Transitioning the Injured Runner Back to the Road and Track:

Biomechanics of Running Versus Sprinting

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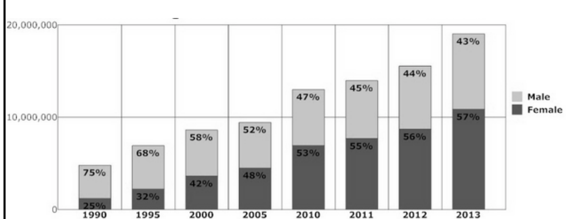
Objectives

- Understand injury rates and injury patterns between distance runners and sprinters.
- Describe the differences in biomechanics between distance runners and sprinters.
- Discuss sprinter-specific sport considerations.

Running Event Finishers 1990-2013



	1990	1995	2000	2005	2010	2011	2012	2013
Female	1,199,200	2,215,500	3,619,600	4,494,400	6,929,000	7,685,700	8,699,000	10,844,200
Male	3,597,800	4,708,000	4,998,400	4,947,600	6,071,000	6,288,300	6,835,000	8,180,800

http://www.runningusa.org/statistics

Track and Field Participation

- HS Participation 2014-15 (www.nfhs.org)
  - Outdoor track and field 1,057,338
    - Second only to Football
  - Indoor track and field 140,466
- NCAA Participation 2013-14
  - Outdoor track and field 27,514
  - Indoor track and field 24,785
  - Cross-country 14,218
- USATF Masters over 10,000 'active' members

Definitions of Runner Populations

POPULATION	DEFINITION
Track: Sprinters	*Track athletes competing in distances of up to 400m*
Track: Middle-Distance	*Track athletes competing in distances of 800-3000m*
Track: Long-Distance	*Track athletes competing in 5000 or 10,000m in races*
Novice Runners	*Runners with no regular running within the previous year*
Recreational Runners	*Non-competitive runners or runners participating in road races shorter than 10km*
Cross-Country	*Runner competing in cross-country races*
Road: Long-Distance	*Runners competing in races between 10km and less than a marathon*
Marathon	*Runners competing in a marathon*
Ultra-Marathon	*Runners competing in races longer than a marathon*

Kluitenberg et al, Sports Med 2015

Injuries Happen…

- 46-65% of runners experience an injury yearly
- Marathon training incidence as high as 90%
- Training errors account for 60–70% of all running injuries
  - Excessive mileage
  - Excessive intensity
  - Sudden change of training routines
  - Etc.

(Lysholm & Wiklander, *Am J Sports Med*, 1987; Macara et al, *Arch Intern Med* 1989; Marti et al, *Am J Sports Med* 1988; Satterthwaite et al, *Br J Sports Med* 1999; Lysholm & Wiklander, *Am J Sports Med* 1987; Renstrom, *Instr Course Lect* 1993)

Injury Prevalence in Track and Field

- Annual injury incidence between 61% and 76% (Bennell et al, *Sports Med* 1999; D'Souza et al, *Br J Sports Med* 1994)
- 2011 IAAF Championships
  - 37.3 injuries per 1000 athlete participations
  - Thigh most common injury site at 27%
  - 48% injuries lead to time-loss

  (Alonso et al, *Br J Sports Med* 2012)

Acute Injury Frequency

	Injury Proportion
Track: Sprinters	7.2%
Track: Middle Distance	12.8%
Track: Long Distance	15.6%
Road: Long Distance	0.9%
Marathon	7.8%
Ultra Marathon	65.6%

Kluitenberg et al, Sports Med 2015-Systematic Review/Meta-Analysis

Acute Injuries in Track and Field Athletes

Am J Sports Med 2015

A 3-Year Observational Study at the Penn Relays Carnival With Epidemiology and Medical Coverage Implications

David Opar,*†‡ PhD, Jonathan Drezner,§ MD, Anthony Shield,† PhD, Morgan Williams,|| PhD, David Webner,¶ MD, Brian Sennett,# MD, Rahul Kapur,# MD, Marc Cohen,# MD,

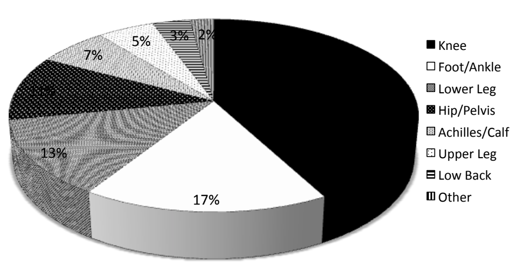
Event	Relative injury rates (injuries per 1000)
100m	13.5
110m Hurdles	14.5
4 x 100m	4.5
4 x 200m	2.7
4 x 400m	6.4
400m Hurdles	13.8
Mile	11.6
5000m	3.7
10,000m	8.5
3000m Steeplechase	18.1

Time-Loss From Injury at 1-Year

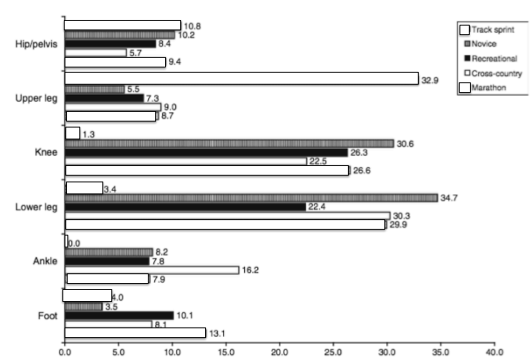
	Injury Proportion
Track: Sprinters	63.8%
Track: Middle Distance	63.9%
Novice Runners	27.3%
Recreational Runners	55.0%
Cross-Country	3.2%
Road: Long Distance	31.7%
Marathon	52.0%
Ultra Marathon	64.6%

Kluitenberg et al, Sports Med 2015-Systematic Review/Meta-Analysis

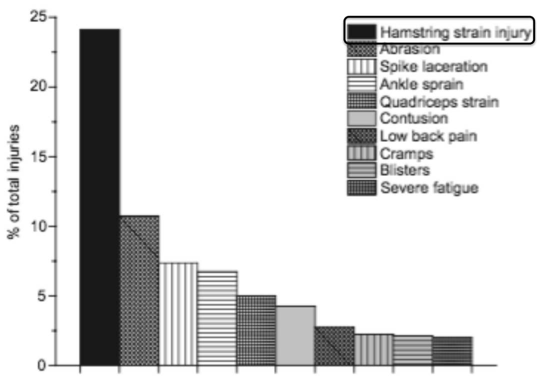
Running-Related Injuries by Location



Tauton et al, Br J Sports Med 2002



Kluitenberg et al, Sports Med 2015



Opar et al, Scan J Med Sci Sports 2014

Sex and Injury Risk

- Overall, females tend to have a higher incidence of RRI compared to males (Taunton et al, Br J Sports Med 2002)
- Female track and field athletes less likely to sustain orthopaedic and lower body strain injuries compared with male athletes
  - 2011 IAAF World Athletics Championship
    - (Alonso et al, Br J Sports Med 2012)
  - 2012 European Athletics Championship
    - (Edouard et al, Clin J Sports Med 2014)
  - Reduced risk of injury in female athletes might be restricted to college/elite athletes
    - 2002-2004 Penn Relays Carnival
      - (Opar et al, Am J Sports Med 2015)

Age and Injury Risk

- Track and field athletes older than 30 years are at an elevated risk for injuries and time-loss (Alonso et al, Br J Sports Med 2012; Edouard et al, Clin J Sports Med 2014)
- Compared with masters male track and field athletes, college and high school athletes had a smaller likelihood of sustaining a minor orthopaedic injury (Opar et al, Am J Sports Med 2015)
- Physiological changes occur in the aging athlete
  - Decline in strength
  - Decline in muscle voluntary activation capacity
  - Etc.

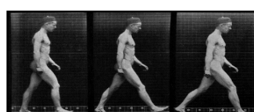
  (Brisswalter & Nosaka, *Sports Med* 2013; Maharam et al, *Sports Med* 1999)

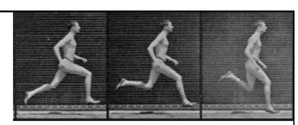
Role of Biomechanics with RRI

- Abnormal biomechanics associated with running injuries
  - PFPS (Noehren et al, Clin Biomech 2012)
  - ITBS (Noehren et al, J Orthop Sports Phys Ther 2014)
  - Tibial Stress Fx (Milner et al, Clin Biomech 2007)

Differences Between Walking and Running

*Critical Velocity ~2.5m/s or 5.6mph





WALKING

- Double-limb and single-limb support

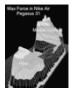
RUNNING

- Series of coordinated jumps requiring vertical support and forward drive
- Single-limb support with a period of double-leg float (or flight) time
  - Less than 40% stance
  - Greater than 60% float
- Runners require greater joint motion and greater eccentric work

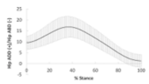
DiCharry J 2010 Clin Sports Med; Novacheck, Gait Posture 1998; Slocum & James, JAMA 1968; Ounpuu, Instr Course Lect 1990

Biomechanics

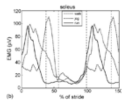
- Factors
  - Kinetics…forces



  - Kinematics…movements

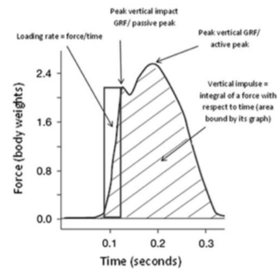


  - Muscle function…electromyography (EMG)



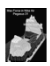
Biomechanics-Kinetics

- Vertical ground reaction force

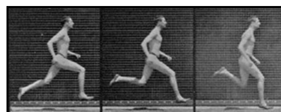


Lieberman et al, Nature 2010

Biomechanics-Kinetics



- During midstance GRFs are highest on the body (DiCharry, Clin Sports Med 2010)
- Greater impact peak and rate in injured runners
  - Associated with:
    - Plantar fasciitis (Pohl et al, *Clin J Sport Med* 2009)
    - Tibial stress fractures (Pohl et al, *J Biomech* 2008)
    - Knee osteoarthritis (Hunt et al, *Knee* 2010; Mundermann et al, *Arthritis Rheum* 2005)
    - PFPS (Cheung & Davis, *JOSPT* 2011; Davis et al, *Med Sci Sports Ex* 2010)
- Vertical impact peak lower in runners with midfoot and forefoot strike patterns (Altman et al, *Med Sci Sports Exerc* 2010; Bishop et al, *J Athl Train* 2006)



RUNNING **SPRINTING**

- Hip flexion and extension range of motion greater with running than walking
- Runners exhibit increased anterior pelvic tilt and thigh angle compared to walkers
- Pelvic motion is minimized in runners to conserve energy and maintain efficiency

Kinematics-Sagittal Plane

DiCharry, Clin Sports Med 2010; Franz, Gait Posture 2009; Novacheck, Gait Posture 1998; Ounpuu, Inst Course Lect 1990

Mean Joint ROM Normative Values for Running*

	Ankle	Knee	Hip
Initial contact	4° dorsiflexion		
Loading response	3° plantarflexion		
Mid stance	17° dorsiflexion		
Toe off	25° plantarflexion		
Early swing	32° plantarflexion		
Mid swing	2° plantarflexion		
Late swing	6° dorsiflexion		

Mean values for healthy recreational runners (9 female, 5 male; 24-45 years of age) measured via motion analysis while running at a fast pace (greater than 7 ½-minute mile).

*Adapted from Pink et al 1994

Mean Joint ROM Normative Values for Running*

	Ankle	Knee	Hip
Initial contact	4° dorsiflexion	15° flexion	
Loading response	3° plantarflexion	21° flexion	
Mid stance	17° dorsiflexion	38° flexion	
Toe off	25° plantarflexion	13° flexion	
Early swing	32° plantarflexion	13° flexion	
Mid swing	2° plantarflexion	103° flexion	
Late swing	6° dorsiflexion	11° flexion	

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Mean Joint ROM Normative Values for Running*

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Initial contact	4° dorsiflexion	15° flexion	20° flexion
Loading response	3° plantarflexion	21° flexion	22° flexion
Mid stance	17° dorsiflexion	38° flexion	17° flexion
Toe off	25° plantarflexion	13° flexion	11° extension
Early swing	32° plantarflexion	13° flexion	9-10° extension
Mid swing	2° plantarflexion	103° flexion	31° flexion
Late swing	6° dorsiflexion	11° flexion	15-17° flexion

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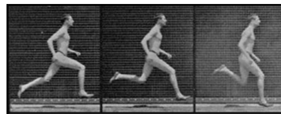

RUNNING

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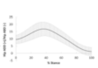
SPRINTING

- Lower center of mass
- Pelvis and trunk tilt forward to maximize propulsion
- Increased lumbar lordosis from midstance to toe-off and then from mid-swing to terminal swing
- Sprinters can reach up to 130° of knee flexion
- Increased PF at toe off and decreased need for DF to clear the limb in swing

Kinematics-Sagittal Plane

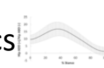
DiCharry, Clin Sports Med 2010; Franz, Gait Posture 2009; Novacheck, Gait Posture 1998; Ounpuu, Inst Course Lect 1990

Biomechanics-Kinematics



- Strike Pattern
  - Rearfoot strike pattern in 75% of runners at initial contact
    (Hasegawa et al, J Strength Cond Res 2007)
  - Rearfoot strike in 89% of runners at 10k
    (Larson et al, J Sport Sciences 2011)
    - 7.7% had an asymmetrical pattern

Biomechanics-Kinematics

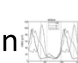


Frontal/Transverse Plane-Kinematic Parameters

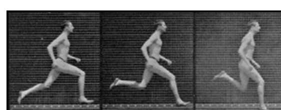
	Mean	SD
Hip adduction	12.1°	4.1
Hip IR	14.3°	12.8
Hip ER	15.0°	12.4
Knee flex max	110.1°	18.4
Knee flex min	8.3°	6.0
Ankle eversion	2.5°	3.0
Pelvic rotation max	7.6°	3.5

(adapted from Riley et al, Med Sci Sports Ex 2008)

Biomechanics-Muscle Function



- Optimal muscle activation is important throughout the gait cycle
  - Prepare the lower limbs for impact
  - Affects lower-limb stiffness
  - Reduce joint loading
    (Nigg & Wakeling, Exerc Sport Sci Rev 2001)



RUNNING

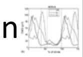
- Quadriceps work eccentrically to decrease the forward speed of the body mass center and provide body weight support, with gluteus medius and maximus providing additional support.
- Hamstrings eccentrically active during terminal swing to slow the forward movement of the thigh.
- Anterior tibialis is active concentrically from terminal stance through swing to provide adequate foot clearance.

SPRINTING

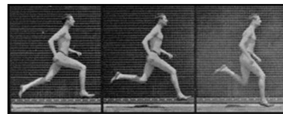
Muscle Function

Hamner, J Biomech 2010; Novacheck Gait Posture 1998; Ounpuu S Inst Course Lect 1990; Abe et al, Physiol Anthropol Appl Human Sci 2001; Kumagai wt al, J Appl Physiol 2000; Lee & Piazza, J Exp Biol 2009; Jacobs et al, J Biomech 1996

Biomechanics-Muscle Function



- Peak activation of leg muscles during braking phase of ipsilateral contact, except rectus femoris (Mero & Komi, Med Sci Sport Ex 1987)
  - Biceps Femoris and Gastrocnemius active during push-off
  - Biceps Brachii of right arm active before and during breaking phase of left leg
  - Lat Dorsi primarily active with Biceps Brachii
  - Rectus abdominus active at the end of ipsilateral contact and then at contralateral contact.
    - May work to assist hip flexors



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SPRINTING

- Greater force and power production
- Calf musculature needs to generate high shortening velocities in order to accelerate rapidly during the first strides
- Maximal angular velocity at the ankle joint during the push-off phase can reach close to 1000 degrees/sec)

Muscle Function

Hamner, J Biomech 2010; Novacheck Gait Posture 1998; Ounpuu S Inst Course Lect 1990; Abe et al, Physiol Anthropol Appl Human Sci 2001; Kumagai wt al, J Appl Physiol 2000; Lee & Piazza, J Exp Biol 2009; Jacobs et al, J Biomech 1996

Biomechanics-Speed

- Stride
  - From when one foot strikes the ground and continues until the same foot again strikes the ground (Slocum & James, JAMA 1968)
- Step length
  - Distance from initial contact of one foot to initial contact of the opposite foot (Dugan Bhat 2005, Ounpuu 1995).
- Cadence
  - 180 steps/min suggested as optimum for performance

Biomechanics-Speed

- Speed = Stride length x Stride frequency
- With increased speed…
  - There is an initial increase in step length, then a transition to an increase in cadence or step rate
  - Stance time decreases and swing time increases (DiCharry, Clin Sports Med 2010; Brisswalter & Legros, Percept Mot Skills 1995; Cavanagh & Kram, Med Sci Sports Exerc 1989; Ito et al, Med Sci Sports Exerc 1983; Yokozawa et al, Int J Sport Health Sci 2005)
  - Peak ground reaction forces and the rate of loading increase (Weyand et al, J Appl Physiol 2000)

Sprint Model

Hay & Reid, *Anatomy, mechanics and human motion (2nd ed)* 1988

Sprint Model

Increasing stride length, stride frequency, or force production, or decreasing ground contact time will all increase speed.

Sprint Model

- Vertical displacement
  - Decreases with increased running speed (Mero et al, Sports Med 1992)
- Hip Extension
  - Faster sprinters extend hip further (Kunz & Kaufmann, Br J Sports Med 1981)
- Maximum Velocity
  - Attained after 25 to 50m depending on performance level
  - Performance is limited by the ability of the athlete to maintain speed (Harrison, ISBS 2010)
- Leg Stiffness
  - Higher leg spring stiffness in sprinters (Harrison et al, *J Strength Cond Res* 2004)
- Breaking Phase
  - Less in faster sprinters (Mero et al, Sports Medicine 1992)

Sprint Model

- Acceleration Phase
  - 30-50m in top sprinters in a 100m race
  - Gradual decrease in contact time
  - COG anterior in early stages of acceleration
- Constant Speed Phase
- Deceleration Phase
  - Stride rate decreases
  - Stride length slightly increases
  - Contact and flight times increase

Curve Running

- Maximum running speed on a flat curve is significantly slower relative to straight plane running (Chang & Kram, J Exp Biol 2007)
  - 200m sprinters up to 0.4s slower on curves
- Attenuation of sprint speed is more pronounced as the radius of curvature is reduced
  - Advantage of up to 0.12s over a competitor in an adjacent inside lane (Jain, Res Q Exerc Sport 1980)

Curve Running-Biomechanics

- Straight path
  - Lateral forces negligible
  - Peak vertical impact GRF equals the peak resultant GRF
- Curved path
  - Lateral force comprises a significant portion of the total resultant force
  - For the peak resultant GRF on the curve, the vertical impact GRF will be smaller relative to a straight path (Greene, *J Biomech Eng* 1985)

Chang & Kram, J Exp Biol 2007

Curve Running-Biomechanics

- To maintain a curved path, a lateral force away from the center of the curve results in a centripetal force
- Trunk lean towards the center of the curve of the track
  - Inside foot pronated at IC
  - Outside foot supinated by 5°+
- Potential exists for runners to adversely alter running symmetry thus increase risk for injury (Beukeboom et al, *Clin J Sports Med* 2000)
  - Inside leg with lower vertical impact GRF and a shorter time to impact force

Hamill et al, Int J Sport Biom 1987

Banked Tracks

- 200-meter oval track
  - Four to eight lanes
- Curves are banked at 10 degrees (18% grade)
- Slight uphill grade going into the curve, then downhill grade coming off the turn
- Angle of the track redirects the runner inward with less effort

Block Start

- 100m-400m races
- Clearance time from the starting blocks accounts for approximately 5% of the total 100m race time (Tellez & Doolittle, Track Tech 1984)
- A lower block angle (40°) leads sprinters to a 3.6% higher block-induced impulse than a higher block angle (65°) (Mero et al J Sports Sci. 2006)

Block Start-Biomechanics

- At push off:
  - Tibia angle 45°
  - Torso in line with tibia
  - Arm motion exaggerated to counterbalance forward rotation over COM
  - Want low heel recovery
  - 75% of total acceleration achieved in first 7 steps

Block Start-Positions

- Stance width reported as 23 ± 1cm (Otsuka et al, J Appl Biomech 2014)
- Anteroposterior inter-block spacing
  - Variation in literature as to the optimal spacing
    - Bunched start (spacing generally <30cm)
    - Medium start (30 to 50cm)
    - Elongated start (>50cm)

Otsuka et al, PLOS One 2015

Runner/Sprinter: Shoewear

Running Shoes

- Highly variable
  - Minimalist to Maximalist

Track Spikes

- Lightweight
  - Less than 7oz
- Spike wells
  - 10 or fewer in forefoot
  - Metal or ceramic
  - ¼ in most common length

Track Spikes

- Taper Angle
  - Upward angle of forefoot
  - Thought to encourage running on forefoot
- Sprint spikes
  - Stiffer foot plate
  - Greater number of spike wells
  - Minimal support
- Distance spikes
  - Flexible foot plate
  - More support through midfoot and rearfoot

Conclusion

- Biomechanical differences may dictate alterations in treatment strategies and return to sport criteria
- Rehab vs. injury prevention vs. performance

THANK YOU

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