Biomechanical Principles in Sprint Running

Basic Concepts

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Content

- Stride Length
- Stride Frequency
- Newton's Laws
- Running Mechanics
- How to Run Faster!!

Asafa Powell 9.77s

Running Speed

- Stride length x stride frequency
- At faster running speeds (above $7m \cdot s^{-1}$) stride frequency increases more then stride length
  - Up to 2.6m stride length & 5Hz frequency
- Force production increased with running speed
  - Up to 4.6 x body weight
  - NB 5.5 x body weight for a heel striker at $9.5m \cdot s^{-1}$
- Max speed ground contact 0.08- 0.1sec

Mero *et al.* (1992)

- increase in stride length, stride frequency, force production or decrease in ground contact will increase speed
- What is your training designed to change?

Newton's 2^{nd} Law of Motion

- Momentum
- Law of acceleration
- Rate of change of momentum of an object (acceleration) is proportional to the force causing it & takes place in the direction in which the force acts
- = mass x velocity (mv)
- Remember F =ma
  - So acceleration can be worked out from a known force quite easily (a=F/m)

Impulse

- Linked to Newton's 2nd Law
- Force x time applied = impulse to an object
- r= 0.74 between propulsive force & running velocity in 1st contact after the blocks (Mero *et al.*, 1992)

Impulse- Momentum Relationship

- Need to exert a force to cause a change in velocity
- Direction of force causes direction of acceleration
- Increase force increases momentum
- Or more precise increase impulse increases momentum

Newton's 3rd Law of Motion

- For every action (force) exerted by 1 object on a 2^{nd}, there is an equal & opposite reaction (force) exerted by the 2^{nd} object on the 1^{st}
  - e.g. ground reaction force

Sprint Components

- Speed = stride length x stride frequency
  - 2m/stride x 4 strides/s = $8 m \cdot s^{-1}$
- Increase in either component should not negatively effect the other

Stride Length

- Sum of
- Takeoff distance
  - Horizontal distance that C of G is forward of the take off foot at the instant the latter leaves the ground
- Flight distance
  - Horizontal distance that the C of G travels while the runner is in the air
- Landing distance
  - Horizontal distance that the toe of the lead foot is forward of the C of G at the instant sprinter lands

Stride Length

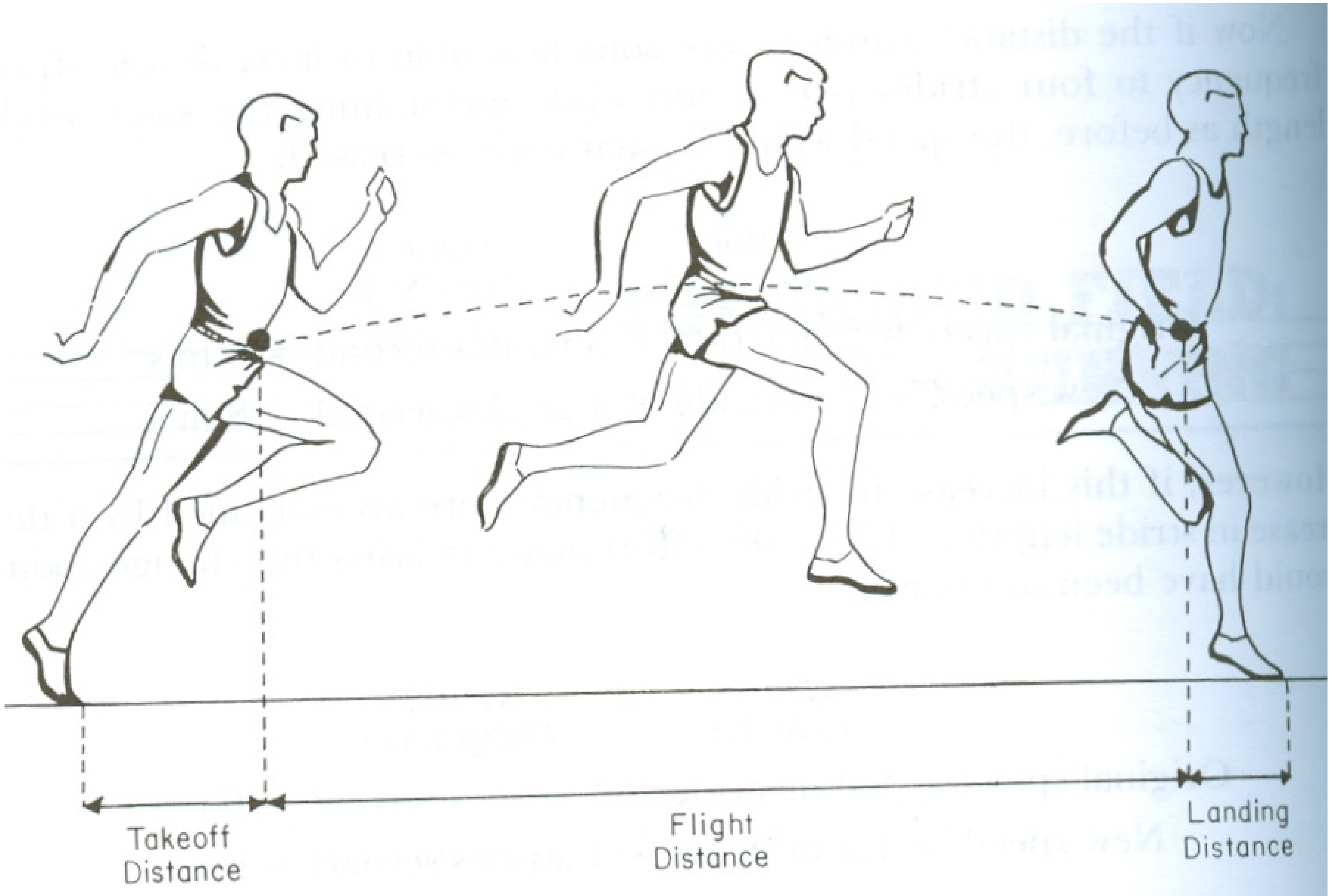


Figure 15-1. Contributions to the total length of a runner's stride.

Landing Distance (Support Phase)

- Smallest of 3 contributions to total stride length
- Arrests athletes downward motion (acceleration due to gravity plus active descent leg)
  - Triple flexion to absorb force
  - Prepare for driving phase

- Need as favourable ground reaction forces as possible
  - Increasing landing distance can increase breaking force so decrease running speed as stride frequency decreases
  - Foot position under the C of G travelling backwards
  - Breaking phase less in faster sprinters (Mero *et al.*, 1992)

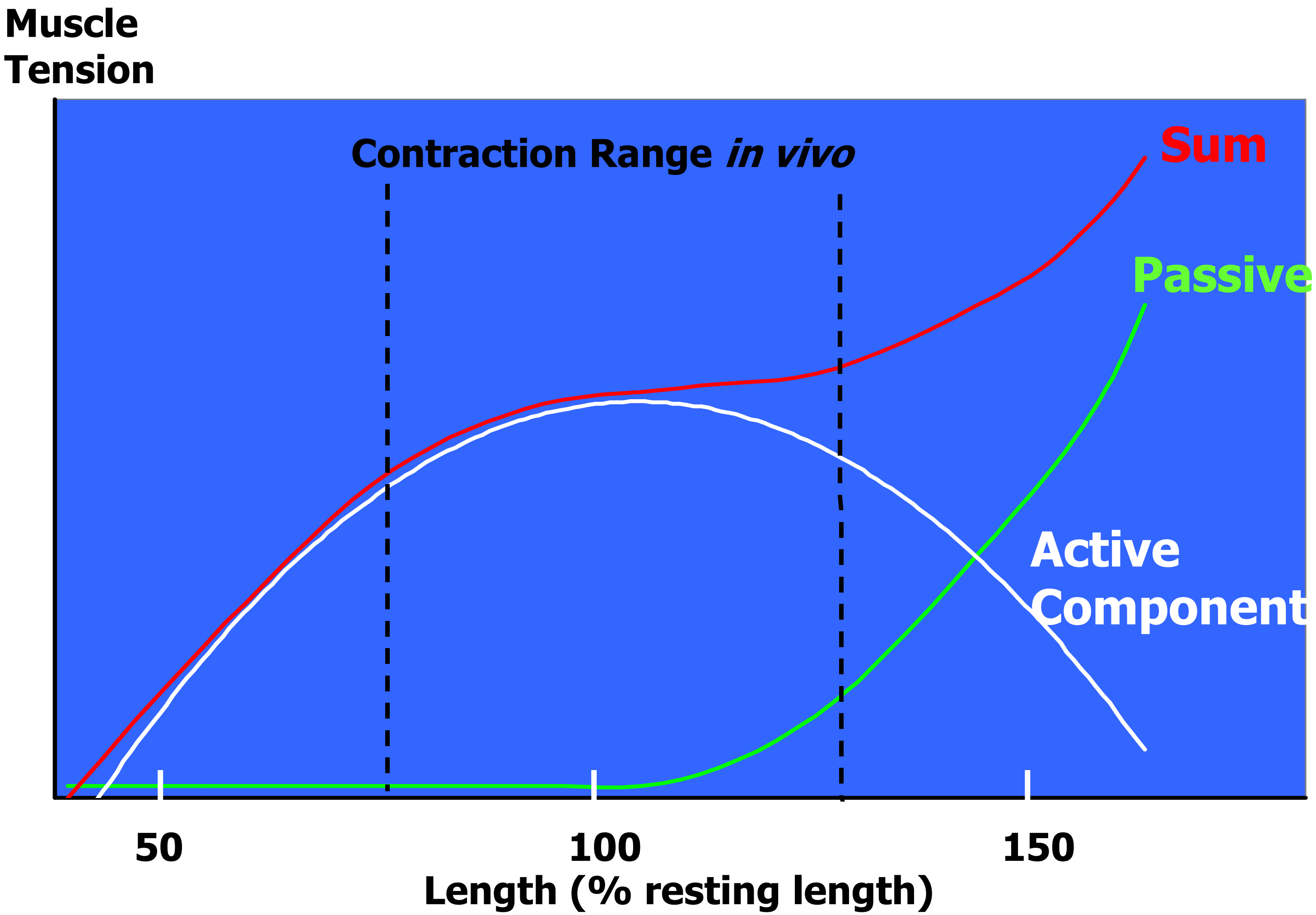
How to Limit Breaking Force?

- Athlete in flight phase
- C of G moving forward with a horizontal velocity determined the moment the athlete left the ground
  - C of G moving at 10 $m \cdot s^{-1}$
  - lead legs foot moving forward at 2 $m \cdot s^{-1}$
  - Landing foot velocity = 12 $m \cdot s^{-1}$
  - Direction foot travelling will alter or maintain athletes motion
  - pawing action on ground contact, but problems with hamstring stress

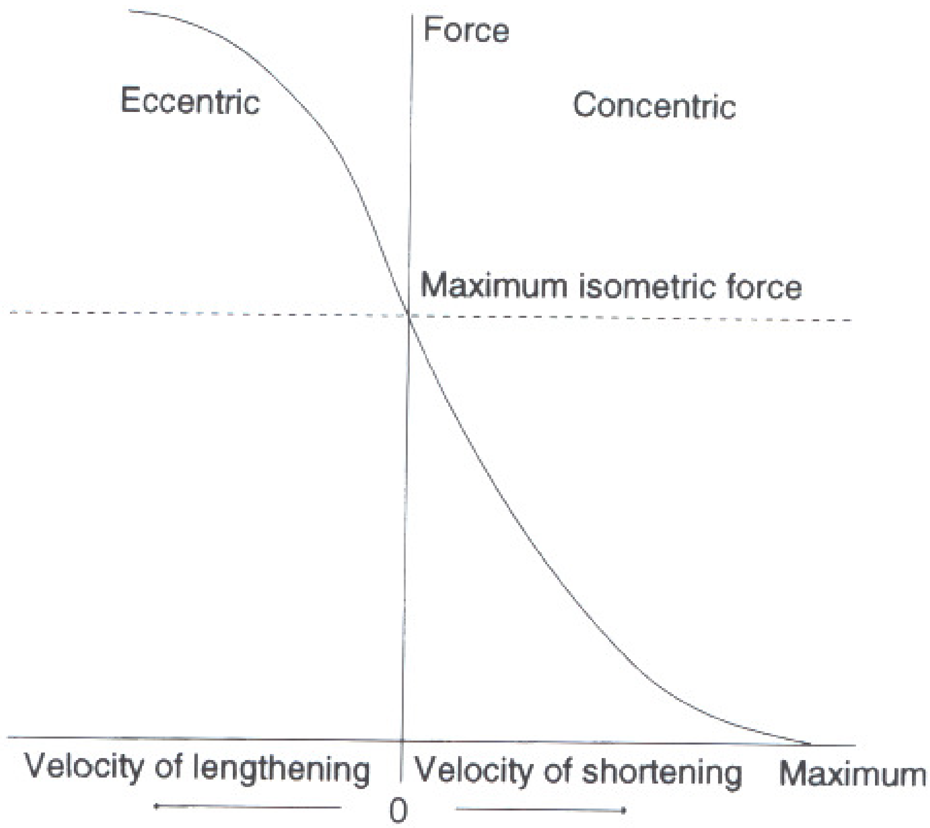
Foot Position

- Importance of dorsi flexed ankle
  - Store strain energy from stretch and recoil of calf complex (achilles tendon)
  - Pre stretch of calf complex helps promote Stretch Shortening Cycle
  - Decrease coupling time between eccentric and concentric contraction
  - Store mechanical work as elastic energy during eccentric phase (Biewener & Roberts, 2000)
  - Peak Achilles tendon force (12-13 x body wt.)

Tension-Length Relationship



Force-Velocity Relationship



- Muscles, tendons & ligaments behave like a spring
  - Higher stride frequencies associated with increased spring (MTU) stiffness (Farley & Gonzalez, 1996)
  - EMG in GA starts 100ms before ground contact helps increase MTU stiffness (Mero & Komi, 1987)

Takeoff Distance (Driving Phase)

- Drive down and backwards through forceful extension of the hip, knee and ankles kinetic chain
  - Projects body upwards & forwards
- Importance of full extension to provide greater impulse maximising forward momentum
- Peak power generated proximal to distal sequence

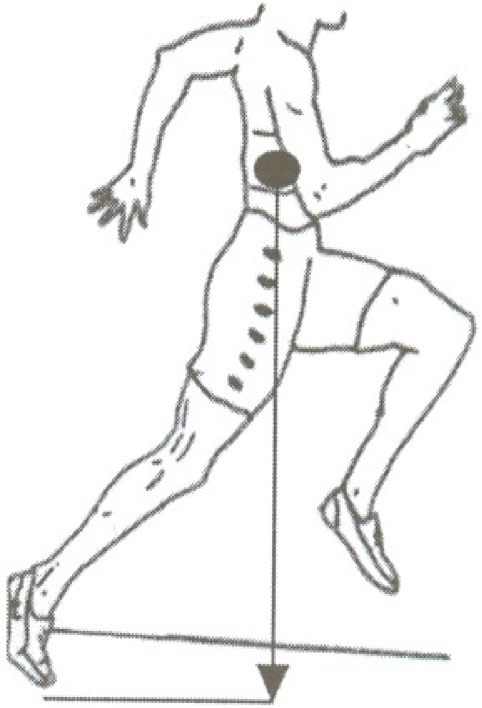
Stride Frequency

- Combination of ground contact time and flight phase time
- Ratio between the 2
  - 2:1 during the start
  - 1:1.3/ 1:1.5 at max speed (Housden, 1964)
  - Start 67% ground contact
  - Top speed 40-45% ground contact (Atwater, 1981)

- Time athlete in contact with ground governed primarily
  - Take off velocity from previous stride
  - By the speed of the foot of the support leg
  - Driving body forward and upward into next flight phase

- Faster sprinters extend hip further (Kunz & Kaufmann, 1981)
  - Increase time force applied
  - Increase impulse
- Short ground contacts in elite sprinting
  - Result of high forward speeds not the cause of them
  - So body travels past foot very quickly
  - v=d/t
  - Time = distance/velocity (t=d/v)

Hip Extension



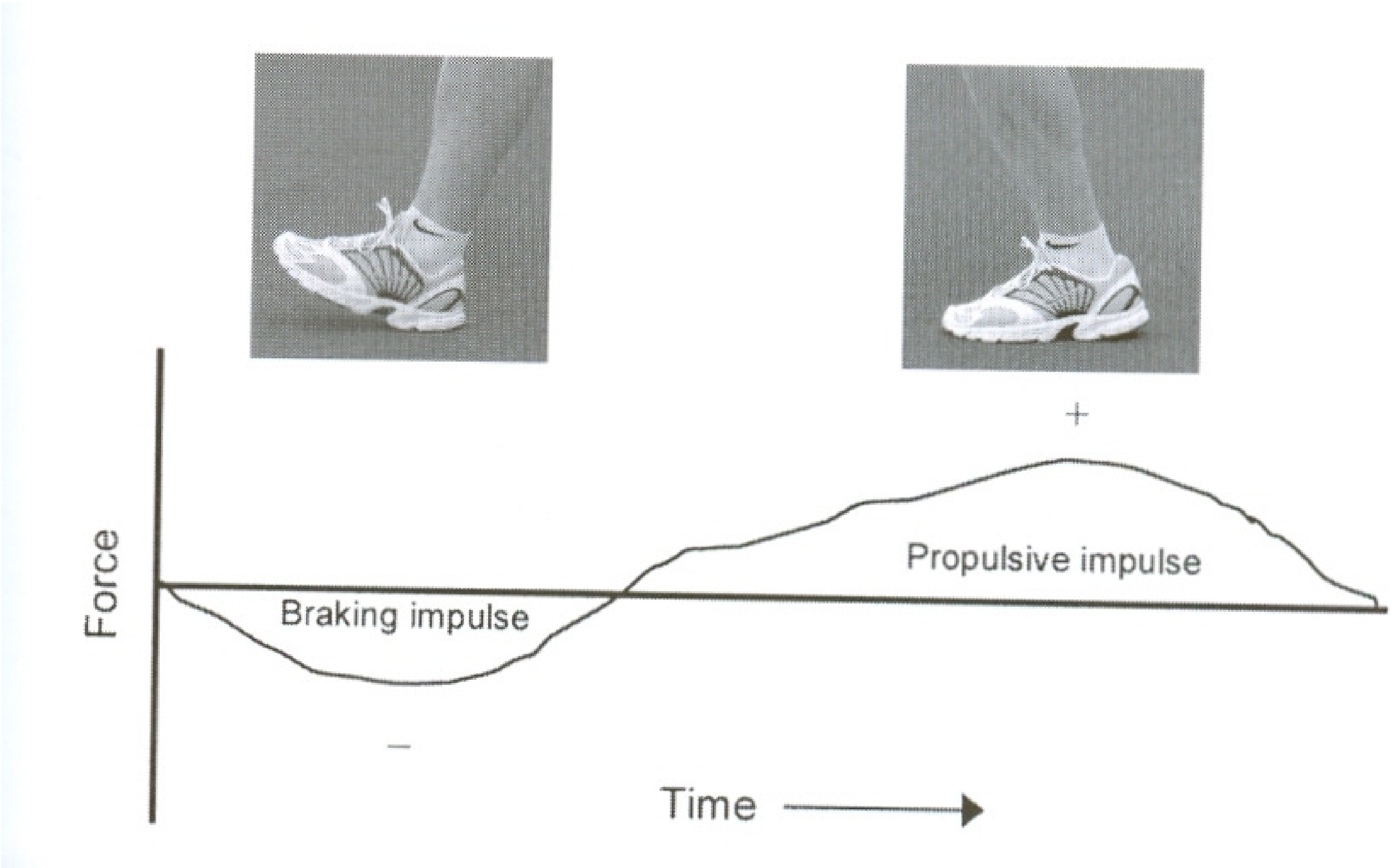
Large distance =
greater time to
produce propulsive
impulse

TABLE 15-3 Hip and Knee Extension Angles at Takeoff in Elite Sprinting

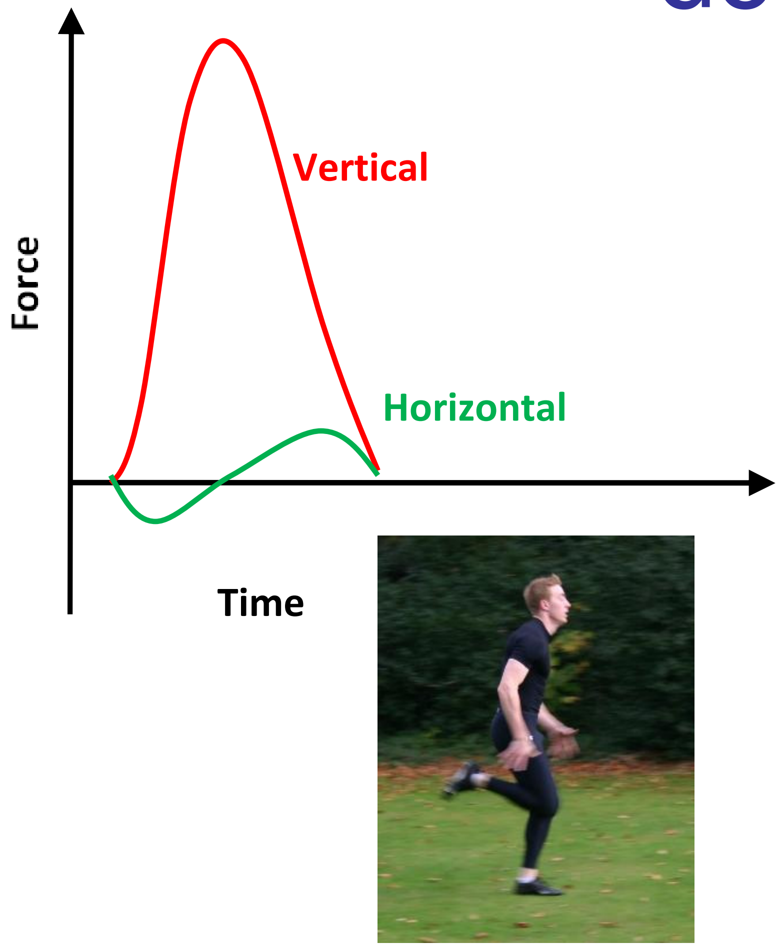
	Carl Lewis (U.S.A.)	*Kirk Baptiste (U.S.A.)*	*Thomas Jefferson (U.S.A.)*
Hip Extension	167	170	167
	167	164	160
Knee Extension	157	156	158
	157	156	156

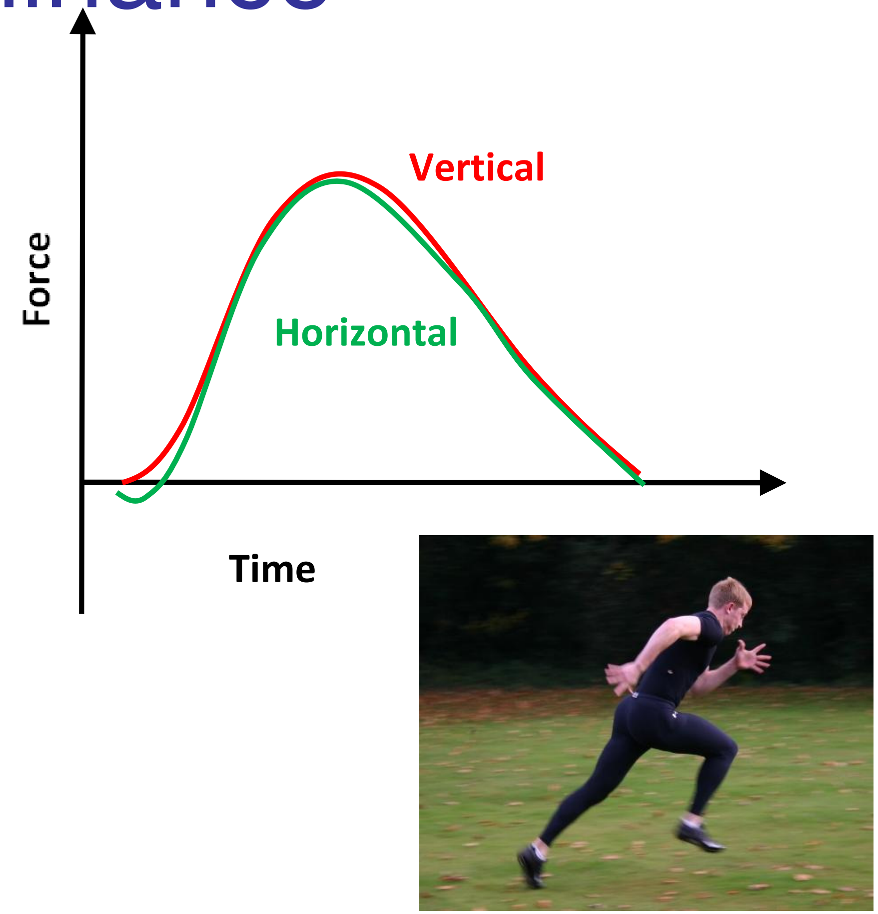
Adapted from Mann, R., and Herman, J. (1985). Kinematic analysis of Olympic sprint performance: Men's 200 meters. *International Journal of Sports Biomechanics, 1:159.*

Braking and Propulsive Impulse



Vertical vs Horizontal force dominance





Flight Phase (Recovery Phase)

- During flight phase body determined by projectile motion
  - Release velocity
  - Angle of take off
  - Height of release
  - Air resistance
- Most important velocity of release
  - Determined by the ground reaction force exerted on the athlete
  - Linked to force produced in triple extension of hip, knee and ankle

Moment of Inertia

- Inertia: body's tendency to resist acceleration
  - Mass increases, inertia increases
- In rotation distribution of mass vital
  - Closer mass to axis of rotation easier to move object
- $I=mk^2$ ($kg \cdot m^2$)
  - I=moment of inertia
  - k=radius of gyration
    - Distribution of mass with respect to axis of rotation (C of G of limb)
  - m=mass

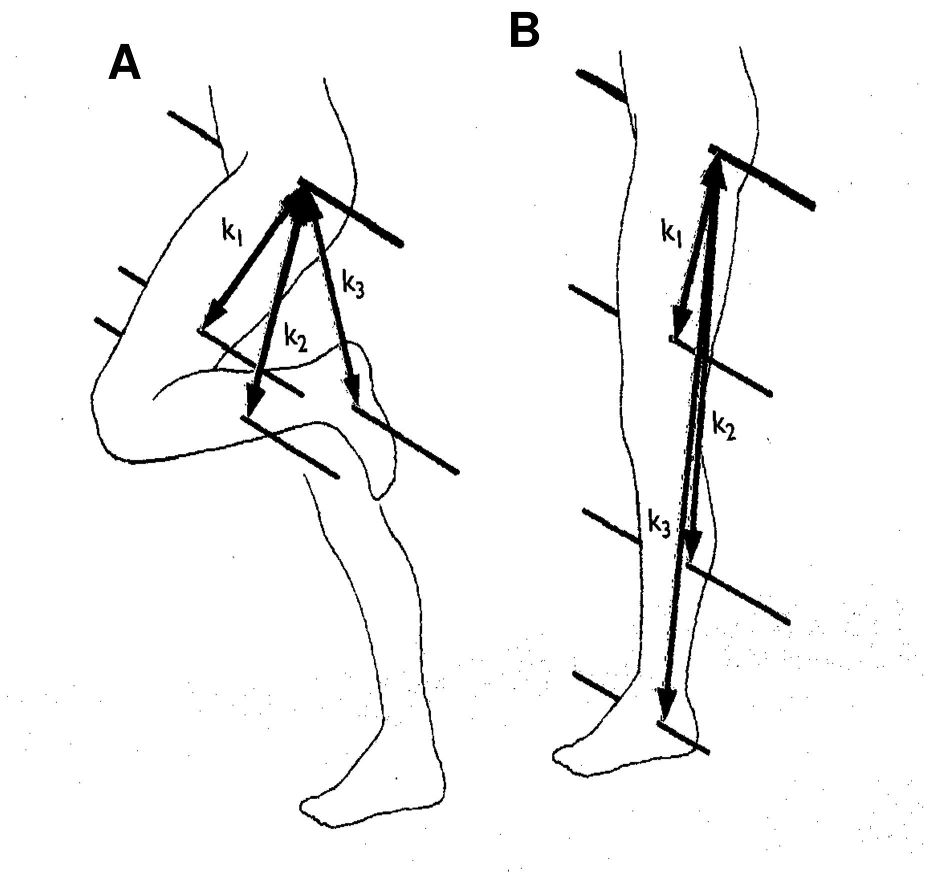
Moment of Inertia

- A. Decreased angul

Inertia/momentum

- B. Increased angula

Inertia/momentum



Recovery Phase

- Foot leaves track
  - Hip will extend initially
  - Then forcefully rotate forward, while knee rotates backwards
  - Mass of leg as close as possible to hip axis of rotation
  - Flexion of hip and knee decreases moment of inertia of whole leg
  - Allows faster forward rotation

- As thigh reaches near horizontal
- Knee will extend & limb will begin to descend to the track
- General more acute angle between trunk and thigh at faster running velocities

Sprint Technique

- Need for smooth co-ordination of legs, arms and trunk
- Legs
  - Cyclical action
- Arms
  - Opposite movement to legs

Importance of the arm action

- Conservation of Angular Momentum
- Newton's Third Law
  – Every (angular) action has an equal and opposite (angular) reaction
  – But total (angular) momentum of the body remains constant in steady state running, unless external forces influence us
- When is angular momentum of foot at its greatest and least?

Foot at Ground Contact

- Support leg straight rotating backwards
- Foot at maximum velocity moving backwards
- Leg mass distributed as far from hip centre of rotation as possible
- Angular momentum at maximum during sprint cycle

- Foot lands outside line of gravity
- Causing a torque (turning effect) at the hip, causing clockwise or counter clockwise rotation (depending on L or R foot touchdown)

Recovery Leg

- Rotates forwards
- Knee and hip flexed
- Mass distributed as close to hip axis as possible
- Angular momentum at its least
- Increases hip rotates in the same direction as the touch down foot

Effect

- Spinning sprinter R then L with each stride
- Unless rotation counter acted
- Why arms are so important

Arm Action

- Arms work contralaterally (opposite)
- To control hip rotation
- Arm opposing support limb needs to have the greatest angular momentum
  - Arm rotates backwards accelerating to increase hand speed and straightening to distribute mass further from shoulder centre of rotation

- Arm opposing recovery limb needs less angular momentum
  - Punches forward with the elbow flexing
  - Distributes mass closer to shoulder axis
- Hinrichs (1987) shows nearly all rotational momentum produced by the legs is counteracted by arm swing

To Run Faster

- Ground Contact Phase
- Swing the leg backwards more quickly
  - Increase torque developed by hip extensor muscles
- Distribute leg mass as close to hip as possible
  - Sprinters thigh musculature closer to the hip (Kumagia et al., 2000)
  - Importance of muscle distribution
    - Calves, hamstrings, glutes and quadriceps position
  - Trained or genetic?

Moment of Force (Torque)

- Angular acceleration (α) of an object is proportional to the net torque (τ) acting on it & inversely proportional to the inertia (I) of the object
  - $\tau = I\alpha$ or $\alpha = \tau / I$
- So angular acceleration increases if torque increase or inertia decreases
- Sprinting muscles at hip joint produce torque around the hip joint

- Increasing torque (*τ)* will increase angular velocity (*ω)* of the leg and conversely increase linear velocity (v) of the foot
- $v = \tau\omega$
- Importance of strengthening hip extensors/posterior chain

- Recovery Phase
- Important to decrease angular momentum
  - Heal to bum recovery as hip musculature relatively small/weak
  - Distribute mass closer to hip axis of rotation

Deceleration Phase

- Stride rate decreases
- Stride length increases slightly
- Ground contact and flight time increase
- Increase breaking phase
- Increased vertical descent of C of G
- Flatter foot strike

Short Vs Tall Sprinters (Limb Length)

- Longer limbs allow greater foot speed with a constant hip angular velocity
- But need more force as mass distributed further from hip (greater angular inertia)
- Short limbs have a greater force advantage, but relatively slower foot speeds
- Differences in training requirements?

Information Sources

- Biomechanics
  - Blazevich, A. (2007) *Sports Biomechanics.* AC Black
- Sprint Technique
  - IAAF Video Guide (Sprints) Part 1, 2, 3

(On UTube)

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