OBSERVATIONAL GAIT ANALYSIS*

Identifying Normal Gait

Tracy A. Dierks, PhD
Assistant Professor
IU Department of Physical Therapy
317-274-3147; tdierks@iupui.edu

Walking Gait

Most Common Human Movement

Walking is inherent, yet hard to learn, yet subconscious.

May become altered with injury or disease

Understand Normal to understand Abnormal
Normal Walking Gait

What Exactly Does Normal Mean?

Within a person, highly repeatable pattern or sequence of limb motions

- Stride-to-stride & day-to-day variability of walking pattern is moderately low

Across several Normal people, ↑ variability

- Differences in Ht, Wt, Age, Sex, Cadence, etc.
- Normalize to reduce between subject variability

Now we have a less variable, more universal pattern we can call Normal
Normal Walking Gait

However, it’s never that simple…

- It’s possible to achieve the same movement pattern from many different combinations of muscles.
  - Coordinating muscles acting across many joints.

“The coordination of a movement is the process of mastering redundant DoFs… its conversion to a controllable system” (Bernstein, 1967)

- Control system is highly flexible & adaptable.
- Can accomplish the same goal in many ways.

Normal Walking Gait

Ψ This motor redundancy is good, but it confounds assessment in that there is no unique solution to a given movement pattern

So what do we do now?

Consider Common Purpose of Walking

Ψ Move body safely & efficiently across ground

Achieved by 5 functions/tasks during each stride

○ All 5 tasks must be performed within the anatomical/internal constraints of the body
Normal Walking Gait

1) Generate Mechanical Energy
   - Velocity: maintain or ↑

2) Absorb Mechanical Energy
   - Shock, stability, or ↓ vel

3) Maintain Support of HAT
   - Prevent collapse of LE during stance

4) Maintain Upright Posture
   - Balance of total body; level head

5) Control Foot Trajectory
   - Safe ground clearance
   - Gentle heel to toe landing
Normal Gait Cycle

Ψ Heel-Strike to next ipsilateral Heel-Strike
Ψ Subdivide into **Stance & Swing** phases
  ○ Stance = period of limb-ground contact
  ○ Swing = period of no limb-ground contact

### Double Support

<table>
<thead>
<tr>
<th>Double Support</th>
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<tbody>
<tr>
<td>R HS</td>
<td>L HS</td>
<td>R HS</td>
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</table>

**Stride** (R HS to R HS)

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### Stance Phase

Subdivide **Stance & Swing** for further analysis

#### 1. Heel-Strike (IC): 0%
- Heel to ground contact
- Little loading

#### 2. Foot-Flat (LR): 10%
- Foot is flat
- Rapid bw transfer

#### 3. MST: 30%
- Stable, fully loaded limb

#### 4. Heel-Off (TSt): 40%
- Bw moves to forefoot

#### 5. Contralateral HS: 50%

#### 6. Toe-Off: 60%
- Toe leaves ground
- Rapid unloading of limb

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**First Frame:**
- The stance phase begins with the heel striking the ground, often referred to as heel-strike. This is the initial contact phase where the foot and leg are initially made contact with the ground.

**Second Frame:**
- After heel-strike, the foot gradually flattens on the ground. This is the foot-flat phase, characterized by the foot remaining flat on the ground for a brief period.

**Third Frame:**
- The stable phase begins, characterized by the body's weight (bw) transferring from the heel to the forefoot, ensuring steady support.

**Fourth Frame:**
- This phase marks the end of the stance phase, where the body's weight moves from the heel to the forefoot, leading into the swing phase.

**Fifth Frame:**
- The contralateral leg begins to move forward, preparing for the next stride.

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**Subdivide Stance & Swing:**

- **Stance Phase:**
  - Heel to ground contact
  - Little loading
  - Foot is flat
  - Rapid bw transfer

- **Swing Phase:**
  - Stable, fully loaded limb
  - Bw moves to forefoot
  - Toe leaves ground
  - Rapid unloading of limb

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Swing Phase

Initial Swing: 60-75%
- Thigh advances
- Foot leaves ground

Mid-Swing: 75-85%
- Thigh advances
- Foot clears ground

Terminal Swing: 85-100%
- Knee extends
- Limb slows down
KINEMATICS OF LOCOMOTION

Gait Parameters
**Stride** – includes movement of both limbs during a gait cycle
- Contains 2 steps

**Stride Length** – distance from HS of 1 foot to next HS of same foot

- Mean: 56” (1.40 m)
  - Male: 1.48 m
  - Female: 1.30 m
ψ **Step** – movement of 1 limb from HS to HS of opposite limb

ψ **Step Length** – distance from HS of 1 foot to next HS of the other foot

ψ **Mean**: 28” (0.70 m)
Step Width or Walking Base Width (BoS) - perpendicular distance between midpoint of heel on 1 foot to same point on other foot
- Mean: 3” (8 cm)

Foot Angle (Toe-out) - angle between long axis of foot & line of forward progression
- Mean: 8° out-toeing
Stride Length: 4½ ft
Step Length: 2¼ ft
Step Width: 3-in
Foot Angle: 8°
Gait Parameters - Temporal

**Stride Time** - time from HS of 1 foot to HS of same foot

**Walking Velocity** – rate of forward linear motion
- Mean: 3 mph (1.3 m/s)
- Male 1.37; Female 1.28

**Cadence** – number of steps per unit time
- Mean: 112 steps/min
- Male 110; Female 118

**Stance Time** - time foot is on ground in a gait cycle

**Swing Time** - time foot is off ground in a gait cycle

**Swing/Stance Ratio** - ratio of swing to stance times

**Double Support Time** - time that 2 feet are in contact with the ground during a gait cycle

**Single Support Time** - time that 1 foot is in contact with the ground during a gait cycle
GAIT CYCLE – FUNCTIONAL TASKS
Gait Cycle - Functional Tasks

Observing gait from a **functional** standpoint
- 3 functional tasks

1. Weight Acceptance (WA)
2. Single Limb Support (SLS)
3. Swing Limb Advancement (SLA)
Weight Acceptance (WA)

Psi Includes HS & FF (loading of limb) in double support

Psi Absorption of ground impact force

Psi Body continues in forward path while maintaining stability
Single Limb Support (SLS)

- Includes MSt & HO; heel comes off ground
- Body progresses over single, stable, fully loaded limb
- Body weight transferred onto metatarsal heads
Swing Limb Advancement (SLA)

- Includes TO & all of Swing
- Limb is unloaded & foot comes off ground
- Limb is moved from behind the body to in front of the body, reaching out to take the next step
GAIT CYCLE – FUNCTIONAL TASKS

The Critical Events – What To Look For At The Ankle, Knee, & Hip
Critical Events

Specific joint positions or motions that contribute to accomplishing Functional Tasks

Each phase has 1 or more Critical Event at the Ankle, Knee, or Hip in the sagittal plane

- Sagittal most important in contributing to gait & is primary focus of observational analysis
- Yet secondary planes also contribute
During each gait phase, the Ankle, Knee, & Hip are commonly described by:

1. **ROM** – what moved where
2. **Torque Demand (TD)**
   - Stability response to LoG position
3. **Muscle Action (MA)**
   - EMG: measured as On or Off
4. **Functional Significance (FS)**
   - What happens?
   - Reasons for ROM, TD, & MA?
Ankle - Weight Acceptance

Heel-Strike

1. **ROM**: Neutral

4. **FS**: Foot correctly positioned for loading; heel-rocker
Loading Response

1. **ROM**: 5° very rapid PF

4. **FS**: Heel-rocker action created; Pretibials pull tibia forward creating forward momentum & flexes knee

(1) (2)
Ankle – Single Limb Support

Mid-Stance

1. **ROM**: DF to 5°

4. **FS**: Body progresses forward over stable foot & tibia; Calf creates knee stability by controlling tibial advancement; Forward momentum maintained while ankle moves into 5° DF = *Ankle Rocker*
Ankle – Single Limb Support

**Heel-Off**

1. **ROM:** DF to 10°; MTP Hyperextension to 30°

4. **FS:** Calf allows max forward progression - controls DF & allows heel rise = *Forefoot Rocker*, contralateral step length
Ankle – Swing Limb Advancement

**Toe-Off**

1. **ROM:** Ankle into 15° PF; MTP into 60° hyperext

4. **FS:** Forefoot remains on floor for balance assist; PF of partially unweighted foot assists with knee flexion & Swing Limb Advancement
Ankle – Swing Limb Advancement

Initial Swing

1. **ROM**: PF to 5°

4. **FS**: begin DF to clear foot in next phase; DF to neutral not yet achieved
**Ankle – Swing Limb Advancement**

**Mid-Swing**
1. **ROM:** DF to 0°

4. **FS:** Foot clears ground by 1 cm

**Terminal Swing**
1. **ROM:** Ankle remains neutral

4. **FS:** Neutral position assures heel contact for HS
**Subtalar - WA**

**Heel Strike & Loading Response**

1. **ROM**: Calcaneus Everts 5°; Subtalar moves into pronation

4. **FS**: Subtalar joint Pronation *unlocks Midtarsal joint* & assists in shock absorption; Pronation induces Tibial Internal Rot, reduces rotatory stress on ankle joint
Subtalar – Single Limb Support

1. **ROM**: Progressive reduction of Eversion to ≈ 2°

4. **FS**: Tib Post & Soleus activity initially provide ecc control of EV, then con to move subtalar towards INV
   - Reduction in calcaneal EV ↑ stability of midtarsal joints, creates rigid forefoot lever during late Stance
   - Promotes Forefoot Rocker
   - Peroneus Longus & Brevis provide lateral stability

![Image](image-url)
Subtalar – Swing Limb Advancement

1. **ROM:** Subtalar joint achieves neutral position

4. **FS:** Foot clears ground; Ankle & Subtalar positioned for Heel-Strike
Ankle & Subtalar

Heel-strike………… neutral  
Loading Response… PF 5°  
Mid-stance………… DF to 5°  
Heel-off……………… DF to 10°  
Toe-off………………. PF 15°  
Initial Swing………… PF 5°  
Mid-swing…………… DF to 0°  
Terminal Swing…….. neutral  

EV 5°, overall pronation  
Reduce EV to about 2°  
Overall neutral
Knee - Weight Acceptance

Initial Contact

1. ROM: Appears neutral, may be slightly flexed to 5°

4. FS: At Heel-Strike, Extension torque stabilizes Knee
Knee - Weight Acceptance

**Loading Response**

1. **ROM**: Knee flexes to 15°

4. **FS**: Shock absorbed & limb stability maintained while forward progression continues
**Knee – Single Limb Support**

**Mid-Stance**

1. **ROM**: Extends to $\approx 5^\circ$ Flexion; appears neutral

4. **FS**: Knee stability maintained by Knee Extension torque & calf activity
Knee – Single Limb Support

Heel-Off

1. **ROM**: Appears unchanged from Midstance

4. **FS**: Joint stability maintained during forward progression
Knee – Swing Limb Advancement

Toe-Off

1. **ROM**: Rapidly flexes to 40°

4. **FS**: Pre-swing KF adds to KF needed for limb clearance

![Diagram of knee swing limb advancement](image)
**Initial Swing**

1. **ROM**: Further rapid knee flexion to 60°

4. **FS**: Foot clears ground as Thigh begins to advance

![Illustration](image)
Knee – Swing Limb Advancement

**Mid-Swing**

1. **ROM**: Knee rapidly Extends to 25°; Tibia achieves vertical position

4. **FS**: Knee Ext necessary as step length begins
Knee – Swing Limb Advancement

Terminal Swing

1. **ROM:** Extends to neutral, may move into 5° Flex

4. **FS:** Step length optimized by leg reaching out

![Diagram of knee swing phases](image-url)
<table>
<thead>
<tr>
<th>Stage</th>
<th>Knee Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel-strike</td>
<td>neutral or KF 5°</td>
</tr>
<tr>
<td>Loading Response</td>
<td>KF 15°</td>
</tr>
<tr>
<td>Mid-stance</td>
<td>KE to 5°, appears neutral</td>
</tr>
<tr>
<td>Heel-off</td>
<td>no change</td>
</tr>
<tr>
<td>Toe-off</td>
<td>rapid KF to 40°</td>
</tr>
<tr>
<td>Initial Swing</td>
<td>KF to 60°</td>
</tr>
<tr>
<td>Mid-swing</td>
<td>rapid KE to 25°</td>
</tr>
<tr>
<td>Terminal Swing</td>
<td>neutral or KF 5°</td>
</tr>
</tbody>
</table>
**Hip & Pelvis - Weight Acceptance**

**Heel-Strike**

1. **ROM**: 20° of Hip Flexion; pelvis is in 5° of forward rotation
2. **FS**: Hip & Pelvis in position of forward reach
**Loading Response**

1. **ROM:** Hip remains in 20° of Flexion; Pelvis remains in 5° forward rotation

4. **FS:** Hip joint stable during shock absorption; Trunk Flexion prevented, Thigh stabilized; Pelvis stable in frontal plane
Mid-Stance

1. **ROM**: Ext to neutral; Rotates backwards to neutral

4. **FS**: Stable position achieved in sagittal plane without Hip Extensors; Pelvis stabilized to prevent Hip drop
Hip & Pelvis – Single Limb Support

Terminal Stance

1. **ROM**: Hip Extends to trailing position of 20° Hyperextension; Pelvis rotates 5° backwards

4. **FS**: Body advances past foot to maximize step length, limb still stable; Pelvic Rot makes gait pattern look smooth
**Toe-Off**

1. **ROM:** Thigh falls forward; appears vertical, but in slight Hyperextension (10°); Pelvis remains in 5° backward rot

4. **FS:** Limb advancement begins; Hip Flex adds to Knee Flex
**Initial Swing**

1. **ROM**: 15° of Hip Flexion; Pelvis remains in 5° backward rot

4. **FS**: Limb advancement continues
Mid-Swing

1. **ROM:** 25° Hip Flexion; Pelvis in neutral rotation

4. **FS:** Thigh advancement slows; momentum created by swinging limb helps carry body past stance limb
**Terminal Swing**

1. **ROM**: Thigh to 20° of Flex; Pelvis 5° forward rot

4. **FS**: Limb positioned for heel-1st ground contact; forward rot of pelvis contributes to step length
Hip & Pelvis

Heel-strike........... HF 20°; Fwd Rot 5°
Loading Response.... no change; no change
Mid-stance.......... neutral HE & Bwd Rot
Heel-off.............. HE_{hyp} 20°; Bwd Rot 5°
Toe-off............... HE_{hyp} 10°; no change
Initial Swing........ HF to 15°; no change
Mid-swing............ HF to 25°; pelvis neutral
Terminal Swing....... HF 20°; Fwd Rot 5°
# Gait Summary - Weight Acceptance

<table>
<thead>
<tr>
<th></th>
<th>Hip</th>
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<th>Ankle</th>
<th>Critical Event</th>
<th>Functional Significance</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ROM</td>
<td>MA</td>
<td>ROM</td>
<td>MA</td>
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</tr>
<tr>
<td>HS</td>
<td>20° Flex</td>
<td>ext’s</td>
<td>5° Flex</td>
<td>quads</td>
<td></td>
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<tr>
<td></td>
<td>20° Flex</td>
<td>ext’s &amp; abd’s</td>
<td>15° Flex</td>
<td>quads</td>
<td></td>
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<tr>
<td>LR</td>
<td>20° Flex</td>
<td>ext’s</td>
<td>5° PF</td>
<td>pre-tibs</td>
<td>• Hip stability</td>
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<td></td>
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<td>abd’s</td>
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<td>• Controlled knee flexion &amp; PF</td>
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<td>• Heel first contact</td>
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<td>• Stabilty</td>
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<td></td>
<td></td>
<td>• Shock absorption</td>
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# Gait Summary - Single Limb Support

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<tr>
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<th>Ankle</th>
<th>Critical Event</th>
<th>Functional Significance</th>
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<tbody>
<tr>
<td></td>
<td>ROM</td>
<td>MA</td>
<td>ROM</td>
<td>MA</td>
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</tr>
<tr>
<td><strong>MSt</strong></td>
<td>0°</td>
<td>abd’s</td>
<td>5°</td>
<td>Initial quads</td>
<td>5° Flex</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Flex</td>
<td></td>
<td>Calf</td>
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<tr>
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<td>5°</td>
<td>None</td>
<td>10° DF</td>
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<tr>
<td></td>
<td>hyper-ext</td>
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<td>Flex</td>
<td></td>
<td>Calf</td>
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# Gait Summary - Swing Limb Advancement

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<tr>
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<tr>
<td></td>
<td>ROM</td>
<td>MA</td>
<td>ROM</td>
<td>MA</td>
<td></td>
</tr>
<tr>
<td><strong>PSw</strong></td>
<td>10° hyper ext</td>
<td>add’s</td>
<td>40° Flex</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15° Flex</td>
<td>flex’s</td>
<td>60° Flex</td>
<td>flex’s</td>
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<td></td>
<td>15° PF</td>
<td>pre-tibs</td>
<td>5° PF</td>
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<tr>
<td><strong>ISw</strong></td>
<td>15° Flex</td>
<td>flex’s</td>
<td>60° Flex</td>
<td>flex’s</td>
<td></td>
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<tr>
<td></td>
<td>5° PF</td>
<td>pre-tibs</td>
<td>5° PF</td>
<td></td>
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</tr>
</tbody>
</table>

- **Foot clearance**
- **Limb advancement**

- Passive knee flex to 40°
- PF

- Hip flex to 15°
- Knee flex to 60°
# Gait Summary - Swing Limb Advancement

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<tr>
<td>ROM</td>
<td>MA</td>
<td>ROM</td>
<td>MA</td>
<td></td>
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</tr>
</tbody>
</table>
| **MSw** | 25° Flex | flex’s initial, then hams | 25° Flex | flex’s | 0° | pre-tibs | • Further hip flex to 25°  
  • DF to 0° | • Foot clearance  
  • Limb advancement |
| **TSw** | 20° Flex | hams | 5° Flex | quads | 0° | pre-tibs | • Knee ext to neutral (possibly 5° flex) |
Systematically Observe Gait

Record Observed Deviations

Determine Significant Deviations That Interfere with Functional Tasks

Consider Possible Causes
- Impaired Strength
- ROM Deficits
- Sensory Deficits
- Pain

Determine Likely Cause

Provide Appropriate Interventions

Re-Assess Gait