



**OHCOW**

Occupational Health Clinics  
for Ontario Workers Inc.

Centres de santé des  
travailleurs (ses) de l'Ontario Inc.

# Symptoms in the Opposite or Uninjured Leg and Limping-Related Back Pain

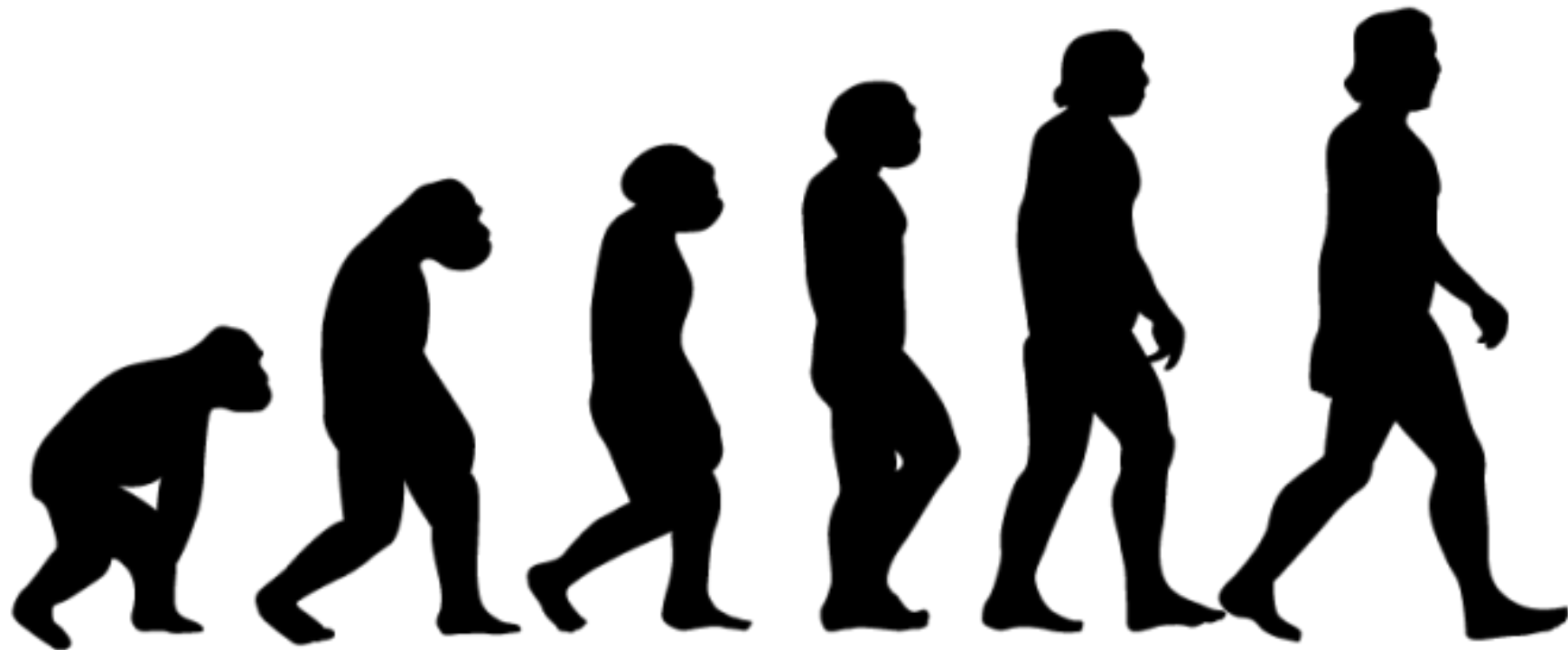
Secondary Effects on Lower-Extremity Joints and the Spine

Trevor Schell - OHCOW Ergonomist, Sudbury

Cathrine Hjelle Feier - UW Post Doctoral Fellow

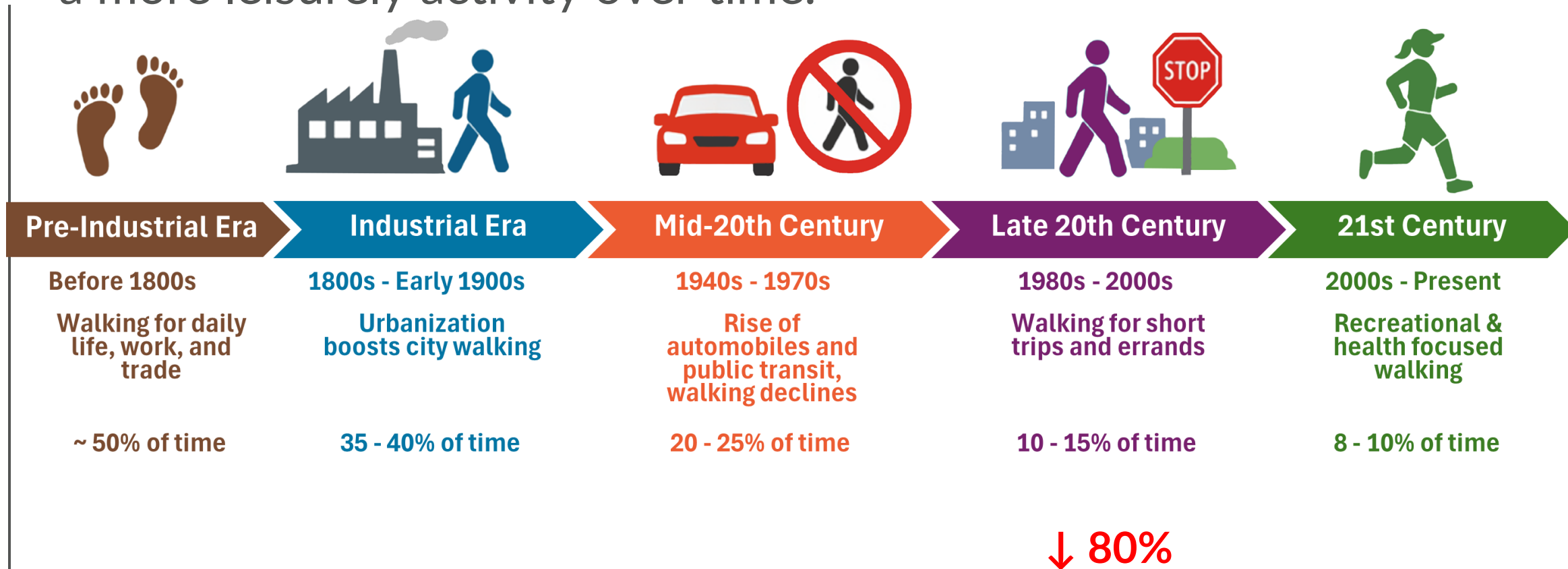
# Walking Over Time

- Walking, or locomotion, is the earliest form of movement humans have used to travel from place to place since human evolution began.

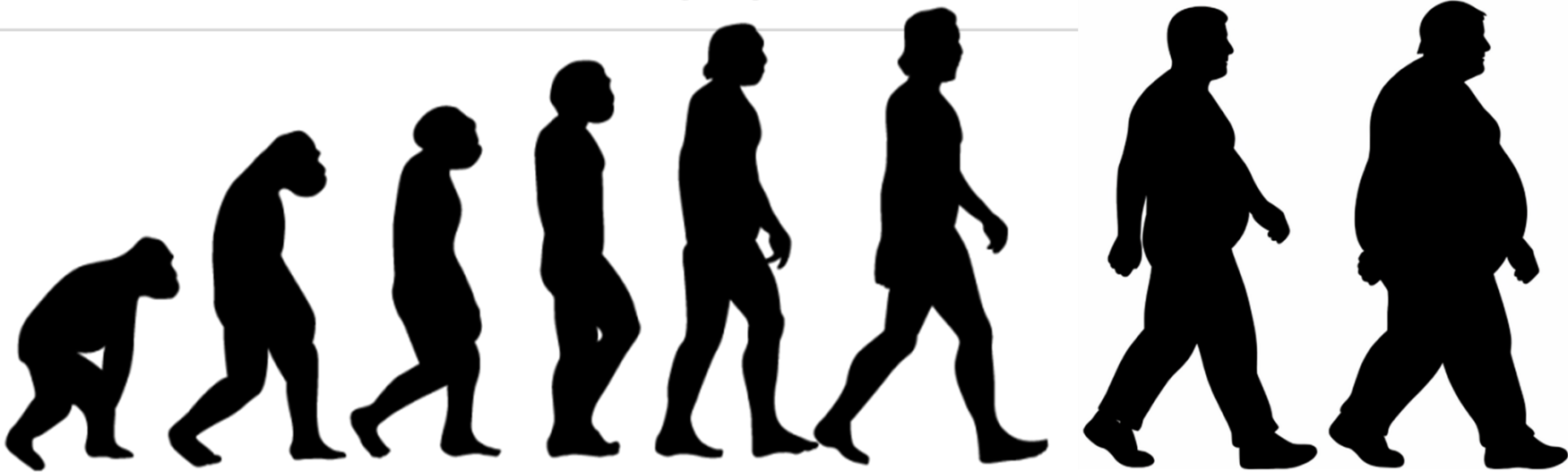
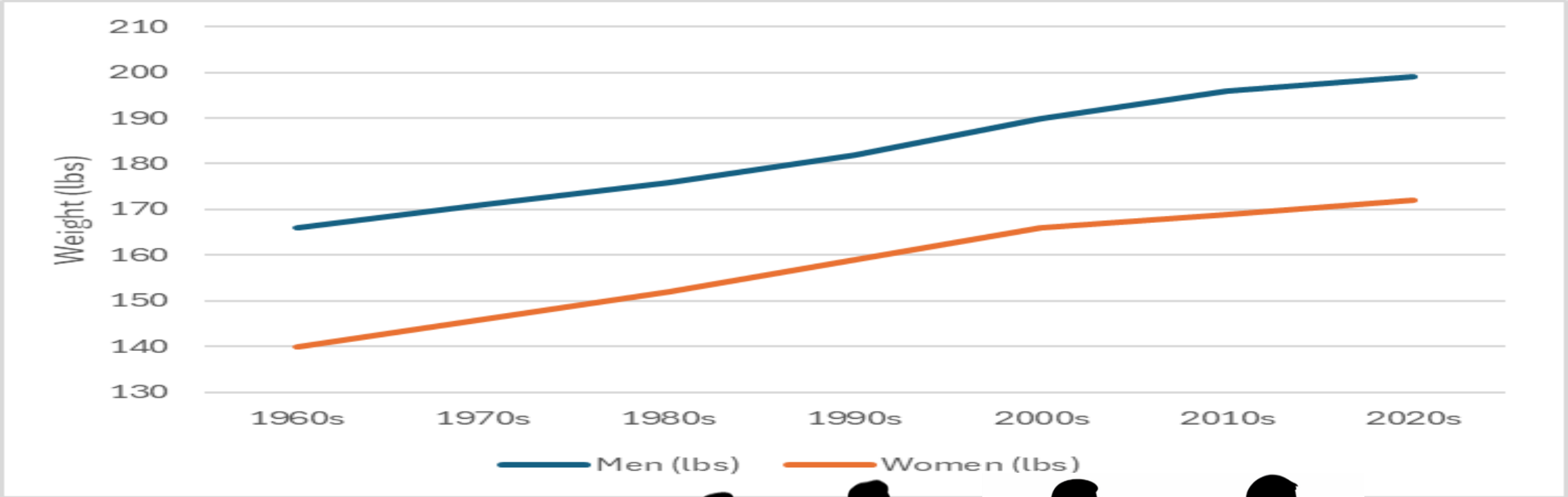


# Walking Over Time

- Walking has shifted from being a primary mode of transportation to a more leisurely activity over time.



# Walking Over Time



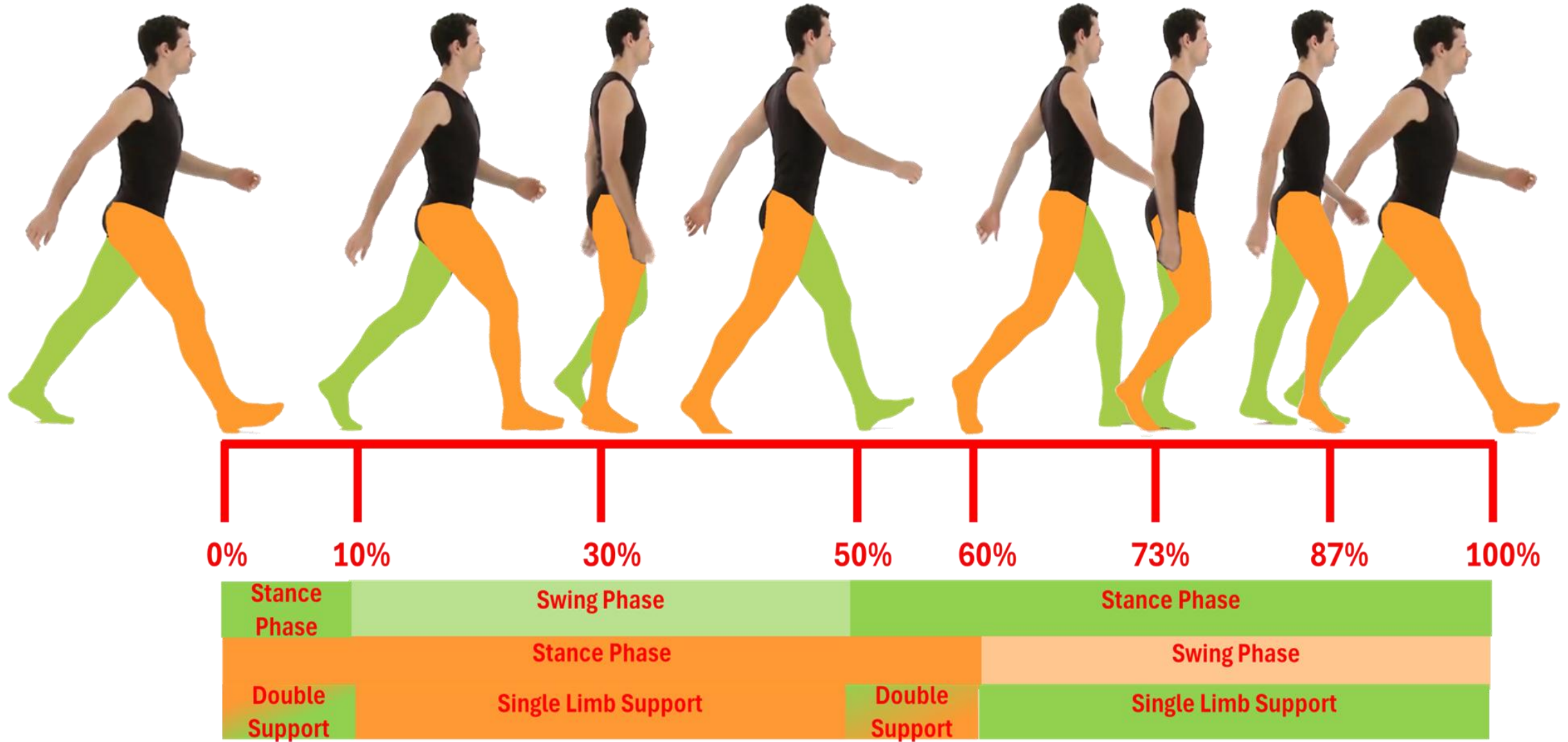
# Human Gait – How We Walk



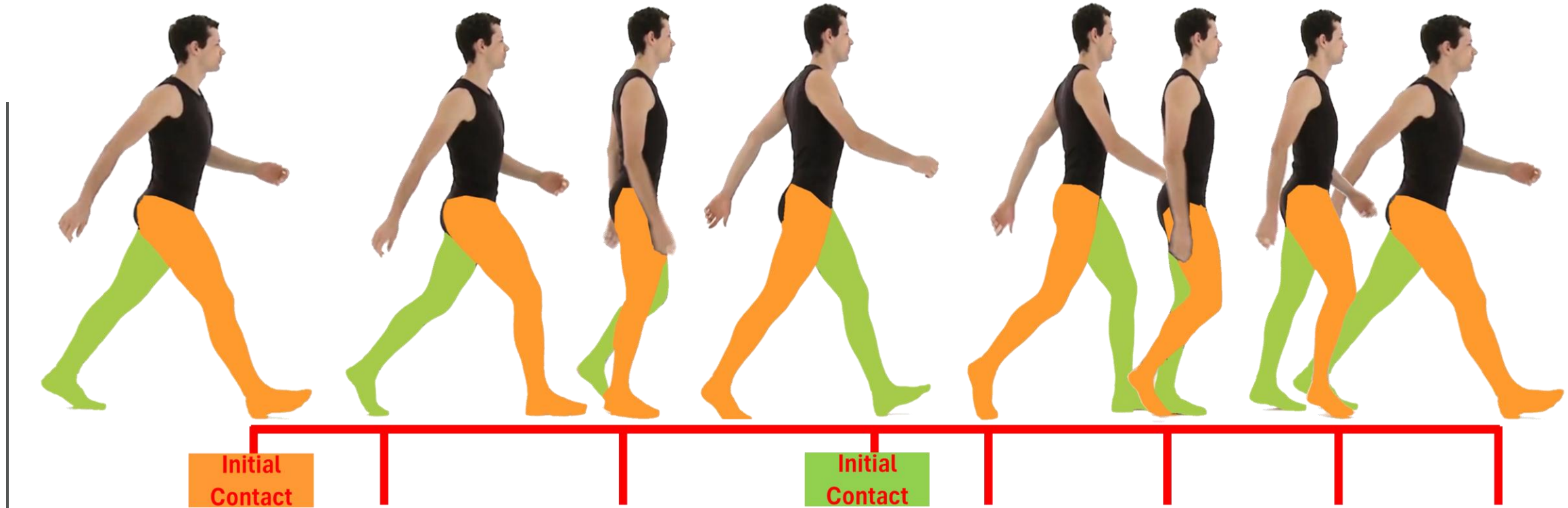
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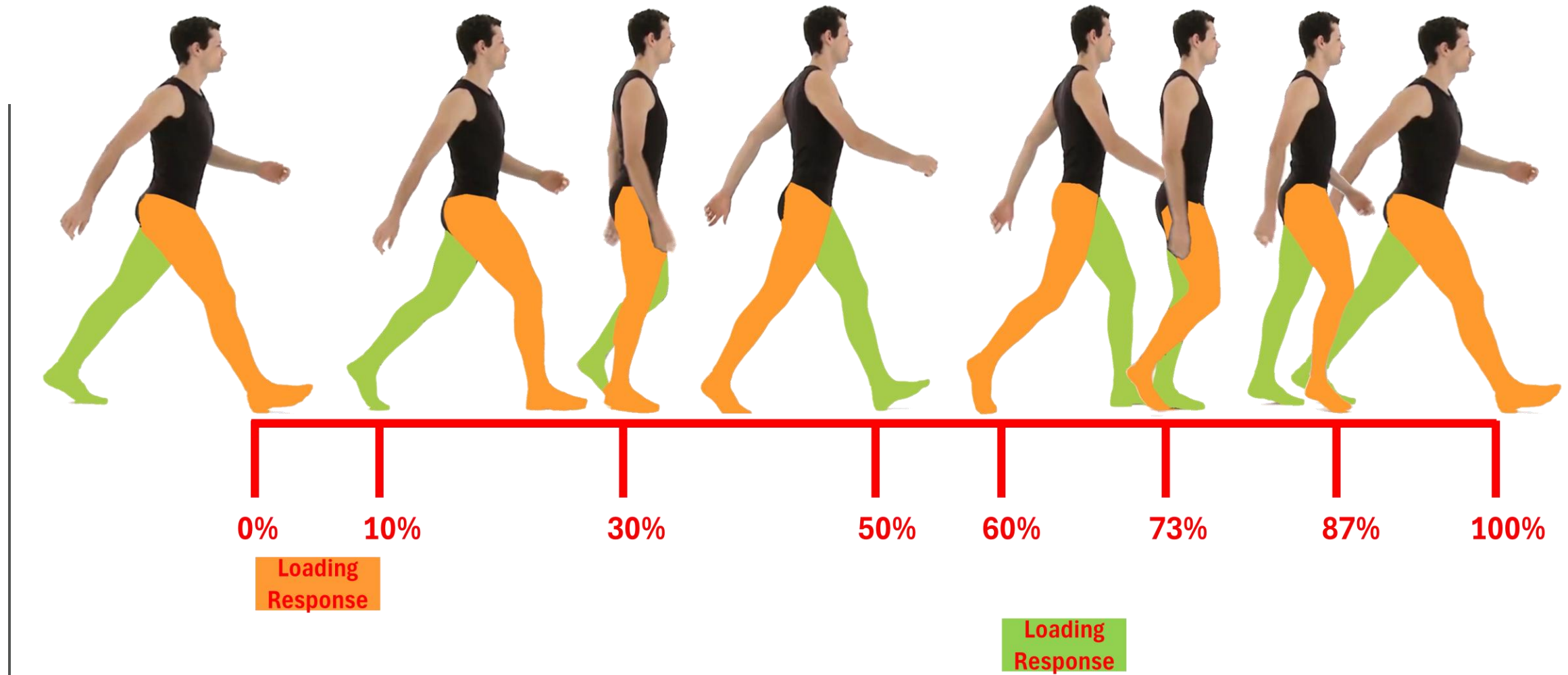
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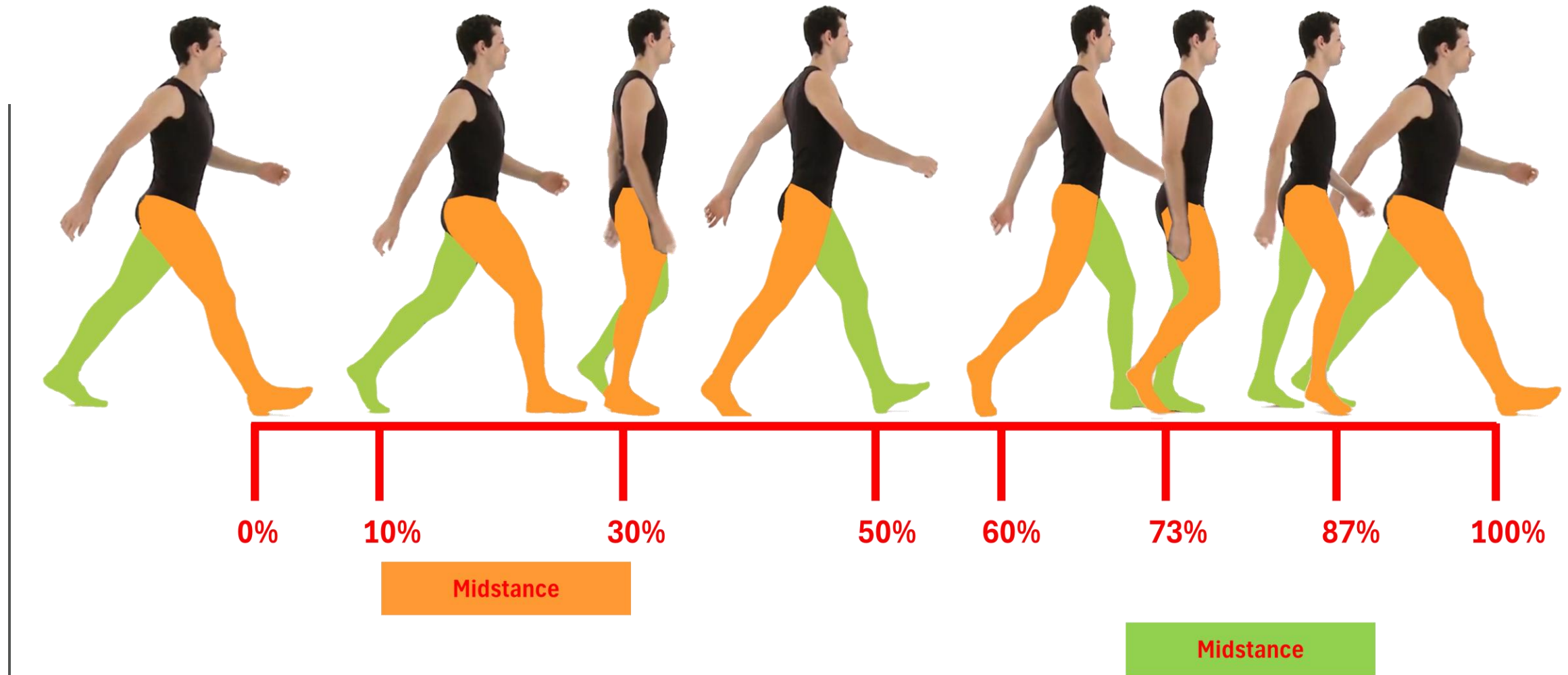
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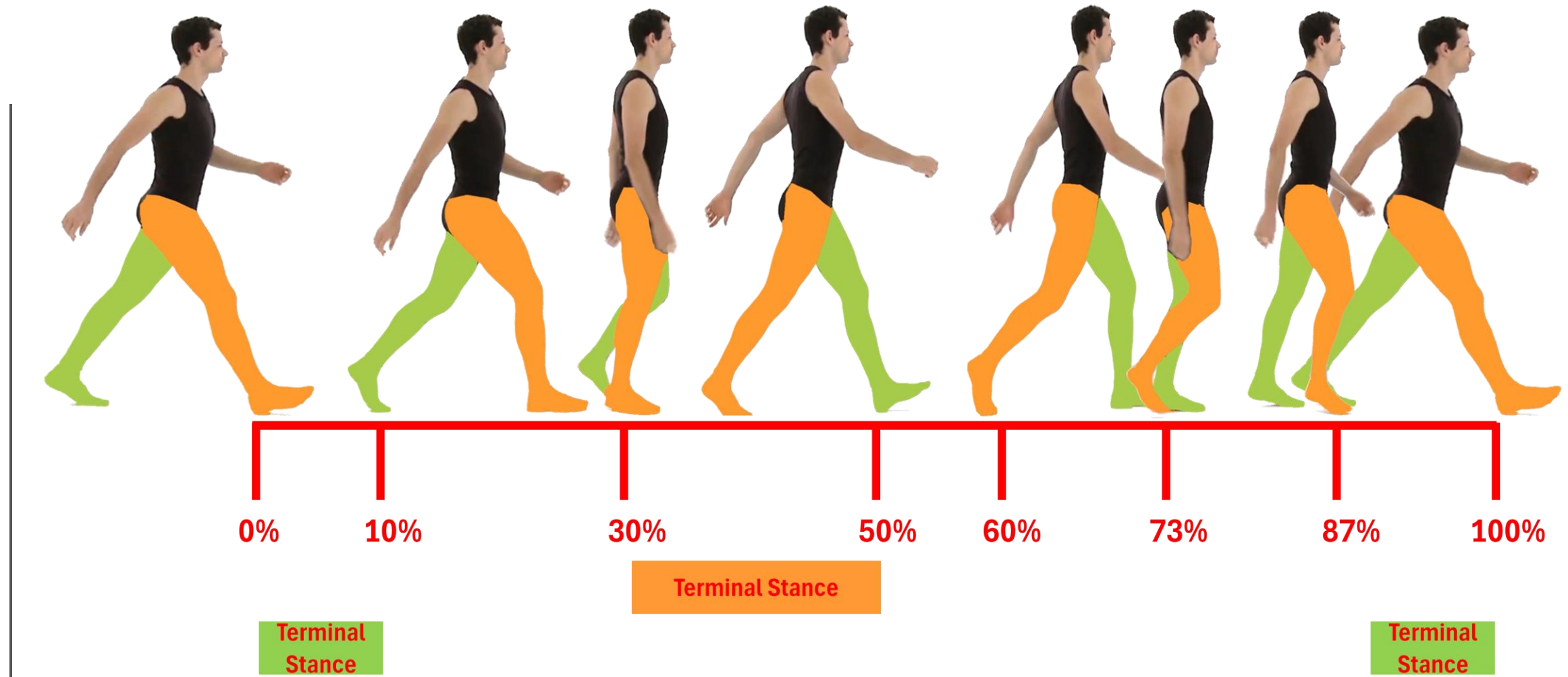
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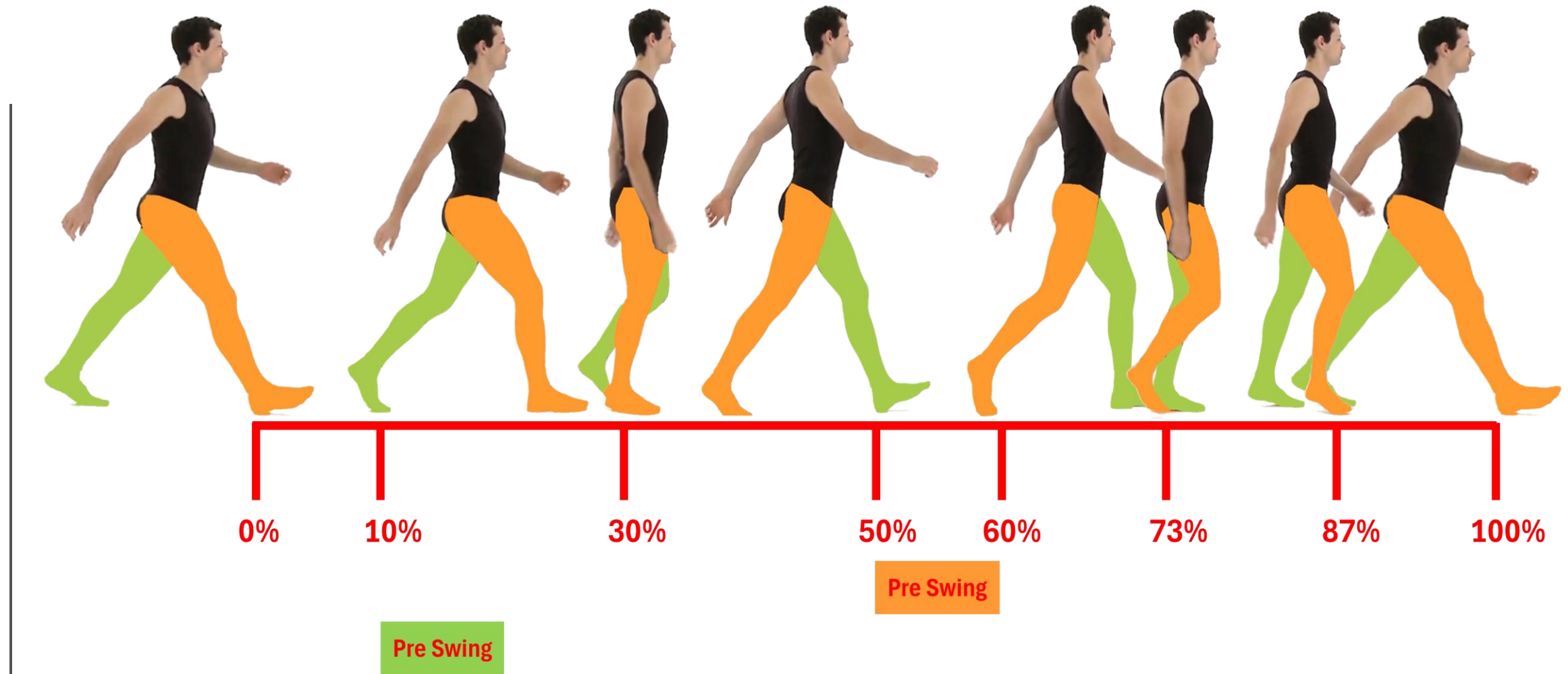
# Human Gait – How We Walk



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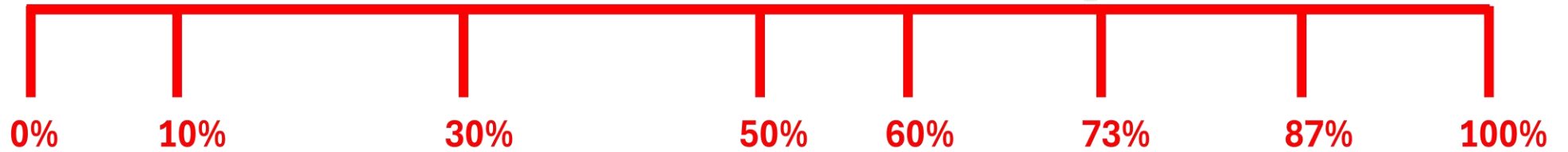
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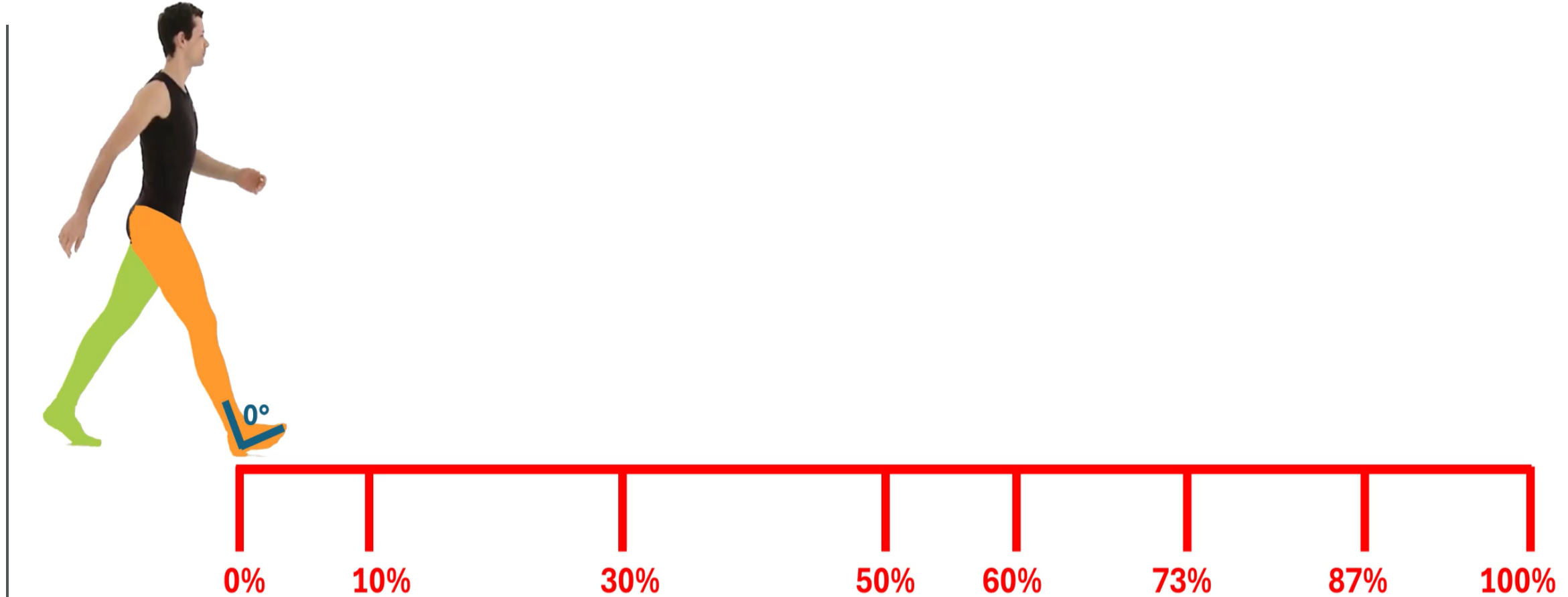


# Human Gait – How We Walk

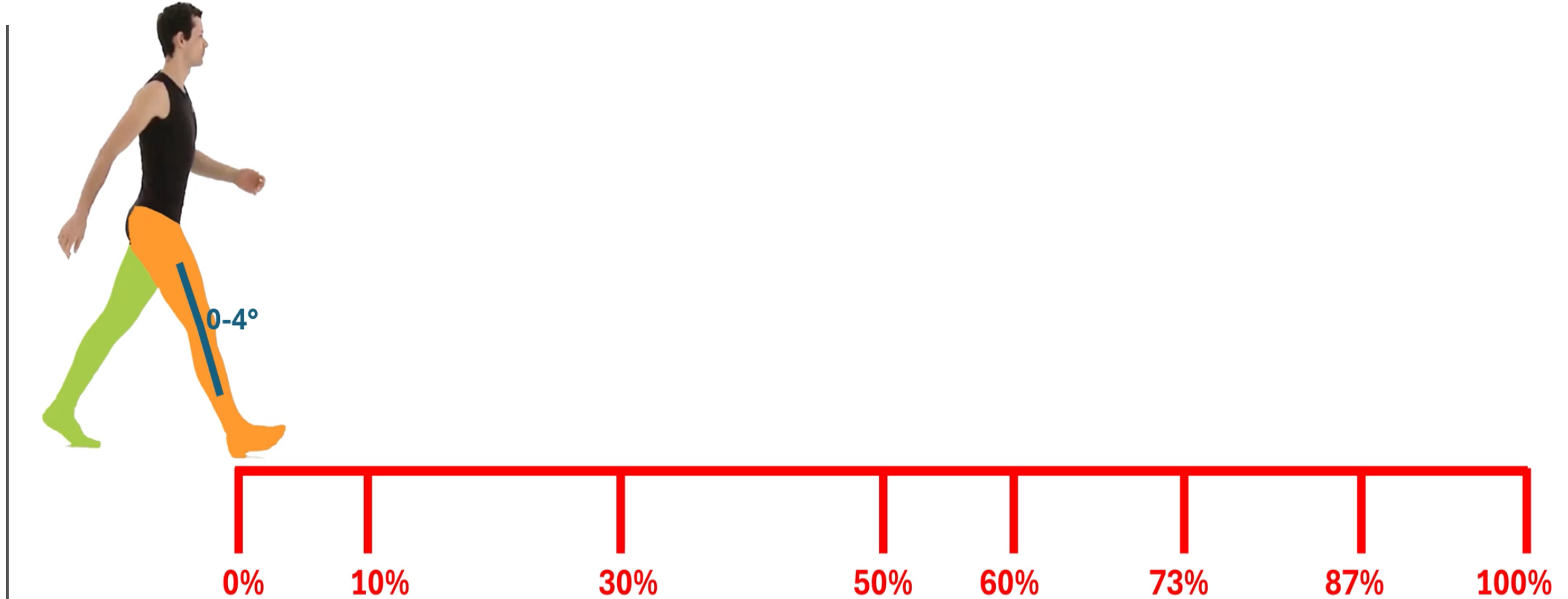


0%	10%	30%	50%	60%	73%	87%	100%
Loading Response	Midstance		Terminal Stance	Pre Swing	Initial Swing	Mid Swing	Terminal Swing
Terminal Stance	Pre Swing	Initial Swing	Mid Swing	Terminal Swing	Loading Response	Midstance	Terminal Stance

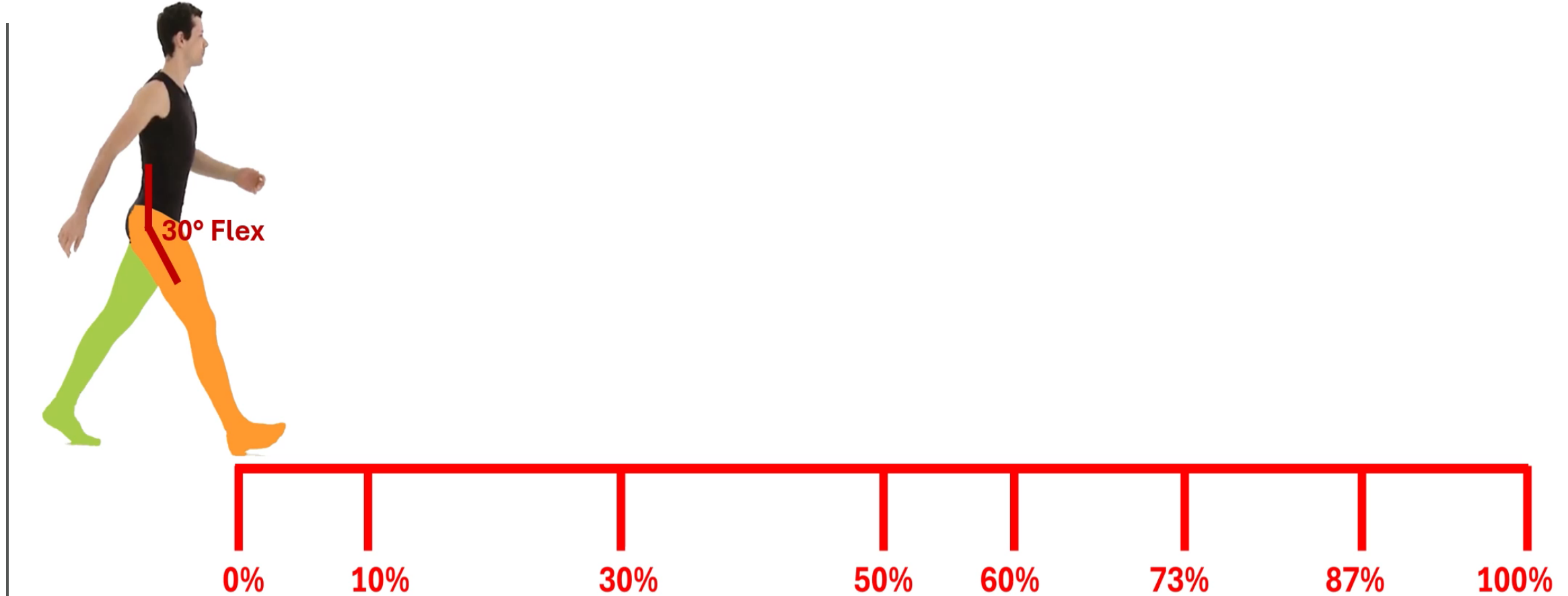
# Human Gait – Joint Angles - Ankle



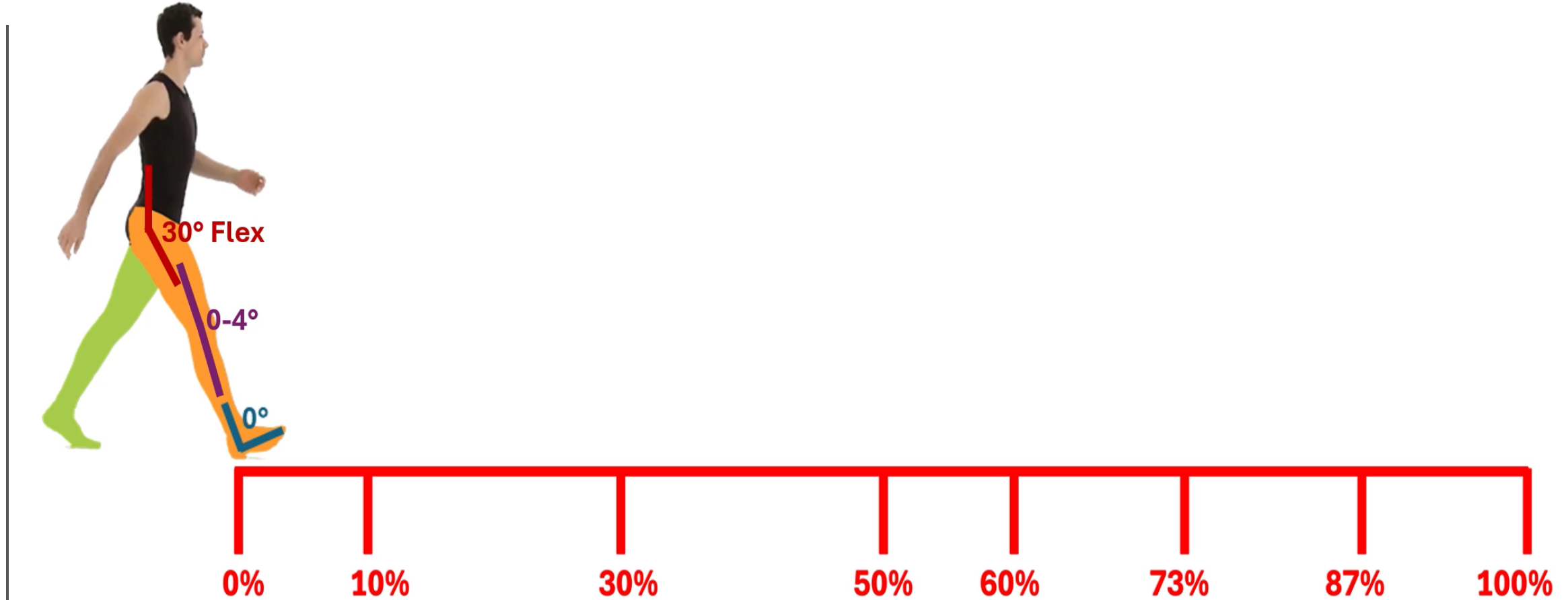
# Human Gait – Joint Angles - Knee



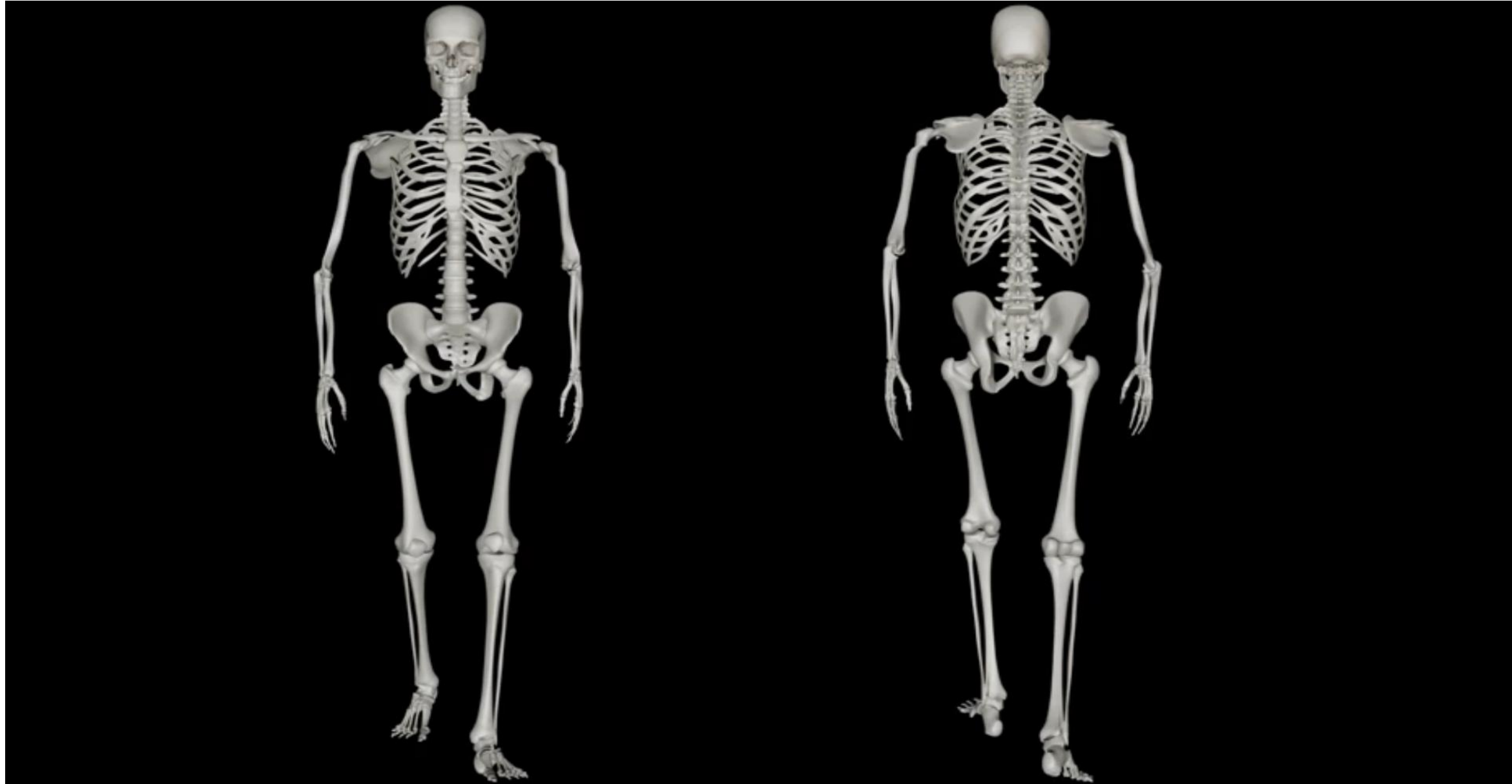
# Human Gait – Joint Angles - Hip



# Human Gait – Joint Angles



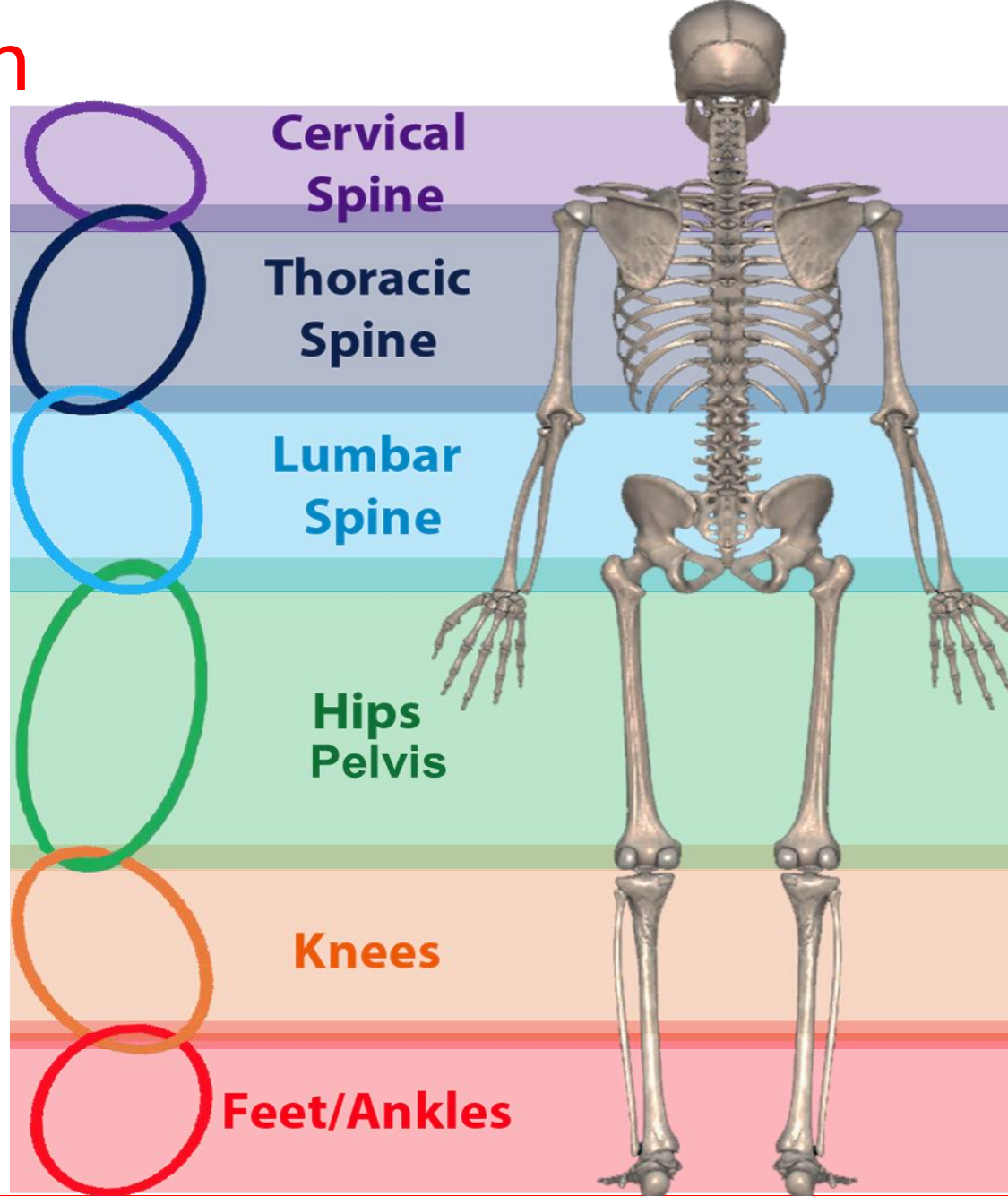
# Human Gait – How We Walk



# Kinetic Chain

- Sequence of joints and segments that transmit forces during movement.
- When walking, forces generated at the ground are transmitted upward through the body, and motion at one joint affects the others.

# Kinetic Chain



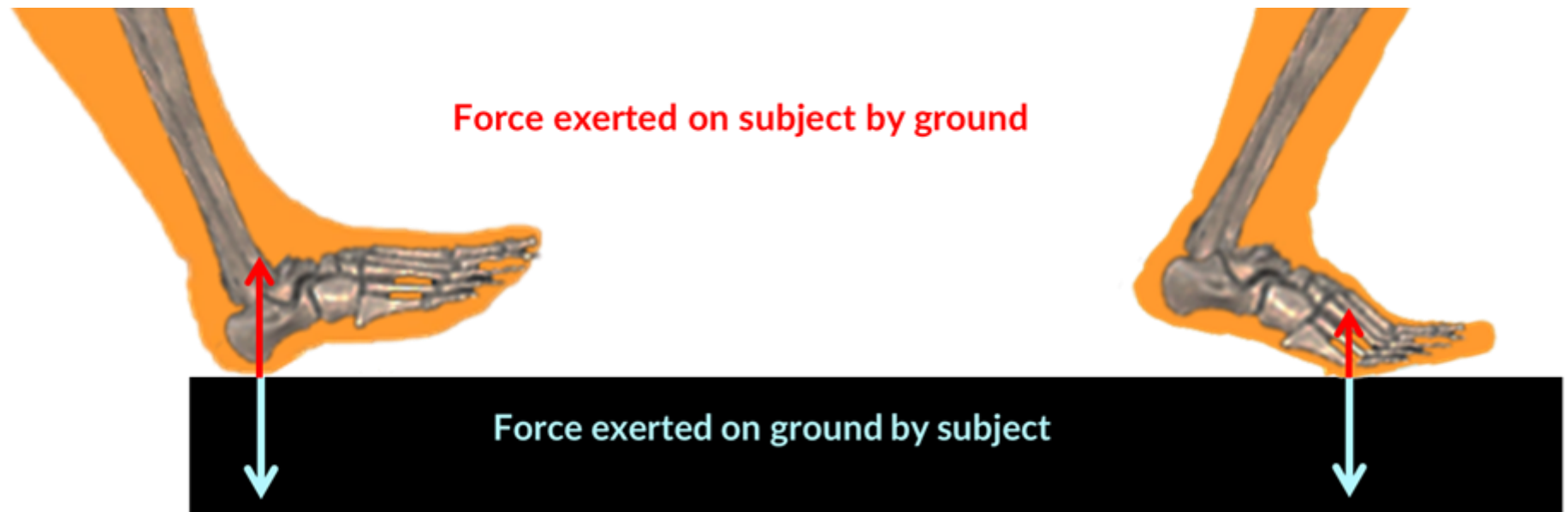
# Lower-Extremity Kinetic Chain

- During the initial phase of the gait cycle (heel strike ):
  - Foot and ankle
  - Knee
  - Hip
  - Pelvis and lumbar spine
- The impact force travels upwards through this chain



# Ground Reaction Forces (GRF)

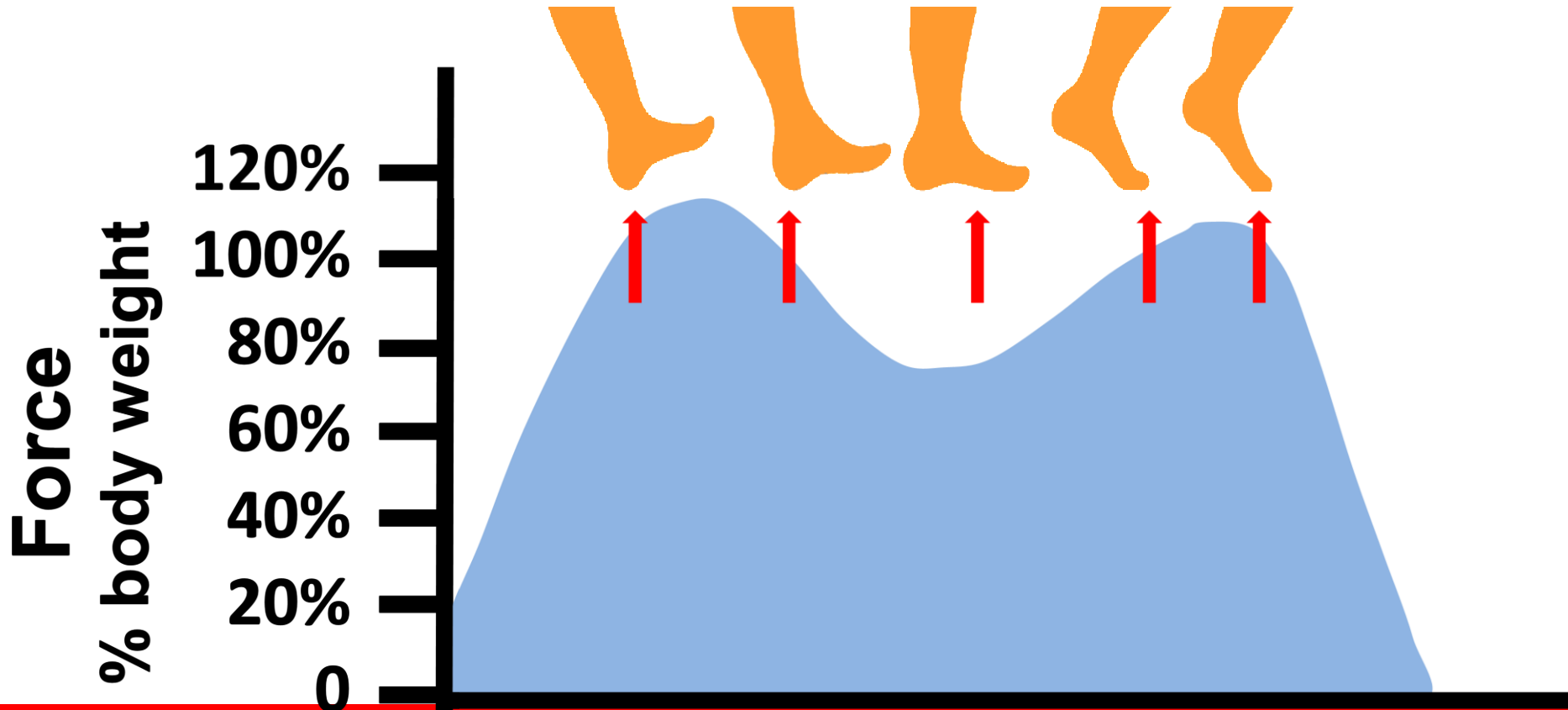
- GRF is the force exerted by the ground on a body in contact with it.
  - Based on Newton's Third Law of Motion
- Two types of GRF
  - Vertical
  - Horizontal



# Ground Reaction Forces (GRF)

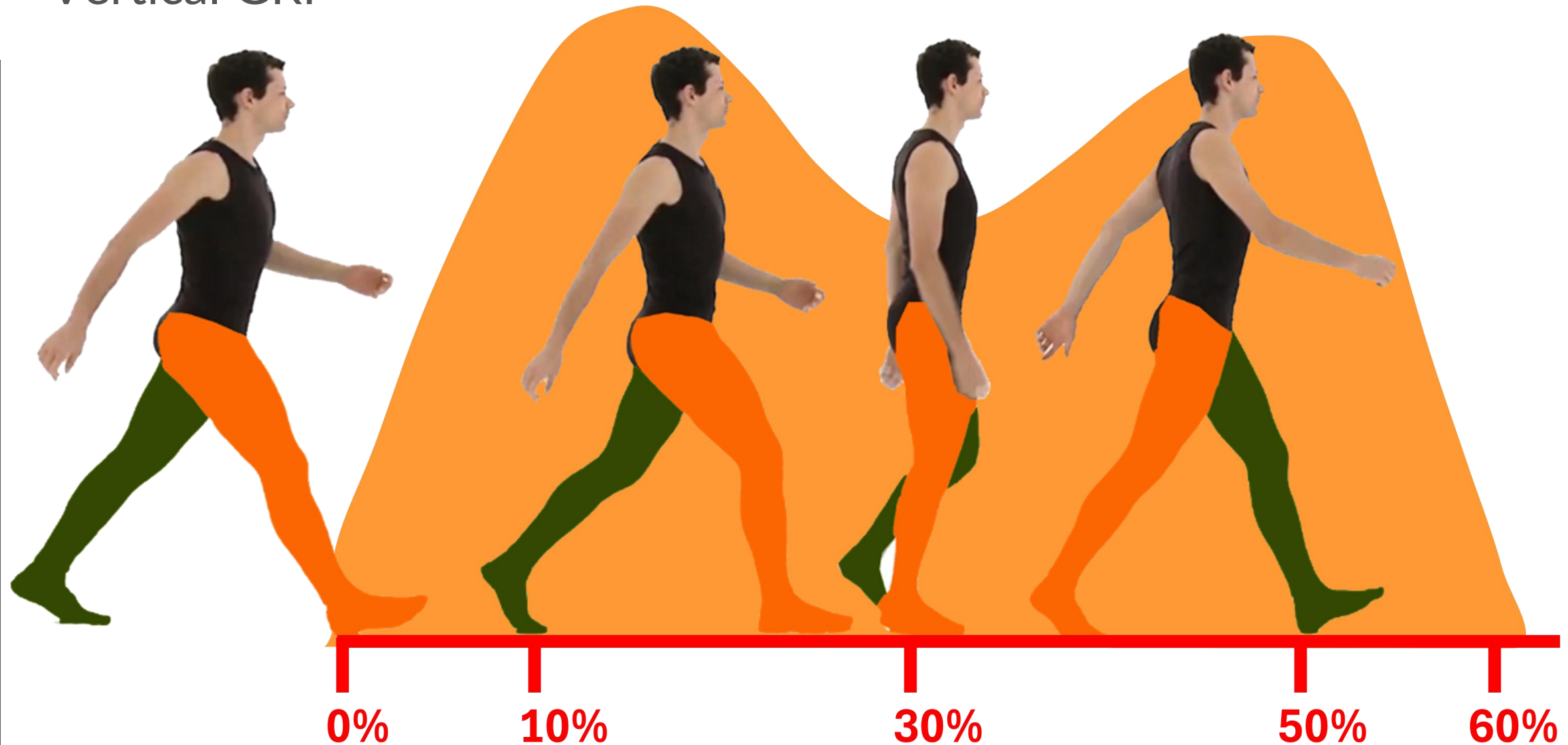
## ■ Vertical GRF (vGRF)

- How the body supports and transfers weight during stance.
- Shock absorption
- Propulsive loading



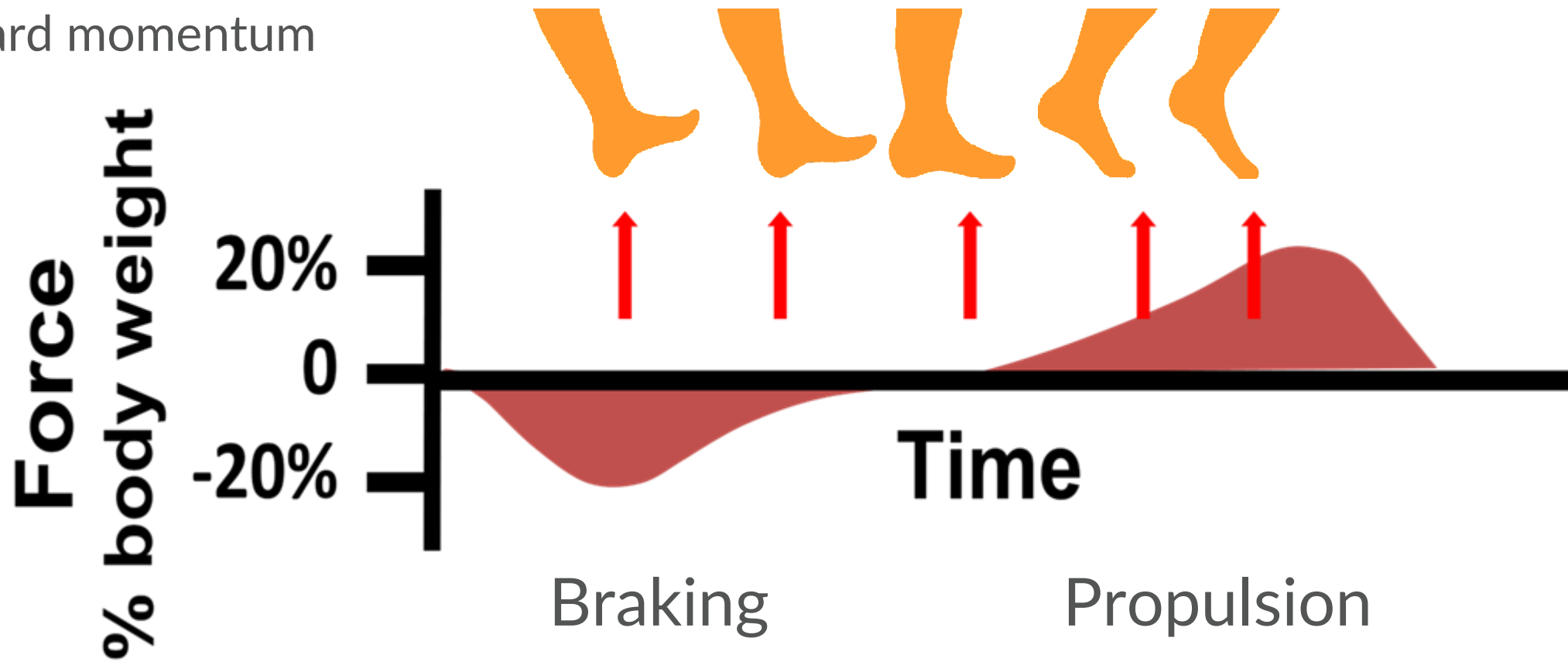
# Ground Reaction Forces (GRF)

- Vertical GRF



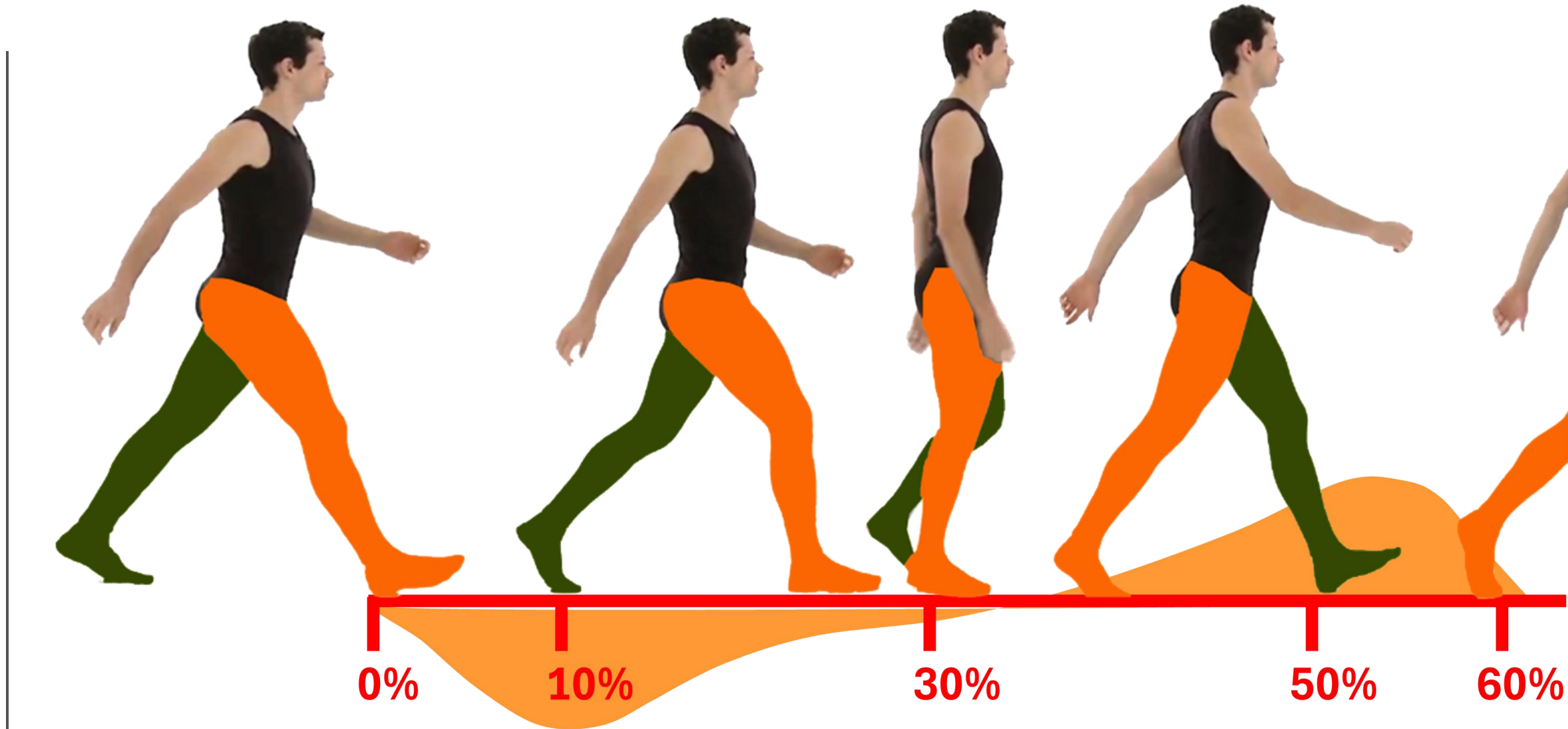
# Ground Reaction Forces (GRF)

- Horizontal GRF
  - Braking
  - Propulsion
  - Forward momentum

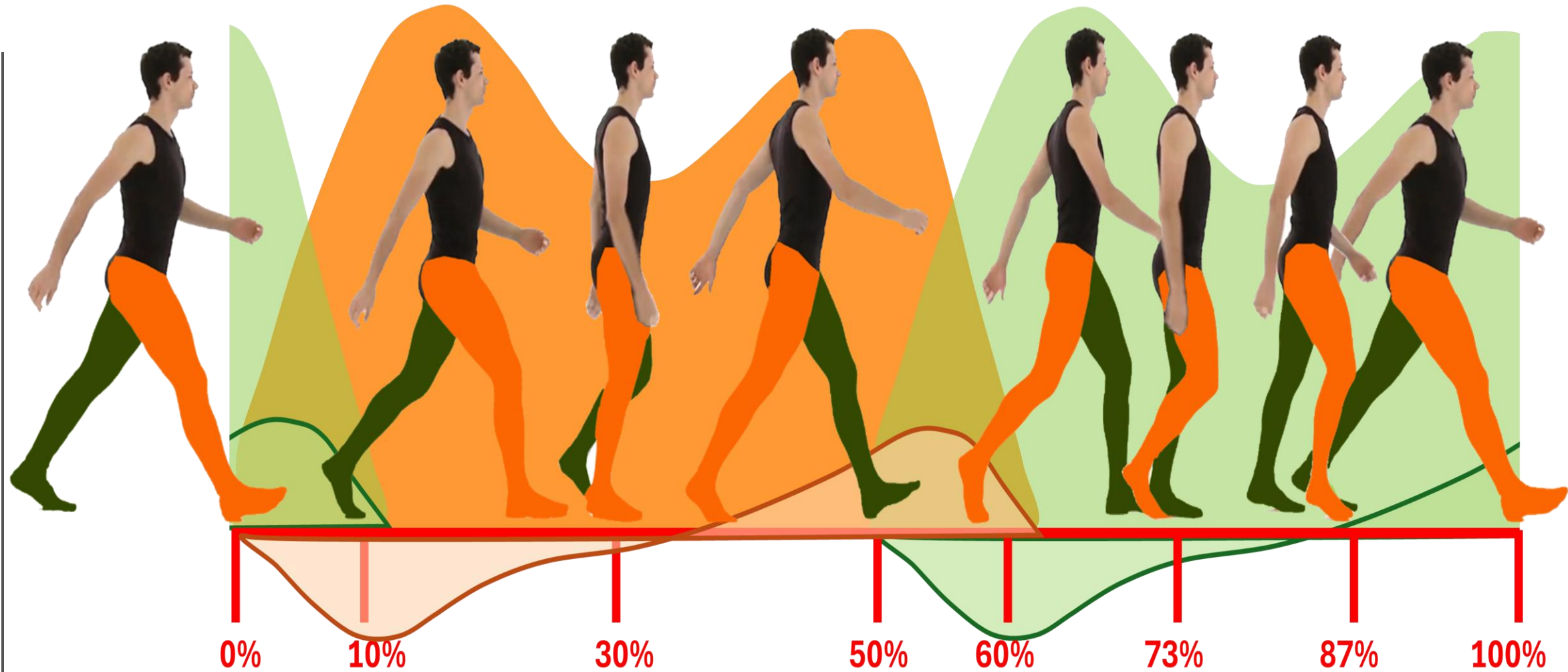


# Ground Reaction Forces (GRF)

- Horizontal GRF



# Ground Reaction Forces (GRF)



# Center of Pressure (CoP)

- CoP = point of application of GRF under the foot
- Represents how load moves during stance
- Changes continuously throughout gait

## Diagnostic uses:

Postural stability and balance  
Subtle neurological or MSK deficits  
Asymmetric weight distribution  
Rehabilitation progress

# Center of Pressure (CoP)

- CoP = point of application of GRF under the foot
- Represents how load moves during stance
- Changes continuously throughout gait



0%

10%

30%

50%

60%

73%

87%

100%



# What Is a Limp?

- A limp occurs when a person alters stance time, force application, or limb motion on one side, resulting in:
  - Unequal GRFs
  - Abnormal CoP progression
  - Disrupted gait cycle symmetry
- A limp is not just a gait abnormality — it is a load-redistribution strategy that systematically alters both GRF magnitude and CoP trajectory, often protecting one limb at the expense of the other.

# Limping and GRF

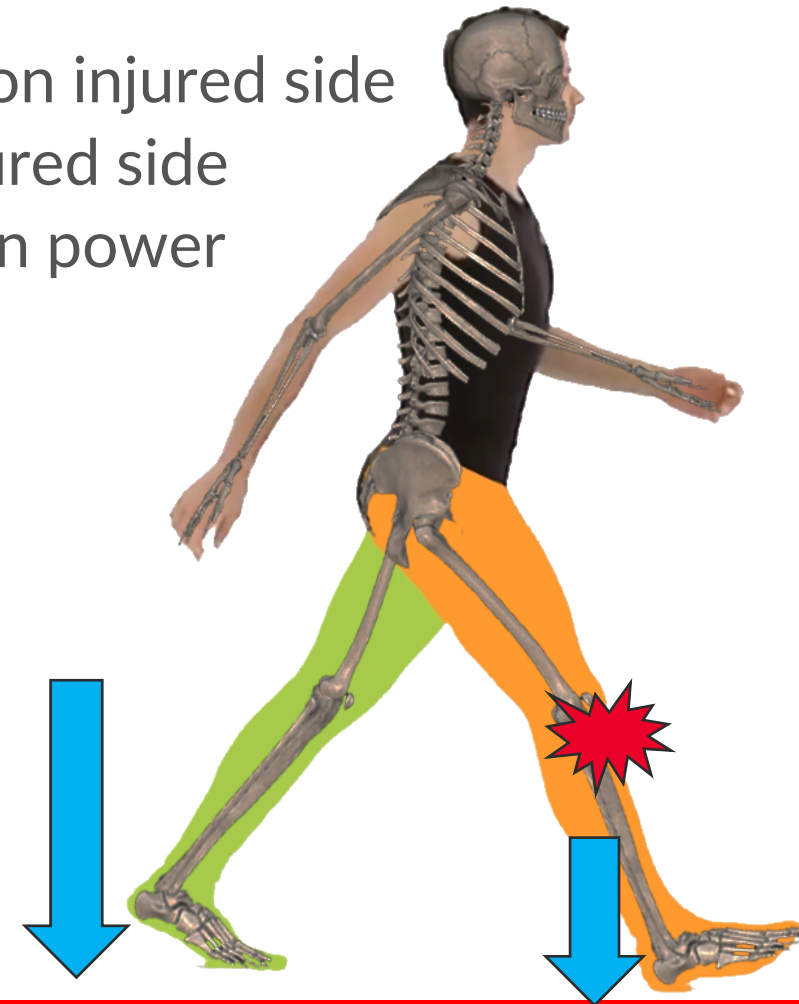
- Reduced loading on the affected limb
  - Lower peak vertical GRF on the painful or injured side
  - Shorter stance time → reduced impulse
  - Minimize joint compression and pain
- Increased loading on the unaffected limb
  - Higher peak GRF on the contralateral limb
  - Longer stance time
  - Increased loading rates



**Clinical implication:**  
Higher risk of secondary injuries on the "good" side.

# Limping and GRF

- Altered braking and propulsion forces
  - Reduced anterior–posterior GRF during push-off on injured side
  - Compensatory greater propulsive forces on uninjured side
  - Often associated with reduced ankle plantarflexion power



# Limping and CoP

- Shortened CoP path on the affected limb
  - Reduced heel-to-toe progression
  - Early toe-off → truncated anterior CoP excursion
- CoP shifts toward the unaffected limb
  - During double support, CoP moves rapidly toward the healthy side
  - Reflects offloading of the injured limb

# Abnormalities - Genu Varus (Bow-Legged)

Normal Alignment

Genu Varus (Bow-Legged)



Parameter	Affected Limb	Unaffected Limb
Vertical GRF (vGRF)	Medial loading ↑, first peak normal	Slight compensation possible
Loading rate	Slightly ↑ medial	Normal
AP GRF	Normal	Normal
Stance time	Normal	Normal
CoP path length	Medial shift	Minimal
CoP anterior progression	Normal	Normal
ML CoP shift	Medial bias	Slight compensatory shift
Spinal effect	Lumbar side-bend away from varus limb; subtle pelvic tilt	Minimal spinal compensation

# Abnormalities - Genu Valgus (Knock-Kneed)

Normal Alignment

Genu Valgus (Knock-Kneed)



Parameter	Affected Limb	Unaffected Limb
Vertical GRF (vGRF)	Slightly ↓ first peak due to lateral foot loading	Slight compensation; may carry slightly more medial load
Loading rate	↓ Medial loading slightly	Normal
AP GRF	Slightly ↓ propulsion efficiency	Slight ↑ propulsion
Stance time	Normal or slightly prolonged	Normal
CoP path length	Slight lateral shift	Minimal change
CoP anterior progression	Slightly ↓	Normal
ML CoP shift	Lateral shift over foot	Minimal
Spinal effect	Mild lateral trunk lean opposite side to maintain balance; pelvic rotation may increase	Minimal spinal compensation

# Abnormalities - External Rotation (Out-Toeing)

Normal Alignment

External Rotation



Parameter	Affected Limb	Unaffected Limb
Vertical GRF (vGRF)	Slight ↓ due to early heel-off	Slight ↑
Loading rate	Slightly ↓	Slightly ↑
AP GRF	↓ Propulsion	↑ Propulsion
Stance time	Slightly shortened	Slightly prolonged
CoP path length	Lateral deviation	Normal
CoP anterior progression	Slightly reduced	Normal
ML CoP shift	Lateral	Slight medial adjustment
Spinal effect	Increased pelvic rotation, lumbar counter-rotation to maintain gait	Minimal

# Internal Rotation (In-Toeing)

Normal Alignment

Internal Rotation



Parameter	Affected Limb	Unaffected Limb
Vertical GRF (vGRF)	Slight ↓ due to inefficient push-off	Slight ↑ to compensate
Loading rate	Slightly ↓	Slightly ↑
AP GRF	↓ Forward propulsion	↑ Forward propulsion
Stance time	Slightly shortened	Slightly prolonged
CoP path length	Medial deviation at forefoot	Minimal
CoP anterior progression	Reduced	Increased
ML CoP shift	Medial	Slight lateral shift
Spinal effect	Increased pelvic rotation, mild lumbar rotation toward rotated limb	Slight lumbar counter-rotation to maintain forward progression

# Pelvic Tilt (Leg Length Discrepancy)

Normal Alignment

Pelvic Tilt/LLD



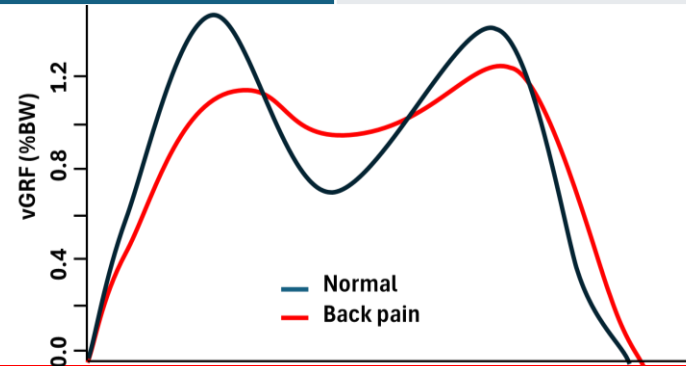
Parameter	Affected Limb (Shorter)	Unaffected Limb (Longer)
Vertical GRF (vGRF)	↓ First peak (weight acceptance), ↓ second peak (push-off)	↑ Both peaks (takes more weight)
Loading rate	↓	↑
AP GRF (propulsion)	↓	↑
Stance time	Shortened	Prolonged
CoP path length	Shortened	Lengthened
CoP anterior progression	Reduced	Increased
ML CoP shift	Minimal or slight toward shorter limb	Compensatory lateral shift for balance
Spinal effect	Trunk leans toward shorter limb → lumbar lateral flexion; pelvis elevated on longer side	Increased lumbar rotation to support longer stance and propulsion

# Low Back Pain (Mechanical)

Normal Alignment



Parameter	Affected Limb (more painful side)	Unaffected Limb
Vertical GRF (vGRF)	↓ Both peaks	↑ Both peaks
Loading rate	↓	↑
AP GRF	↓ Propulsion	↑ Propulsion
Stance time	Shortened	Prolonged
CoP path length	Shortened	Lengthened
CoP anterior progression	Reduced	Increased
ML CoP shift	Slight shift away from painful side	Increased lateral stabilization
Spinal effect	Stiffened, lateral trunk lean away from pain	Compensatory rotation or side-bend to maintain balance



# Stroke (Hemiplegic Gait)

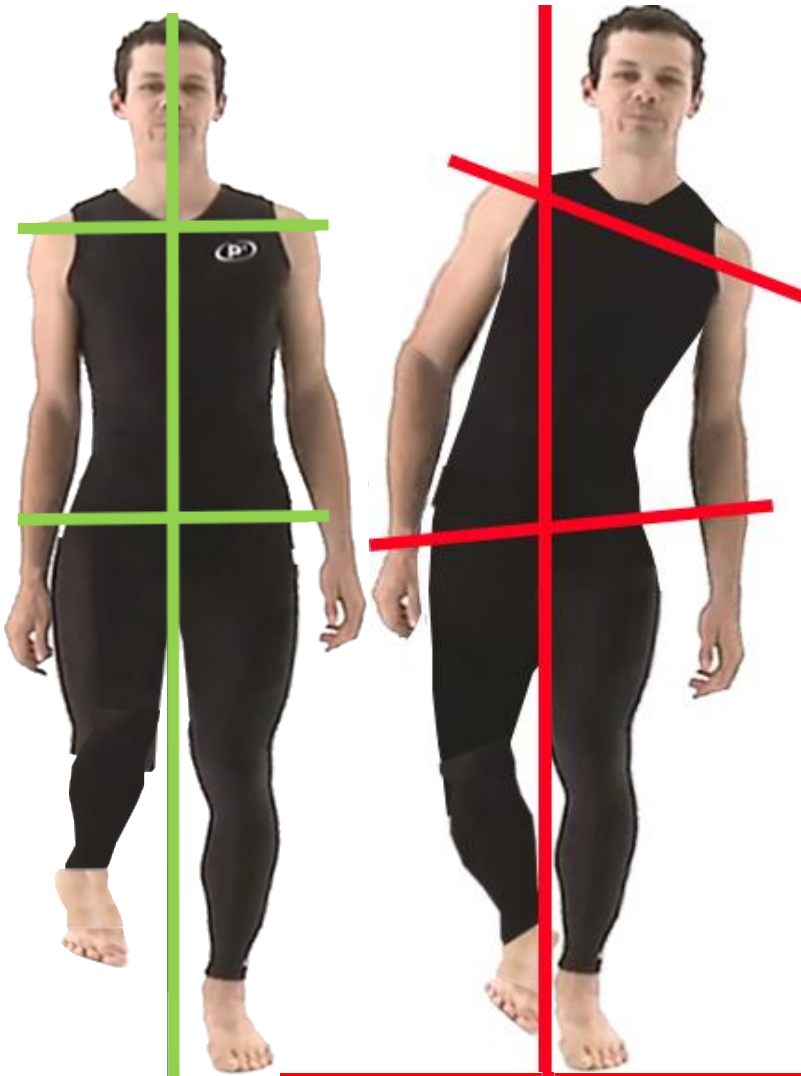
Normal  
Alignment

Hemiplegic



Parameter	Affected (Hemiplegic) Limb	Unaffected Limb
Vertical GRF (vGRF)	↓ Both peaks, often irregular	↑ Both peaks
Loading rate	↓	↑
AP GRF	↓ Propulsion, impaired braking	↑ Propulsion
Stance time	Shortened	Prolonged
CoP path length	Irregular, possible foot drag	Lengthened, stable
CoP anterior progression	Reduced	Increased
ML CoP shift	Lateral deviation, unstable	Increased M-L stabilization
Spinal effect	Lateral trunk lean toward affected limb, pelvic hiking, exaggerated rotation	Lumbar rotation to support contralateral limb

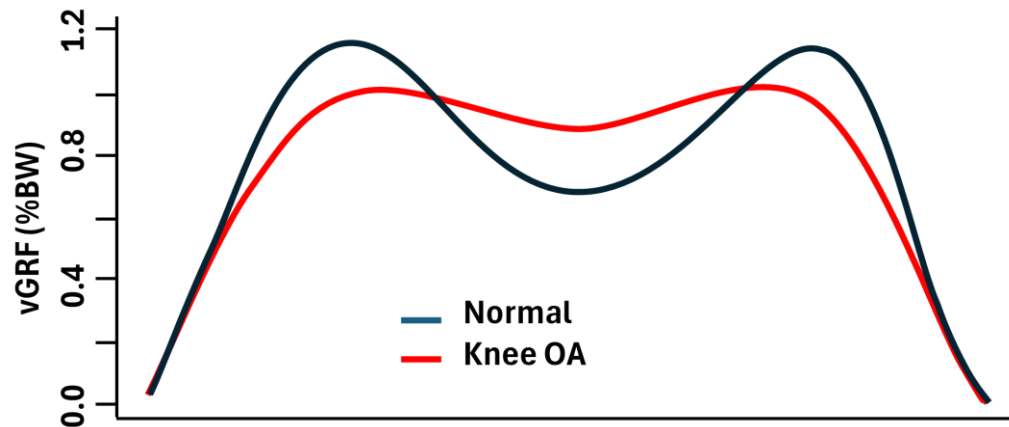
# Gluteus Medius Weakness (Trendelenburg)



Parameter	Weak Side	Strong Side
Vertical GRF (vGRF)	Slight ↓ due to instability, shortened stance	Slight ↑ to compensate
Loading rate	↓	↑
AP GRF	Slightly ↓ propulsion	↑ Propulsion
Stance time	Shortened	Prolonged
CoP path length	Shortened	Lengthened
CoP anterior progression	Reduced	Increased
ML CoP shift	Lateral shift toward weak side	Increased stabilization
Spinal effect	Trunk leans over weak side, pelvis drops contralateral side	Lumbar rotation/side-bend for stabilization of contralateral limb

# Antalgic Limp

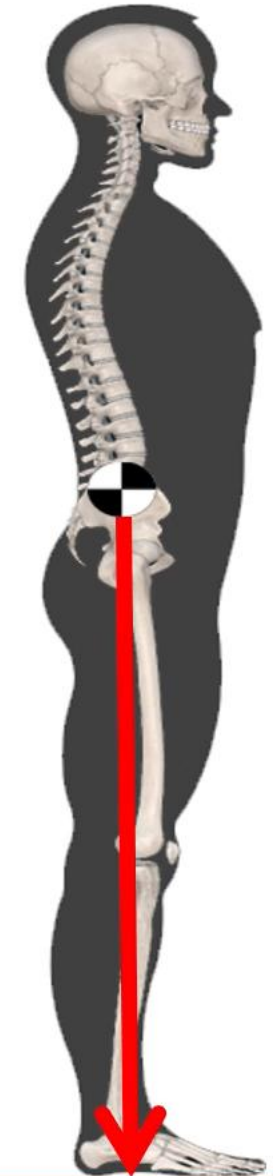
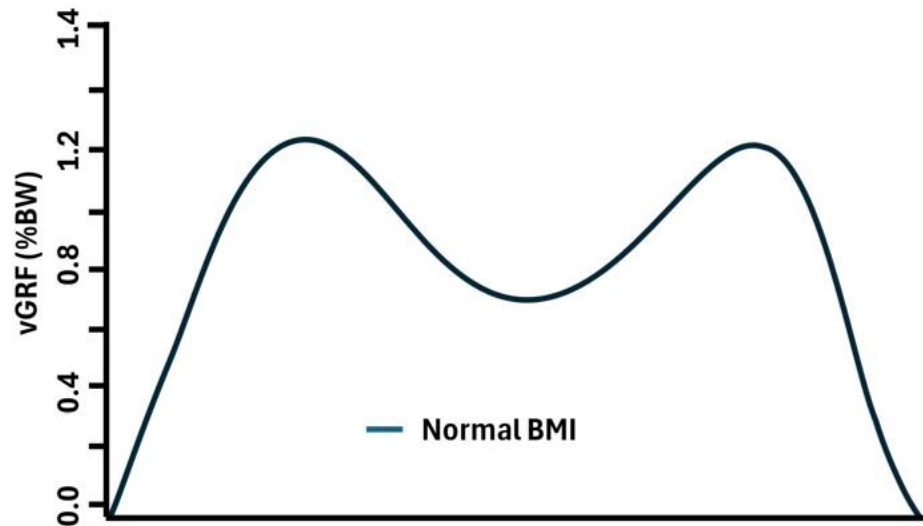
Parameter	Affected (Painful) Limb	Unaffected Limb
Vertical GRF (vGRF)	↓ Both peaks	↑ Both peaks
Loading rate	↓	↑
AP GRF	↓ Propulsion	↑ Propulsion
Stance time	Shortened	Prolonged
CoP path length	Shortened	Lengthened
CoP anterior progression	Reduced	Increased
ML CoP shift	Lateral trunk lean toward painful side	Increased lateral stability demand
Spinal effect	Trunk leans toward painful side, contralateral pelvic drop	Lumbar rotation/side-bend to support longer stance



# Additional Causes

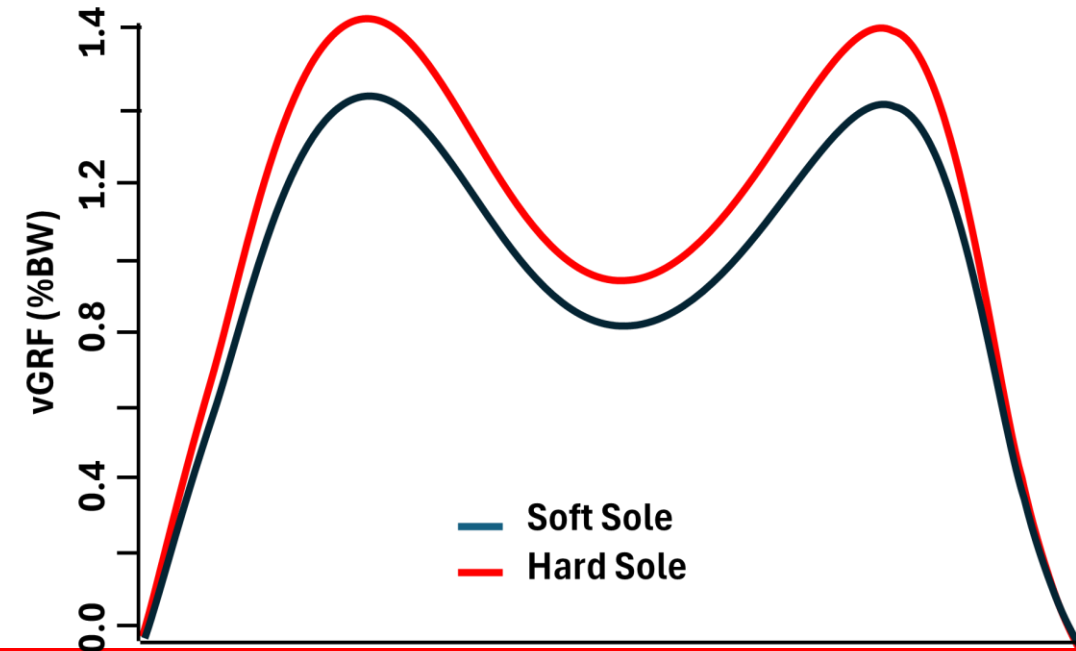
## ■ Increased Body Weight

- Alters a person's centre of gravity for which the body must adapt to this change.
- Increases the amount of ground reaction force due to the weight gain.
- Increased impact force



# Additional Causes - Footwear

- Hard sole
  - Have poor heel and arch support
  - Reduced shock absorption
  - Minimizes proper toe off
- Steel Toed Boots weigh more than composite
  - Increased impact



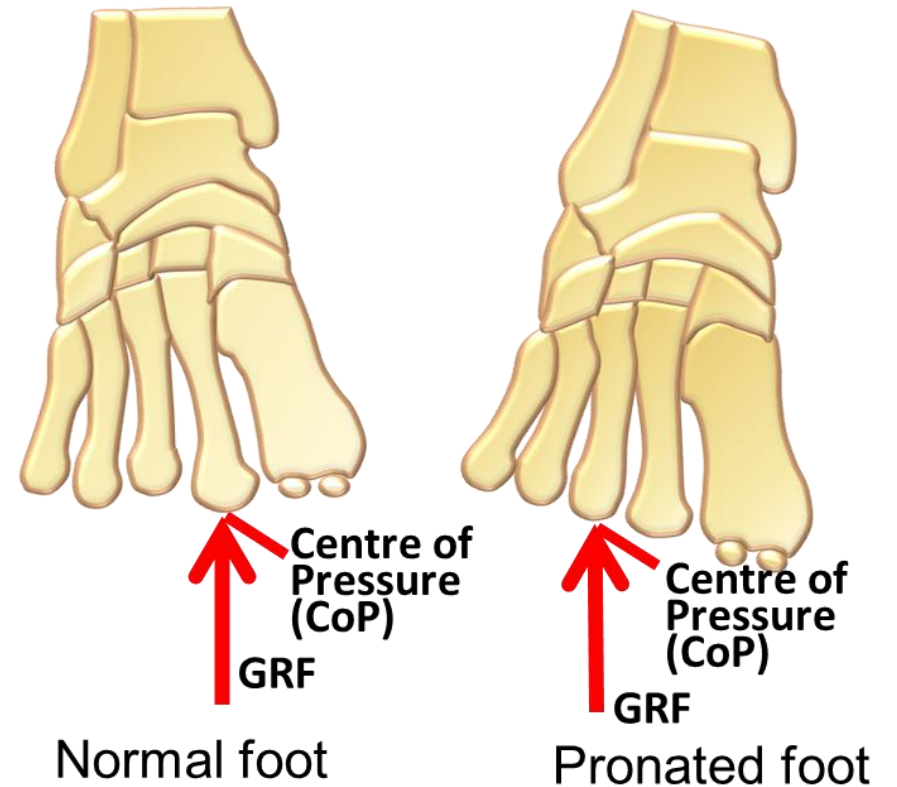
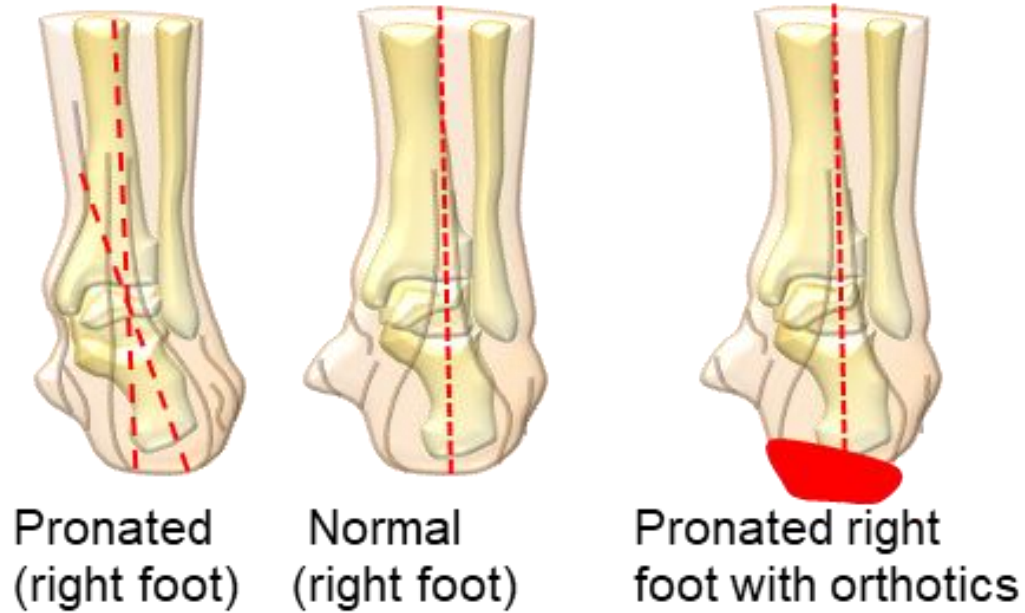
# Prevention and Risk Reduction

- If possible, correct the underlying cause of pain in the affected leg
- Exercise therapy
- Weight management
- Seek medical assistance early



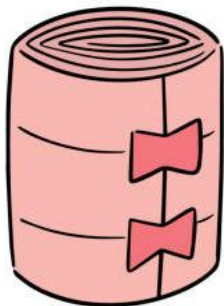
# Prevention and Risk Reduction

- Early identification of gait changes
  - Appropriate footwear and surfaces
  - Strengthening and rehabilitation



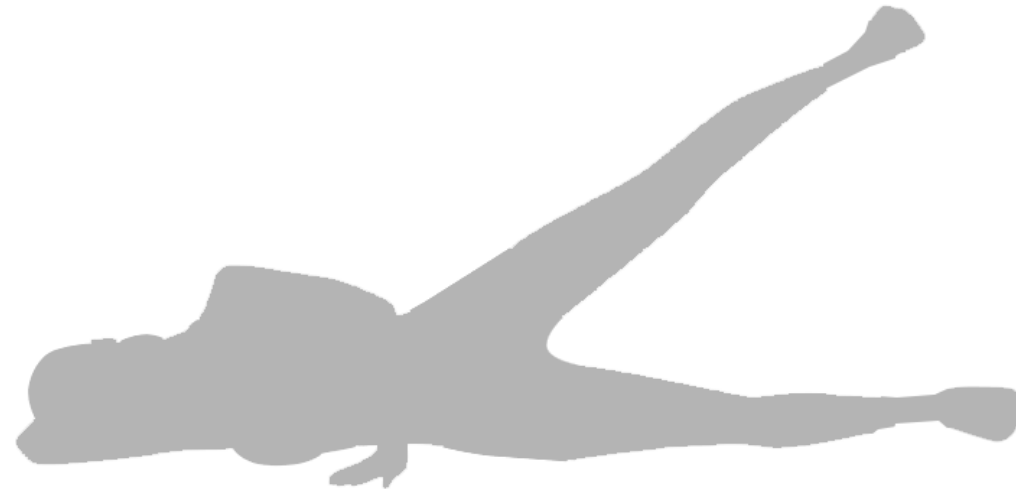
# Prevention and Risk Reduction

- Limp due to pain (ankle, knee, hip) - early pain management to minimize the risk of overload pathology in the opposite limb
  - Seek medical care for early diagnosis
  - Load modification
  - Anti-inflammatory strategies
  - Taping/bracing
  - Temporary assistive device (e.g. cane)
  - Handrail use or ramp over stairs to reduce contralateral overload



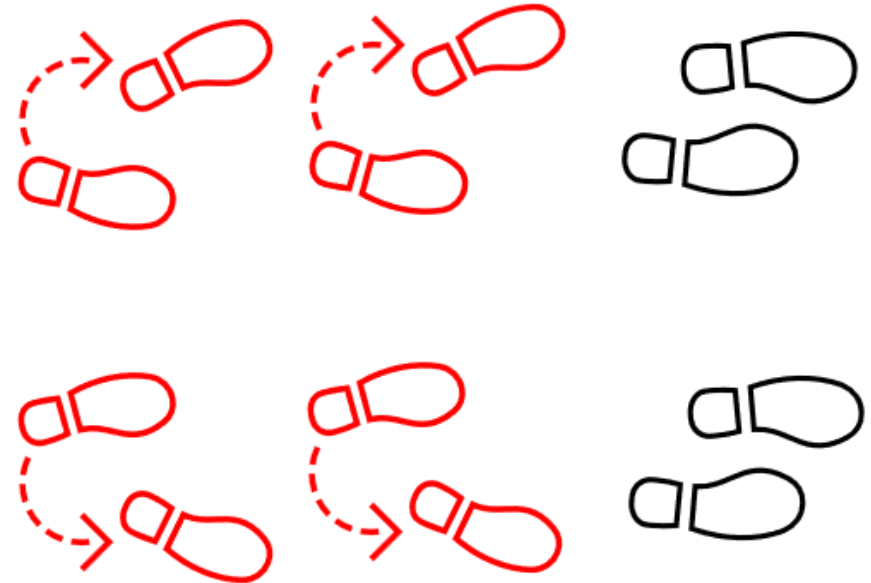
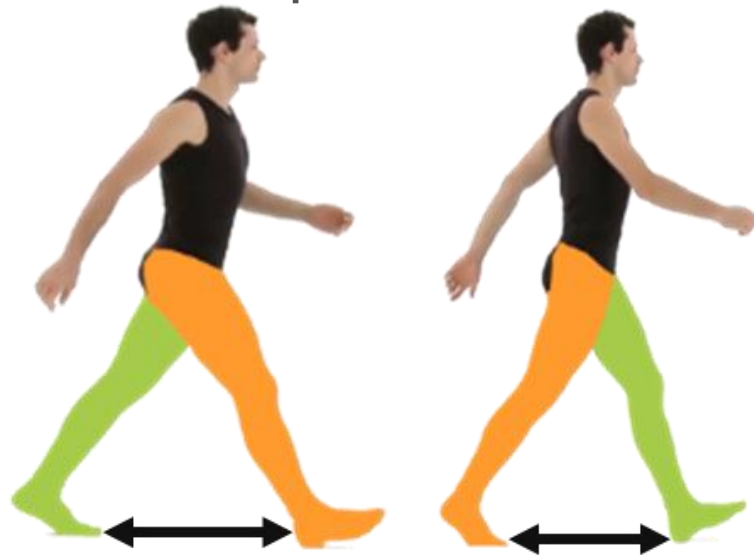
# Prevention and Risk Reduction

- Leg length discrepancy:
  - Heel lift/shoe modification (gradual correction)
  - Gluteus medius strengthening:
    - Side-lying leg lifts, clamshells, lateral banded walks
  - Lateral stability drills:
    - Lateral lunges, banded side-steps, lateral step-ups, hip hikes
  - Step-down control exercise – trains balance, knee, and hip stability when lowering one leg slowly



# Prevention and Risk Reduction

- Normalize gait mechanics - seek professional care and guidance for gait retraining
  - Step length symmetry
  - Stance time symmetry
  - Heel-to-toe transition smoothness
  - Controlled push-off



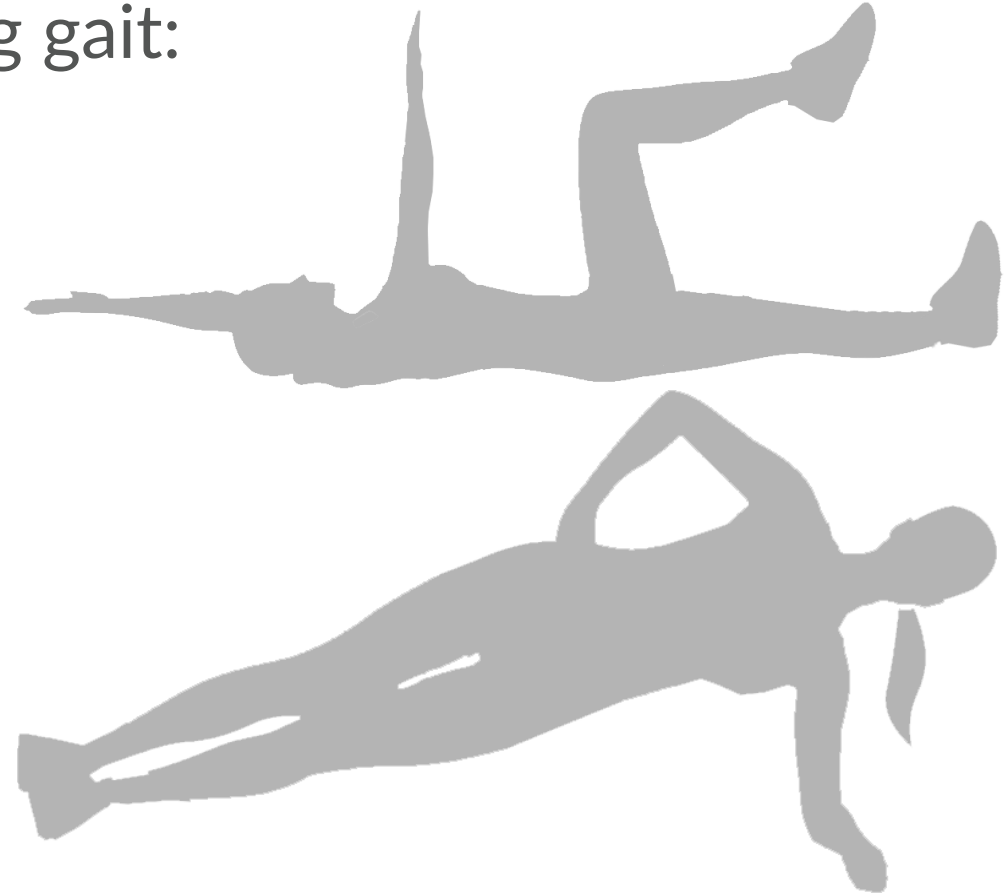
# Prevention and Risk Reduction

- Bilateral strength program to reduce compensatory overload – create a "buffer zone"
  - Hip abductors:
    - Side-lying leg lifts, clamshells, lateral banded walks
  - Hip extensors:
    - Glute bridges, single-leg glute bridges
  - Knee extensors:
    - Squats, lunges, wall-sits, step-ups
  - Plantarflexors:
    - Calf raises, resistance band plantar flexion



# Prevention and Risk Reduction

- Trunk exercises to minimize effects of asymmetric loading and increased lateral flexion/rotation during gait:
  - Bird-dog progression
  - Plank and side plank variations
  - Dead-bugs
  - Pallof press (anti-rotation exercise)



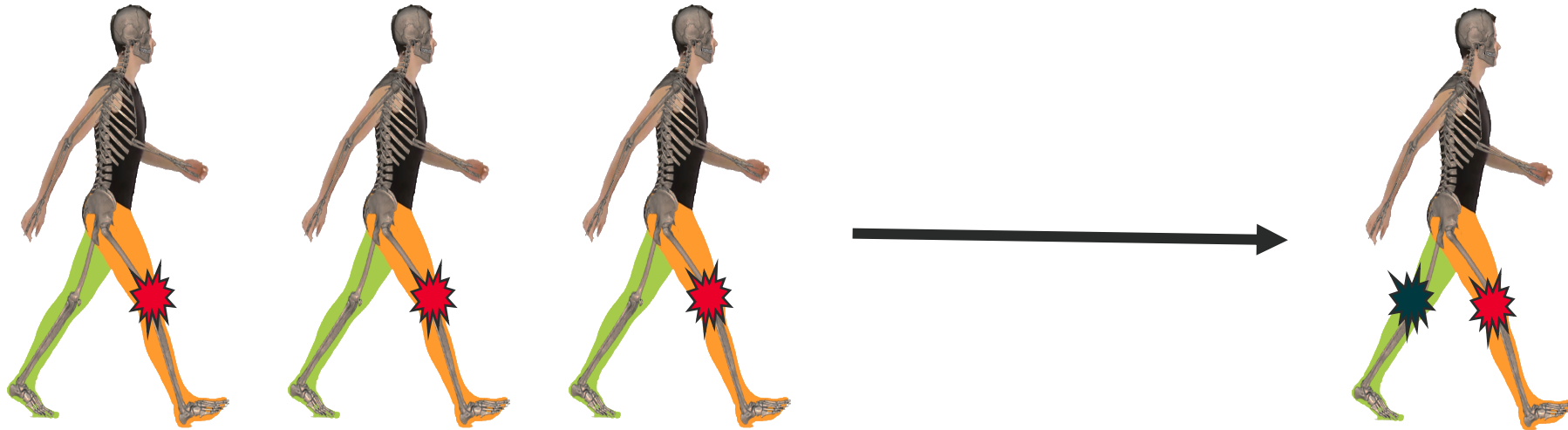
# Prevention and Risk Reduction

- If asymmetry cannot be eliminated:
  - Reduce magnitude (shock attenuation)
  - Reduce duration (postural variation)
  - Reduce repetition (workflow design)
  - Improve capacity (strength and recovery)



# Prevention and Risk Reduction

The unaffected limb becomes symptomatic when:  
 $\text{Load Magnitude} \times \text{Repetition} \times \text{Time} > \text{Tissue Capacity}$



# Prevention and Risk Reduction

## ■ Work Surfaces

- Walking on hard surfaces increase the ground reaction force
- Use anti-fatigue mats if you stand for prolonged periods of time
- Some work boots have anti-fatigue insoles to reduce impact
- Anti-fatigue over-shoes to reduce impact



# Prevention and Risk Reduction

- Composite Vs. Steel Toe



# Contact us:



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