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·s$^{-1}$) stride frequency increases more than 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 ·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\textsuperscript{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
  - \( \text{mass} \times \text{velocity} \) (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 $1^{st}$ 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 2nd, there is an equal & opposite reaction (force) exerted by the 2nd object on the 1st
  - e.g. ground reaction force
Sprint Components

• Speed = stride length x stride frequency
  – 2m/stride x 4 strides/s = 8m·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 takeoff 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·s$^{-1}$
  - lead legs foot moving forward at 2 m·s$^{-1}$
  - Landing foot velocity = 12 m·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

Contraction Range *in vivo*

Muscle Tension

Length (% resting length)

50 100 150

Sum

Passive

Active Component
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
  – \( v = \frac{d}{t} \)
  – 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

<table>
<thead>
<tr>
<th></th>
<th>Carl Lewis (U.S.A.)</th>
<th>Kirk Baptiste (U.S.A.)</th>
<th>Thomas Jefferson (U.S.A.)</th>
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<tr>
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Braking and Propulsive Impulse
Vertical vs Horizontal force dominance

Vertical

Horizontal

Force

Time

Vertical

Horizontal

Force

Time
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 angular Inertia/momentum
- B. Increased angular 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 ($\alpha$) of an object is proportional to the net torque ($\tau$) 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 ($\tau$) will increase angular velocity ($\omega$) 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

• Sprint Technique
  – IAAF Video Guide (Sprints) Part 1, 2, 3 (On UTube)
References

References