Understanding Human Gait

Erick J Janisse, CO, CPed

Definitions

Definitions

- *Gait* Gait is the pattern of movement of the limbs of animals, including humans, during locomotion over a solid substrate.
  - Normal gait must be rhythmic and soundless, having “springiness” in the feet - which work alternatively in a definite cyclic order.

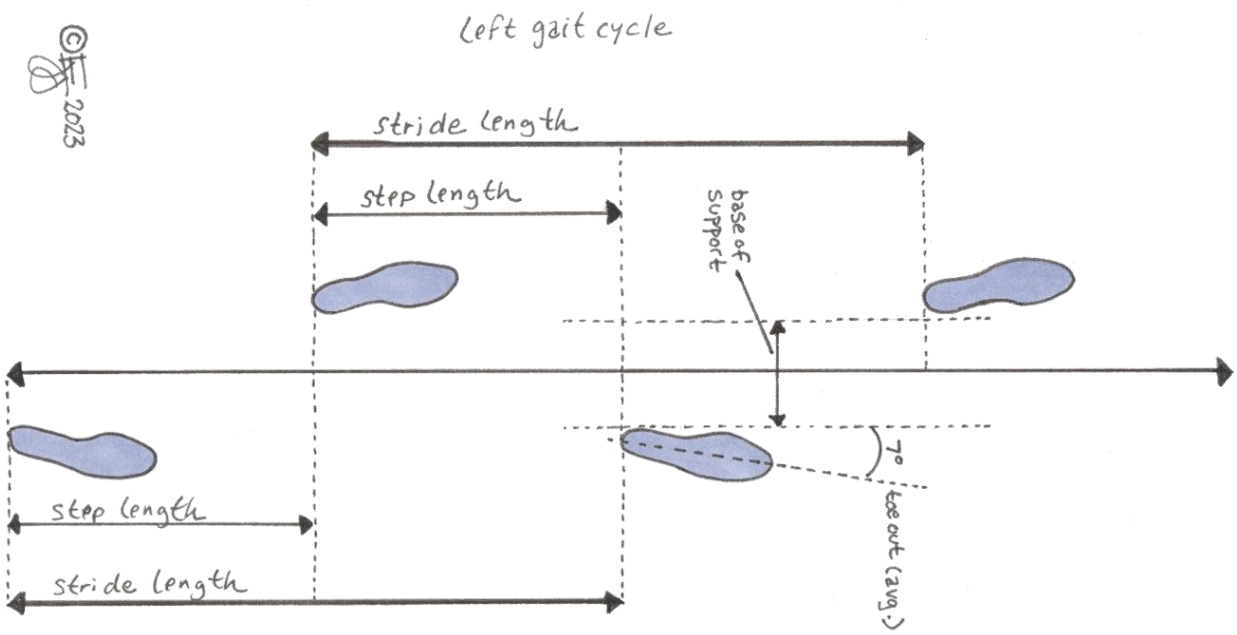
- *Toe Out* In normal walking, the foot is placed on the ground at an angle taken from the center of heel to second toe.
  - Average “toe out” or “foot angle” is 7˚.

Definitions

- *Step Length* The distance between the heel strike of one lower limb to the heel strike of the other lower limb.

- *Stride Length* The distance between the heel strike of one lower limb to the next heel strike of the same lower limb.

- *Stride Duration* The time taken for completion of heel strike of one lower limb to the next heel strike of same lower limb (i.e. completion of one gait cycle).


left gait cycle
stride length
step length
base of support
7°
toe out (avg.)
step length
stride length
right gait cycle

Definitions

- *Base of Support* The distance between a person's feet while standing and during ambulation.

- *Cadence* The Number of steps taken in one minute.
  - Average adult cadence is 90-120 steps/minute.

- *Walking Velocity* Speed of ambulation on a level surface.
  - Average adult walking velocity is 262ft/minute.

Balance Vs. Proprioception

- Balance is the body's ability to keep itself upright (function of the inner ear).

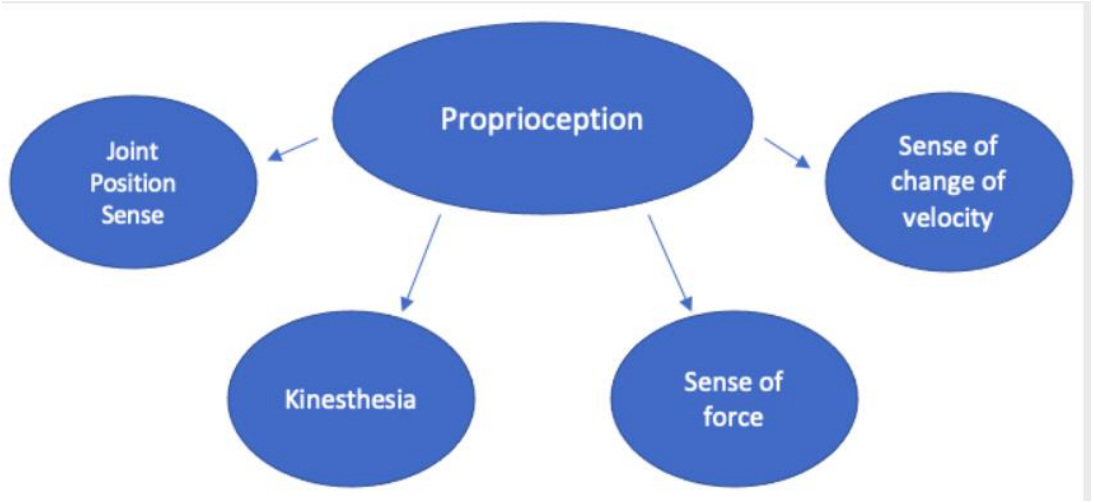
- Proprioception is the body's ability to know where it is in space and sense movement (function of the somatosensory system).

Somatosensory Nerves

- **Nociceptors**: are nerve endings specific for pain. These tell our brain to pull our foot away from a sharp object.
- **Thermoreceptors**: give input to our brain on temperature and can determine if an object we touch is hot, cold or somewhere in between.
- **Mechanoreceptors**: nerve fibers vary in diameter, length and size for a few different sensations. They determine light touch, discrimination of different points on our skin, and pressure. If you lightly brush your skin with a cotton swab, you are activating your light touch receptors. Now, use that cotton swab to push gently into your arm and you are now signaling your brain through a different type of nerve fiber for deep pressure.
- **Proprioceptors**: these nerve fibers tell our brain if our joints or muscles are moving or stationary. They also tell us how fast we are moving in relation to force of movement and velocity.

Components of Proprioception

- **Joint Position Sense:**
  - Active: ability of our brain to sense which direction our body part is moving.
  - Passive: ability of our brain to sense where our body part is when it is stationary.
- **Kinesthesia**: ability of our brain to sense when part of our body is moving.
- **Sense of Force**: ability of our brain to sense the effort, tension and heaviness of joint movement of a specific body part.
- **Sense of Change of Velocity**: ability of our brain to determine the speed of movement of a body part. This part of our proprioception is closely linked to our cerebellum.



Terminology

Gait Cycle

- The basic unit of measure for gait analysis is the *gait cycle*.

- A gait cycle is broken into two phases for each extremity:

    - Stance phase (foot is on the ground) – 60% of gait cycle
    - Swing phase (foot is off the ground) – 40% of gait cycle

Subdivision of Gait Phases

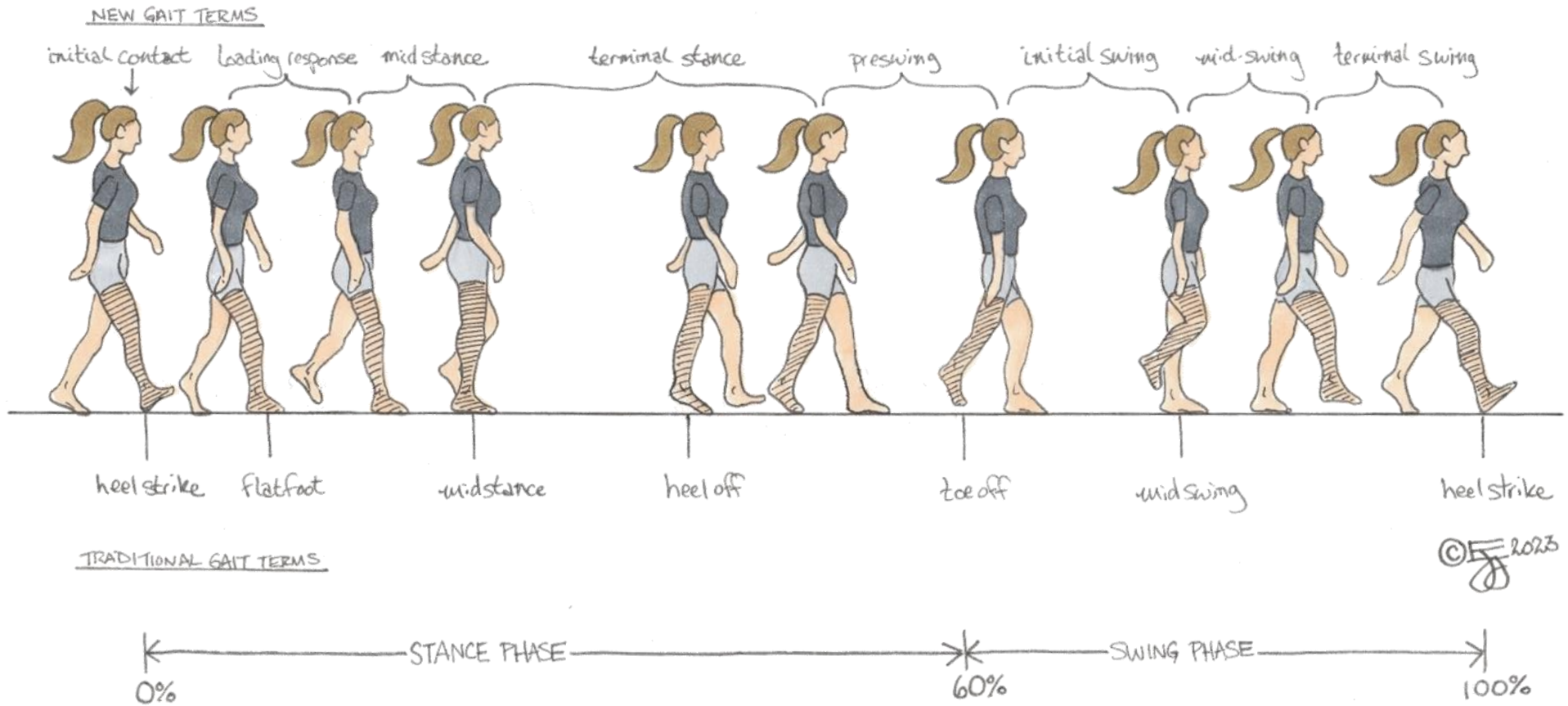
Stance Phase

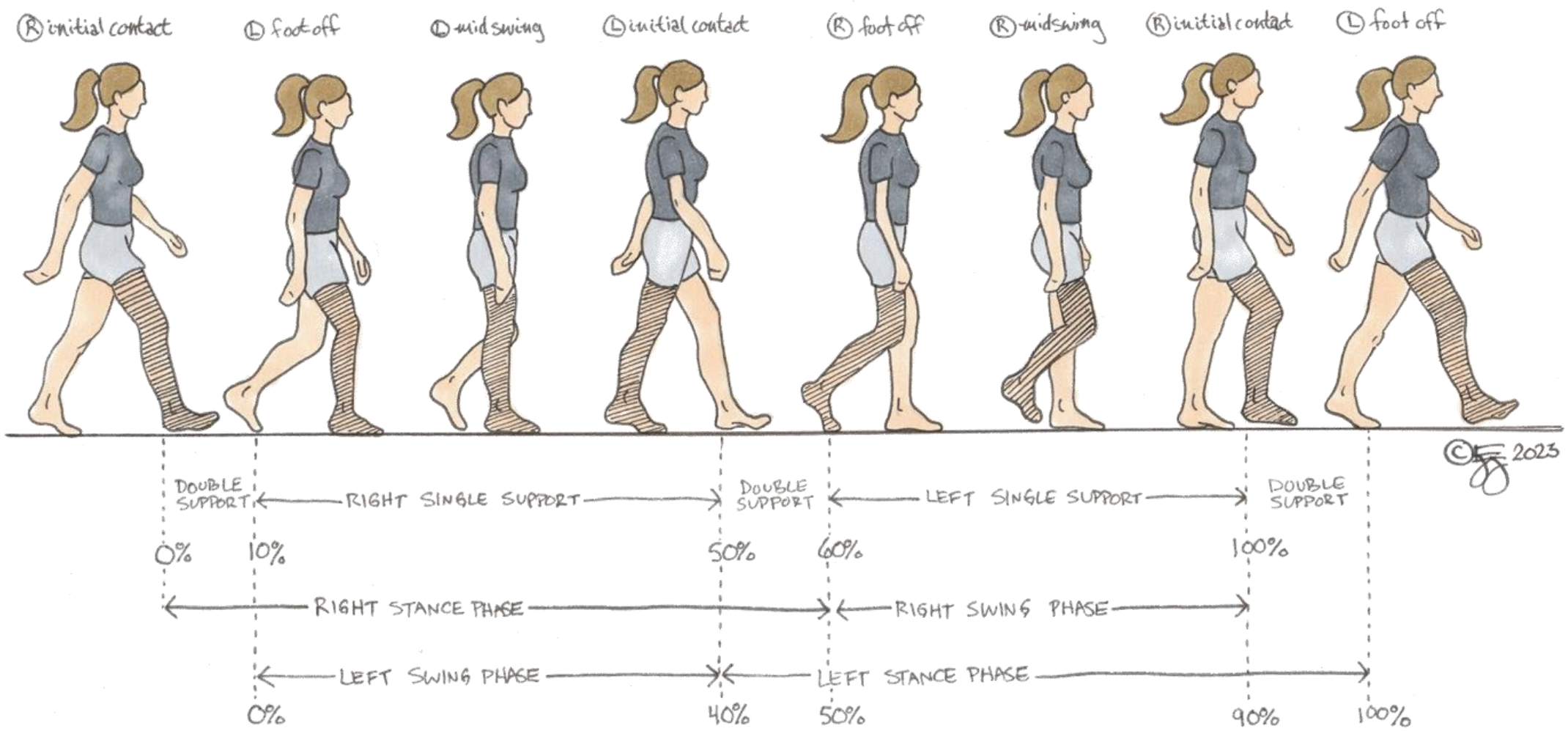
1. Heel Strike (Initial Contact*)
2. Flat Foot (Loading Response*)
3. Midstance
4. Heel Off (Terminal Stance*)
5. Toe Off (Pre-Swing*)

Swing Phase

1. Acceleration (Initial Swing*)
2. Mid-swing
3. Deceleration (Terminal Swing*)

*Rancho Los Amigos terminology


NEW GAIT TERMS
initial contact
loading response
mid stance
terminal stance
preswing
initial swing
mid-swing
terminal swing
heel strike
flatfoot
midstance
heel off
toe off
mid swing
heel strike
©2023
TRADITIONAL GAIT TERMS
STANCE PHASE
SWING PHASE
0%
60%
100%


Ⓡ initial contact
Ⓛ foot off
Ⓛ mid swing
Ⓛ initial contact
Ⓡ foot off
Ⓡ mid swing
Ⓡ initial contact
Ⓛ foot off
©2023
DOUBLE SUPPORT
RIGHT SINGLE SUPPORT
DOUBLE SUPPORT
LEFT SINGLE SUPPORT
DOUBLE SUPPORT
0%
10%
50%
60%
100%
RIGHT STANCE PHASE
RIGHT SWING PHASE
LEFT SWING PHASE
LEFT STANCE PHASE
0%
40%
50%
90%
100%

Stance Phase (Traditional)

- Heel Strike:
  - Begins with initial contact & ends with foot flat. Stance phase begins the moment the heel contacts the ground.

- Foot Flat:
  - Occurs immediately following heel strike. Foot flat is the point at which the plantar foot is in full contact with the ground.

- Midstance:
  - Midstance is the point at which the center mass of the body passes directly over the supporting extremity.

Stance Phase (Traditional)

- Heel Off:
  - Heel off is the point immediately following midstance wherein the heel of the reference extremity leaves the ground.

- Toe Off:
  - Toe off is the point following heel off when only the toe of the reference extremity is the only remaining part of the foot in contact with the ground.

Swing Phase (Traditional)

- Acceleration:
  - Begins once the toe leaves the ground and continues until mid-swing, or the point at which the swinging extremity is directly under the body.
- Mid-swing:
  - Mid-swing occurs approximately when the swinging extremity passes directly beneath the body (or from the end of acceleration to the beginning of deceleration).
- Deceleration:
  - Occurs after mid-swing when limb is decelerating in preparation for heel strike.

Stance Phase (Rancho Los Amigos)

- Initial Contact:
  - Refers to the initial contact of the foot (heel) of leading lower extremity.
  - In abnormal gait it is possible for either the whole foot or the toes, rather than the heel, to strike first.

- Load Response:
  - Begins at initial contact and ends when the contralateral extremity lifts off the ground at the end of the double-support phase. Load response occupies about 11% of gait cycle.

Stance Phase (Rancho Los Amigos)

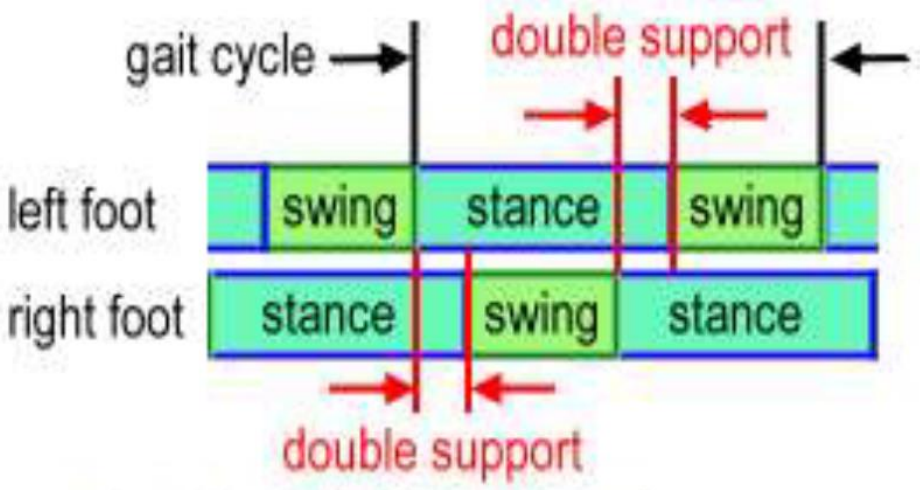
- Midstance:
  - Begins when the contralateral extremity lifts off the ground at about 11% of the gait cycle. Ends when the body is directly over the supporting limb at about 30% of the gait cycle.
- Terminal Stance:
  - Begins when the body is directly over the supporting limb at about 30% of the gait cycle. Ends just before initial contact of the contralateral extremity at about 50% of the gait cycle.
- Pre-Swing:
  - The last 10% of stance phase. Begins with initial contact of the contralateral foot at 50% of the gait cycle and ends with toe-off at 60% of the gait cycle.

Swing Phase (Rancho Los Amigos)

- Initial Swing:
  - Begins when the toe leaves the ground and continues until maximum knee flexion occurs.
- Mid-Swing:
  - Encompasses the period from maximum knee flexion until the tibia is vertical.
- Terminal Swing:
  - Includes the period from the point at which the tibia is in the vertical position to the point immediately before initial contact.

Double Limb Support

- During normal gait, for a moment, both lower extremities are in simultaneous contact with the ground.
- This occurs when the heel of the one foot and the toe of the other foot are simultaneously contacting the ground.
- During DLS, the center of gravity is at its lowest point.
- During DLS, both legs are supporting the body weight.
- The period of this double support is inversely proportional to the cadence of the gait.
- There are two DLS periods per gait cycle.



Four “Rockers” of Stance Phase

Phase	Foot Rocker	Event
Initial Contact/Loading Response	Heel Rocker	Heel contact → Forefoot loading
Midstance	Ankle Rocker	Forefoot Loading → Heel Rise
Terminal Stance	Forefoot Rocker	Heel Rise → Toe Off
Pre-Swing	Toe Rocker	

Perry, J., and J. Burnfield. 2010. *Gait Analysis: Normal and Pathological Function*, 2nd ed. Thorofare, NJ, Slack Incorporated.

Kinematics

Kinematics

- *Kinematics* is study of angular rotations of each joint during movement.
- It can be observed and measured at the foot, ankle, knee and hip during gait.
- Observed in all three cardinal planes:
  - Sagittal - hip flexion, extension
  - Coronal (Frontal) - hip abduction, adduction
  - Transverse - hip rotation, tibia, foot

Gait Cycle Variables

- Pelvic Rotation
  - In normal gait, the pelvis rotates 8˚ within the transverse plane of body (4˚ forward on swing leg and 4˚ posteriorly on stance leg).

- Pelvic List
  - Pelvis rotates within the frontal plane. Pelvic list leads to adduction of the weightbearing limb and abduction of the non-weightbearing limb, thereby improving the efficiency of the hip abductor mechanism.

Gait Cycle Variables

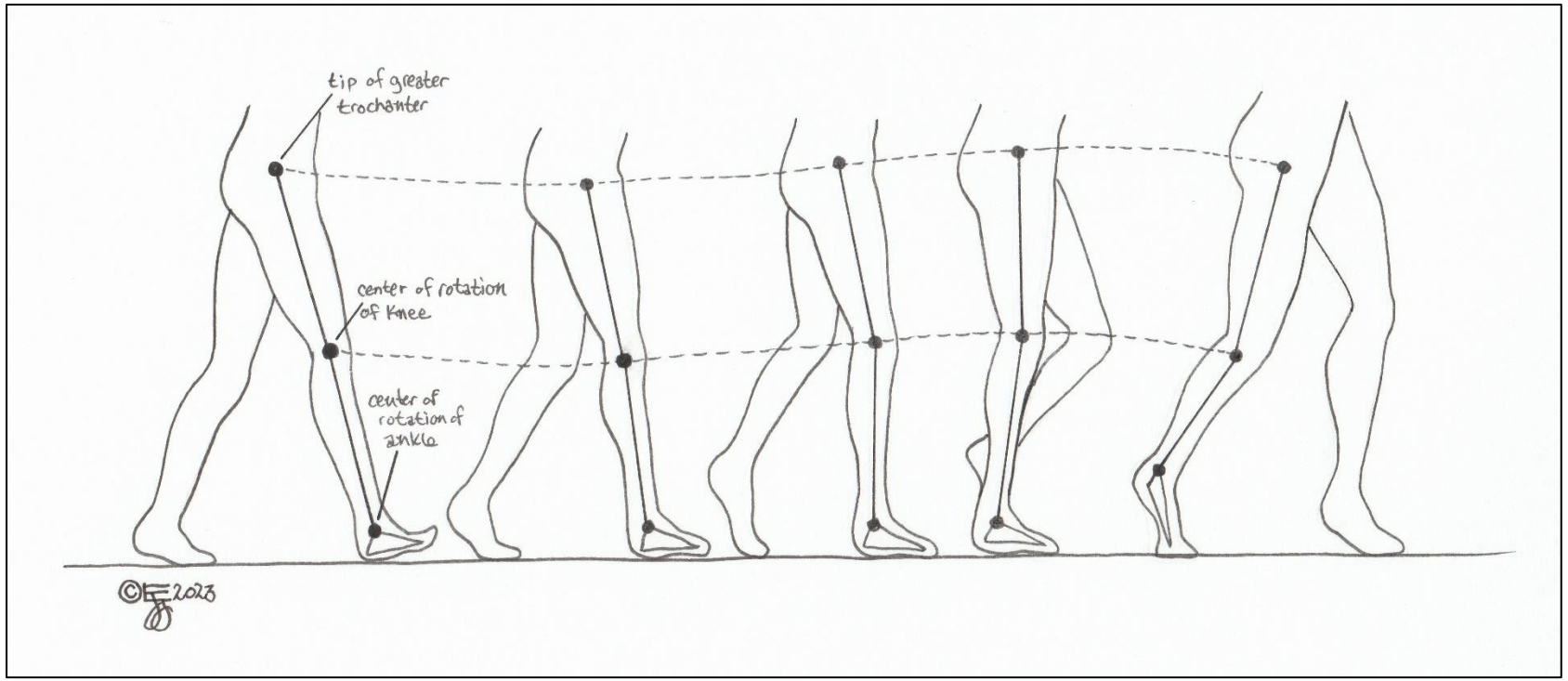
- Knee Flexion in Stance Phase
  - Knee should remain flexed during all components of stance phase, except heel strike, to prevent excessive vertical displacement of center of gravity.
  - This reduces the vertical displacement of center of gravity as of body is carried forward over stance limb.

Gait Cycle Variables

- Knee flexion in stance
  - Early knee flexion (15 degrees) at heel strike
  - Lowers COG, decreasing energy expenditure
  - Also absorbs shock of heel strike
  - At midstance, the knee extends as the ankle plantarflexes and foot supinates
  - Restores leg to original length
  - Reduces fall of pelvis at opposite heel strike

Knee Flexion in Stance Phase

For example: During toe off, when the ankle reaches 20˚ of plantarflexion, this tends to cause the center of gravity to rise. The knee flexes to approximately 40˚ to counterbalance it.



Gait Cycle Variables

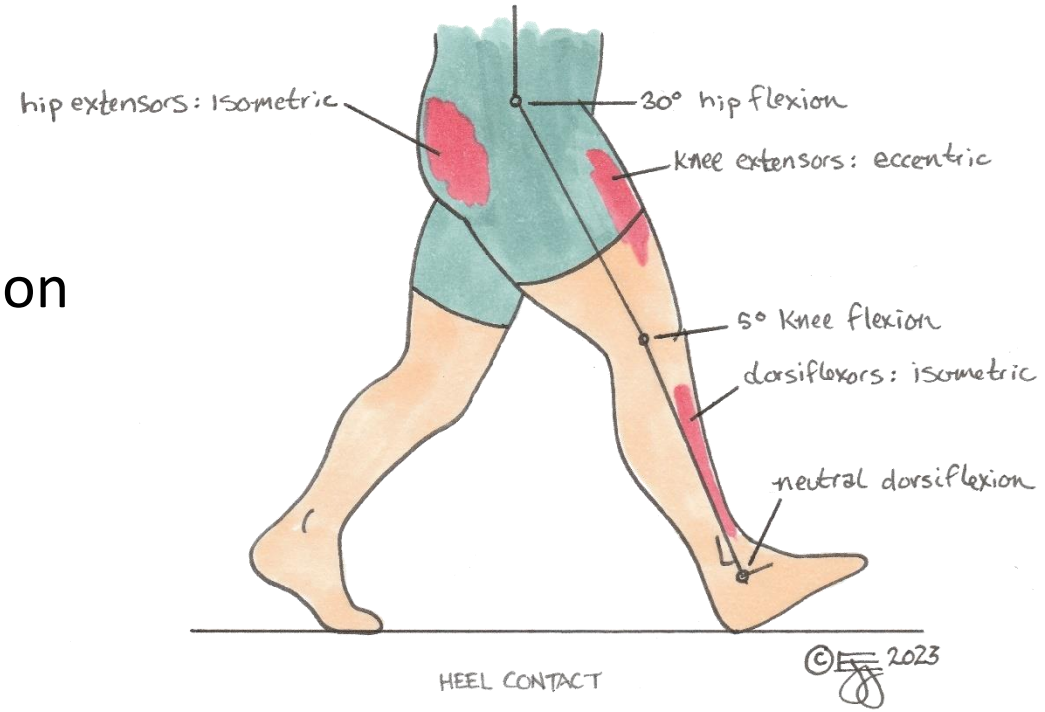
- Center of gravity (COG)
  - In standing position is 5cm anterior to S2 vertebral body
  - Vertical displacement:
    - During gait cycle COG displaces vertically in a rhythmic pattern
    - The highest point is during midstance phase
    - The lowest point occurs at the time of double limb support
  - Horizontal displacement
    - COG displaces 5cm horizontally during adult male step

Gait Cycle Variables

- Lateral Displacement of the Pelvis:
  - Reduces lateral movement of center of gravity toward stance foot during gait cycle.

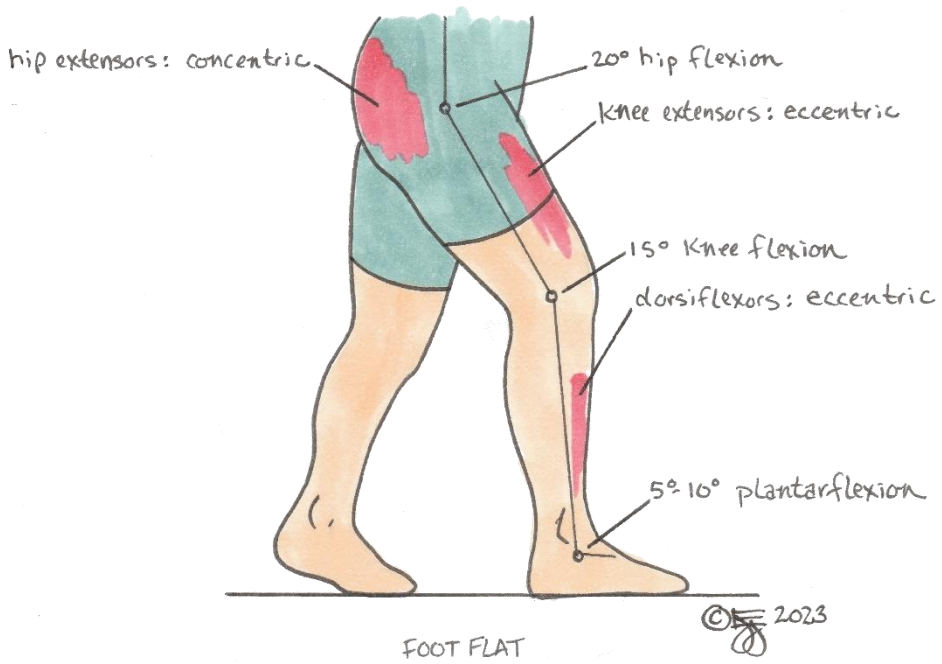
Stance Phase

- Initial contract(heel strike)
  - Hip external rotation
  - Tibia internal rotation
  - Ankle- foot, supination plantar flexion



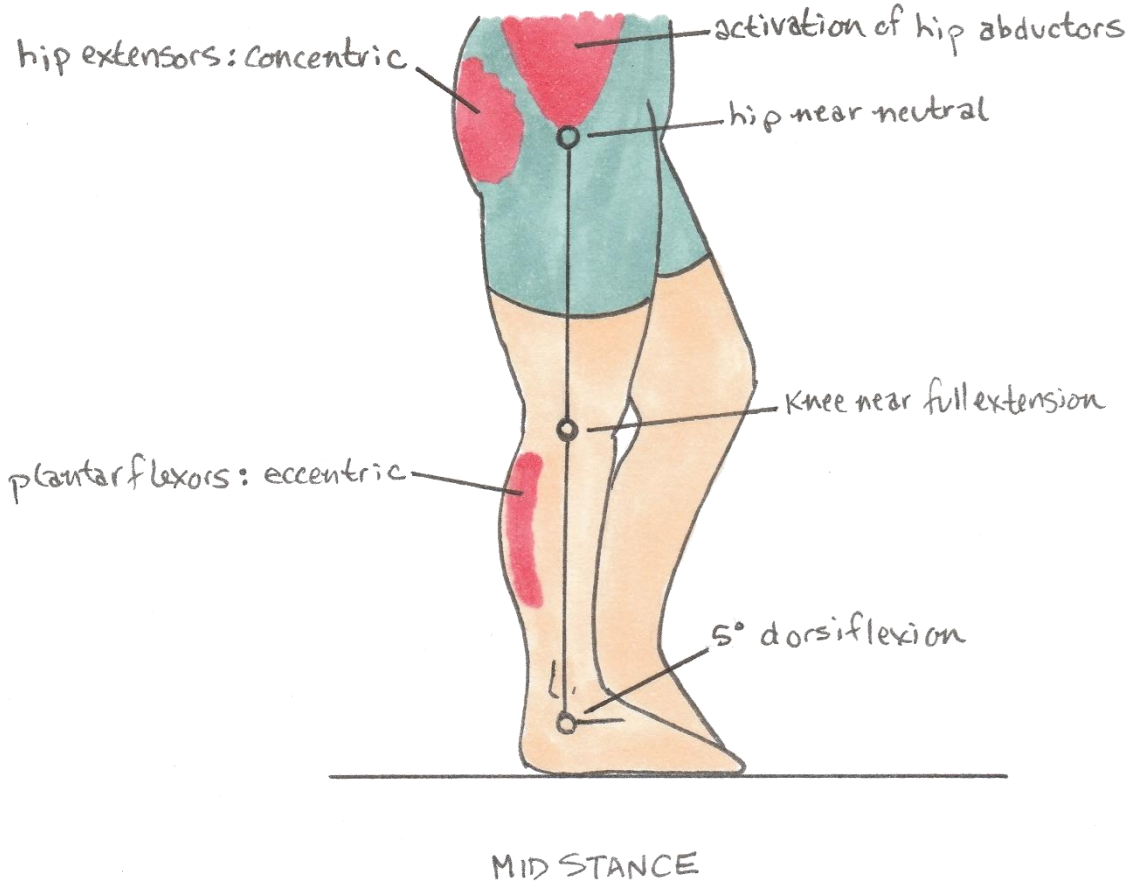
Stance Phase

- Loading response(initial double limb support)
  - Hip internal rotation
  - Knee flexion, 15˚-20˚
  - Tibia internal rotation
  - Ankle- foot, pronation plantarflexion



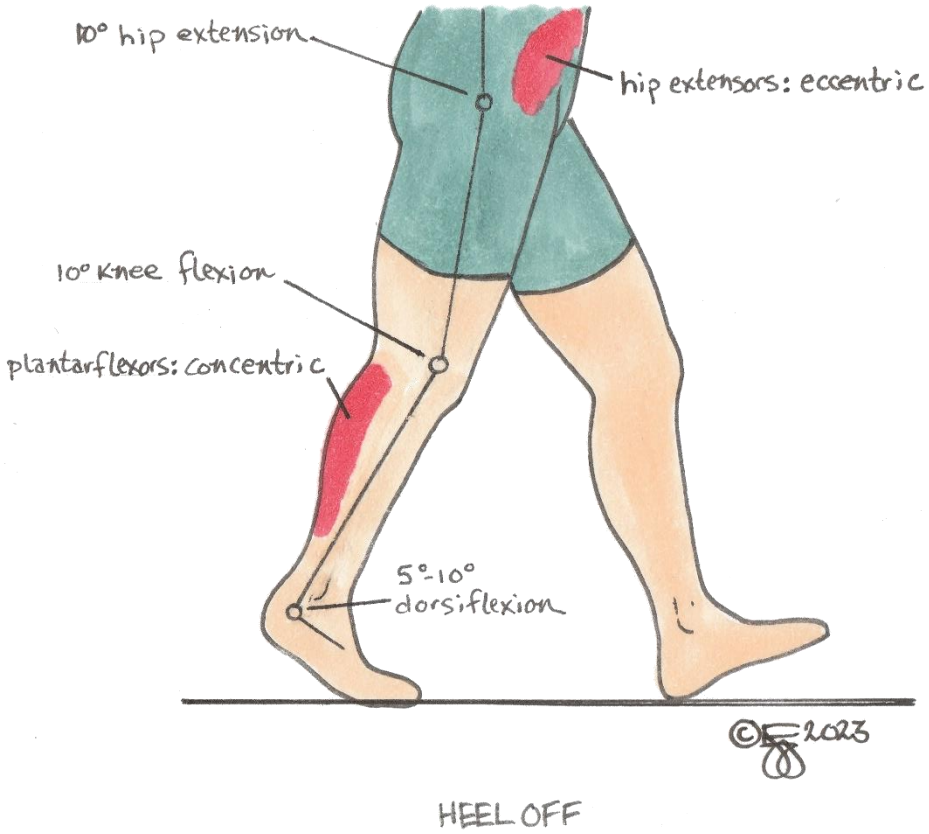
Stance Phase

- Mid stance
  - Hip neutral
  - Knee flexion, 5˚-15˚
  - Tibia neutral
  - Ankle- foot, almost neutral, 5˚ dorsiflexion



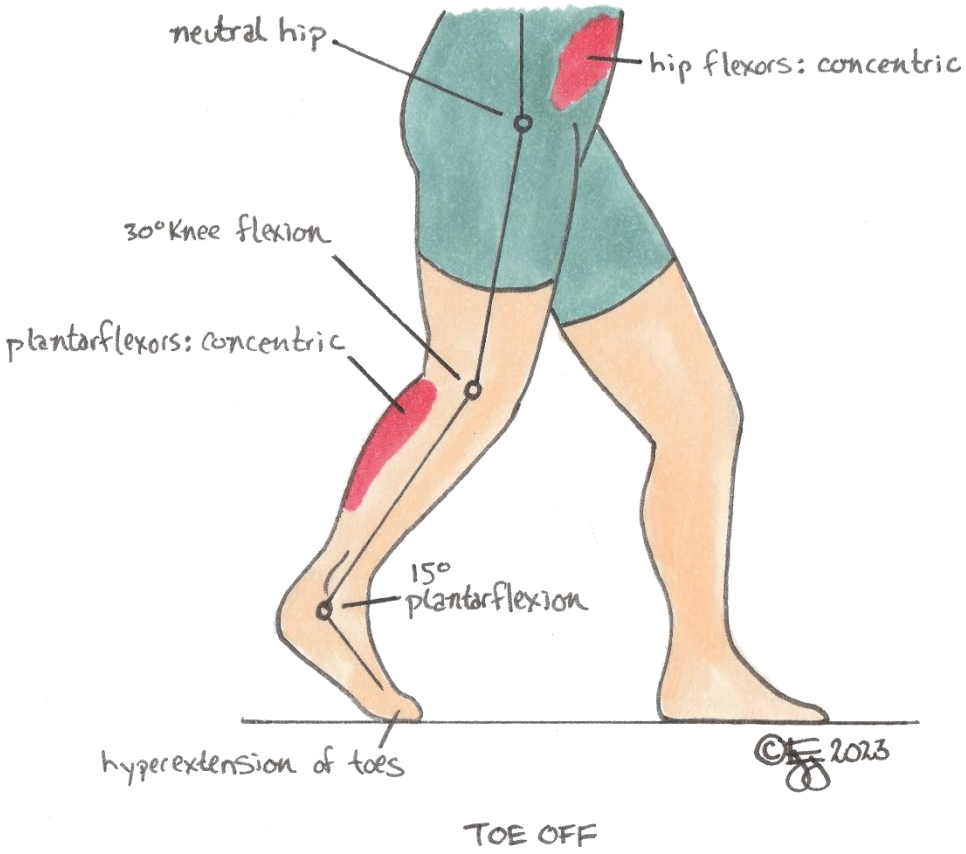
Stance Phase

- Terminal phase
  - Hip external rotation
  - Tibia external rotation
  - Ankle- foot, supination, 15˚ dorsiflexion(max)



Stance Phase

- Pre-swing(second double limb support)
  - Hip external rotation
  - Tibia external rotation
  - Ankle- foot, supination, 15˚-20˚ plantarflexion



Kinetics of Gait

- Kinetics is study of forces that produce a change in motion.
- It is concerned with forces developed *within* the body by muscular action; as well as external forces *acting on* the body.
  - External forces include:
    - Center of gravity
    - Ground reaction force

Kinetics

- Muscle Activity
  - ***Concentric contraction***: Muscle shortening on stimulation generates power and accelerates body forward.

    - Examples: Gastrocnemius-soleus contracts to lift the heel off the ground.

      Iliopsoas (iliacus, psoas major, psoas minor) contracts flexing the hip and the pulling the stance phase limb off the ground.

Kinetics

- Muscle Activity
  - ***Eccentric contraction***: Muscle lengthens on stimulation and slows down and stabilizes the joint motion.

    - Examples: Quadriceps contract during initial contact, enabling the muscles to serve as shock absorber during walking.

      Tibialis anterior contracts at initial contact, firing during plantarflexion as the foot is lowered to ground so that the foot is gently lowered to ground.

      Gastrocnemius-soleus contracts eccentrically through the stance phase, controlling rate of dorsiflexion of ankle.

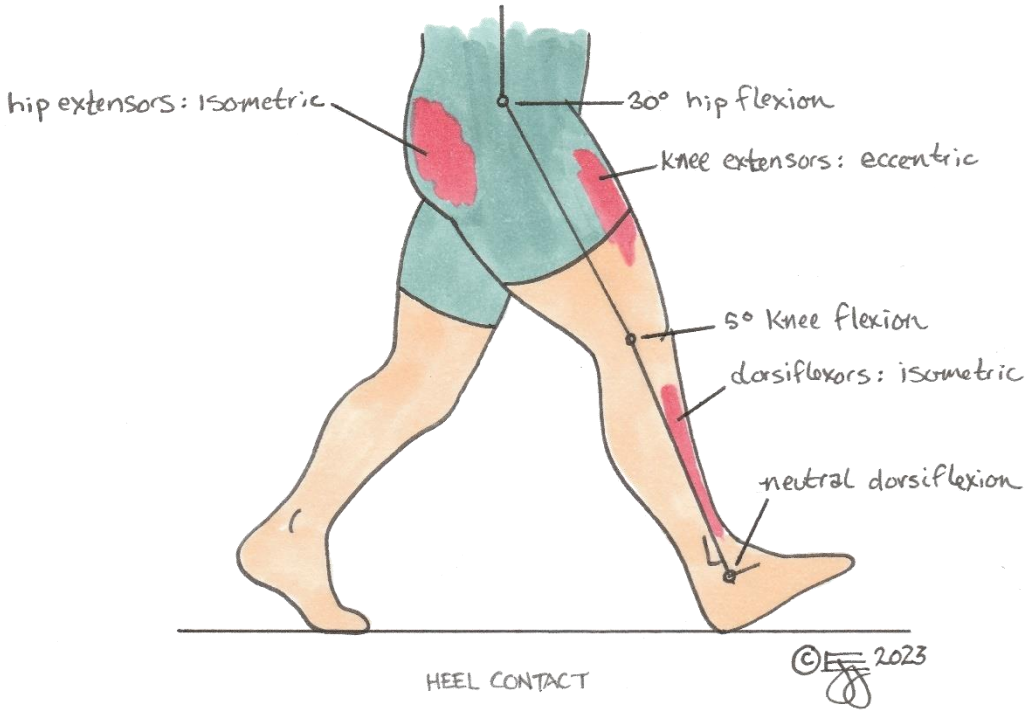
Kinetics

- Muscle Activity
  - ***Isometric contraction***: Muscles are engaged but not changing in length and there are no movements in surrounding joints.
    - Example Hip extensors at heel strike

Let’s Put It All Together…

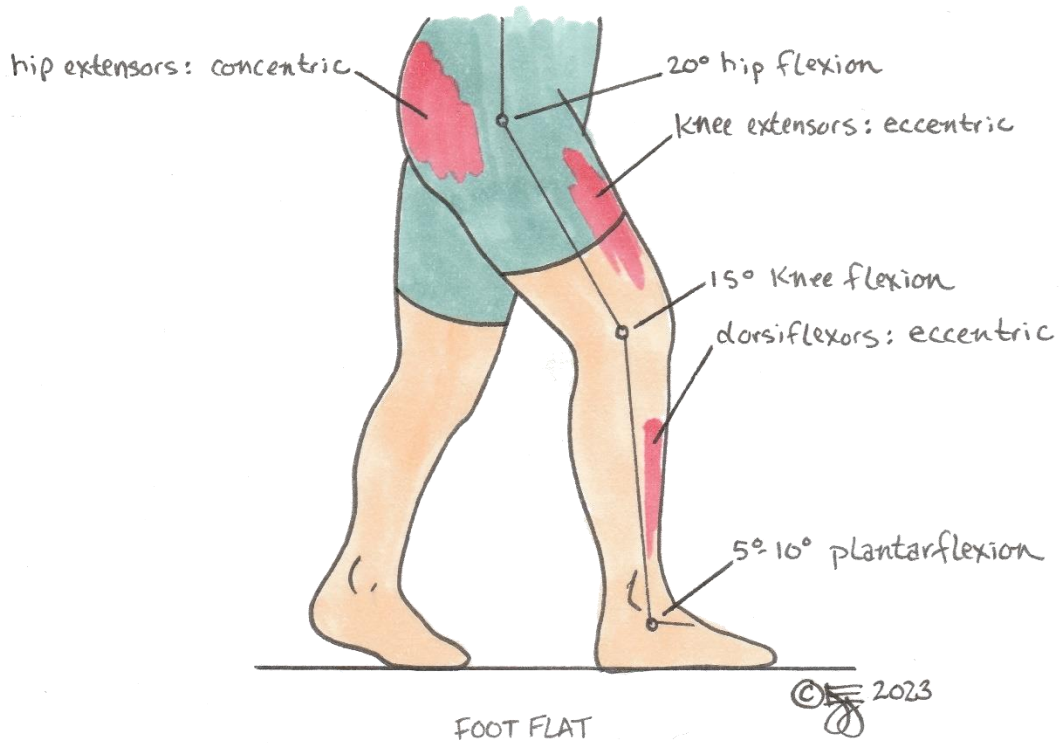
Stance Phase

- Initial Contact (Heel Strike)
  - Muscular Contractions
    - Hip extensors to stabilize the hip
    - Eccentric contraction of quadriceps
    - Isometric and eccentric contraction of tibialis anterior



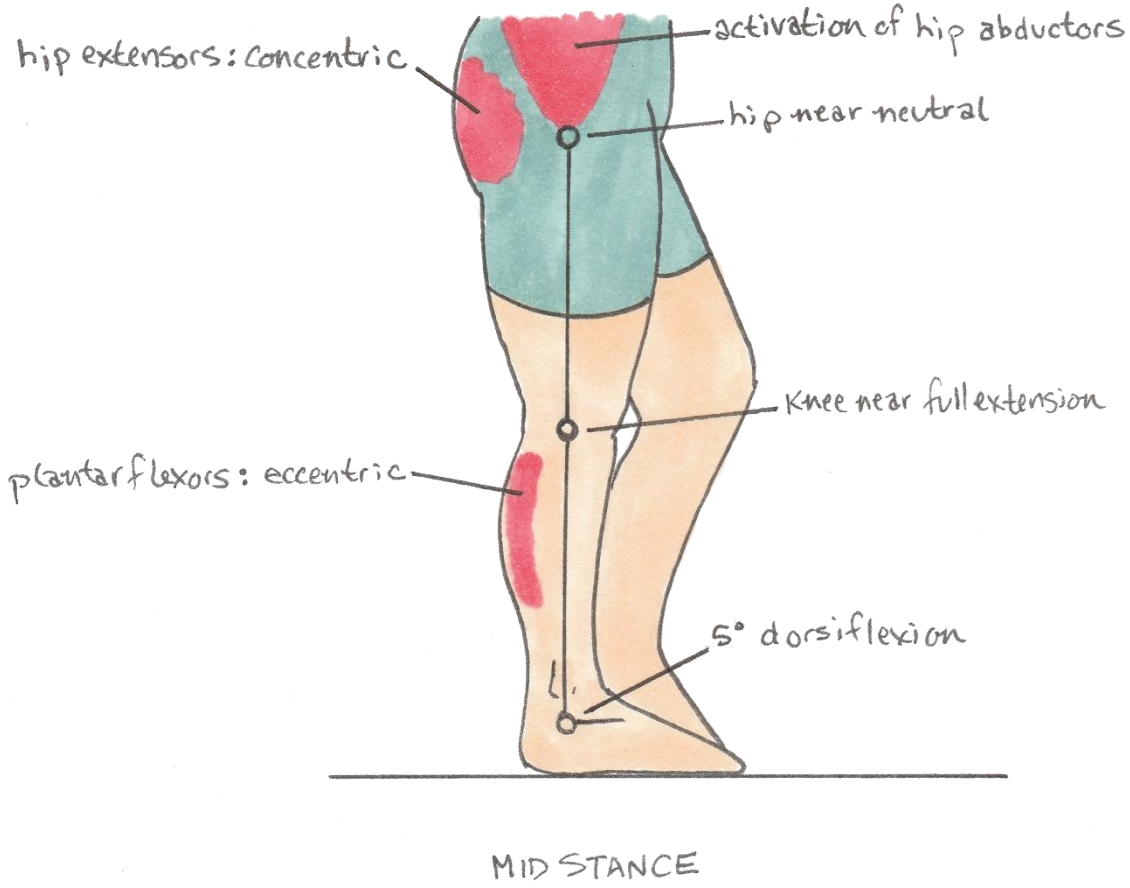
Stance Phase

- Loading response (Foot Flat)
  - Initial double limb support, occurs after initial contact until elevation of opposite limb. Body weight is transferred onto the supporting limb
    - Eccentric contraction of tibialis anterior, dorsiflexion to control plantar flexion
    - Quadriceps contract to stabilize knee



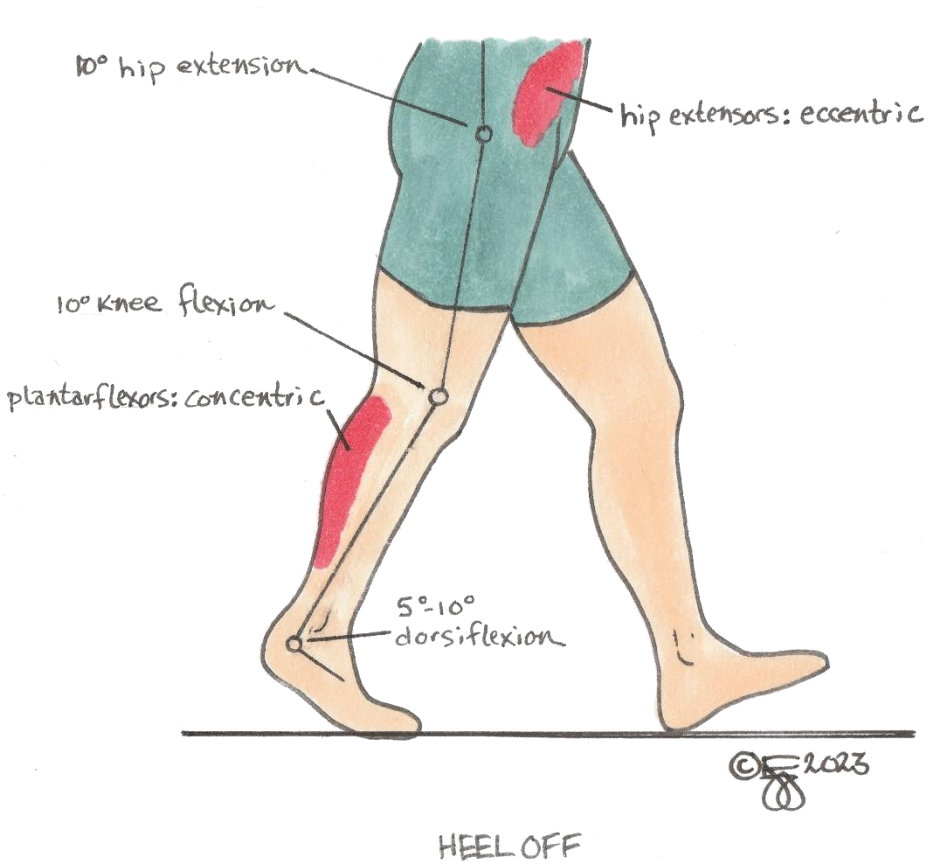
Stance Phase

- Midstance
  - Occurs from elevation of opposite limb until both ankles are aligned in coronal plane.
  - Eccentric contraction of gluteus medius and calf muscles.



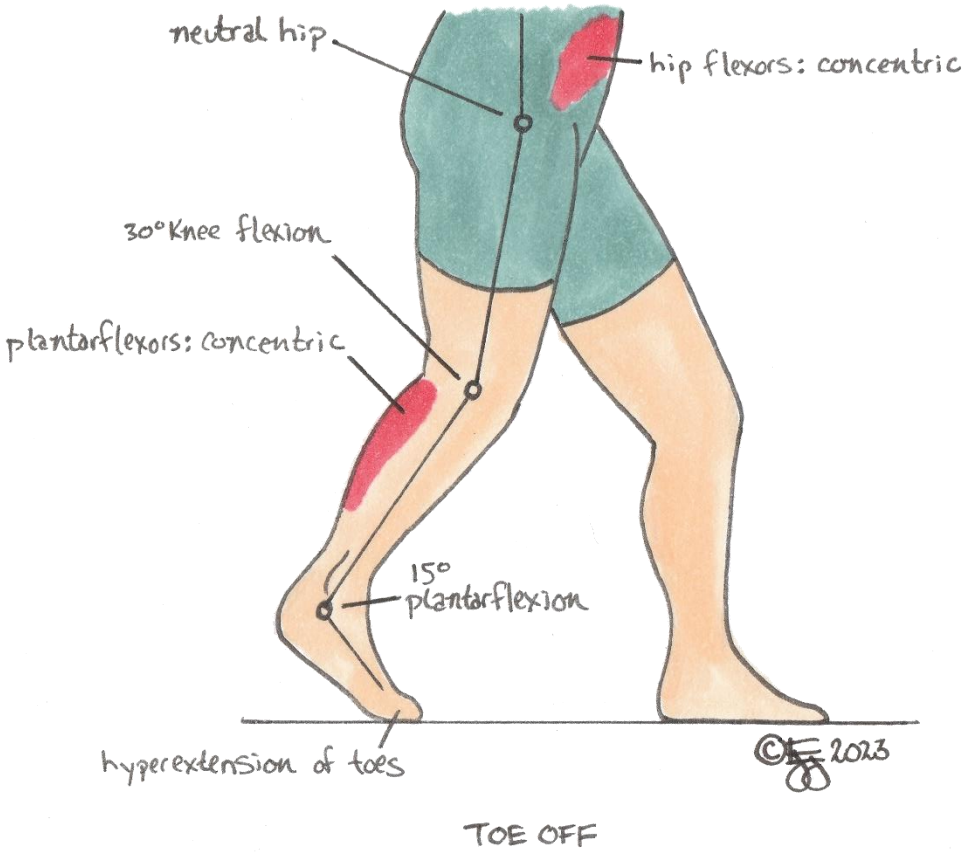
Stance Phase

- Terminal Phase (Heel Off)
  - Begins when the supporting heel rises from the ground and continues until the opposite heel touches the ground.
  - Toe flexors and tibialis anterior, eccentric hip flexors, concentric plantar flexors.



Stance Phase

- Pre-Swing (Toe Off)
  - Second double limb support period. Begins at initial contact of opposite limb and continues until just prior to elevation of ipsilateral limb.
  - Concentric hip flexors to propel advancing limb, concentric gastric-soleus



Hip – Stance Phase

Phase	Normal Movement	Normal Muscle Movement
Heel strike to foot flat	30˚ flexion	Erector spinae, gluteus maximus, hamstrings
Foot flat to midstance	30˚ flexion (neutral)	Gluteus maximus at beginning to oppose flexion movement, then activity ceases as moment changes from flexion to extension
Midstance to heel-off	extension	No activity
Heel-off to toe-off	10˚ hyperextension to neutral	Iliopsoas, adductor magnus, adductor longus

Knee – Stance Phase

Phase	Normal Movement	Normal Muscle Movement
Heel strike to foot flat	0˚- 15˚ flexion	Quadriceps contracts initially to hold knee in extension, then eccentrically oppose the flexion movement to control amount of flexion.
Foot flat to midstance	15˚ flexion - 5˚ extension	Quadriceps contract in early part, then no further activity is required.
Midstance to heel-off	5˚ of flexion - neutral	No activity required.
Heel-off to toe-off	0˚- 40˚ flexion	Quadriceps required to control amount of knee flexion.

Ankle/Foot – Stance Phase

Phase	Normal Movement	Normal Muscle Movement
Heel strike to foot flat	0˚-15˚ plantarflexion	Eccentric action of tibialis anterior oppose plantar flexion movement.
Foot flat to midstance	15˚ plantarflexion - 10˚ dorsiflexion	Gastrocnemius/soleus act eccentrically to oppose dorsiflexion movement and control tibial advance.
Midstance to heel-off	10˚-15˚ dorsiflexion	Gastrocnemius/soleus act eccentrically to oppose dorsiflexion movement and control tibial advance.
Heel-off to toe-off	15˚ dorsiflexion - 20˚ plantarflexion	Gastrocnemius, soleus, peroneus brevis and longus, flexor hallucis longus contract to plantarflex the foot.

Swing Phase

- Initial Swing (Acceleration)
  - Start of single limb support for opposite limb. Period runs from elevation of limb until the point of maximal knee flexion.
    - Hip flexors concentrically contract to advance the swinging leg, concentric tibialis anterior.
- Mid-swing (Foot Clearance)
  - Following knee flexion to point where tibia is vertical.
    - Ankle dorsiflexors contract to ensure foot clearance on swing-through.
- Terminal Swing (Deceleration)
  - Occurs from the point where tibia is vertical to immediately prior to initial contact.
    - Hamstring muscles decelerate forward motion of thigh.

Hip – Swing Phase

Phase	Normal Movement	Normal Muscle Movement
Acceleration to mid-swing	20˚ – 30˚ flexion	Hip flexor activity to initiate swing. Iliopsoas, rectus femoris, gracilis, sartorius, tensor fascia lata
Mid-swing to deceleration	30˚ flexion - neutral	Hamstrings

Knee – Swing Phase

Phase	Normal Movement	Normal Muscle Movement
Acceleration to mid-swing	40˚ – 60˚ flexion	Little activity in quadriceps, biceps femoris(short head),gracilis, sartorius contract concentrically.
Mid-swing	60˚ flexion – 30˚ extension	
Mid-swing to deceleration	30˚ - 0˚ extension	Quadriceps contract concentrically to stabilize knee in extension in preparation for heel strike.

Ankle/Foot – Swing Phase

Phase	Normal Movement	Normal Muscle Movement
Acceleration to mid-swing	Dorsiflexion to neutral	Dorsiflexors contract to bring the ankle in neutral and prevent toes from dragging on the floor.
Mid-swing to deceleration	Neutral	Dorsiflexion

Deviations & Compensations

Compensations

- Hip tightness
  - To maintain stride length, compensate with more anterior and posterior hip tilt.
  - Creates excessive stress on lumbar spine.

Compensations

- High-heeled shoes
  - To keep stride length, compensate with increased knee flexion.
  - Causes excessive stress on knee joints.

Abnormal Gait

- There are numerous causes of abnormal gait and there can be great variation depending upon the severity of the problem.
  - If a muscle is weak, how weak is it?
  - If joint motion is limited, how limited is it?

- In ‘limping’ the patient avoids weight bearing on the affected side as far as possible (diminished stance phase).
  - Limping denotes a painful condition on the affected side.

- In lurch, the patient prolongs the stance phase to improve the stability.
  - Lurching denotes variable failure of abduction mechanism.

Abnormal Gait

- Causes of gait deviations/abnormality
  - Pain
  - Joint and/or muscle ROM limitation
  - Muscular weakness/paralysis
  - Neurological involvement (Upper motor neuron lesion/ Lower MNL)
  - Leg length discrepancy

Abnormal Gait

- Abnormal gait caused by pain.
  - Other descriptive terms:
    - Limping
    - Antalgic
    - Avoidance

Abnormal Gait due to Neurological Disturbance

- Muscular paralysis
  - Spastic (Circumduction Gait, Scissoring Gait, Dragging or Paralytic Gait, Robotic Gait[Quadriplegic]) and
  - Flaccid (Lurching Gait, Waddling Gait, Gluteus Maximus Gait, Quadriceps Gait, Foot Drop or Stepping Gait,)
- Cerebellar dysfunction (Ataxic Gait)
- Loss of kinesthetics sensation (Stamping Gait)
- Basal ganglia dysfunction (Festinating Gait)

Abnormal Gait

- Due to abnormal deformities:
  - Equinus gait
  - Equino-varus gait
  - Calcaneal gait
  - Knock- and bow-knee gait
  - Genu recurvatum gait
- Due to Leg Length Discrepancy (LLD):
  - Equinus gait
  - Shoulder/hip drop

Antalgic (Painful/Avoidance) Gait

- Due to pain anywhere from foot to hip.
- The patient avoids bearing weight on the affected limb.

- Reduced stance phase
- Shortened step length
- Shortened stride length
- Shortened reciprocal arm swing
- Increased velocity of steps

Scissoring Gait

- One leg crosses directly over the other with each step like crossing the blades of a scissor.
- Scissoring gait results from spasticity of bilateral adductor muscle of hip.
- Example: cerebral diplegia

In-Toeing Gait

- In-toeing gait usually results due to metatarsus adductus, tibial bowing with tibial torsion or persistent femoral anteversion.
- Usually resolves by 8 years of age.

Out-Toeing Gait

- The normal range for out-toeing is from 0˚ to 30˚.
- In most infants/toddlers this out-toeing resolves spontaneously.
- When it associated with lateral tibial torsion, it can become worse with growth and may need surgical correction.

Steppage (Foot Drop) Gait

- During the heel strike attempt, the toes drop on the ground first (due to foot drop). To avoid this and to clear the ground, the patient flexes the hip and knee excessively, raises the foot and slaps it on the floor forcibly.
- In few cases, the patient starts walking while dragging the toes on the
- ground without making any attempt to flex the hip and the knee and raise the foot to clear the ground. This is called a *dragging gait*.

Toe-Walking Gait

- By the age of 3 years heel strike pattern of gait must be established. If toe walking is persisting beyond 3 years, it should be taken as abnormal and pathology and needs to be researched/investigated for the following.
- Causes of persistent (beyond 3 year) toe-walking are:
  - Cerebral palsy- spastic diplegia
  - Muscular dystrophies
  - Residual polio deformities
  - Post burn contractures
  - Post infective (in calf muscles/regions) contracture
  - Spinal cord tumors
  - Idiopathic- it is the most common.

Spastic (Hemiplegic or Circumduction) Gait

- Spastic muscles do not allow the hip and knee to be flexed enough for the foot to clear the ground, so the patient rotates the hip sideways during the swing phase and places the foot in flattened manner or places the toes first before heel strike.
- Gradually, due to plantarflexion contractures, heel strike can no longer be achieved. On the affected side, the upper limb is usually flexed.

Waddling (Duck) Gait

- Occurs when there is disturbance in the abduction mechanism of the hip; increased lordosis.
- While walking the body sways from-side-to-side on a wide base. Therefore, the patient lurches on both sides while walking like a duck.
  - Examples:
    - In bilateral congenital dislocation of hip
    - Pregnancy
    - Myopathy
    - Paralysis of abductors of hips

Trendelenburg Gait

- May be unilateral or bilateral.
- Bilateral Trendelenburg's Gait is very similar to the waddling gait.
- When unilateral, patient lurches on the affected side and the pelvis drops on the opposite side of hip.
- (Gluteus Medius gait is also very similar to Trendelenburg gait.)

  - Examples:
    - Fracture of femoral neck
    - Polio paralysis

Reeling Gait

- In a reeling gait situation, the patient tends to walk irregularly on a wide base, swinging sideways without stability and balance with
- tendency toward falling with each step.
  - Cerebellar incoordination
  - Alcohol inebriation

Festinating (Short Shuffling) Gait

- Due to rigidity of muscles the patient adopts a stooping posture (flexed neck, trunk, hip & knee), in which the center of gravity falls anteriorly.
- The patient, with stooping body, is propelled forward quickly in successions as if trying to “catch up with” their center of gravity.
  - Examples:
    - Parkinson’s disease
    - Wilson’s disease
    - Cerebral atherosclerosis

Stamping Gait

- The patient raises his feet abnormally high and jerks them forward to strike the ground slowly with a stamp due to lack of kinesthetics.
  - Examples
    - Sensory ataxias like tabes dorsalis, syringomyelia, DM, leprosy
    - Peripheral neuritis
    - Brain stem lesion in children

Abnormal Gait

- Knock-knee Gait
  - While walking, the patient flexes the hips slightly, the knee points appose each other, and the ankle and feet are kept apart with tendency of toe-in.

- Genu Recurvatum Gait
  - In paralysis of the hamstring muscles (e.g. in polio) the knee goes in hyperextension while transmitting weight in the midstance phase.

Calcaneal Gait

- Results from paralysis plantar flexors causing dorsiflexor contracture. The patient will be walking on his heel (heel walking).
- Characterized by greater amounts of ankle dorsiflexion and knee flexion during stance and a shorter step length on the affected side.
- Single-limb support duration is shortened because of the difficulty of stabilizing the tibia & the knee

Quadriceps Gait

- Quadriceps action is needed during heel strike and foot flat when there is a flexion movement acting at the knee.
- Quadriceps weakness/ paralysis will lead to buckling of the knee during gait and thus loss of balance. Patient can for compensate this if he has normal hip extensor and plantar flexors.
- Compensation:
  - With quadriceps weakness, the individual may lean forward over the quadriceps at the early part of stance phase, as weight is being shifted on to the stance leg.
  - Normally, the line of force falls behind the knee, requiring quadriceps action to keep the knee from buckling.
  - By leaning forward at the hip, the COG is shifted forward & the line of force now falls in front of the knee.
  - This will force the knee backward into extension.
- Another compensatory maneuver is to use is the hip extensors and ankle plantar flexors in a closed chain action to pull the knee into extension at heel strike.
- In addition, the person may physically push on the anterior thigh during stance phase, holding the knee in extension

Gluteus Maximus Gait

- The gluteus maximus act as a restraint for forward progression.
- The trunk quickly shifts posteriorly at heel strike (initial contact).
- This will shift the body's COG posteriorly over the gluteus maximus, moving the line of force posterior to the hip joints.
- With foot in contact with floor, this requires less muscle strength to maintain the hip in extension during stance phase.
- This shifting is referred to as a “Rocking Horse Gait” because of the extreme backward-forward movement of the trunk.

The End