Introduction to Neuromuscular Disorders in Cerebral Palsy and Clinical Gait Analysis

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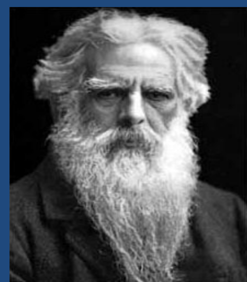
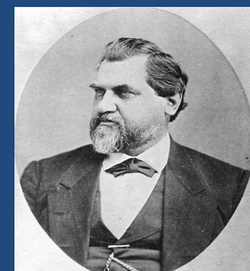
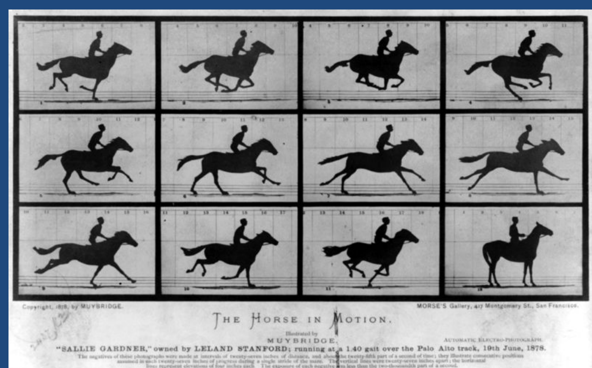
Motion Analysis at Stanford

Edward Muybridge & Leland Stanford *1878*







Muybridge used chronophotography, a technique invented by French photographer, Etienne-Jules Maray (1830-1904). Muybridge set up a series of cameras with threads attached, as the horse galloped by the cameras were triggered.

Teaching Points

- Four Neuromuscular Disorders of *Spastic* Cerebral Palsy
- Phases of the Gait Cycle
- Kinematic, Kinetic and EMG measures of Gait
- Analysis of Common Gait Disorders
- Upper Limb Kinematics of Reach & Grasp Cycle

Motion & Gait Laboratory

A Clinical Service and Research Laboratory

Biomechanical Analysis of Gait and Upper Limb Function

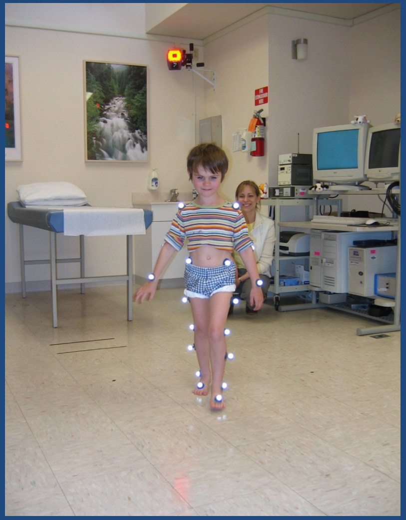
Kinematics: 3-D Joint motion recorded by

8 digital motion capture cameras

Kinetics: Forces across joints

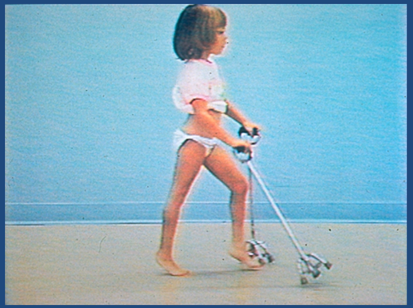
calculated from ground reaction force & kinematics

EMG: muscle activity while walking or reaching



Cerebral Palsy (CP)

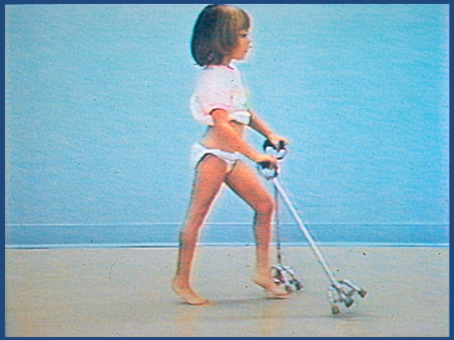
- A disorder of the development of movement and posture resulting from a brain injury around the time of birth.
- **3**/1000 children in general population have CP
- **50-150**/1000 children born very preterm have CP
- Types of CP
  - Spastic *Most common form of CP*
  - Dyskinetic *Involuntary movements*
  - Ataxic *Poor balance, accuracy*



- Gait Analysis identifies specific deficits, guides treatment.

Neuromuscular Disorders in *Spastic* CP

Arise from brain injury and subsequent loss of descending neural activation & inhibition



- Muscle Weakness
- Short Muscle-tendon Length
- Muscle Spasticity
- Impaired Selective Motor Control

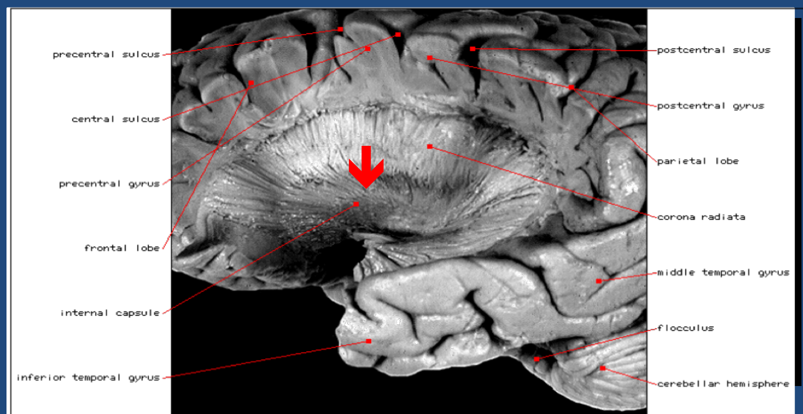
Spastic CP may occur with Dyskinetic & Ataxic CP

Neuromuscular Disorders

Arise from Brain Injury in *Spastic* CP

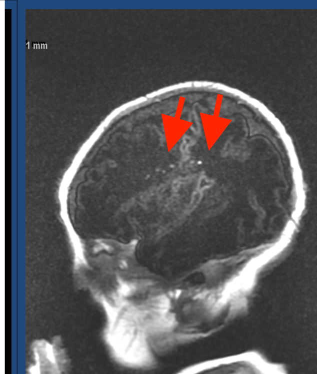
Cortical Spinal Tract (CST) motor neurons descend in Posterior Limbs of Internal Capsule (PLIC)

Motor Cortex



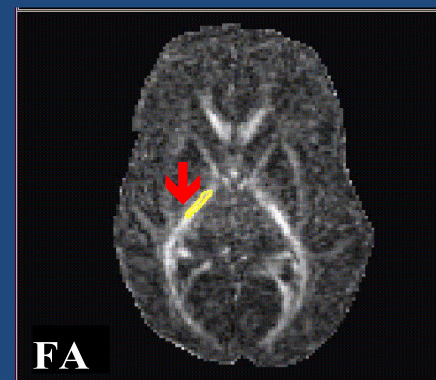
Sagittal view of the brain

Superior



Sagittal T1

Anterior



Axial DTI

PLIC microstructure in preterm infants predicts neurodevelopment

Rose et al, 2005, 2007 Dev Med Child Neurol; Rose et. al, 2015 Ped Res

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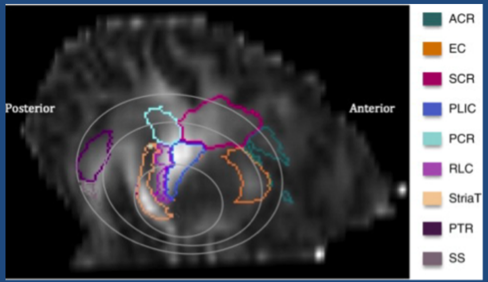
Neuromuscular Disorders

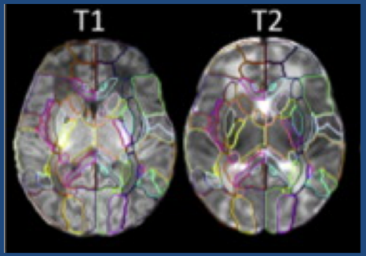
Arise from Brain Injury in *Spastic* CP

Neuroimaging research on neonatal brain region microstructure assessed on DTI using exhaustive feature selection and linear regression - predicts motor development assessed on BSID-III

Sagittal DTI

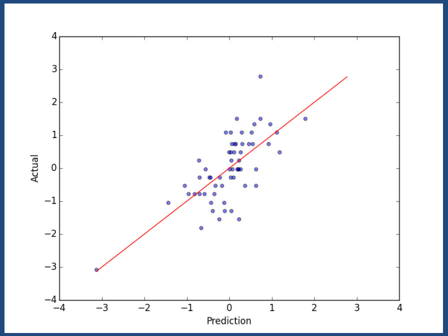


Anterior



BSID-III Composite Motor Score
Predicted by L posterior-limb-of-internal-capsule, R parahippocampal gyrus, R middle temporal gyrus.

Model accounted for 32% variance in Motor Composite Score (LOOCV R^2=0.317).



Rose et al., 2015 Ped Res; Schadl et al., 2017 NIMG Clinical

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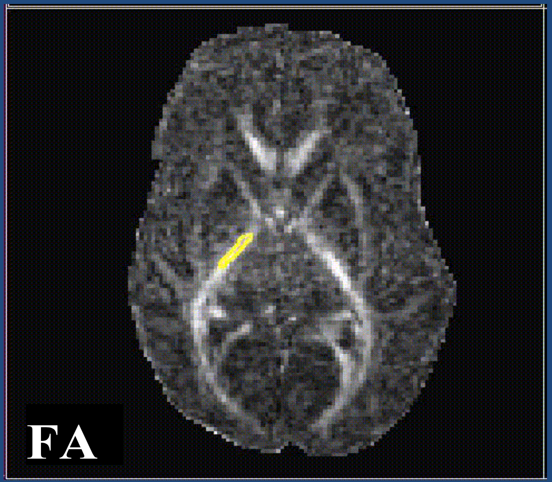
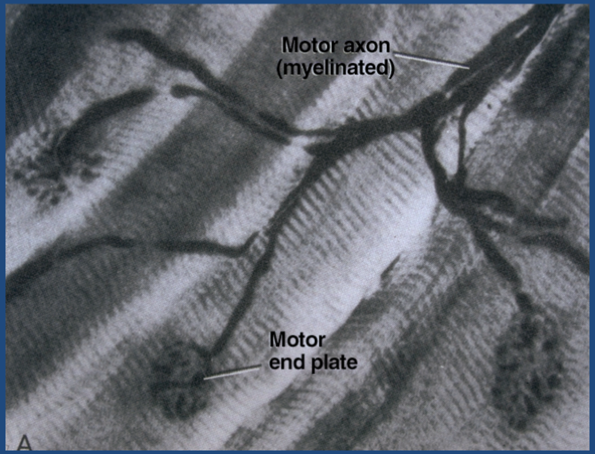
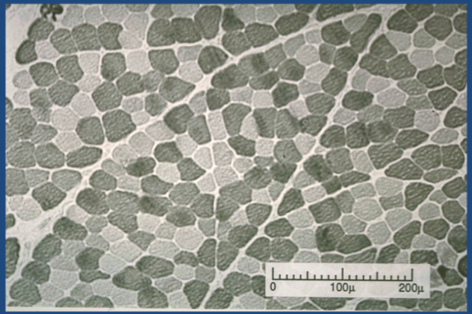
Neuromuscular Disorders

Arise from Brain Injury in *Spastic* CP

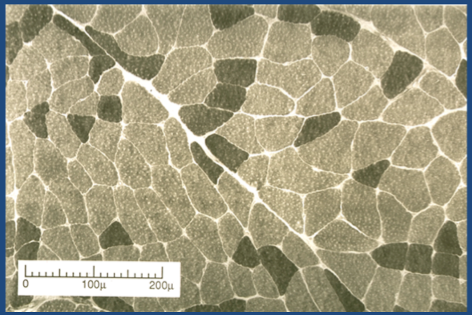




Normal



CP



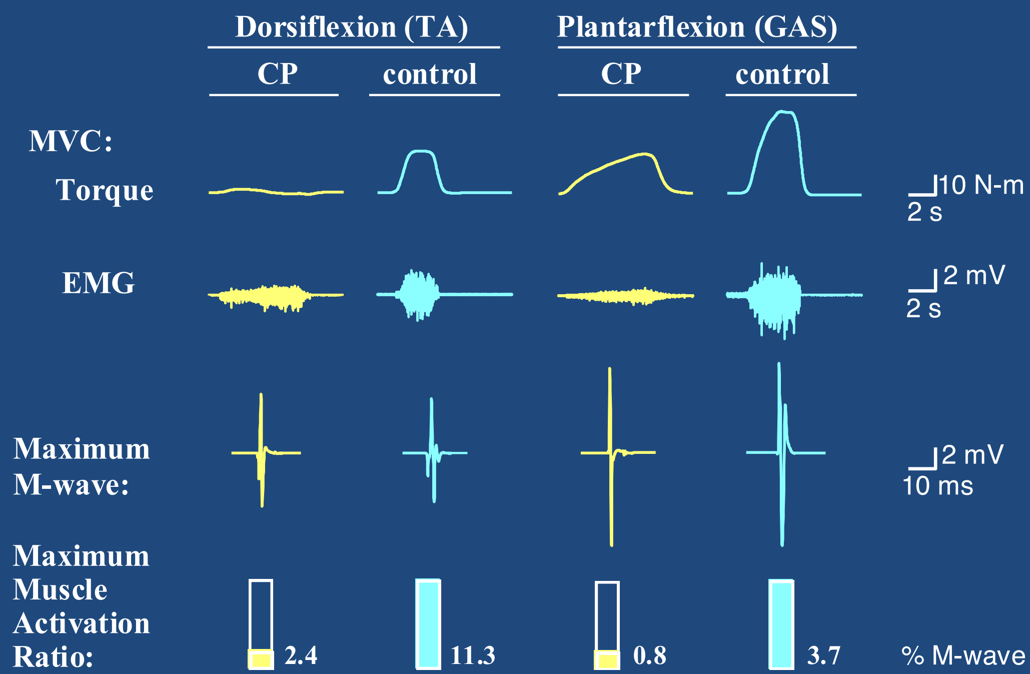
Injury to developing brain ↓ motor neuron firing rate ↑ type-1 fibers, size variation

Rose et al, 2015 J Ped Res; Rose & McGill, 2005 Dev Med Child Neurol; Rose et al, 1994 J Orthop Res

Neuromuscular Disorders in *Spastic* CP

Weakness

↓ Max Neuromuscular Activation: *Max EMG / M-wave*



Rose & McGill, 2005 *Dev Med Child Neurol*

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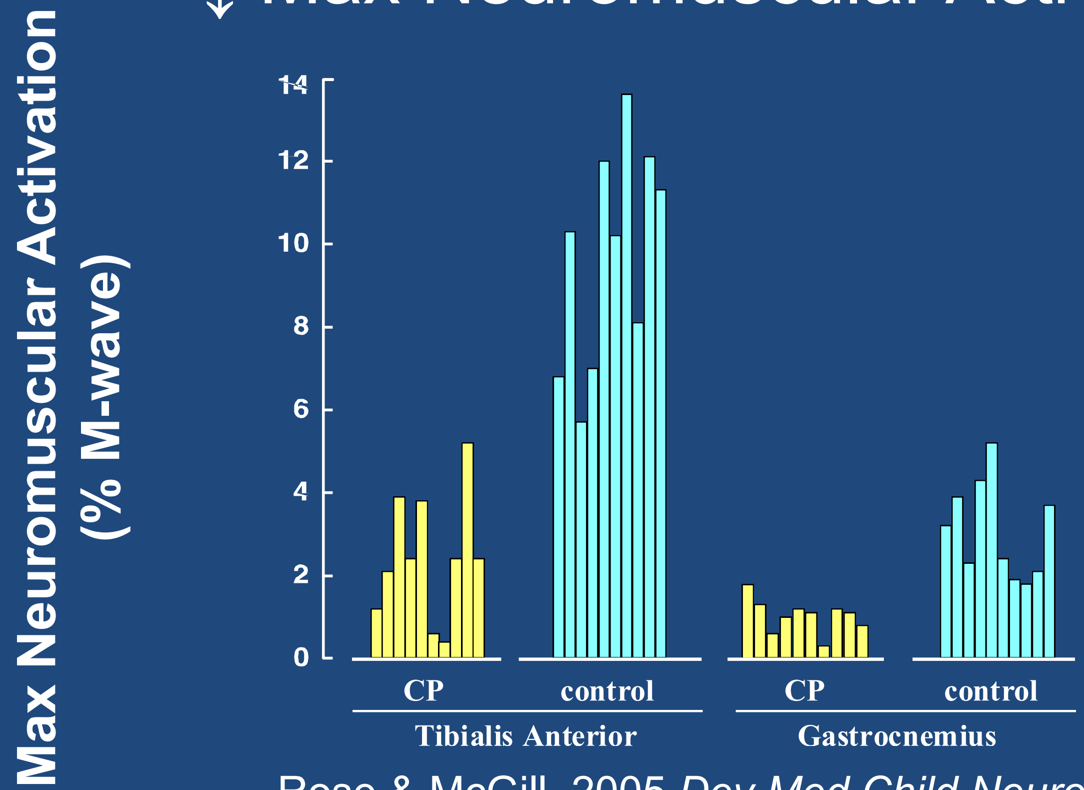
Neuromuscular Disorders in *Spastic* CP

Weakness

↓ Max Neuromuscular Activation

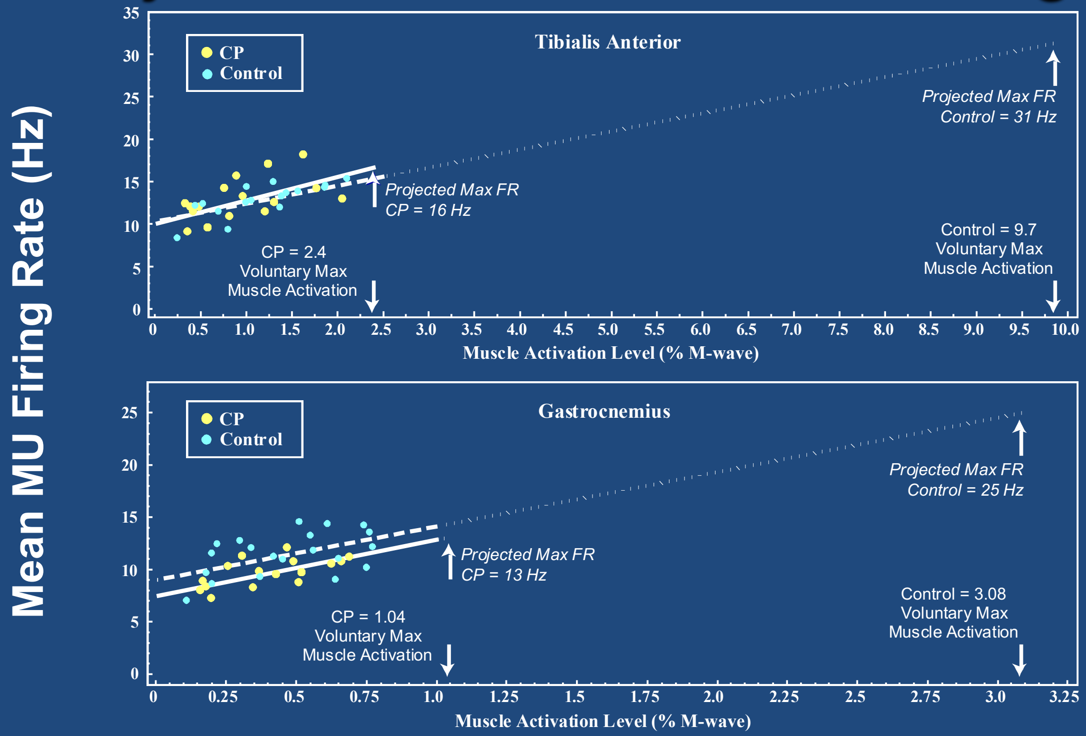


Rose & McGill, 2005 *Dev Med Child Neurol*

Neuromuscular Disorders in *Spastic* CP

Weakness

↓ Projected Max Motor-unit Firing Rates



Rose & McGill, 2005 *Dev Med Child Neurol*

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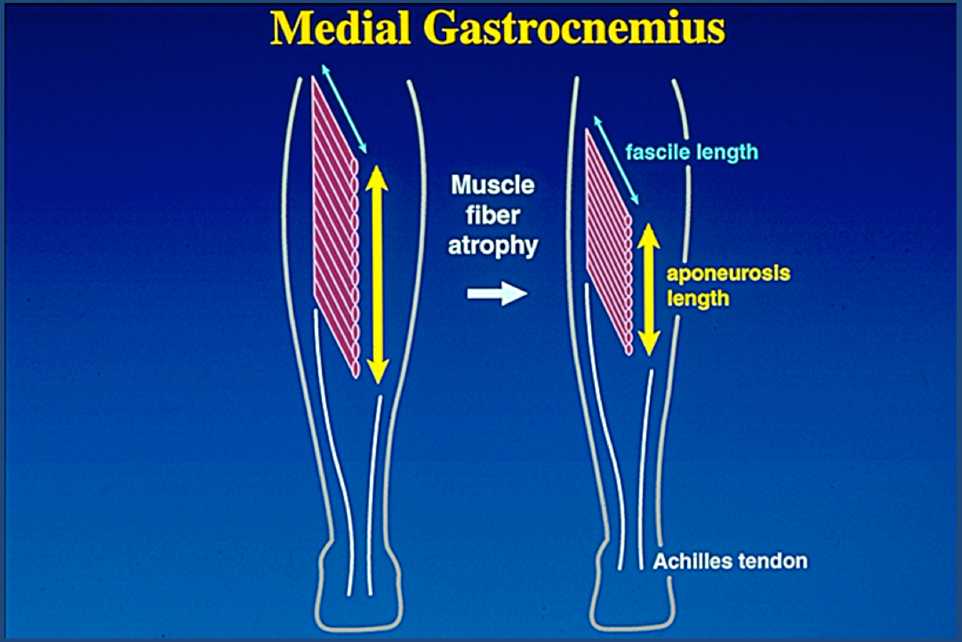
Neuromuscular Disorders in *Spastic* CP

Short Muscle-tendon Unit

- Growth Rate Discrepancy ↓ Muscle to Bone Length Ratio
- Muscle Atrophy & Weakness



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Neuromuscular Disorders in *Spastic* CP

Impaired Selective Motor Control

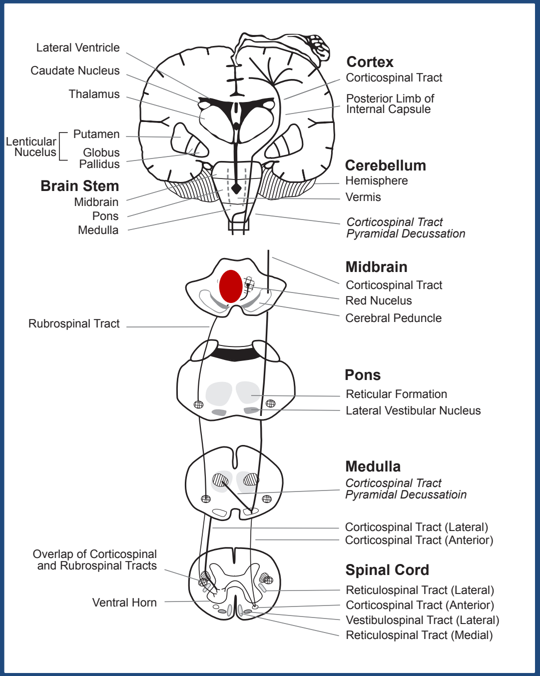
Obligatory co-activation of flexors or extensors

Mediated by Red Nucleus and Rubrospinal Tract:

Develops in infancy, less prominent in adults

Develops after Cortical Spinal Tract Injury, assessed on DTI
Acute stroke patients Yeo & Jang (2010)
Chronic stroke patients Radlinska et al. (2010)

Activates synergist muscles - flexion and extension patterns
↑Flexors ↓ Extensors Belhaj-Saif & Cheney (2000)
↑ Extensors ↓ Flexors Yang et al. (2011)



Red Nucleus

Provides imperfect motor compensation

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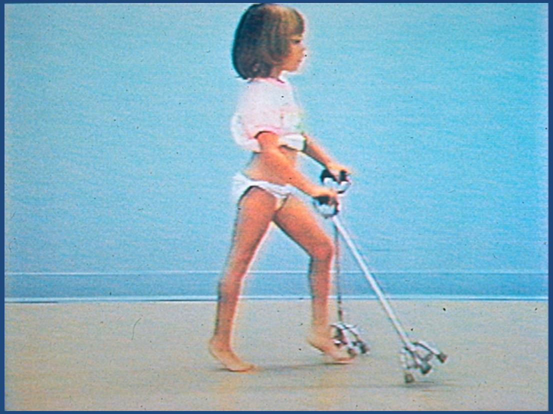
Neuromuscular Disorders in *Spastic* CP

Review

- Muscle Weakness
- Short Muscle-tendon Length
- Muscle Spasticity
- Impaired Selective Motor Control



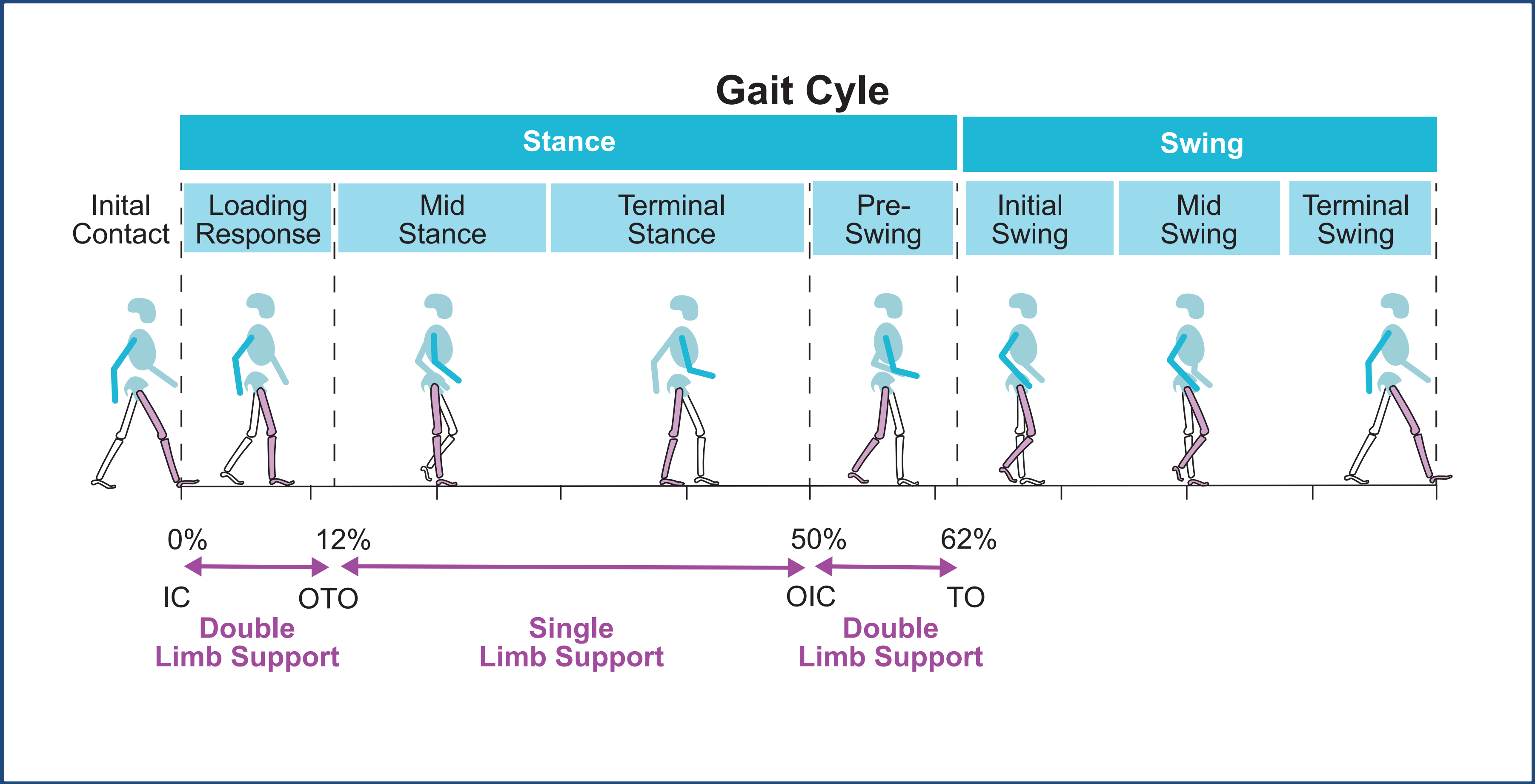
Neuromuscular Disorders

Result in *Gait Disorders*

Gait Analysis

- Identifies abnormal gait biomechanics
- Identifies neuromuscular contributions to gait
- Provides treatment recommendations

Gait Analysis



Gait disorders are analyzed in relation to the gait cycle

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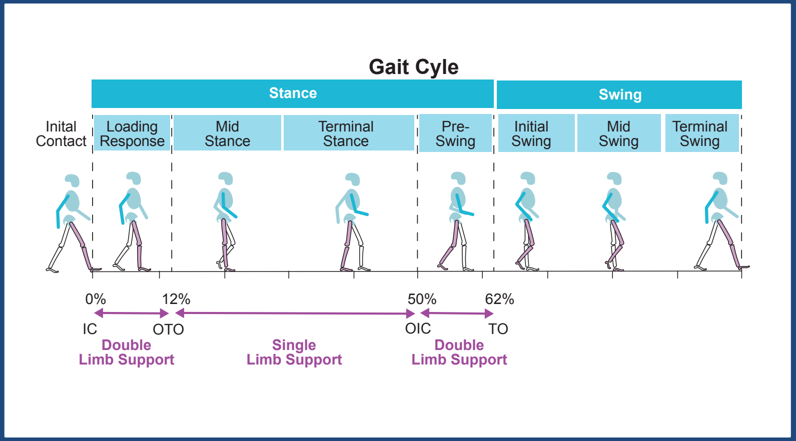
Gait Events

Stance Phase



Initial contact - Toe-off

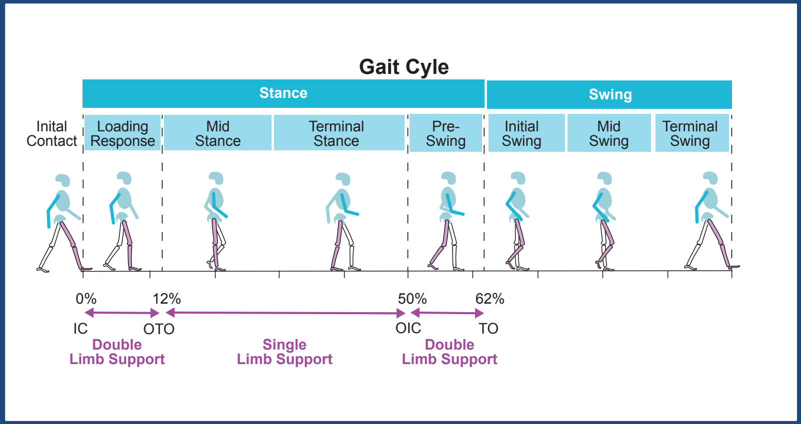
***Early Stance*: Double Limb Support Initial contact - opposite toe-off**

***Mid Stance*: Single Limb Support Opposite toe-off - opposite initial contact**

***Terminal Stance*: Double Limb Support Opposite initial contact - toe-off**

Gait Events

Swing Phase



Toe-off - Initial contact

***Early Swing*: Peak knee flexion of 60 degrees**

***Mid Swing*: Rapid knee extension – tibia perpendicular to ground**

***Terminal Swing*: Knee extends, limb decelerates prior to initial contact**

Gait Temporal-spatial Parameters

Stride length: Distance from heel to heel of a single limb

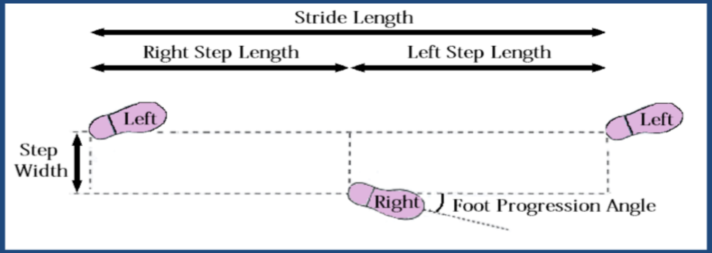
Step Length: Distance from heel to opposite side heel

Cadence: Number of steps per unit time

Walking velocity: *step length x cadence*

Step width: Mediolateral distance between the two heels

Foot progression angle: Foot longitudinal axis vs. gait progression



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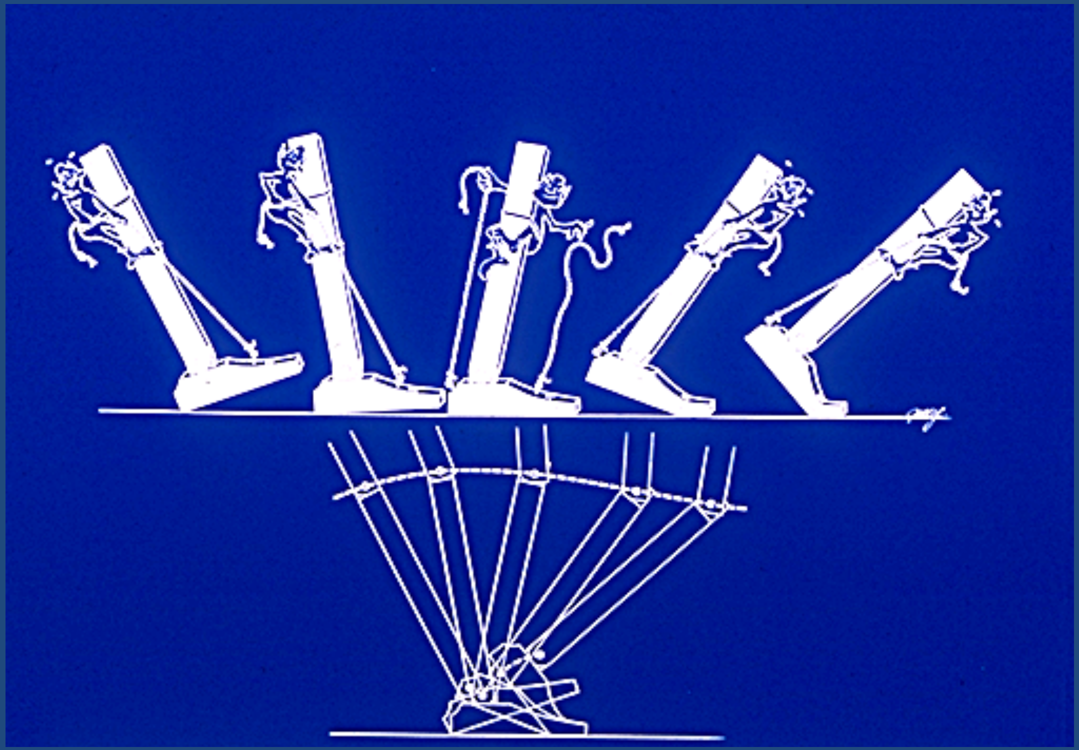
Stance Phase

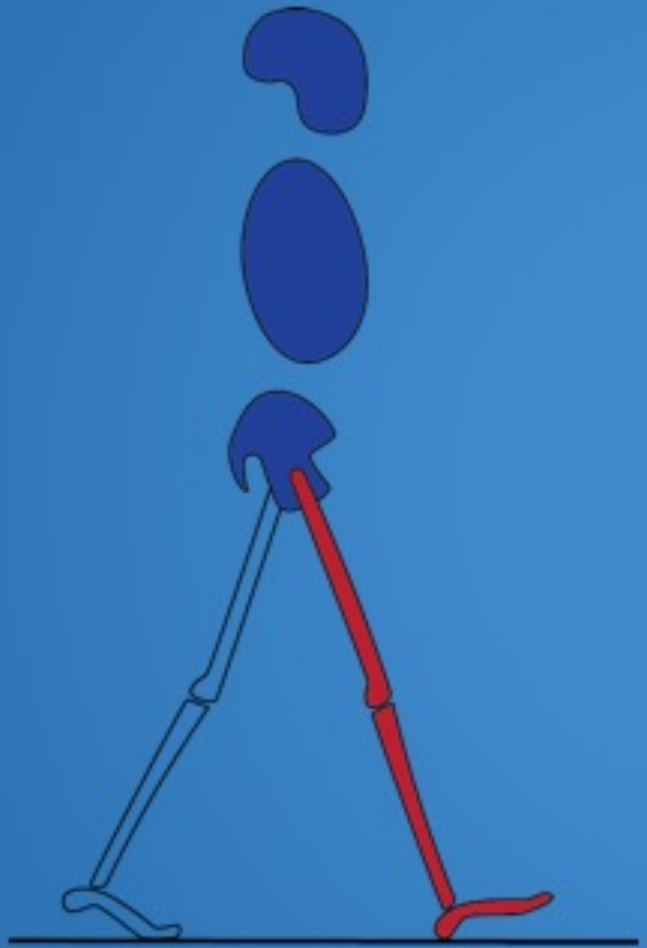
3 Foot & Ankle Rockers



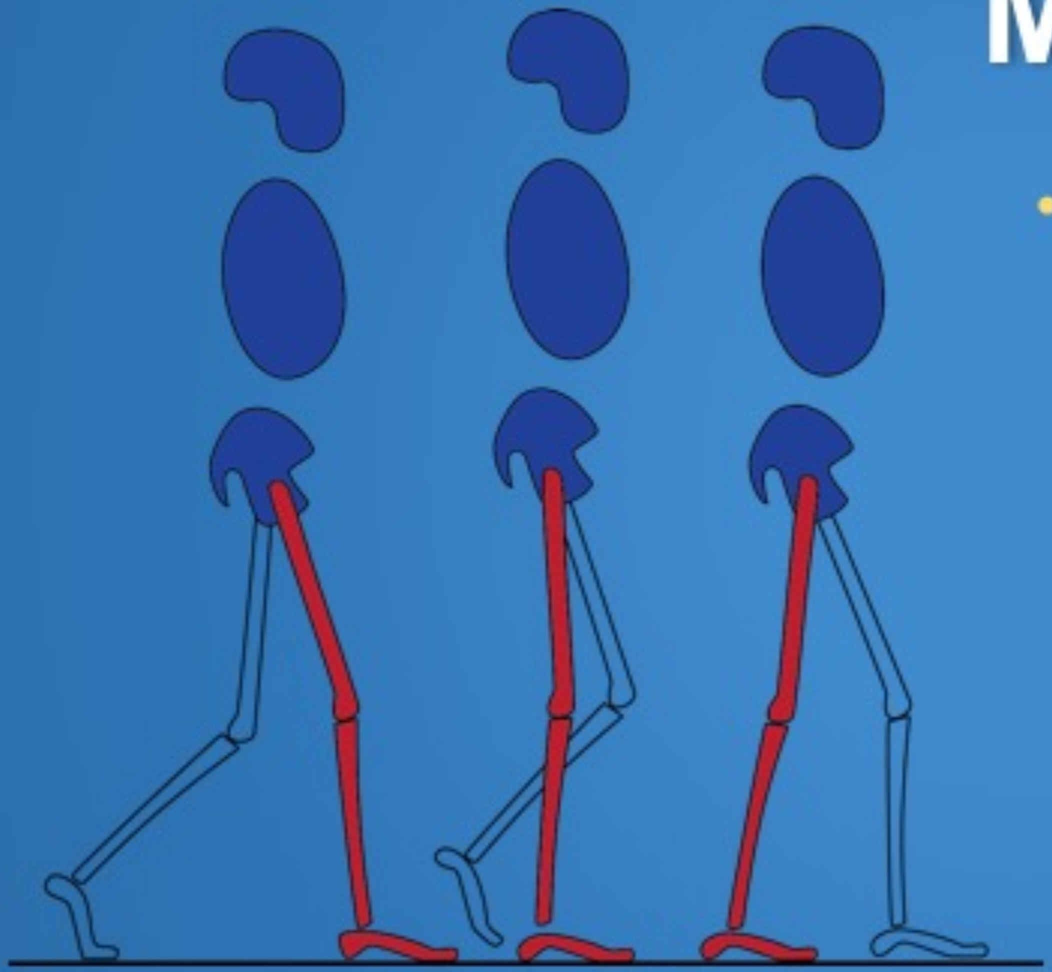
From: *Human Walking*, Rose J & Gamble JG, Editors. 3rd Ed, 2006

Initial Contact

- Heel First Contact

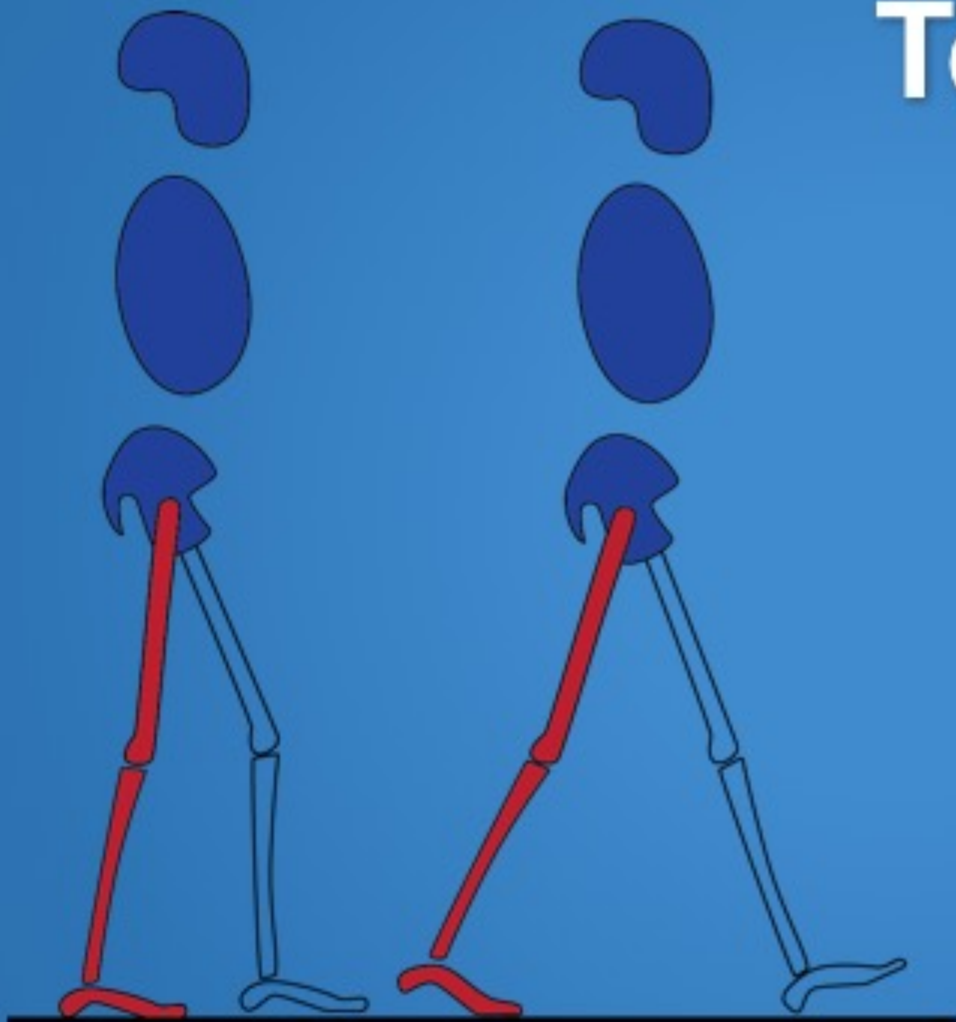


Mid-Stance



- Controlled Tibial Advancement

Terminal-Stance

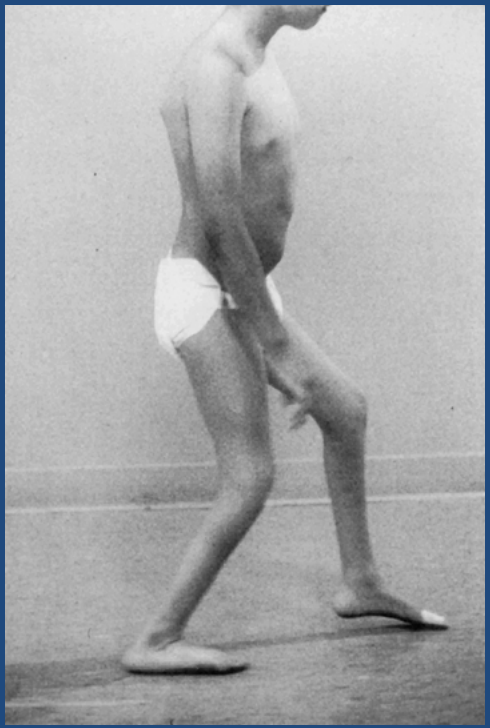


- Locked Ankle
- Heel Rise
- Trailing Limb

Stance Phase Gait Abnormality

Flexed-knee Gait

Unrestrained ankle rocker & absent forefoot rocker



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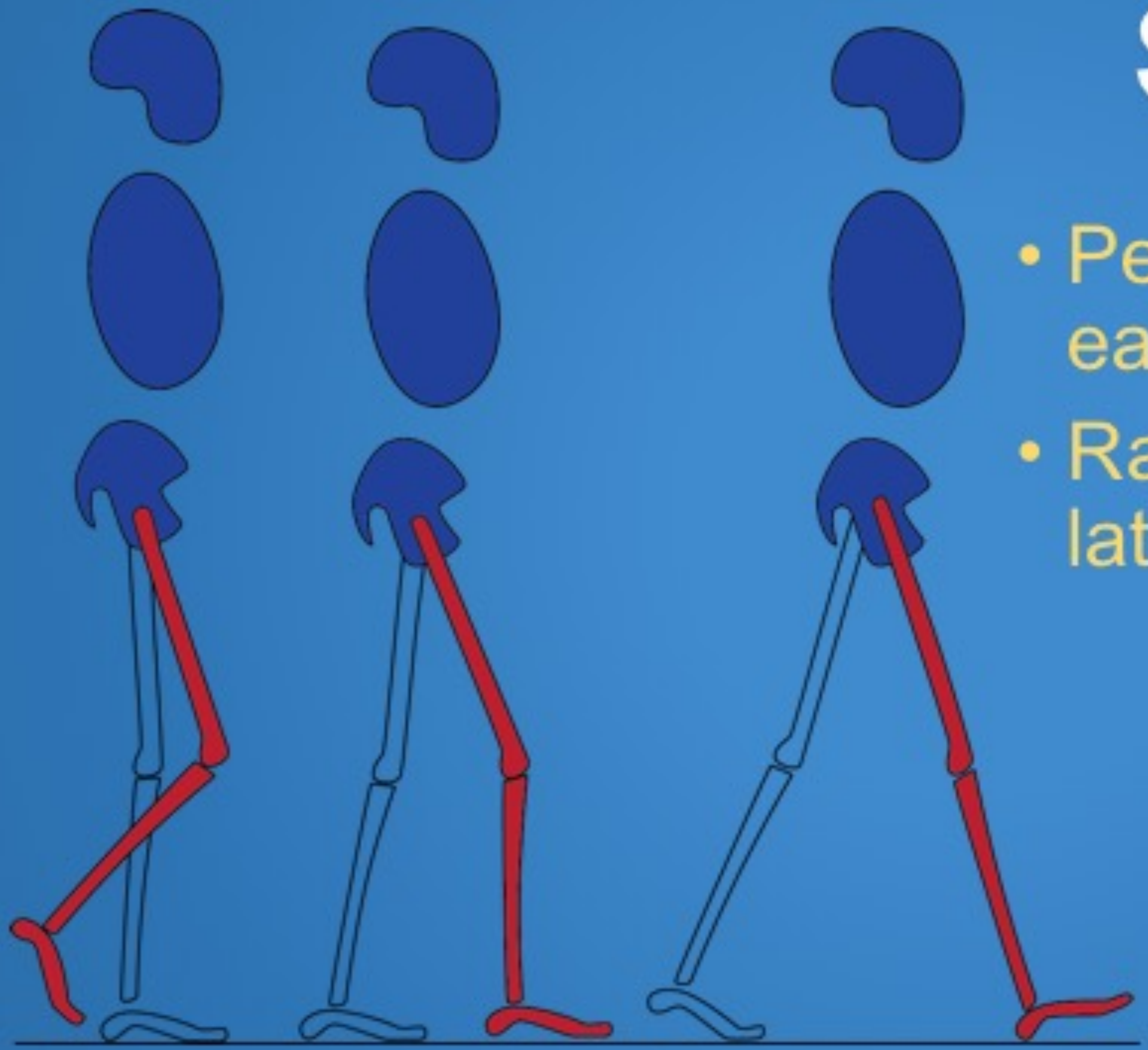
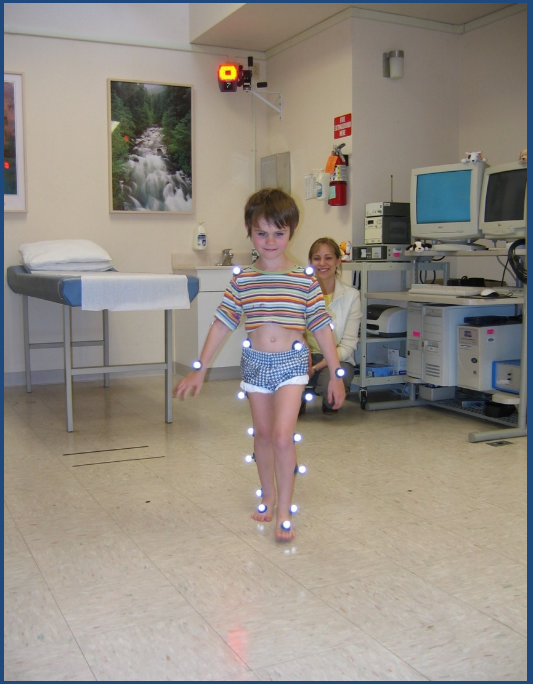


Swing

- Peak knee flexion in early swing
- Rapid knee extension in late swing

Gait Analysis: Kinematics & Kinetics



Kinematics: 3D Joint Motion

8 Digital Motion Capture Cameras

Records Position of Light Reflective Markers

Kinetics: Forces passing through Joints

Force Plate Embedded in Floor

Records Ground Reaction Force (GRF) Vectors

Calculated from GRF & Kinematics

Gait Kinematics & Kinetics

Planes of Motion

Sagittal Plane (Side View)

flexion-extension

dorsi-plantarflexion

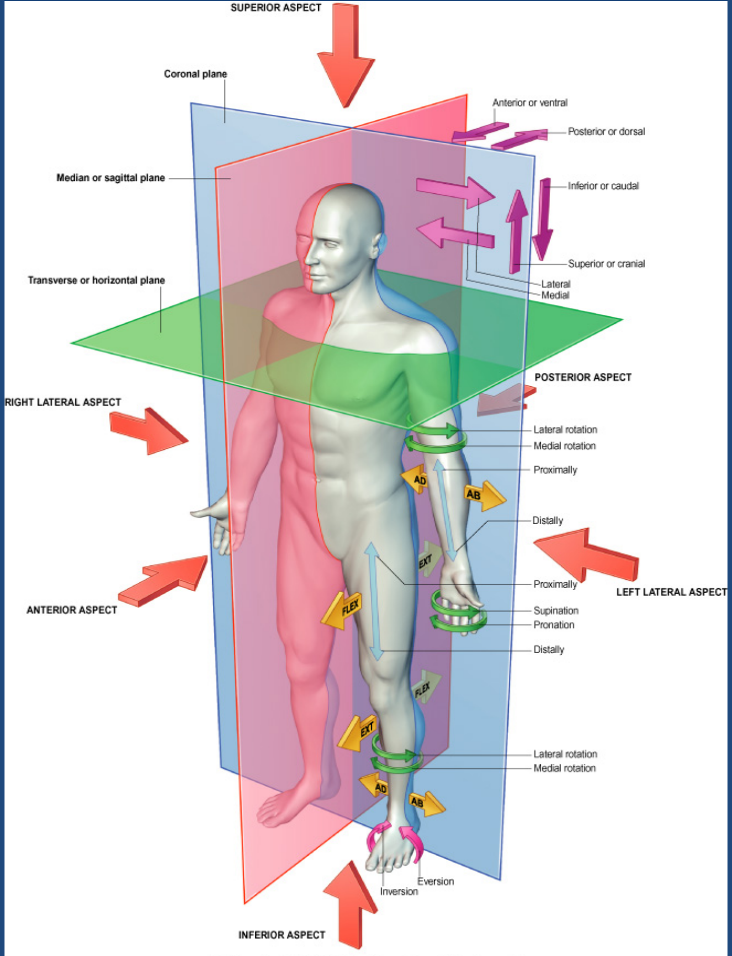
Frontal Plane (Coronal)

adduction-abduction

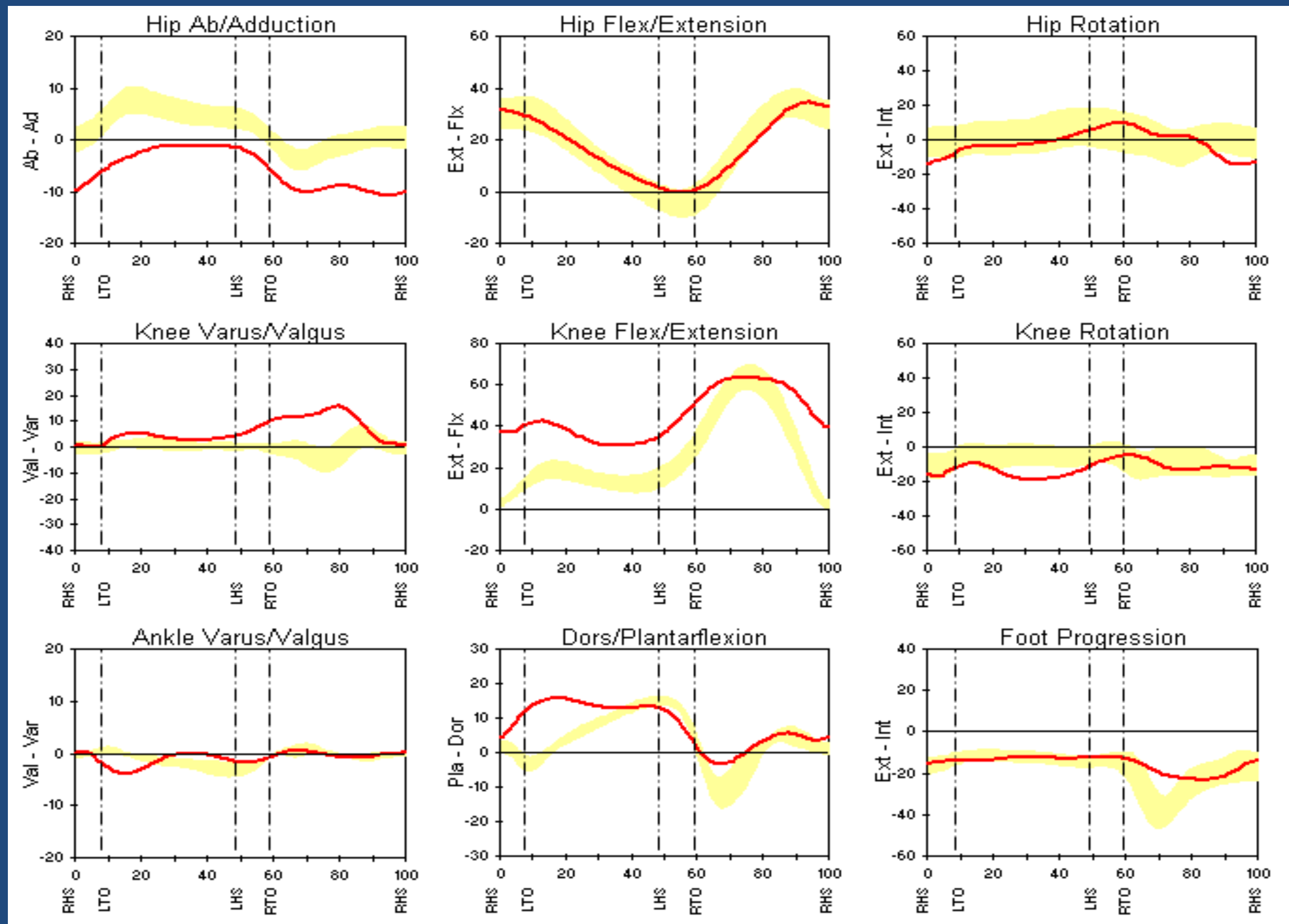
inversion-eversion

Transverse Plane (Axial)

medial-lateral rotation



Gait Kinematics



Normal

CP

Frontal Sagittal Transverse

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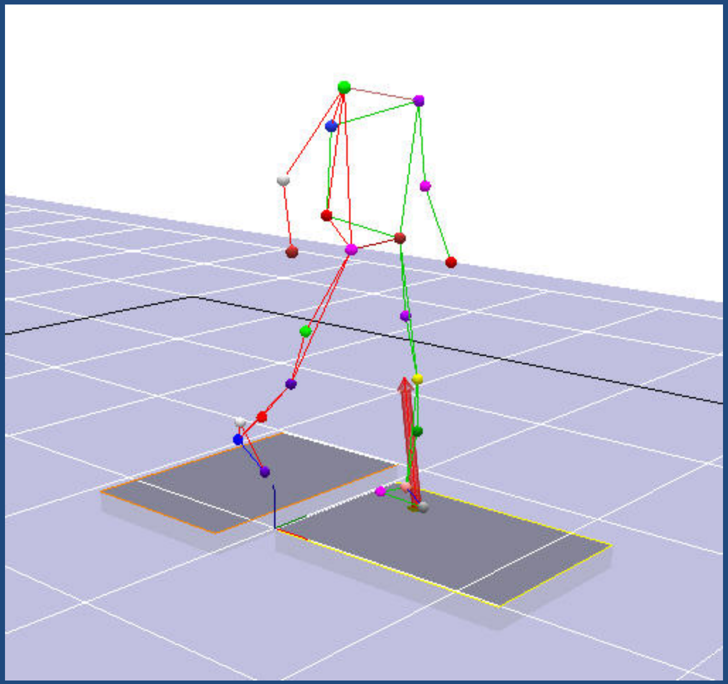
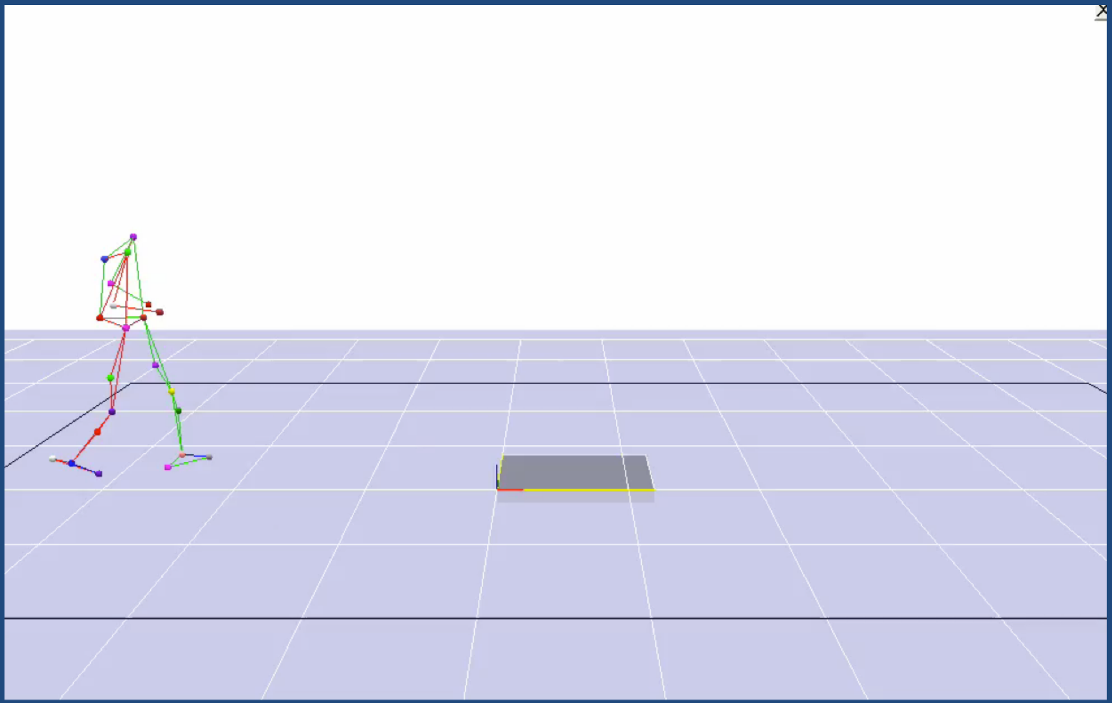
Gait Kinetics





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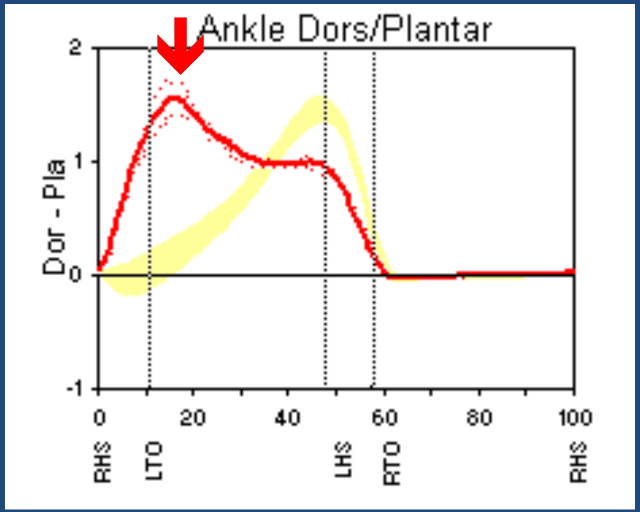
Gait Kinetics

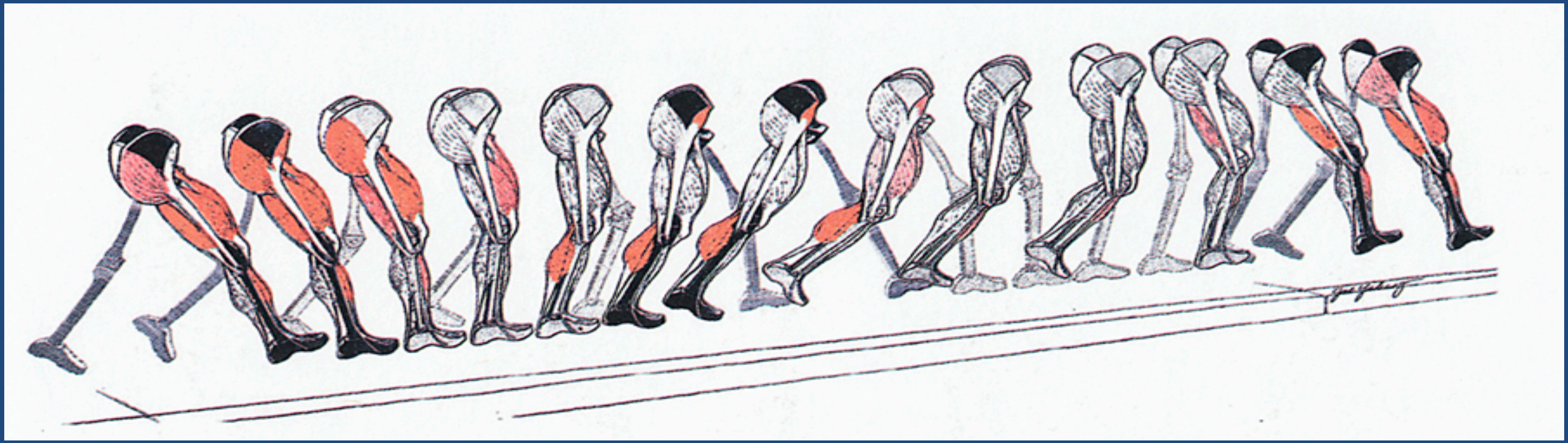
- Normal ankle plantarflexor moments peaks in terminal stance
- Increased plantar flexor moment in loading "double bump" due to plantar flexion at initial contact, toe-walking in CP
- Decreased moment in terminal stance associated with a reduced forefoot rocker, reduced forward momentum at toe-off.



Normal

CP

Gait Muscle Activity



Stance *Swing*

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Muscle Activity Recorded on EMG

Hip & Knee Extensors:

Gluteus Maximus & Medius

Hamstrings

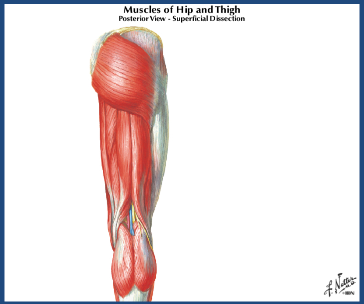
- Semitendinosus
- Semimembranosus
- Biceps Femoris

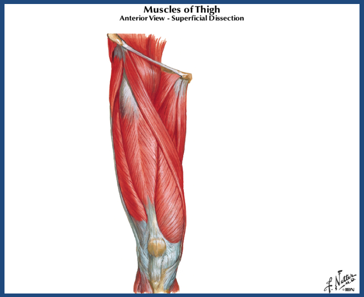
Quadriceps

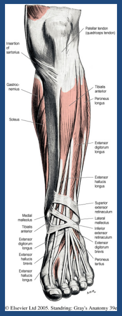
- Rectus Femoris
- Vastus Lateralis & Medialis

Ankle Plantarflexors & Dorsiflexors:

- Gastrocnemius & Soleus
- Tibialis Anterior







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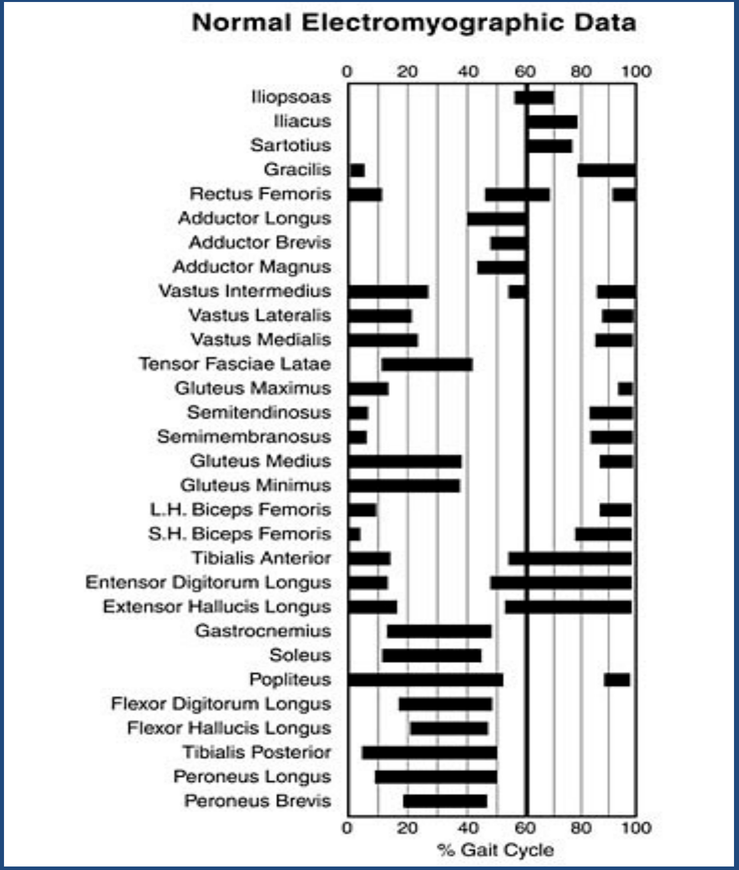
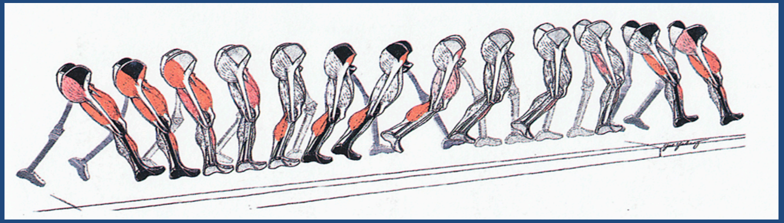
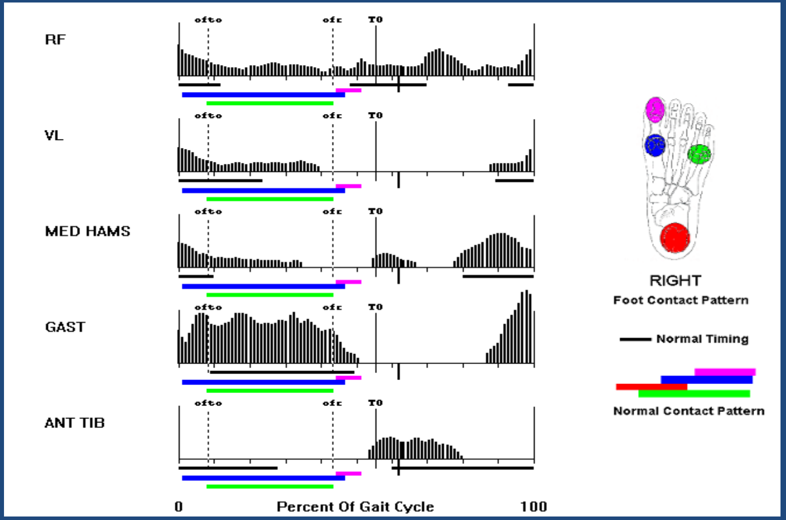
Gait EMG





Normal



CP

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Diplegic Spastic Cerebral Palsy

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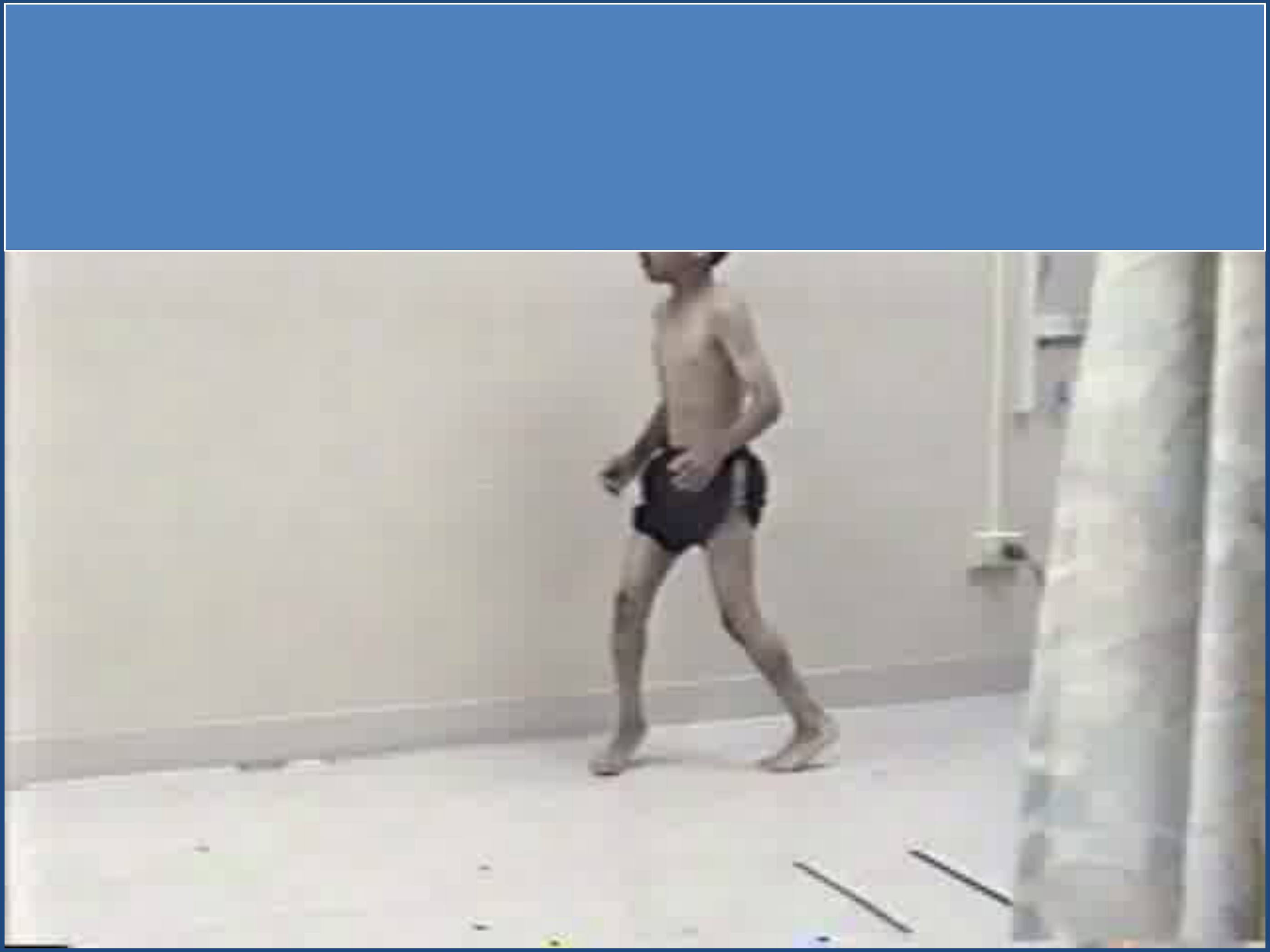
Diplegic Spastic Cerebral Palsy



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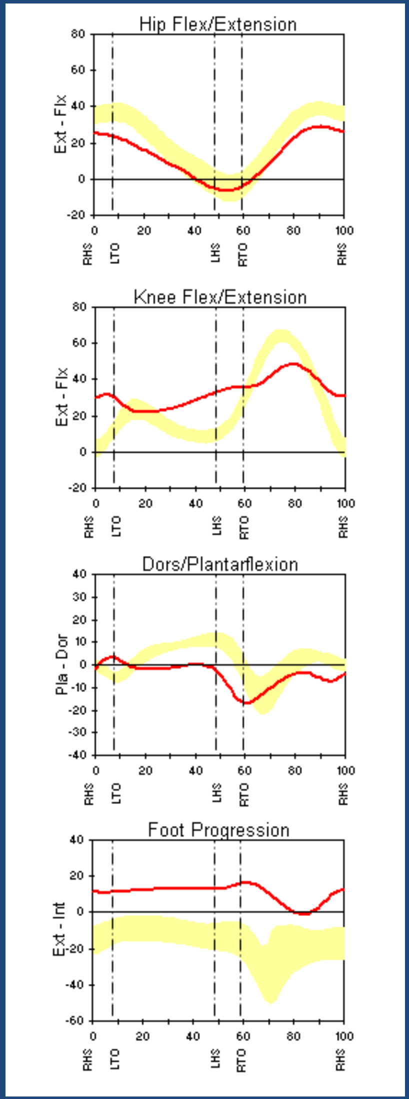
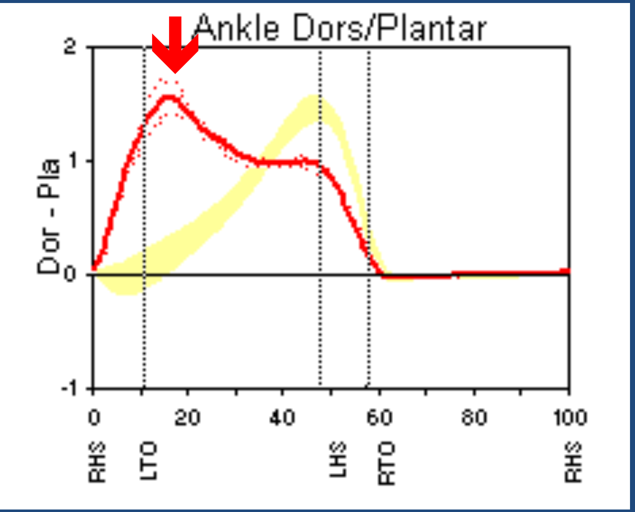
Kinematics

- Nearly normal hip motion
- Increased knee flexion at IC and stance
- Reduced peak knee flexion in swing
- Increased plantar flexion in stance & swing
- Internally rotated foot progression

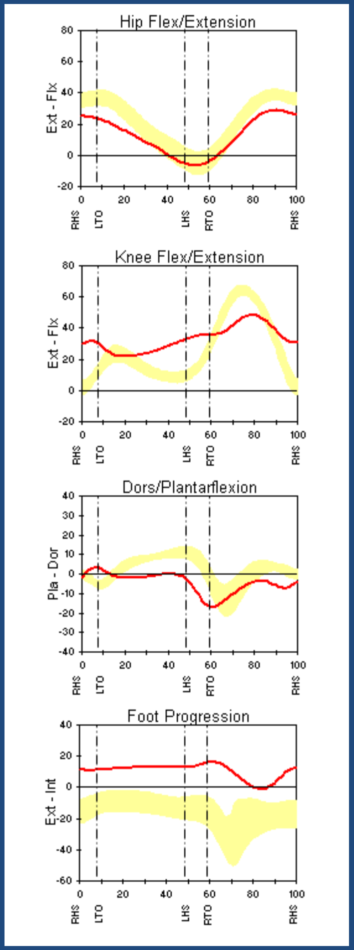


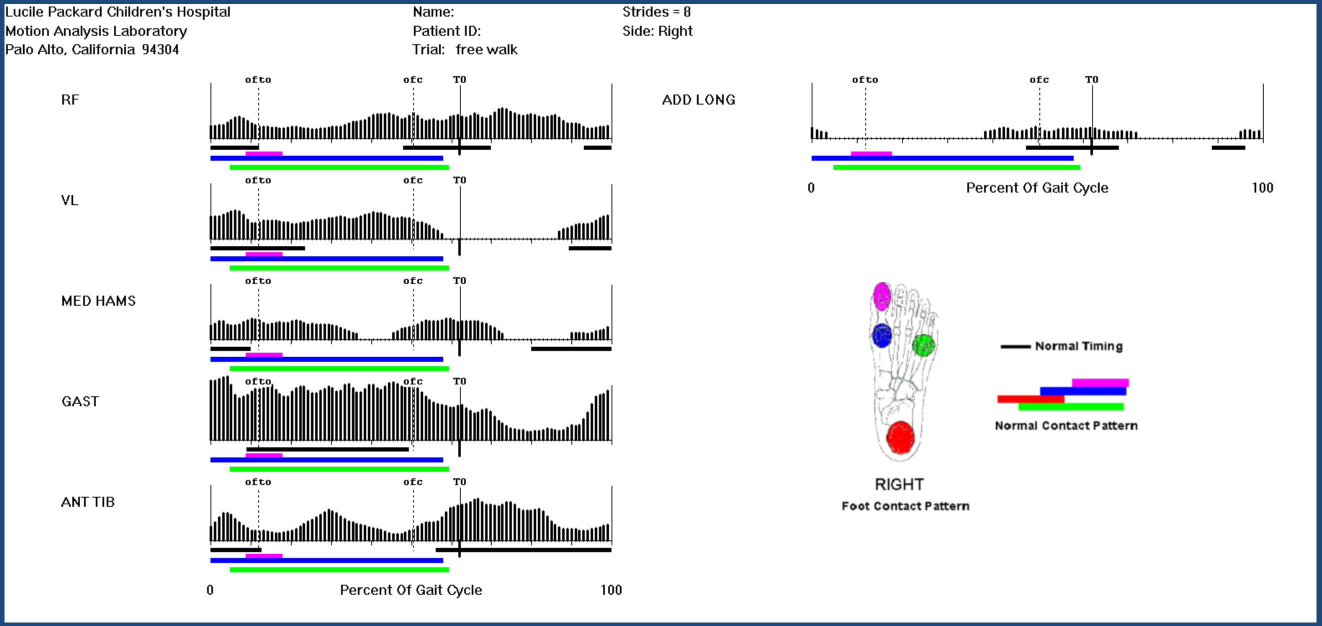
Kinetics

- Normal ankle plantarflexor moment peaks in terminal stance
- Increased plantar flexor moment in loading "double bump" due to increased plantar flexion at initial contact and toe-walking
- Decreased moment in terminal stance associated with a reduced forefoot rocker, reduced forward momentum at toe-off



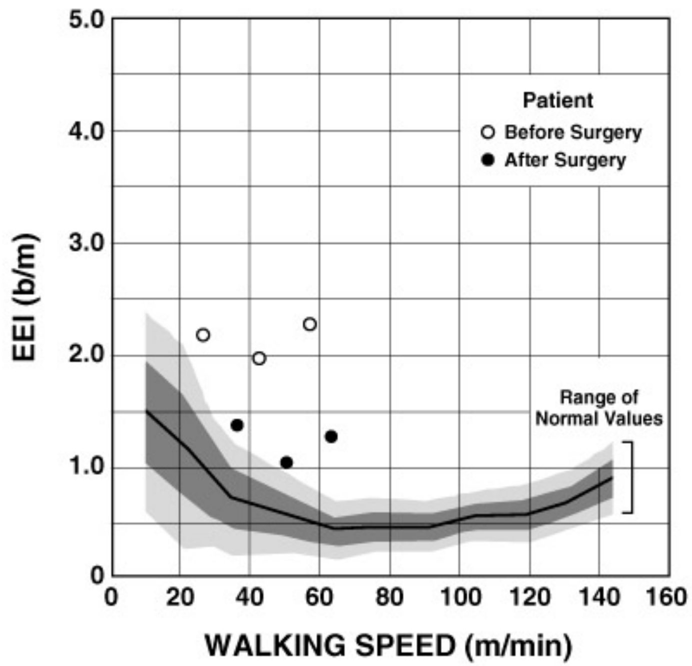
3D Kinematics & Dynamic EMG





Energy Expenditure

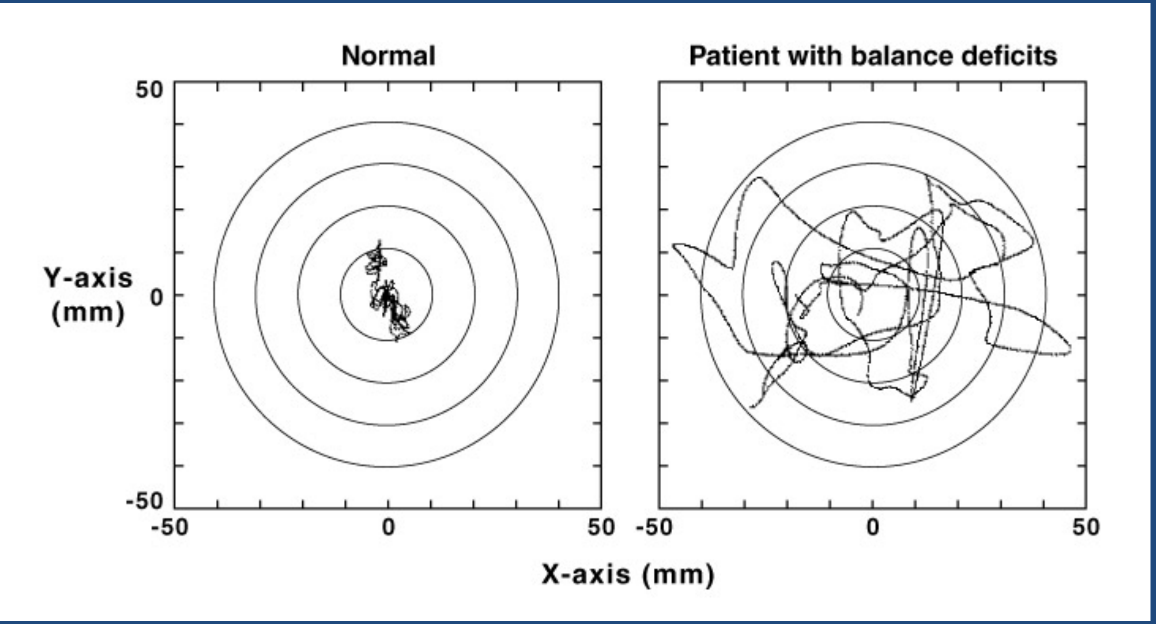
Energy Expenditure Index



$$EEI = \frac{\text{Walking Heart Rate} - \text{Resting Heart Rate}}{\text{Walking Speed}}$$

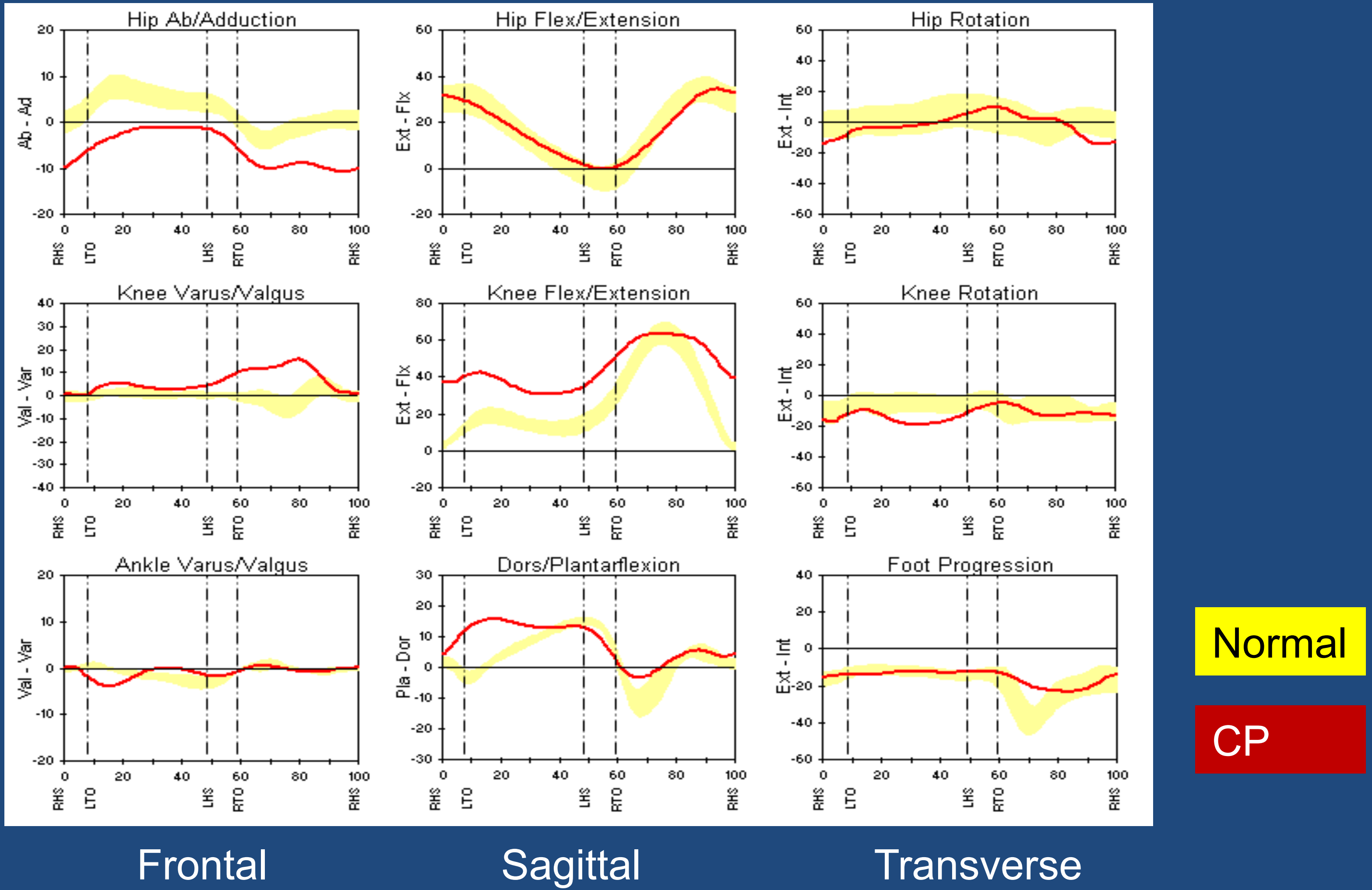
Postural Balance

- Force Plate Center of Pressure
- Postural Sway with Eyes Open/Closed



Diplegic Cerebral Palsy

Gait Kinematics



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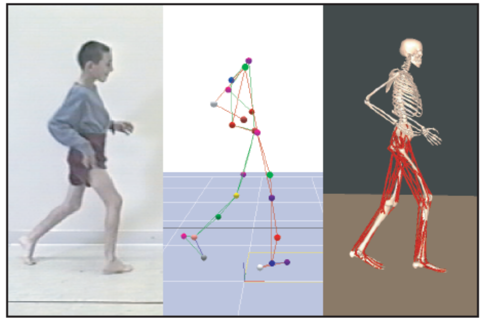
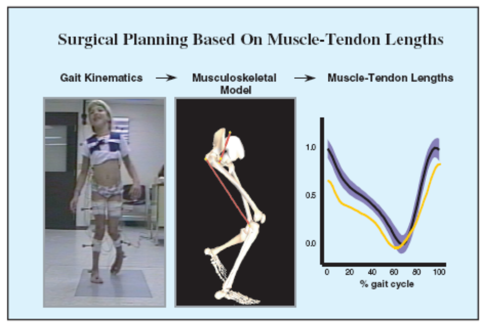
Musculoskeletal Models of Gait



Computer models are generated from gait kinematics (joint motion) and kinetics (joint forces) and reveal the biomechanical features that influence gait.



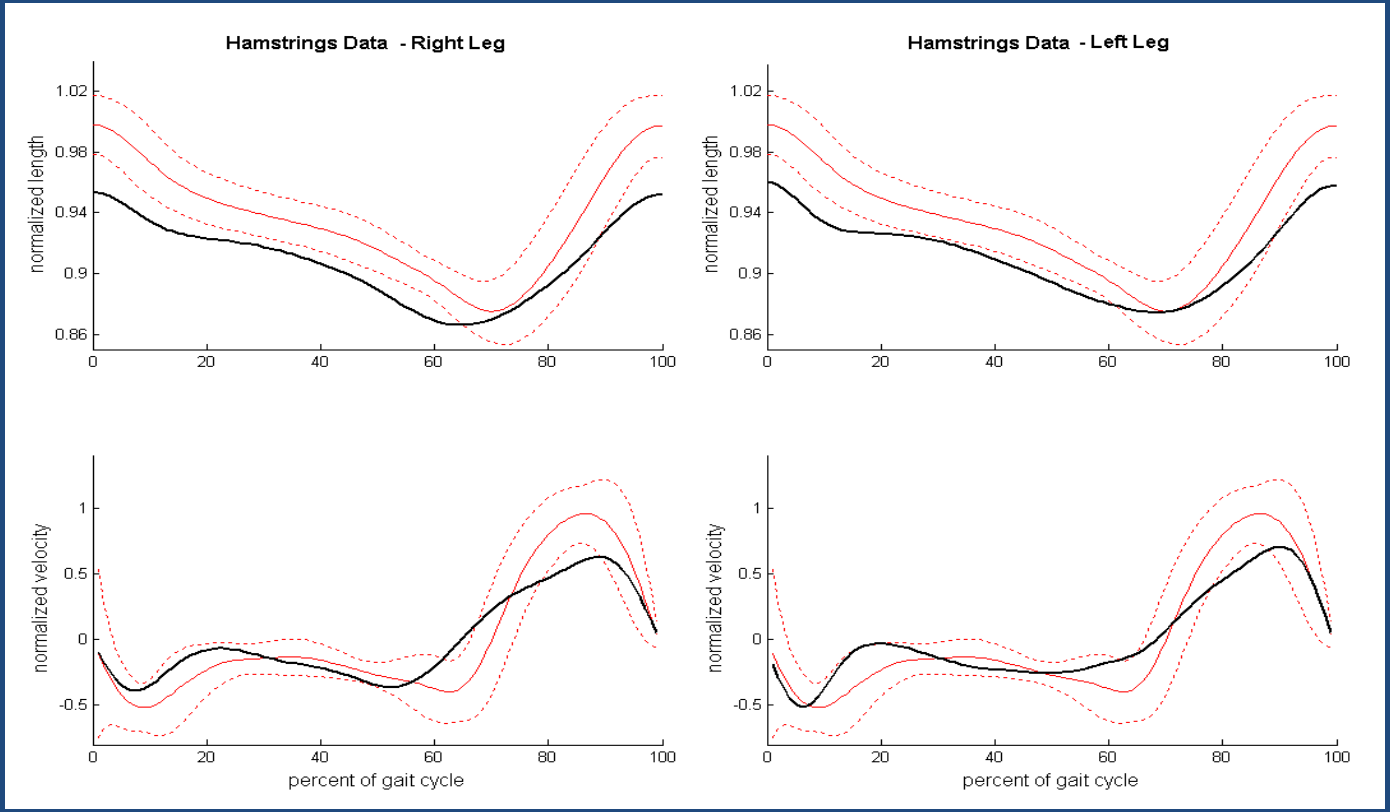
The changing muscle lengths during gait are calculated using the computer model. Muscles that are too short and limit gait can be identified and selected for treatment.

Delp et al, 2005

JRose, Stanford University

Biomechanical Model

Hamstrings' Length & Lengthening Velocity



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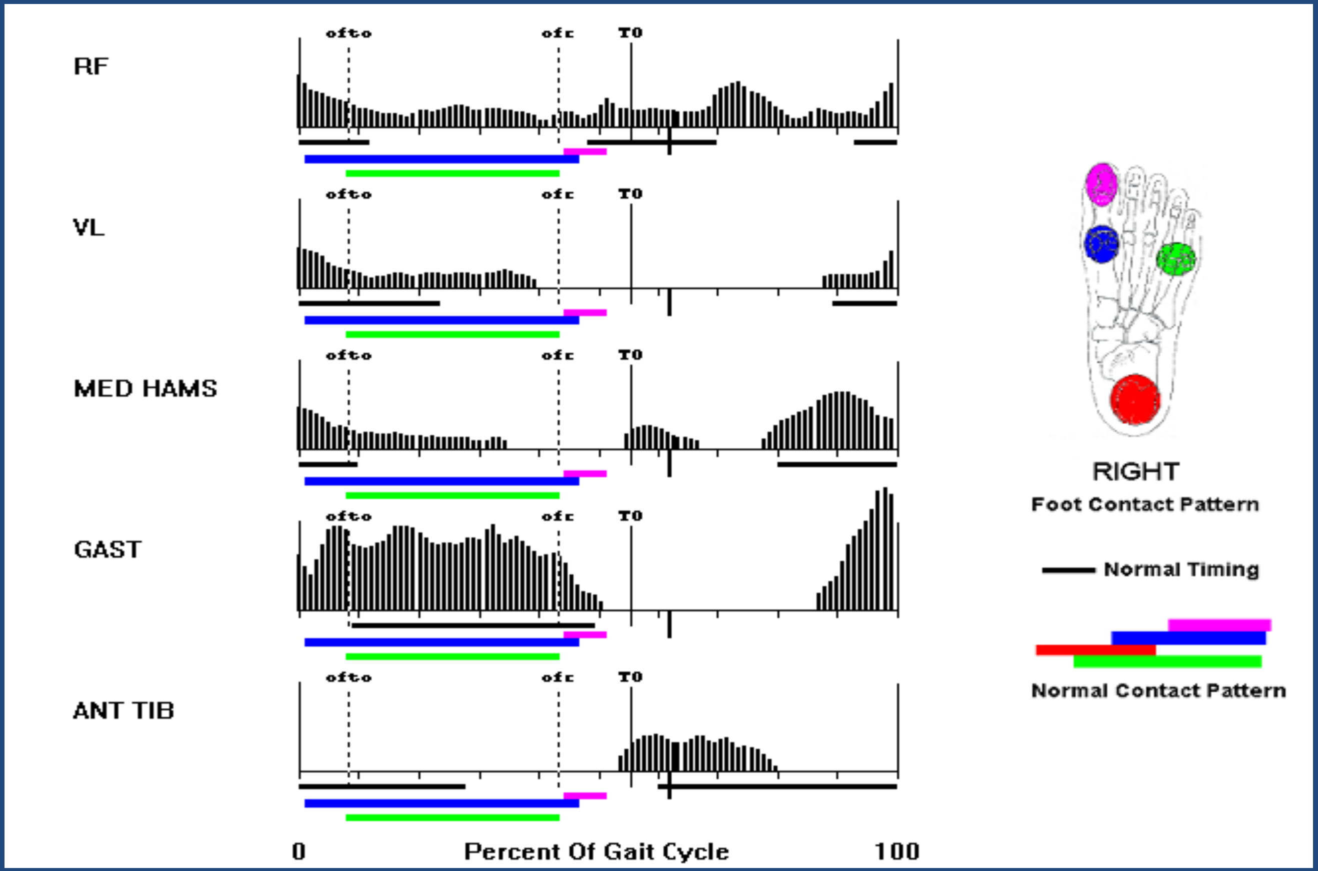
Gait EMG



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Pathologic Gait

Neuromuscular Conditions: CP, Stroke, TBI

- Dropfoot
- Equinus
- Equinovarus
- Flexed-knee Gait
    - Pseudo-equinus (knees bent, ankles at neutral, forefoot contact)
    - Jumped (knees bent, ankles true equinus)
    - Crouch (knees bent, ankles dorsiflexed)
- Stiff–knee gait (inadequate peak knee flexion in swing)

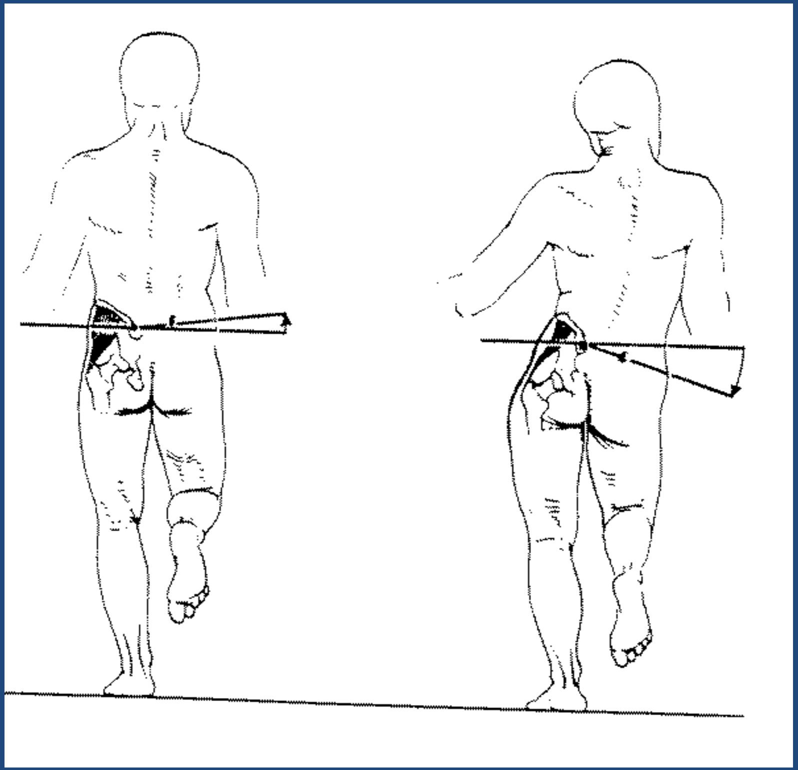
Pathologic Gait

- Trendelenburg - *weak hip abductors -* ipsilateral trunk lean, contralateral pelvic drop
- Coxalgic – *painful hip -* ipsilateral trunk lean
- Antalgic – *painful joint*- reduced loading, short stance
- Quad Avoidance – *weak knee -* remains extended in stance, swing

Pathologic Hip Gait

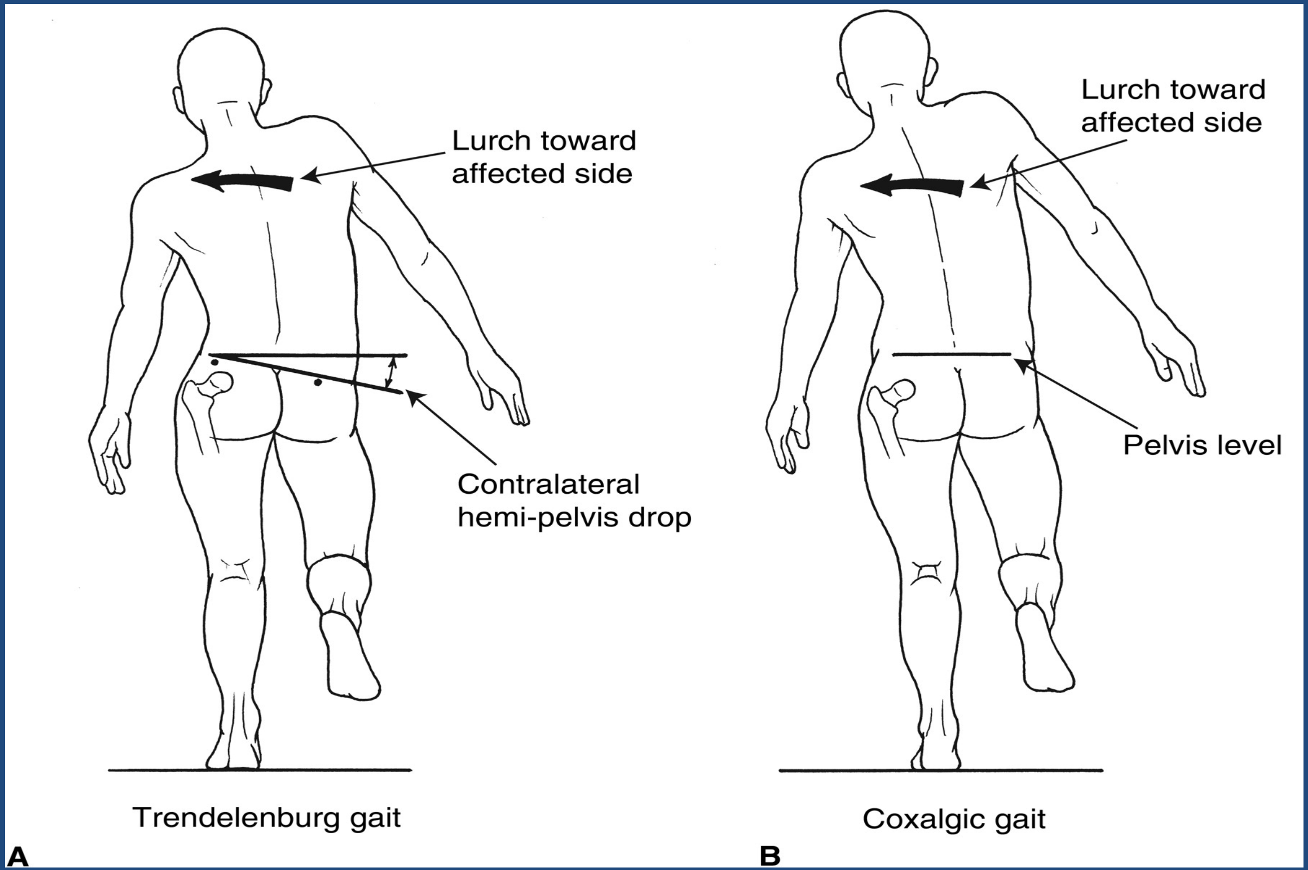
Trendelenburg Gait

- Weak hip abductors
- Contralateral pelvic drop
- Ipsilateral trunk lean



Pathologic Hip Gait

Trendelenburg (*weak*) versus Coxalgic Gait (*pain*)



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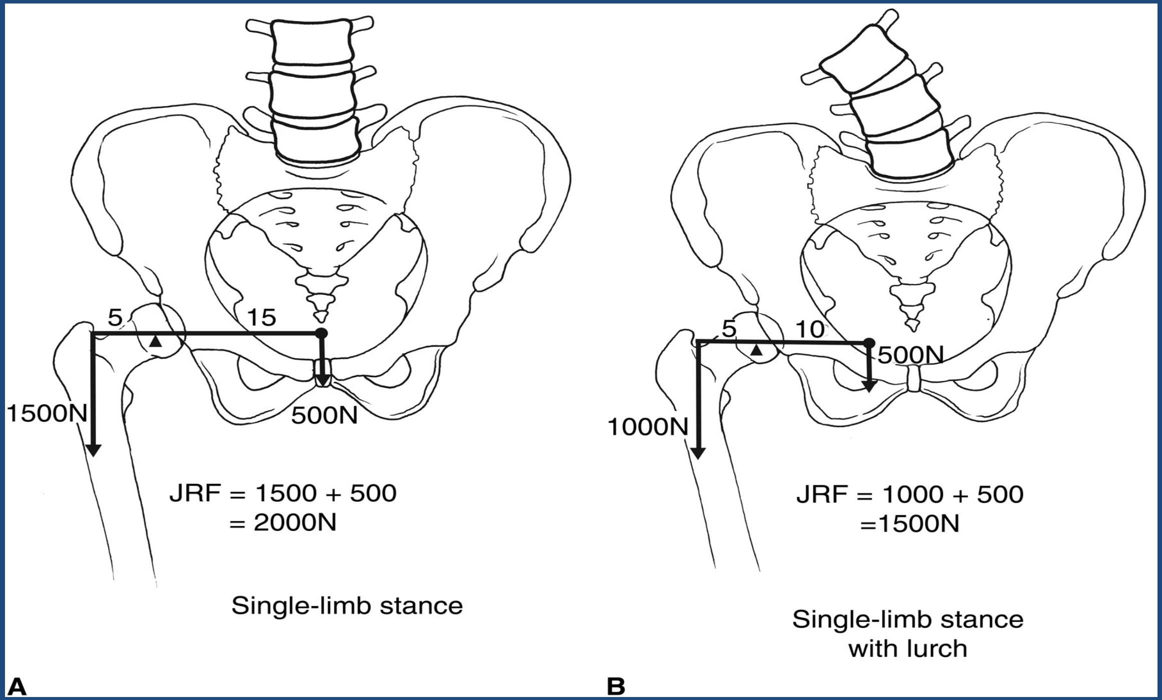
Pathologic Hip Gait *Biomechanics*

Lateral Trunk Lean Shifts Center of Mass towards Hip Joint



Reduces Hip Joint Reaction Force = abductor force + body weight

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Antalgic Gait

Painful hip, knee, foot

- Reduced loading on affected limb by decreasing stance time
- Example - ‘stone in your shoe’
- Shortens stance phase time
- Lengthens swing phase time
- Lengthens step length - asymmetric step length

Quad Avoidance Gait

Weak Quadriceps

- Knee remains extended throughout gait cycle
- Avoids demand on quadriceps at initial contact
- Stiff-knee gait avoids knee flexion in swing
- Reduces foot clearance in swing

Gait Technology: FES-assisted Gait

Hip & Knee Extensors:

Gluteus Maximus & Medius

Hamstrings

Semitendinosus

Semimembranosus

Biceps Femoris

Quadriceps

Rectus Femoris

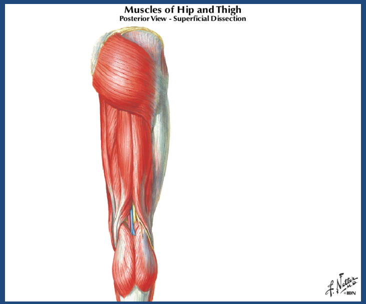
Vastus Lateralis & Medialis

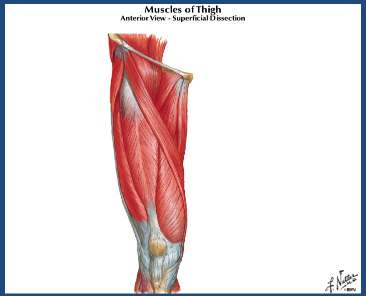
Calf

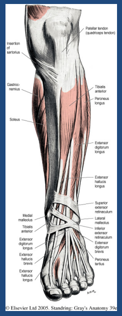
Soleus

Ankle Dorsiflexors:

Tibialis Anterior







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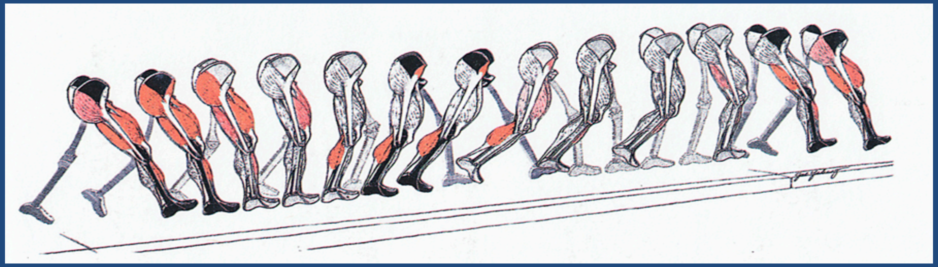
Multichannel FES-assisted Gait

Gait Event	**Target Muscles**
Double limb support (IC - OTO)	*Gluteus Max & Med, Quads*
Single limb support (OTO – OFC)	*Soleus*
Swing (TO – IC)	*Tibialis Anterior*
Terminal Swing (Peak knee flexion - IC)	*Quads*



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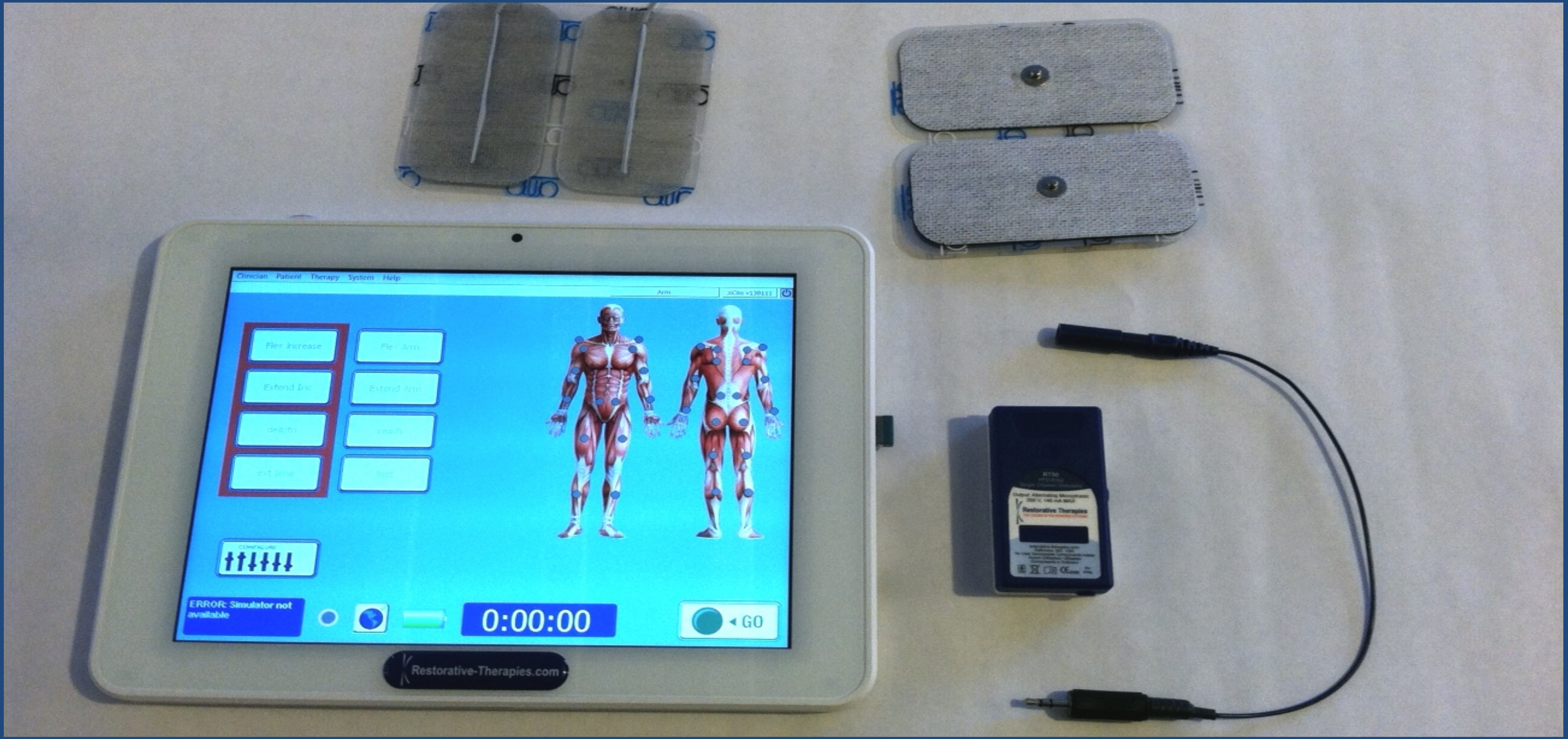
Multichannel FES-assisted Gait
Restorative Therapies, Inc. Xcite RT50z



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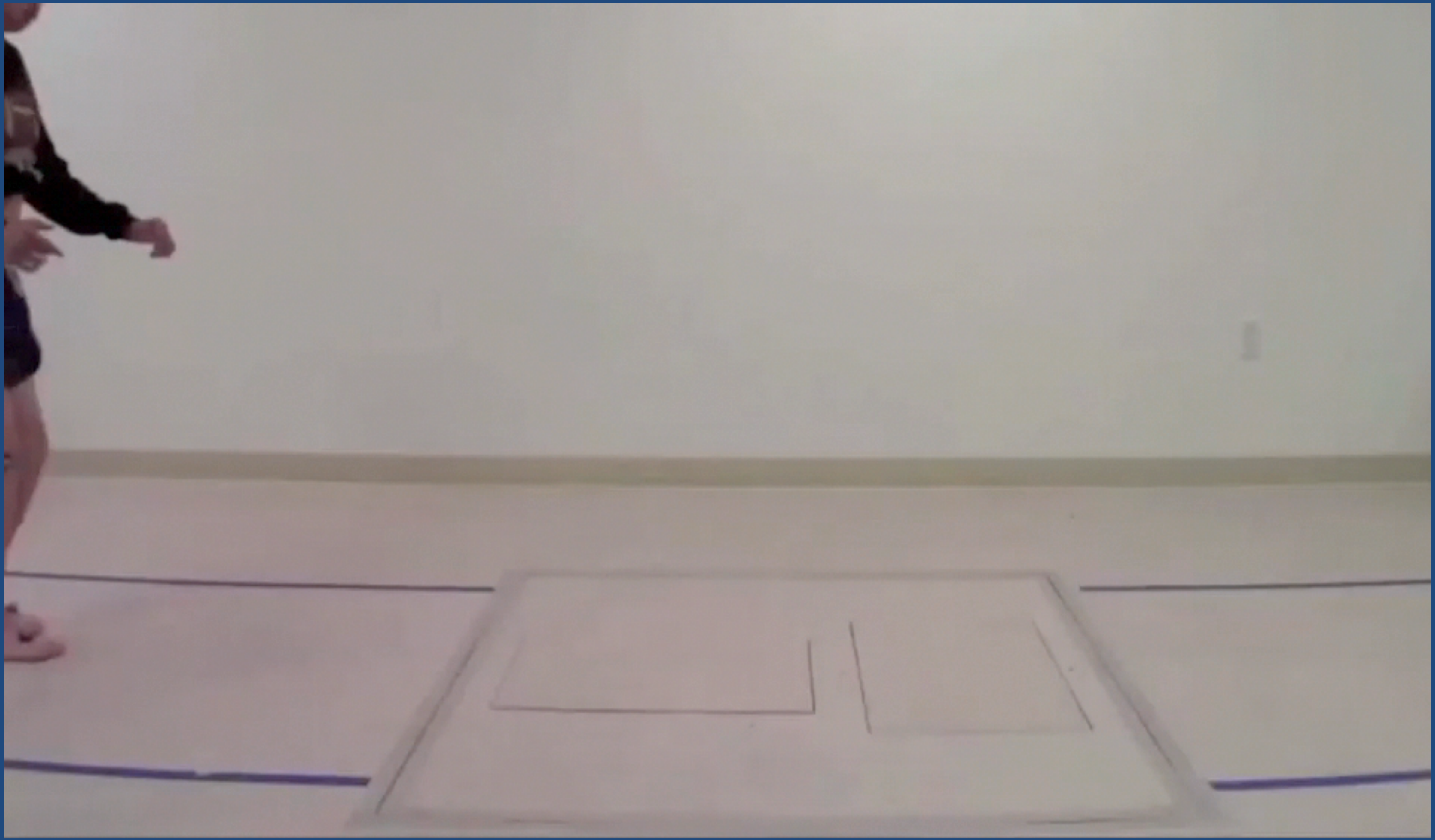
Baseline



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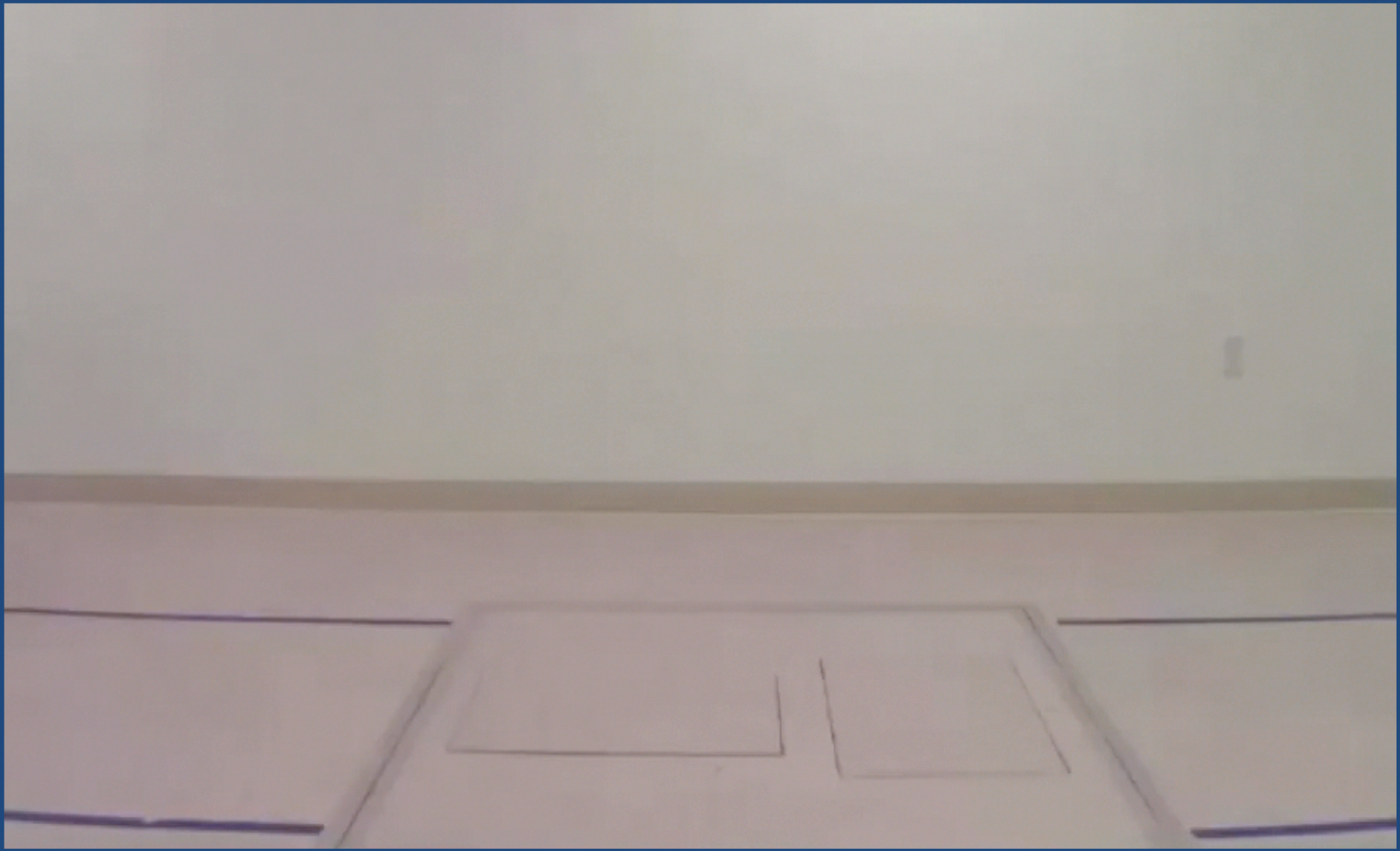
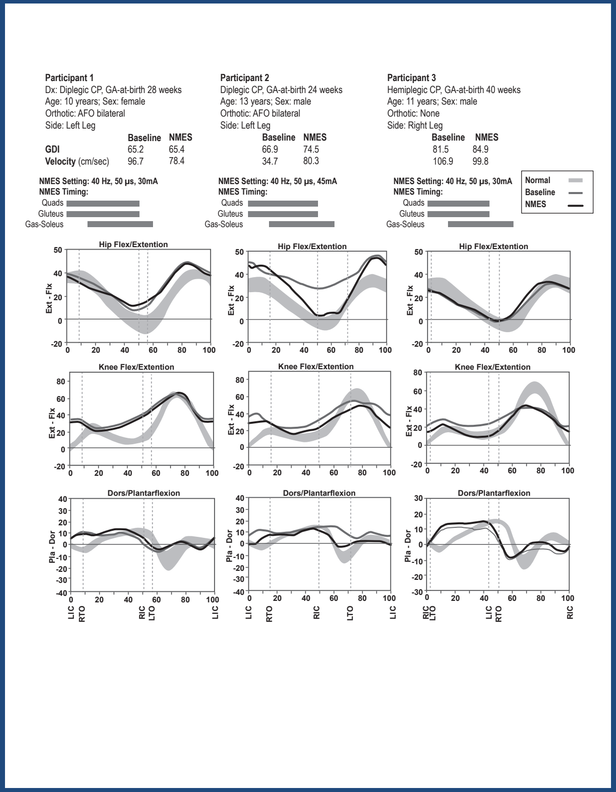
Multichannel FES-assisted Gait



Multichannel FES-assisted Gait

Kinematics



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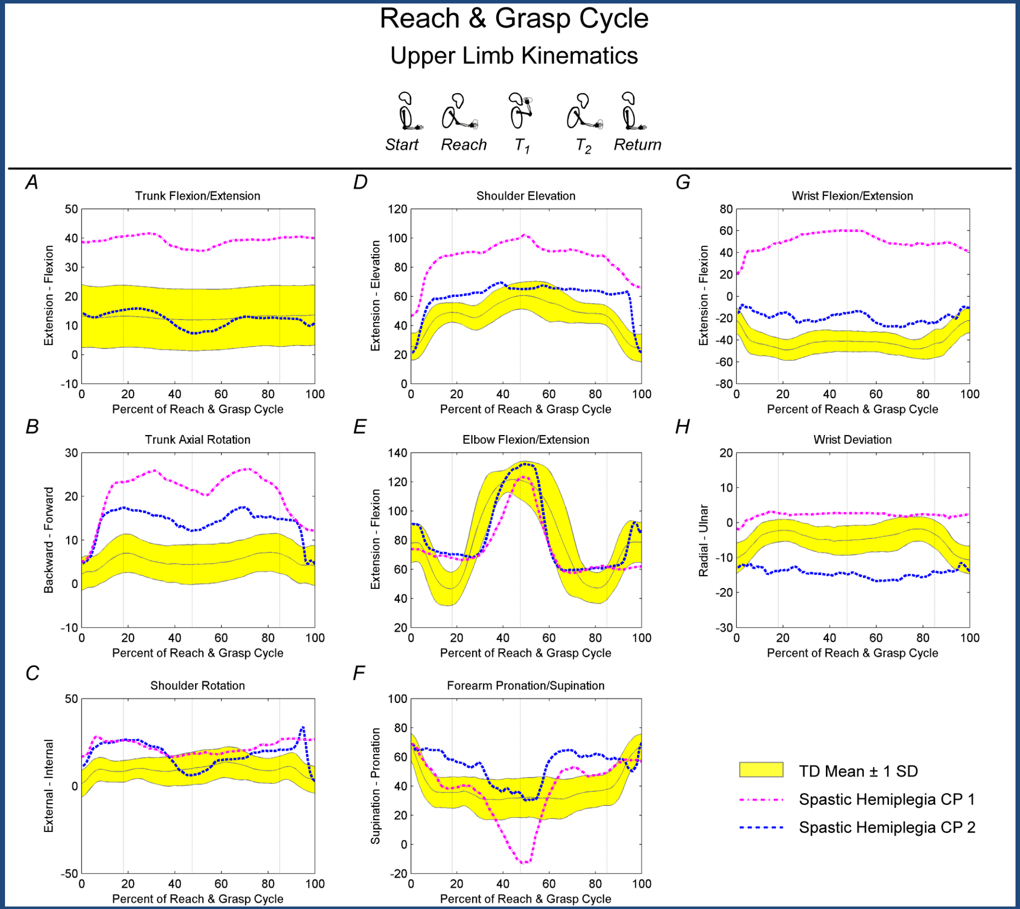
Upper Limb Kinematics



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Thank You

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