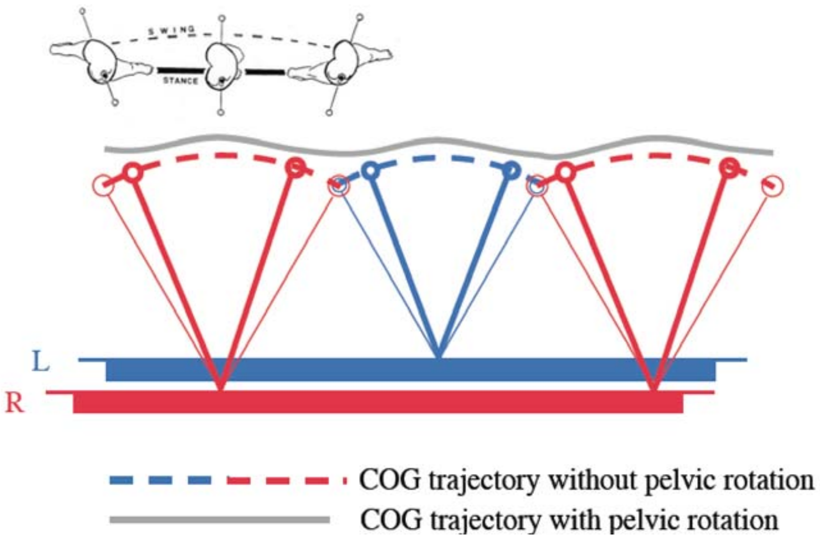
- **Associated hip movement:** Internal and external rotation during stance phase.
- **Function: Pelvic rotation during normal gait decreases the vertical displacement of COG 3/8 inches (~0.9cm)**

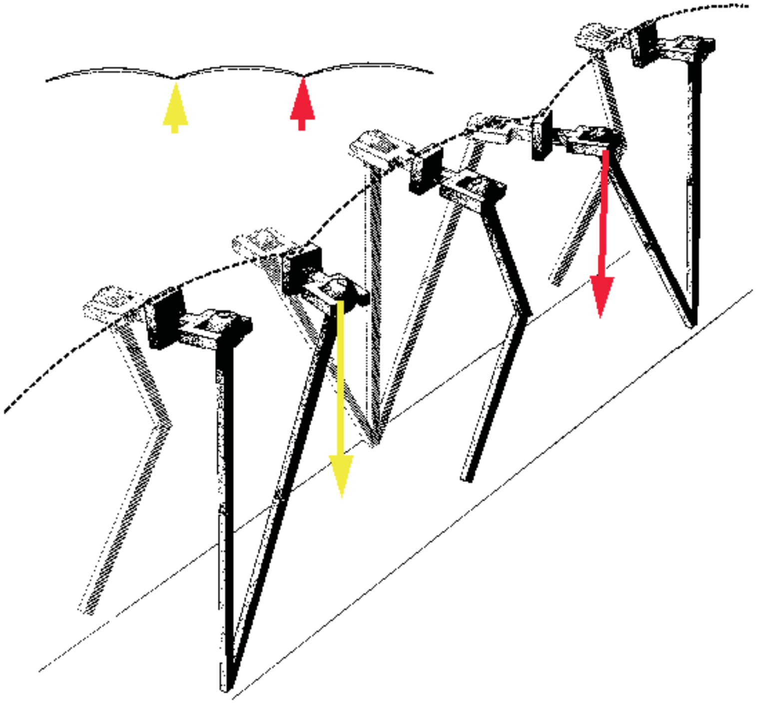


Determinants of Gait

2) Pelvic Tilting

In normal pattern of walking:

- The pelvis tilts downward on swing leg (0n the side which is opposite to that of weight bearing leg) along the frontal plane around sagittal axis. The maximum tilting is at mid-swing.
- **The average magnitude:** The average of the angular displacement is (5°) five degrees.
- **Associated hip movement:** There are relative hip adduction in stance phase and hip abduction in the swing phase.
- **Function:** Pelvic tilting helps to decrease vertical displacement of center of gravity 1/8 inch.



Determinants of Gait

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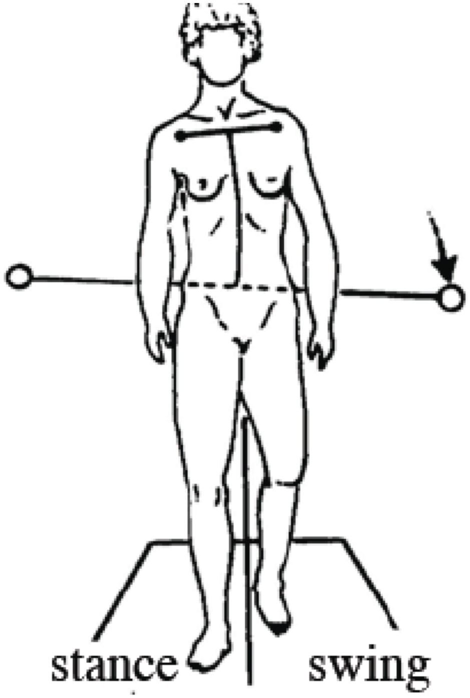
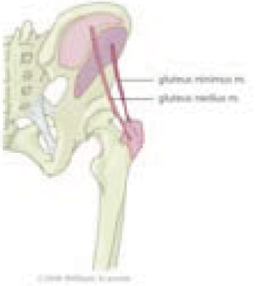
- **Associated hip movement:** There are relative hip adduction in stance phase and hip abduction in the swing phase.
- **Function:** **Pelvic tilting helps to decrease vertical displacement of center of gravity 1/8 inch (~0.3cm)**





Determinants of Gait

3) Knee Flexion in the Stance Phase

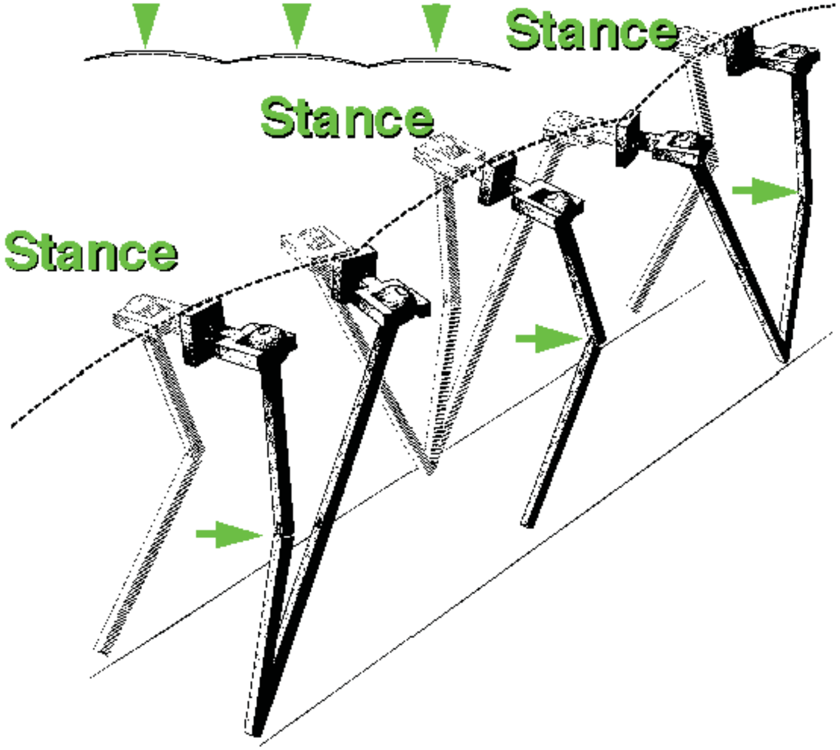
In normal pattern of walking:

- **At initial contact,** the knee is almost (0 ±5°).
- **At loading response,** the knee begins the first excursion of flexion after the heel strike (= 15° – 20°)
- **It has 3 functions:**

1) Shock absorption.

2) Minimize displacement of COG.

3) Decrease energy expenditure.



Determinants of Gait

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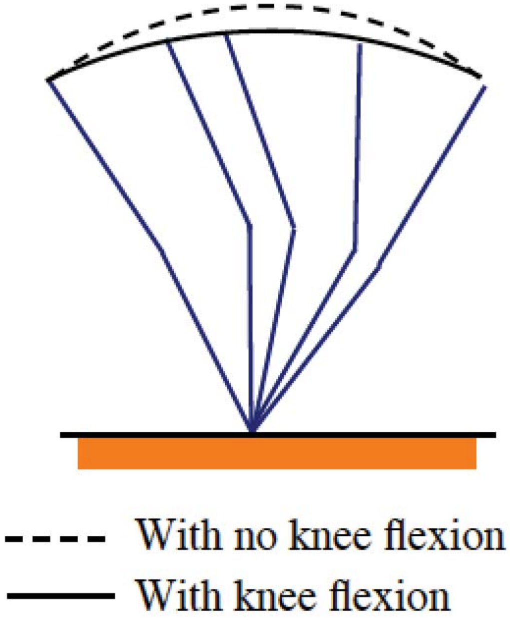


Determinants of Gait

4) & 5) Foot and Knee Mechanism

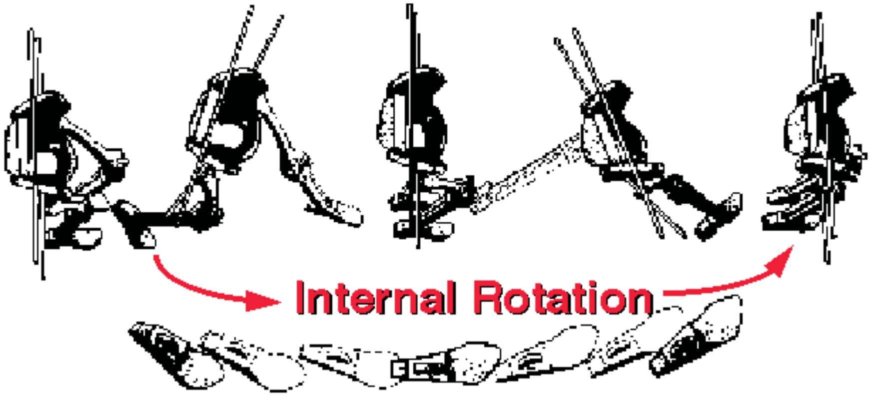
In normal pattern of walking:

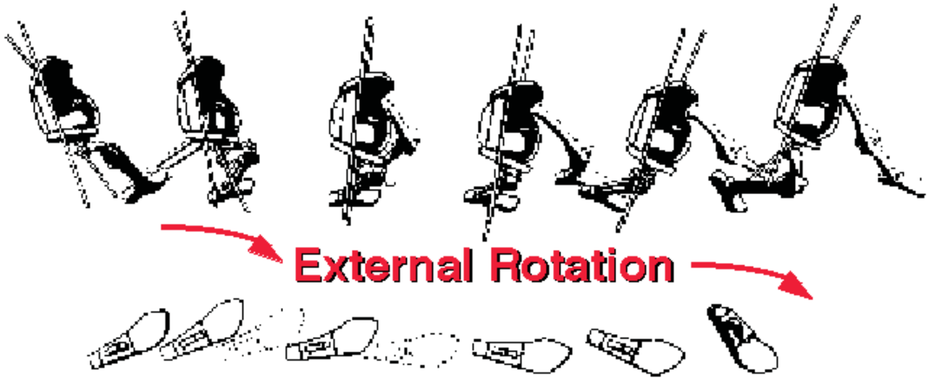
Early in the stance phase:

- The foot is dorsiflexed while the knee is almost fully extended. So, the extremity is at its maximum length and the center of gravity reaches its lowest point in a downward displacement.

Late in the stance phase:

- The foot is plantar flexed while the knee is in the beginning of flexion. That will maintain the center of gravity in its beginning of progression with minimum displacement.





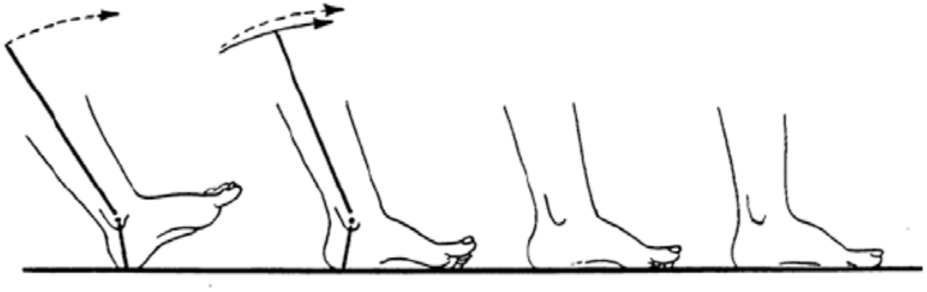
Determinants of Gait

4) & 5) Foot and Knee Mechanism

Functions:

At heel-strike:

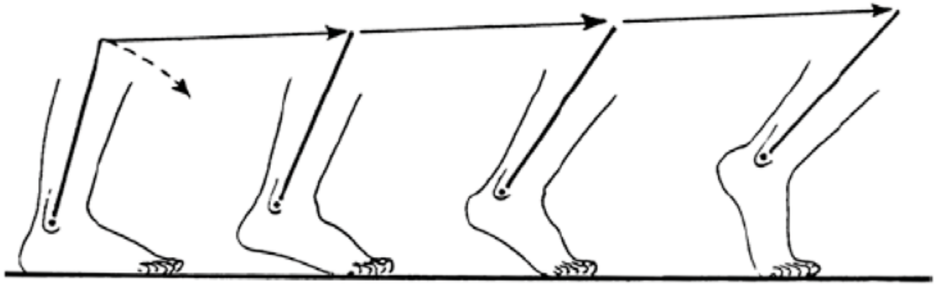
- If the ankle were immobile, the COG would rise (dashed arrow) as if the leg were a stilt
- Dorsiflexion at the ankle lowers the trajectory of the COG (solid arrow)



Dorsi-flexion during heel strike

At heel-off:

- If the heel was not permitted to elevate, the leg would rotate forward about the ankle joint and the COG trajectory would fall abruptly (dashed arrow)
- Raising the heel off the ground by plantarflexion provides for a more horizontal COG trajectory (solid arrow)



Plantar-flexion during heel off

Determinants of Gait

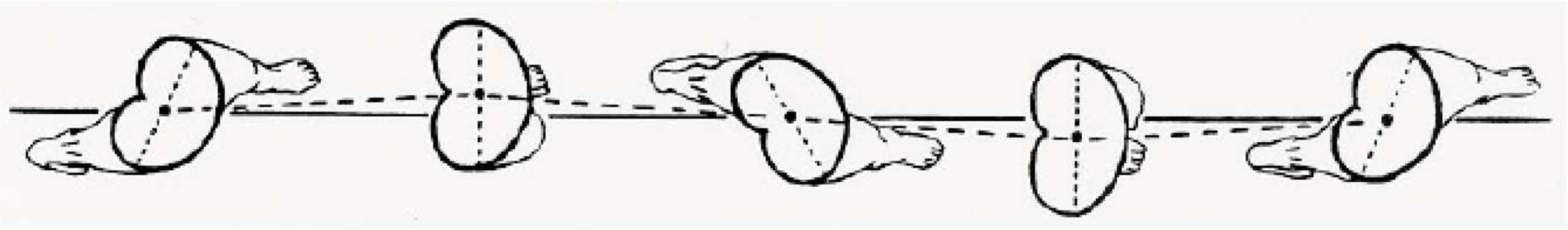
6) Lateral Displacement of body and COG

In normal pattern of walking:

- The center of gravity is displaced laterally over the weight – bearing extremity twice during the cycle of motion in the horizontal plane.
- The motion is produced by the horizontal shift of pelvis and relative adduction of hip.

Magnitude:

- The maximum lateral displacement is lateral at mid-stance on the side of weight bearing leg (4.5 cm each stride).



Determinants of Gait

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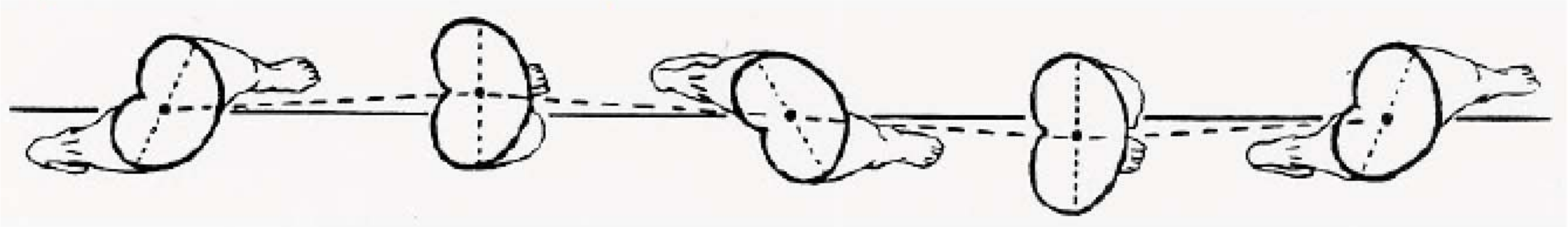
- The motion is produced by the horizontal shift of pelvis and relative adduction of hip.

Magnitude:

- The maximum lateral displacement is lateral at mid-stance on the side of weight bearing leg (4.5 cm each stride).

Function:

- **Moves the COG closer to the stance leg, making it easier for the stance-side hip abductors to raise the swing leg and control pelvic tilt**



Determinants of Gait

Sum of the Six Effects

“The pathway of the center of gravity is a smooth curve in both horizontal and vertical planes”

From Saunders, Inman, and Eberhart, The Journal of Bone and Joint Surgery

Determinants of Gait

Functions

- Increase the efficiency and smoothness of pathway of gait
- Decrease the vertical and lateral displacement of center of gravity to two inches excursion
- Decrease the energy expenditure
- Make gait more graceful

Agenda

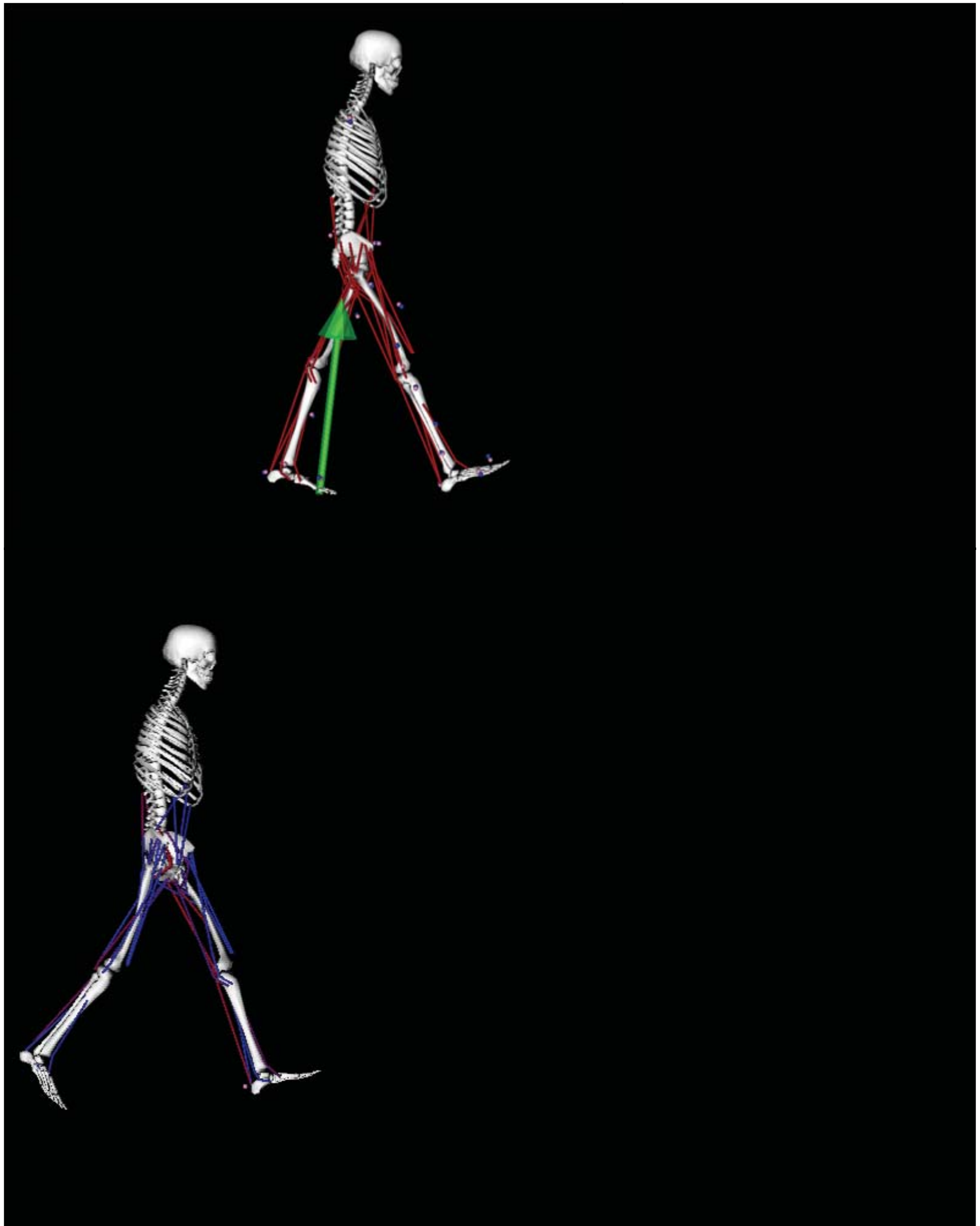
- Muscle Physiology
- Muscle-Tendon Unit
- Force-Velocity, Force-Length Relationship
- Muscle Jacobian
- Muscle/Task Relationship
- Production of Movement
- Gait Cycle
- Determinants of Gait
- **Gait Analysis**
- **Gait Abnormalities: A Case Study**

Gait: Experiment and Simulation

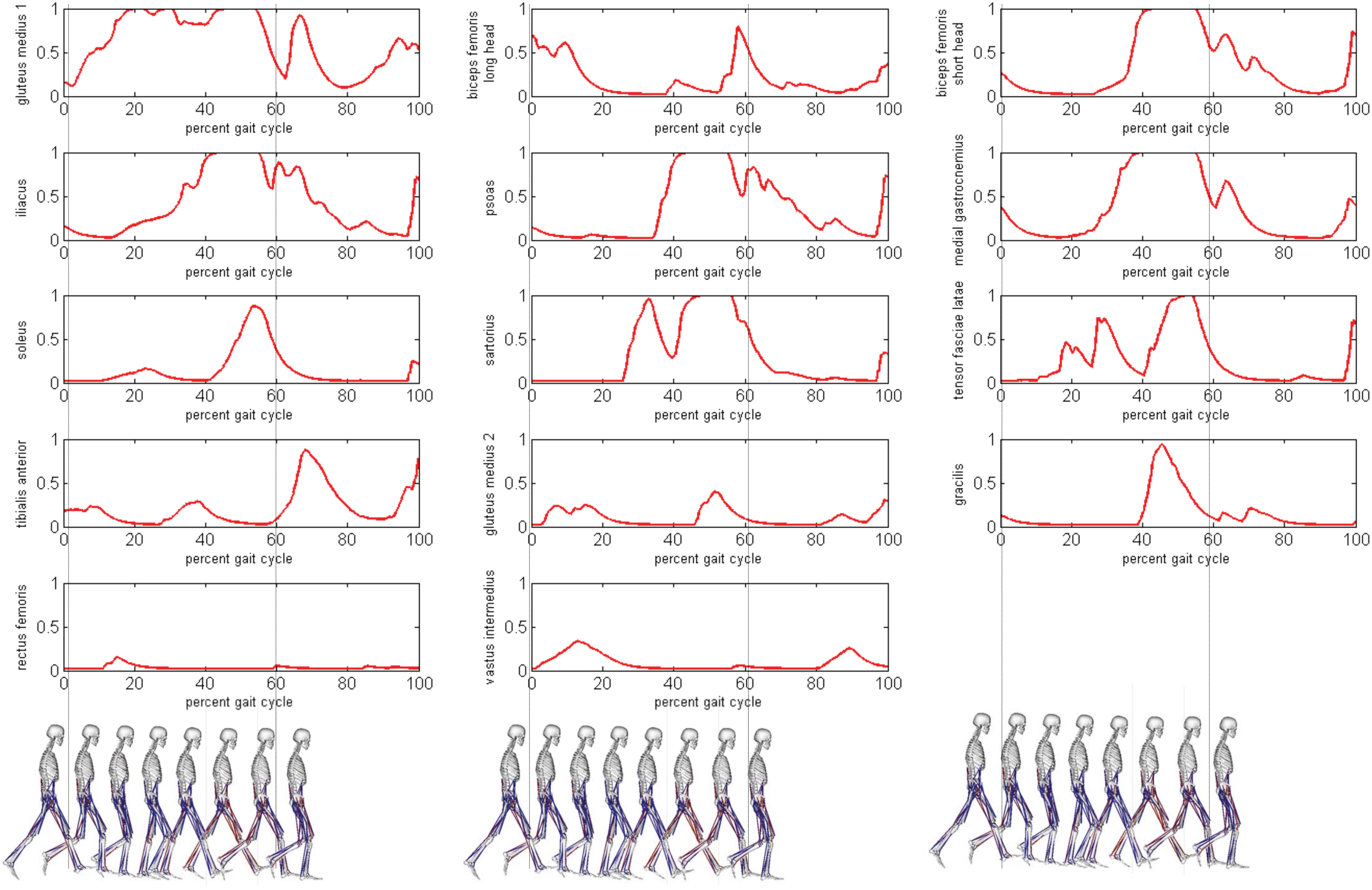
Healthy Male
Free Speed (1.75m/s)

- Motion Capture
- Force Plate
- Electromyography

23DOF actuated by
92 muscle-tendon units



Muscle Activations during Normal Gait (1.75m/s)



EMG-informed Computed Muscle Control for Dynamic Simulations of Movement

Project Overview

Description: This project is an EMG-informed control plug-in that interfaces with OpenSim to provide robust estimates of muscles activation patterns.

Available Downloads and Their Potential Uses: This project contains the motion capture, force plate, EMG data of a normal human walking together with the three-dimensional simulations (IK, RRA and CMC results) and the human model. To download the simulations and associated documentation, please see the Downloads section of this project. Please see https://simtk.org/home/opensim for more information on OpenSim and its branch /Branches/JasonEmel485Project/ in order to reproduce or modify the simulations . These simulations were generated using OpenSim version 1.5, which is the software version we recommend to those using these simulations.

Purpose/Synopsis: Develop a modified version of Computed Muscle Control (CMC) based on filtered EMG data to track the desired muscles and to create dynamic simulations of movement.

Audience: Users interested in analyzing human movement through EMG-based muscle activation patterns.

Downloads & Source Code

EMG-informed CMC

This project also makes **source code** available.

Project Lead

Emel Demircan
Contact

Driving Biological Problems

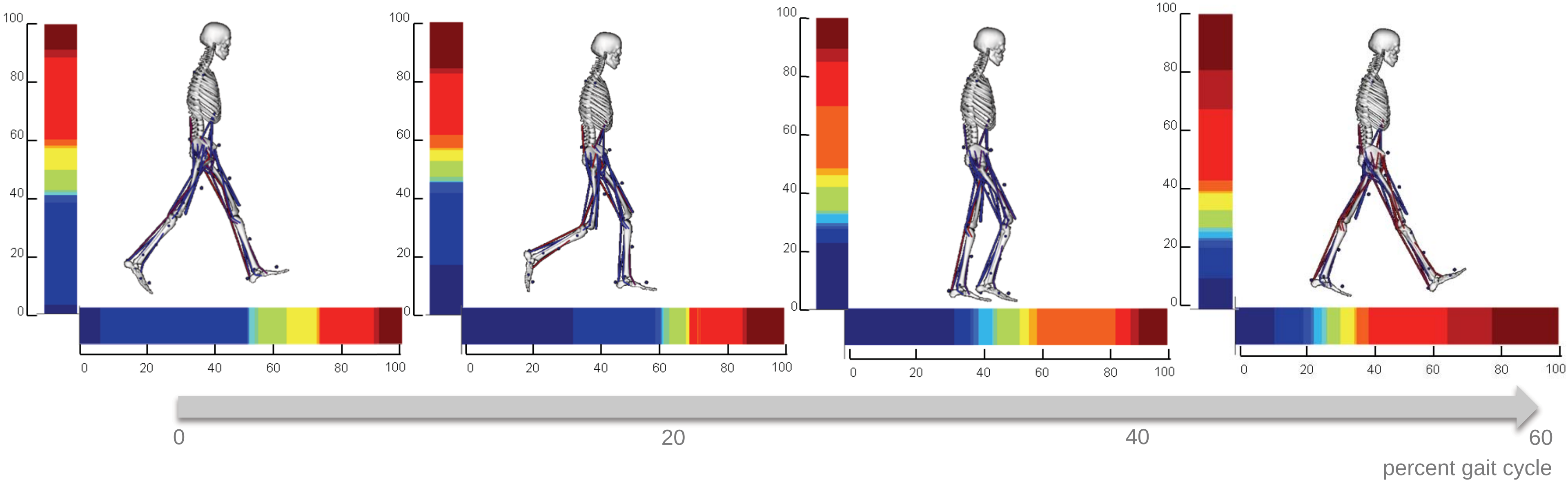
This project is part of

Neuromuscular Biomechanics

Demircan E., Wheeler J., Anderson F. C., Besier T., and Delp S., “EMG-Informed Computed Muscle Control for Dynamic Simulations of Movement.” In *Proc. of the **XXII Congress of the International Society of Biomechanics***, Cape Town, South Africa, July 2009

Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait

$$\ddot{x} = J(q)A(q)^{-1}(L^T m_{max} a - g(q) - J_{c_1}^T F_{ext_1} - J_{c_2}^T F_{ext_2})$$



Results	Our findings	Liu et al. 2006	Neptune et al. 2004	Liu et al. 2008
Gluteus medius, vasti, hamstrings, gastrocnemius, soleus and dorsiflexors are important modulators of accelerations	✔	✔	✔	✔

Demircan, E. and Khatib, O., “Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait”, Advances in Robot Kinematics, Springer, 13th International Symposium, Innsbruck, Austria, June 2012

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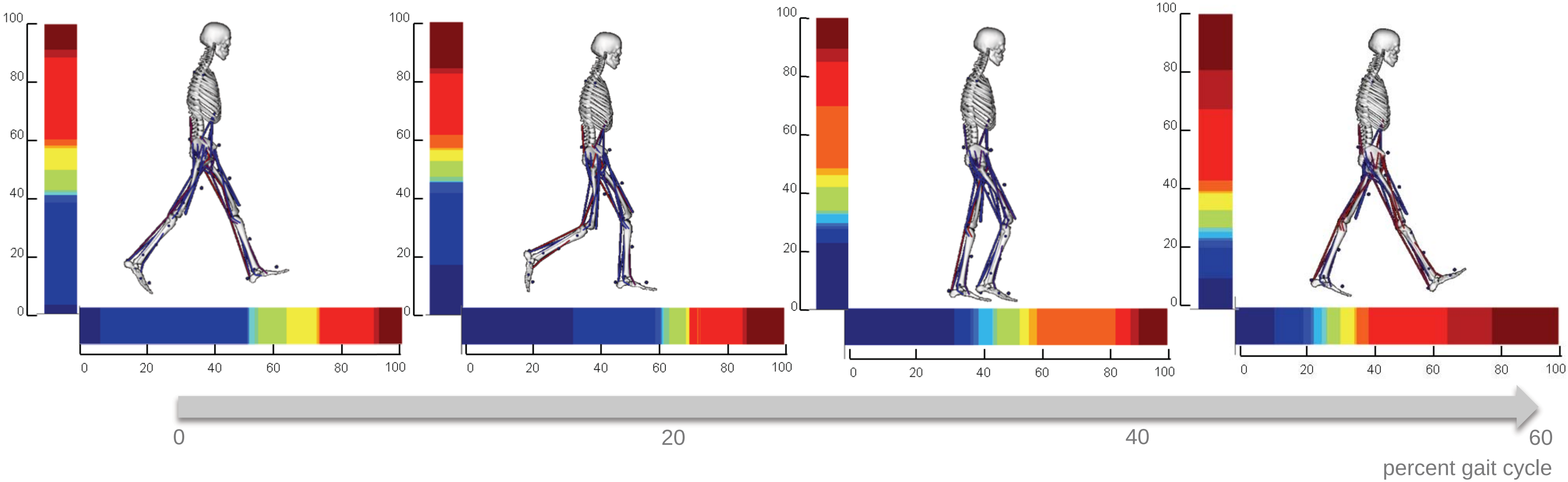

Results	Our findings	Liu et al. 2006	Neptune et al. 2004	Liu et al. 2008
Hamstrings and gluteus medius were primary contributors to support and progression in early stance.	✔	-	-	✔

- ■ gluteus medius
- ■ biceps femoris long head
- ■ biceps femoris short head
- ■ sartorius
- ■ tensor fasciae latae
- ■ gracilis
- ■ gluteus max
- ■ iliacus
- ■ psoas
- ■ rectus femoris
- ■ vasti
- ■ medial gastrocnemius
- ■ soleus
- ■ tibialis anterior

Demircan, E. and Khatib, O., “Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait”, Advances in Robot Kinematics, Springer, 13th International Symposium, Innsbruck, Austria, June 2012

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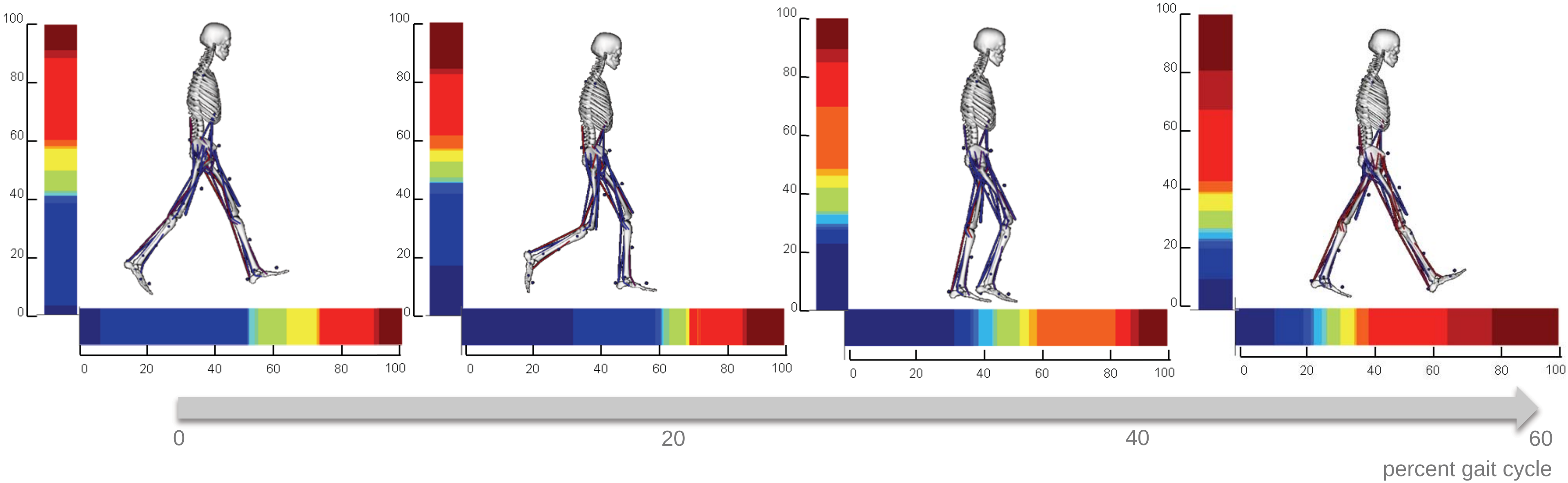

Results	Our findings	Liu et al. 2006	Neptune et al. 2004	Liu et al. 2008
At faster speed, greater forces in the soleus and gastrocnemius are observed in late stance.	✔	-	-	✔

Demircan, E. and Khatib, O., "Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait", Advances in Robot Kinematics, Springer, 13th International Symposium, Innsbruck, Austria, June 2012

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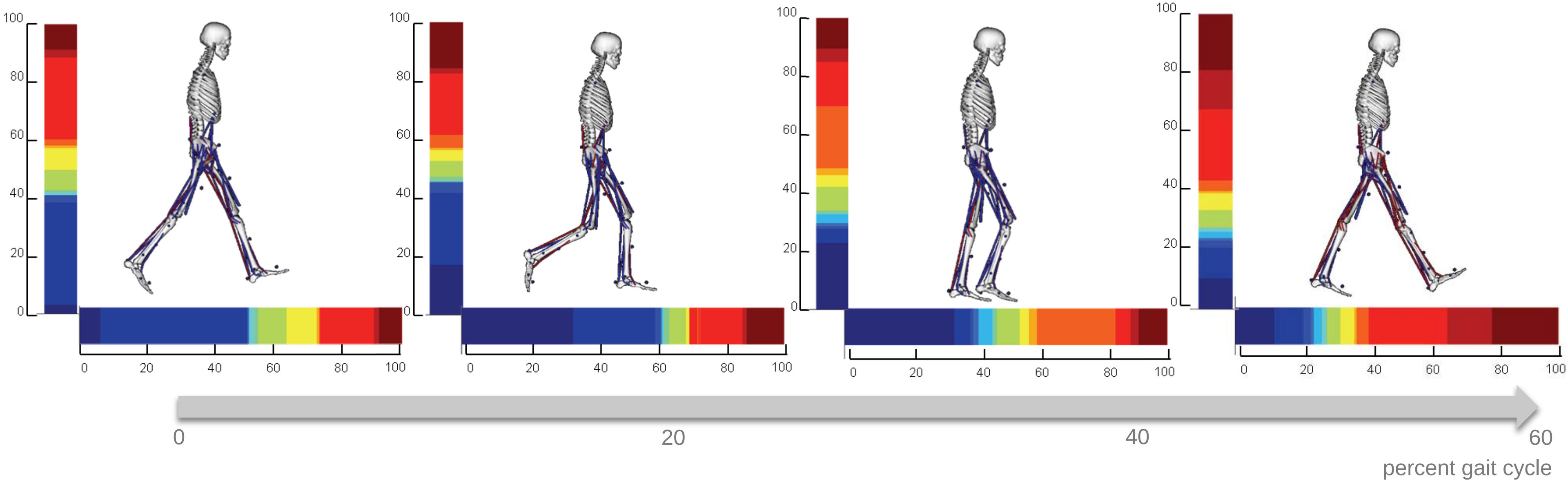
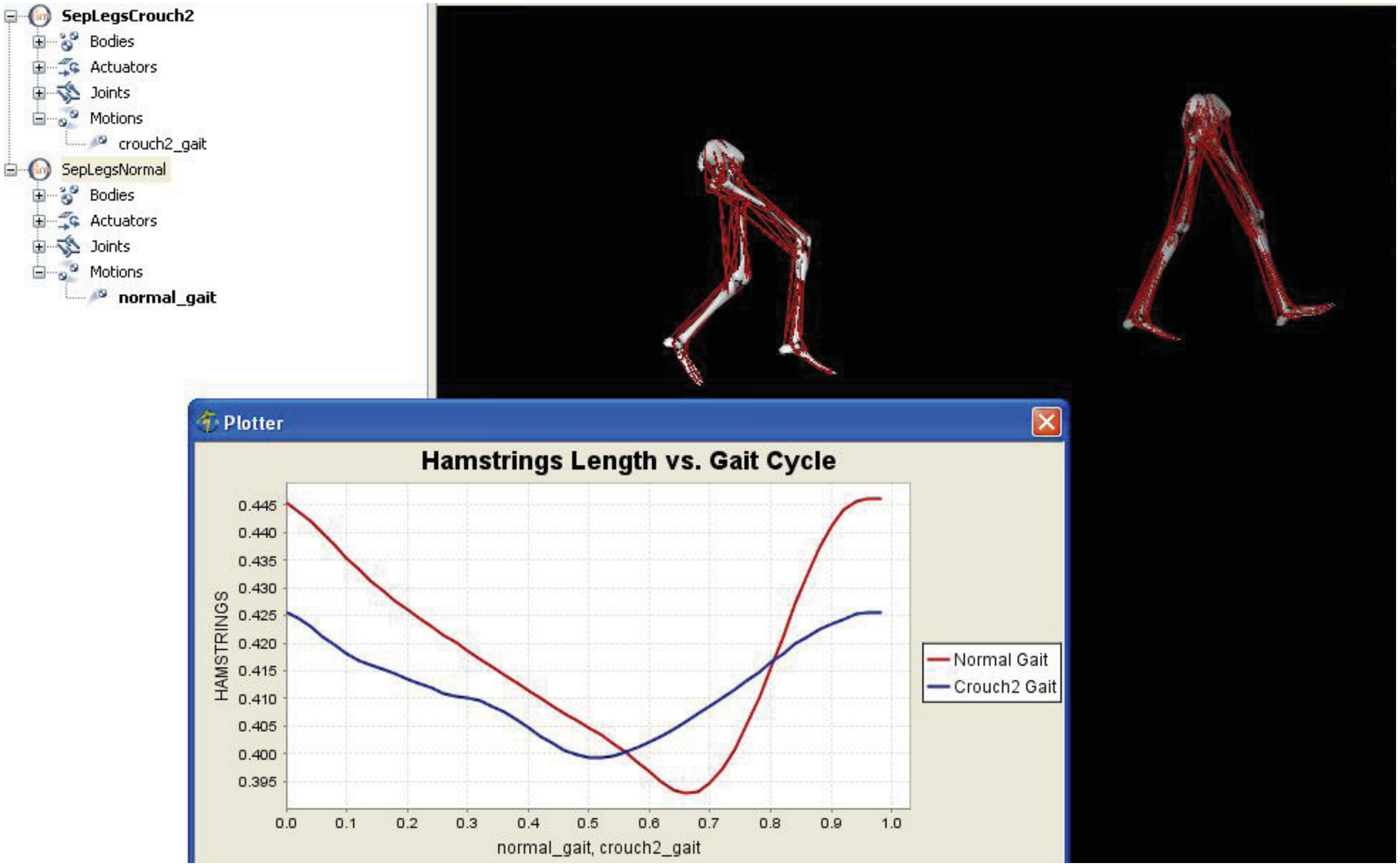


Results	Our findings	Liu et al. 2006	Neptune et al. 2008	Liu et al. 2008
Hip flexors (iliacus, psoas, rect fem) didn’t contribute significantly to mass center acceleration.	✔	-	✖	✔

Demircan, E. and Khatib, O., “Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait”, Advances in Robot Kinematics, Springer, 13th International Symposium, Innsbruck, Austria, June 2012

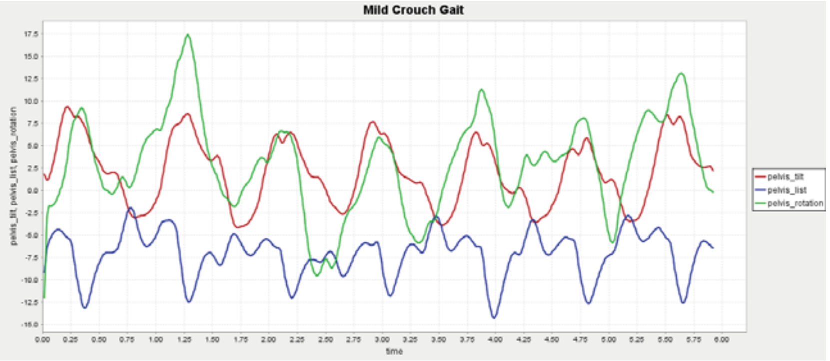
Musculoskeletal Disorders

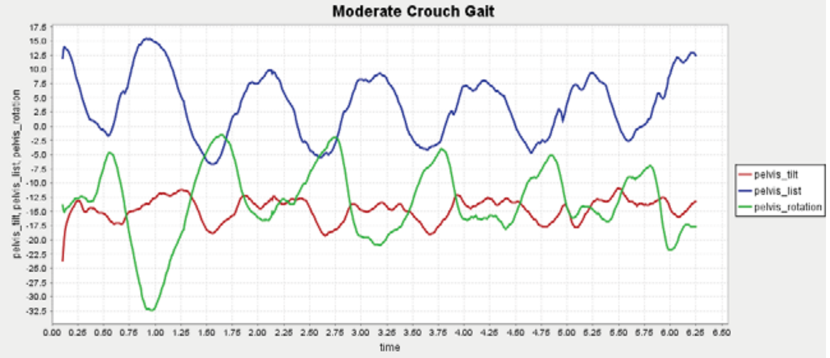
Crouch vs. Normal Gait

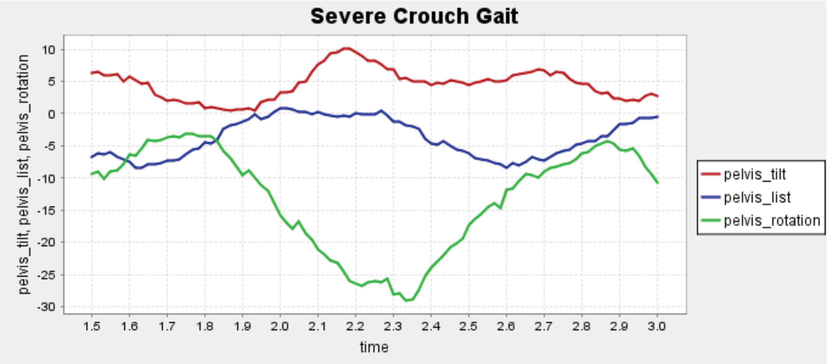


Professor Scott Delp – Department of Bioengineering
Professor Jessica Rose - Stanford Children Gait Hospital
Department of Orthopeadic Surgery, School of Medicine

Reeducation of Musculoskeletal Disorders







Today

- Muscle Physiology
- Muscle-Tendon Unit
- Force-Velocity, Force-Length Relationship
- Muscle Jacobian
- Muscle/Task Relationship
- Production of Movement
- Gait Cycle
- Determinants of Gait
- Gait Analysis
- Gait Abnormalities: A Case Study

Organization of an Academic Paper

- Abstract
- Introduction
- Methods
- Experimental Setup (if any)
- Results
- Discussion and/or Conclusions
- Acknowledgments
- References

How to Review an Academic Paper?

- *Summarize* the paper in your own words:
  - Say what the authors have done, what their **contribution** is, and what the **significance** of that contribution is (write your own abstract).
  - The point here is for you to show you have read and understood the point of the paper.

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

How to Review an Academic Paper?

- *Analyze* the technical content and examine:
  - the extent to which the work is relevant to this workshop/conference/journal,
  - the extent to which the work answers a valid research question,
  - the research methodology,
  - the quality of results and argumentation,
  - awareness of related work (including the correct number of appropriate references),
  - the degree of significance of the results,
  - do the conclusions follow from the work described?

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

How to Review an Academic Paper?

- Keep the review *Critical* and *Constructive!*
  - advise the authors for improvements and inform them about the weaknesses, typos, inconsistencies, errors of the paper.

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

How to Review an Academic Paper?

- Analyze the *quality of writing*:
  - Can you understand the development of the argument?
  - Does the abstract describe what you read?
  - Do the introduction and conclusions tell a story on their own?
  - Have the authors kept to the format and length requirements of the publishers?
  - Are the diagrams and figures readable?
  - Are the references and citations formatted properly?
  - Are the references "fully formed"? (Are all the authors listed? Is all the information about the venue that would be needed to retrieve the paper listed?)

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

How to Review an Academic Paper?

- Typos:
  - Do you spot any grammatical errors, typos and other minor textual problems?
  - How is the English level throughout the paper?

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

How to Review an Academic Paper?

- Conclusions:
  - Answer the questions "Will it interest people who attend this conference/ read this publication? Why? Who?“
  - Justify your overall recommendation.

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

Some Useful References

- Dale J. Benos, Kevin L. Kirk and John E. Hall. How to Review a Paper. *Advan. Physiol. Edu.* 27: 47-52, 2003**;** http://advan.physiology.org/cgi/content/full/27/2/47 (Last accessed 16th Jan 2007)

- Ralph E. Johnson, Kent Beck, Grady Booch, William Cook, Richard Gabriel, Rebecca Wirfs-Brock. 1993 *How to Get a Paper Accepted at OOPSLA*. http://www.acm.org/sigplan/oopsla/oopsla96/how93.html (last accessed 16th Jan 2007)

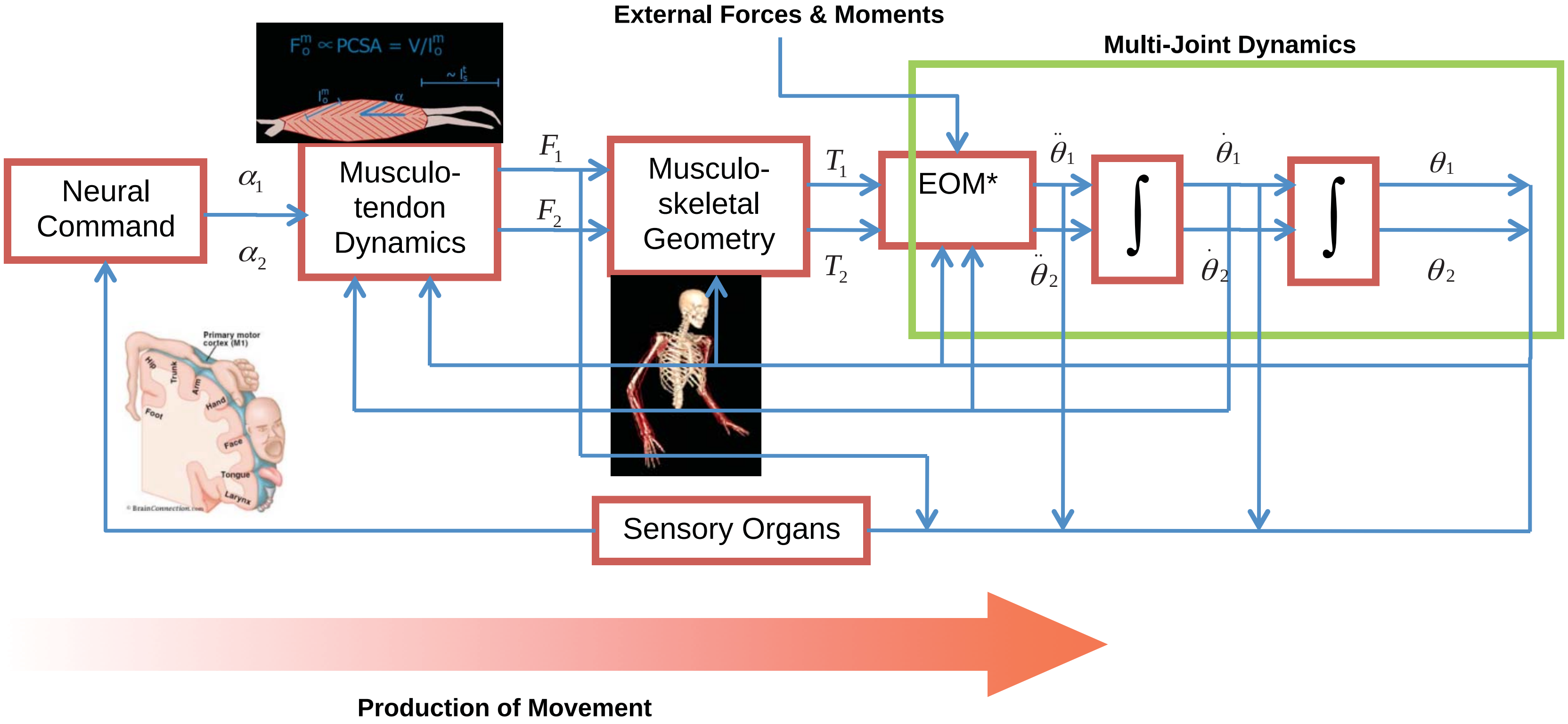
- Ian Parberry A Guide for New Referees in Theoretical Computer Science. ACM SIGACT News (Nov 1989) Available at http://portal.acm.org/citation.cfm?id=74090

- Barak A. Pearlmutter. *How to Review a Scientific Paper.* http://www.cs.unm.edu/~bap/how-to-review.html (last accessed 16th Jan 2007)

Source: http://users.ecs.soton.ac.uk/hcd/reviewing.html

From Neural Command to Motion

Human Motion Production

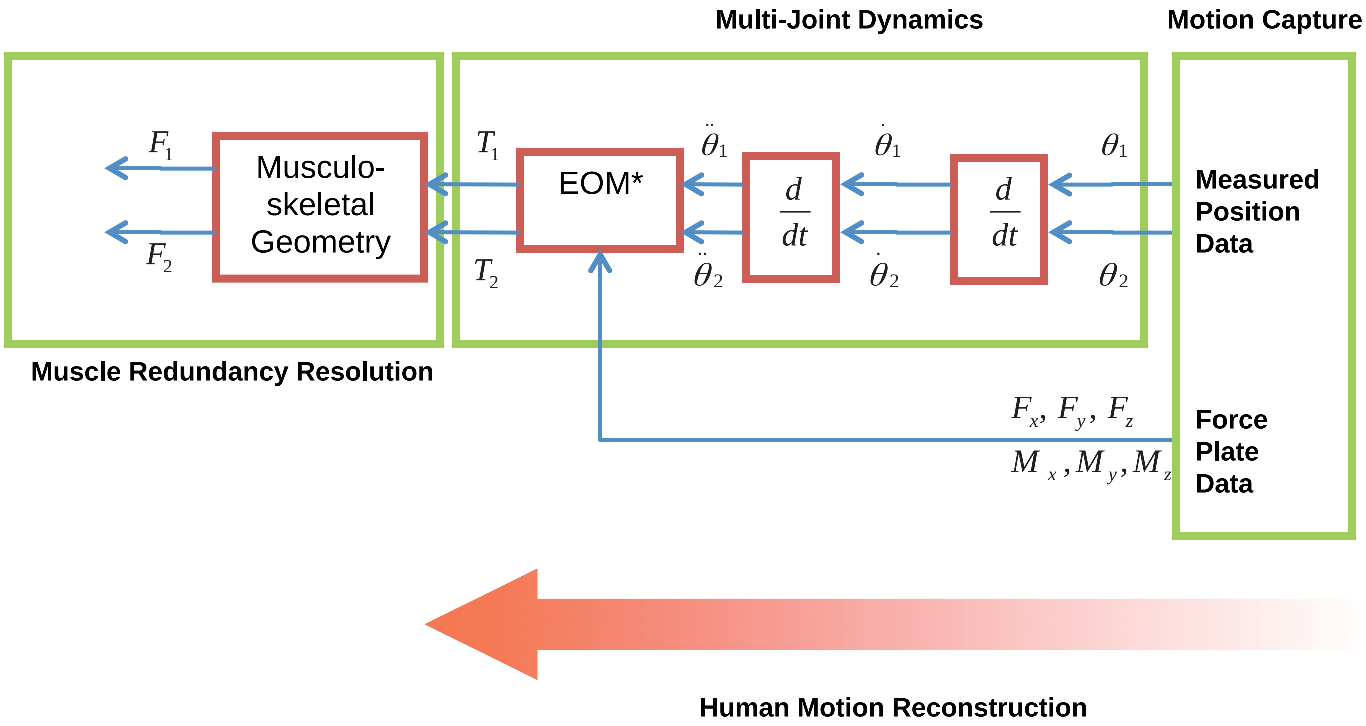


(Adapted from: Buchanan et al. 2004. Neuromusculoskeletal modeling: estimation of muscle forces and joint moments and movements from measurements of neural command. Journal of Applied Biomechanics)

: equations of motions

Motion Capture Systems

Human Motion Reconstruction



(Adapted from: Buchanan et al. 2004. Neuromusculoskeletal modeling: estimation of muscle forces and joint moments and movements from measurements of neural command. Journal of Applied Biomechanics)

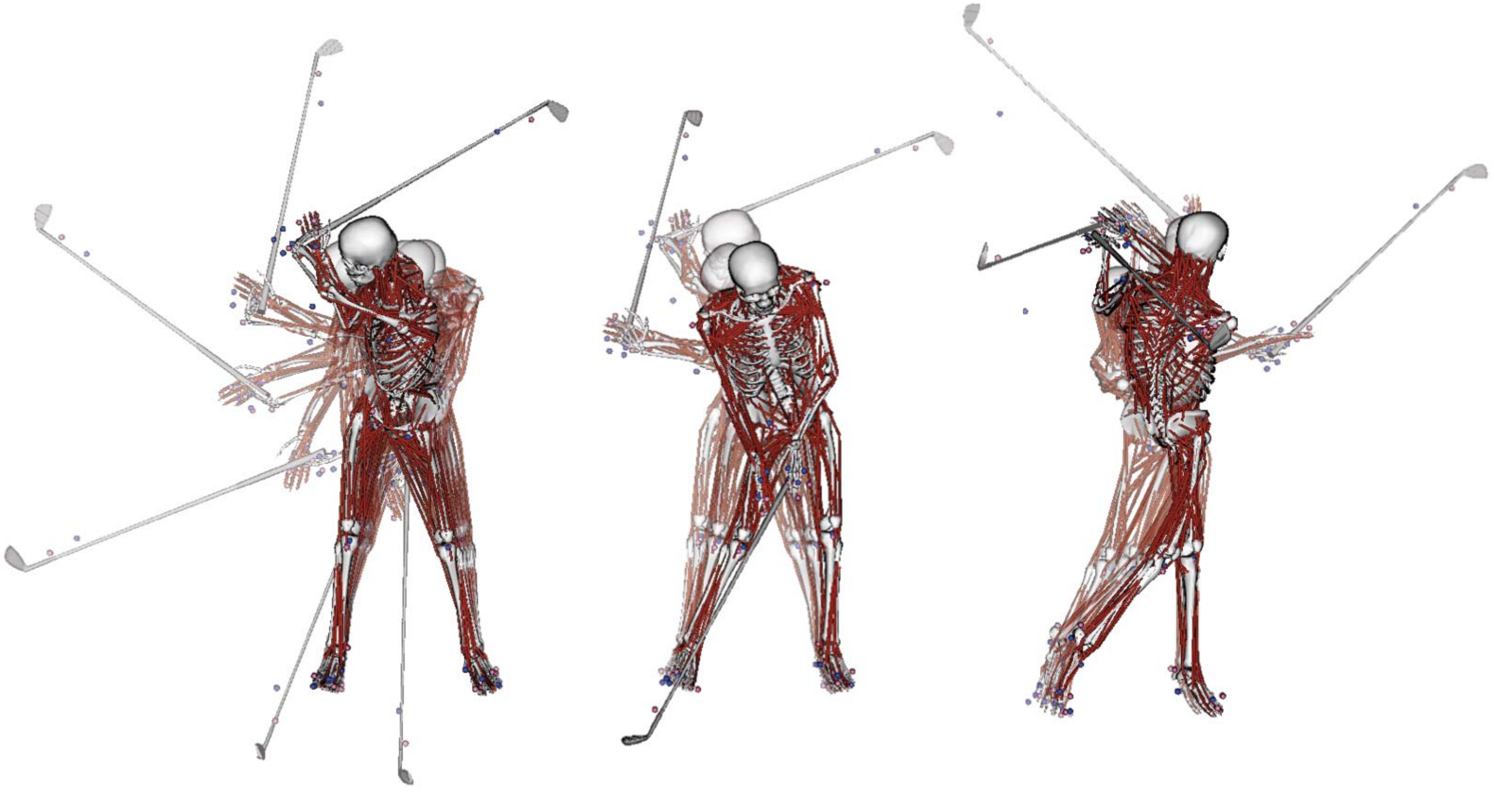
**: equations of motions*

Thank you!

Mechanical Engineering Seminar (U-Grad)
Special Topics in Mechano-Informatics II (Grad)
"Biomechanics of Human Movement"

May 9th, 2014

Dr. Emel Demircan



Effect of Muscle Architecture on Muscle Function

- Comparison of two muscles with different fiber lengths: