Using Movement Biomechanics to Advance Sports Injury Management

Bryan Heiderscheit, PT, PhD, FAPTA
Professor
Department of Orthopedics and Rehabilitation
Department of Biomedical Engineering
Director, UW Runners’ Clinic
Director of Research, Badger Athletic Performance
Co-director, UW Neuromuscular Biomechanics Lab
I, Bryan Heiderscheit, have relevant financial relationships to be discussed, directly or indirectly, referred to or illustrated with or without recognition within the presentation as follows:

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- Research Funding: NBA & GE Healthcare
- Committees: NFL Soft Tissue Injury Workgroup
Using movement biomechanics to advance sports injury management:

1. Injury risk in distance runners

2. Hamstring strain injury mechanisms and recovery

3. Injury risk monitoring
Where is the Knee Pain?

9:40 min/mile pace

172 steps/min

180 steps/min
Running Injury Management

- Ensure mechanical demands of running are less than the individual’s capacity to meet those demands

Running Demands

- high
- low

Physical Status

- strong
- weak

Injury Risk

- Individual
  - strength
  - flexibility
  - alignment
  - behavior
Step Rate Manipulation

Preferred
(160 steps/min)

Preferred + 10%
(176 steps/min)

Energy Absorbed (% preferred)

Step Rate

Increased Pre-Activation

- Increased gluteal activation during late swing with increased step rate

- Gluteus medius pre-activation in swing may facilitate reduction of hip adduction angle and abduction moment in stance

Chumanov & Heiderscheit (2012) Gait Posture
Training Protocol

- Goal is to alter the landing mechanics and running form, not to achieve a constant step rate.

- Single session on treadmill
  - 5-10% increased step rate via a metronome
  - May require verbal cueing to refine

- Step rate monitoring devices facilitate outdoor training
  - Need to consider speed

PSF (144) with knee pain
158 without knee pain
Step Rate and Injury Risk

- Step rate among high school runners (n=68) measured pre-season
  - fixed speed (8 min/mile) and preferred

- Lower extremity injuries tracked through subsequent competitive season
  - 38% experience lost day(s) due to injury
  - 19% experienced shin injury

- Runners with step rate < 164 steps/min had the highest risk of shin injury [OR 5.85 (1.1-32.1, p<0.04)]

Movement Analysis

3D Lab

2D Camera

UNIVERSITY OF WISCONSIN
BADGER
Athletic Performance

UW Neuromuscular Biomechanics Lab
# Kinematic Predictors of Kinetics

<table>
<thead>
<tr>
<th>Step Rate</th>
<th>Foot Inclination Angle at Initial Contact</th>
<th>Peak Knee Flexion during Stance</th>
</tr>
</thead>
</table>

- Mechanical Energy Absorbed about the Knee ($R^2=0.58$)

- Provides clinicians with a simple approach to estimate running kinetics and mechanism to change loading

Identify Key Flaws

- Overstriding
- Bounce
- Excessive Compliance

Running has sustained popularity in the United States and other countries, due in part to an awareness of its multiple health benefits. However, musculoskeletal running-related injuries are quite common, with reported injury rates varying from 19% to 75%.

Recurrent Tibial Stress Fractures

6:00 min/mile @ 176 steps/min
Body Posture and Alignment

Heel to COM distance
Knee flexion angle
Tibial inclination angle
Joint center alignment
Pelvis anterior tilt
Foot inclination angle
Pelvic lateral tilt
Trunk lateral tilt
Loading Response

- Reduced GRF during loading response
  - Impact peak (↓ 10%)
  - Loading rate (↓ 12%)
  - Braking impulse (↓ 14%)

Ground Reaction Forces (N/kg)
Improved Pelvic-Hip Control

- Peak pelvic anterior tilt
- Pelvic rotation excursion
- Peak pelvic lateral drop
- Peak hip adduction

Reduced pelvic-hip motion

Returned to normal training mileage (70+/week)
Outcomes

- Development of clinical tools
  - Clinical outcome tool (UWRI)
  - Standardized running assessment

- Expanded specialty clinic services
  - Addition of Active Moms Clinic

- Education and training programs for area high schools and novice runners

- Injury surveillance with area high schools following structured preseason assessments
  - Expanding to 3 other cities across the country
Hamstring Strain Injury

- Most common injury among sprinting athletes
  - Kujala et al. (1997) *Sports Med*

- 24% incidence rate among college sprinters and jumpers

- 30% re-injury rate

When did it happen?
Injury is likely during terminal swing

Heiderscheit et al. (2005) *Clin Biomech*
Chumanov et al. (2007) *J Biomech*
Chumanov et al. (2011) *Med Sci Sports Exerc*
Muscle Volume Changes

Injured

Healthy

<table>
<thead>
<tr>
<th></th>
<th>BFLH</th>
<th>BFSH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-12%</td>
<td>+22%</td>
</tr>
<tr>
<td><strong>p</strong></td>
<td>&lt;0.01</td>
<td>=0.06</td>
</tr>
</tbody>
</table>

**Compared to healthy controls**

Silder et al. (2008) *Skel Radiol*
Persistent Scar Tissue

- 92% increase in biceps tendon volume
  - healthy controls, ~10% absolute bilateral difference

Silder et al. (2008) *Skel Radiol*
Dynamic Deficits

No significant bilateral differences in peak musculotendon stretch

Inertial Loading

Healthy
Injured

Strains greater for injured subjects

Silder et al. (2010) Clin Biomech
Post-Injury Remodeling

- 7 days post-injury:
  - Persistent edema (~20%)
  - Evidence of scar tissue
- 2 mo. post-injury:
  - Edema resolved
- 7 mo. post-injury:
  - Fully formed scar tissue

Persistent Strength Deficits

- Strength deficits pronounced at long muscle lengths
- Shift in angle of peak torque occurred in both limbs despite only one limb displaying scar tissue
- Neuromuscular deficit at return to sport
  - Likely accounts for strength loss and shift in angle of peak torque

Silder et al. (2013) J Orthop Sports Phys Ther
Hamstring Loads during Sprinting

- 80% to 100% running speed:
  - Force increases by ~50%
  - Negative work increases by ~70%

Measured Kinematics ➔ Forward Dynamics

Chumanov et al. (2007) J Biomech
Outcome

- Developed and disseminated rehabilitation program
  - Re-injury rates < 8%
  - Integrated within local clinics and athletics department

- Risk factor identification and injury prevention program
  - Education program for area schools
  - Mass testing of collegiate student-athletes

- Ongoing 3-yr study on over 300 athletes with support from NBA-GE

Heiderscheit et al. (2010) *J Orthop Sports Phys Ther*
Badger Athletic Performance dedicates itself to the mission of maximizing student-athlete’s individual on-field performance through the integration of science, training, and injury management.
Facilities & Resources

Clinical Research Facilities

UW Athletics

UW Health Sports Medicine
The American Center
& Research Park

Computational and Imaging Facilities

Mechanical Engineering
Biomedical Engineering

Wisconsin Institutes for Medical Research (WIMR)
Depth and Breadth

UW Athletics

- High level athletes
- 4+ yrs of longitudinal data
- Control for multiple factors

UW Health Clinics

- Broad population base
- Large volume
- Community integration
Badger Athletic Performance
Hamstring Eccentric Strength & Injury

**Expected knee flexor eccentric strength can be reasonably estimated**
- **Males:** mass and height ($R^2=0.30$)
- **Females:** mass ($R^2=0.20$)

**Applying injury risk cut-offs from other sports does not work**
- $<250\text{-}300 \text{ N per limb}$
- $>15\%$ bilateral asymmetry

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**Males:**
$$\text{ECC-KF (N)} = 3.5\times \text{BM (kg)} - 4.6 \times \text{Height (cm)} + 935.4$$

**Females:**
$$\text{ECC-KF (N)} = 3.6\times \text{BM (kg)} + 47.4$$

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Sanfilippo & Heiderscheit (2018) National Athletic Trainers Assoc annual meeting
MSK Injury Risk following Concussion

The odds of sustaining an acute lower extremity MSK injury during the 90-day period following return-to-play was 2.48 times higher in concussed athletes than controls during the same 90-day period (OR: 2.48; 95% CI= 1.04-5.91; p= 0.04)

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>Cases of Concussion</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>87</td>
<td>189</td>
</tr>
<tr>
<td>Acute Fracture</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Muscle Strain/Tear</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Ligament Sprain/Rupture</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Average Game Exposures</td>
<td>5.1 ± 6.4</td>
<td>5.9 ± 6.5</td>
</tr>
<tr>
<td>Total Game Exposures</td>
<td>448</td>
<td>1084</td>
</tr>
</tbody>
</table>

Prospective Injuries

- Injury History
- Vitamin D & Iron
- Aerobic Fitness
- Bone Mass
- Running Mechanics

Injury

Mileage

Nutrition

Sleep

Mood

cross-country season

Need to Explore New Technology

- For now, nothing is as accurate as a professional gait lab
- Gait labs are expensive
- People like to exercise outside of a lab
- We don’t always need gold standard equipment to deliver meaningful data to evaluate and provide feedback on a given task
Large Multi-modal Data Capture

Cloud based storage, processing & analysis

Population based insights

Individualized actuation

- Mobile Phone – aggregate & process multimodal data
- Smartwatch – GPS, heart rate, sleep, macro gait metrics
- Inertial Sensor – spatiotemporal, kinematic & kinetic gait metrics

Inertial Measurement Units (IMU)

- Accelerometers (accelerations)
- Gyroscopes (angular velocity)
- Magnetometer (orientation)
- Sensor fusion

- Accurate for global running metrics: vertical oscillation, cadence, contact time

- Joint angles and body displacement must be calculated and can be challenging
  - Define relative position
  - Very sensitive to placement
  - Account for long range drift

Consistency of Metrics

- Location and orientation dependent
- Proprietary algorithms
- Similar names but measuring different things
  - **Accelerations**(g) → **GRFs**(N): On average, peak vertical GRF is underestimated by ~400N
  - not a standard difference of variation across participants, and therefore cannot simply be accounted for in the algorithm
  - an arbitrary unit of load
  - How is this interpreted?

User Education

- Just because it’s getting easier to measure, doesn’t make it easier to use

- Need to understand:
  - what is being measured
  - the process by which it is being reported
  - system limitations

- Must ensure
  - Approach is measuring what you think it is
  - Consistent output
  - Interpretable and actionable
  - Are you patient’s better with its use?
Ideal World

- Industry-clinician partnership early in development
1. Movement analysis technology can provide insights into injury mechanisms and recovery

2. Able to identify neuromuscular deficits and monitor load that may contribute to re-injury risk

3. Not all technology is created equal
Heiderscheit Lab

Lab Members

Scientist
- Dan Cobian, DPT, PhD

Staff
- Jen Sanfilippo, MS, LAT
- Mikel Stiffler, MS
- Grant Thomas, BS

Post-doc
- Scott Crawford
- Rita Deering, DPT, PhD

PhD students
- Colin Grove, DPT, MS
- Evan Nelson, DPT
- Christa Wille, DPT
- Keith Knurr, DPT

Contributing Alumni
- Amy Silder, PhD
- Liz Chumanov, DPT, PhD
- Dina Hoerth, MS
- Rachel Lenhart, MD, PhD
- Max Michalski, MD, MS
- Liga Blyholder, MPH
- Shane McClinton, DPT, PhD
- Lace Luedke, DPT, PhD
- John Scerpella, MPH

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- NBA-GE Medical Collaboration
- UW Sports Medicine Classic
Collaborators

**Athletic Training**
- David Bell, PhD, LAT
- Tim McGuine, PhD, LAT

**Biostatistics**
- Stephanie Kliethermes, PhD

**Engineering**
- Darryl Thelen, PhD

**Orthopedic Surgery**
- Geoff Baer, MD, PhD
- Pam Lang, MD
- Tammy Scerpella, MD
- Andrea Spiker, MD
- Brian Walczak, DO

**Physical Therapy**
- Marc Sherry, DPT, LAT
- Jill Thein-Nissenbaum, DSc, PT

**Radiology**
- Ken Lee, MD, MS
- Rick Kijowski, MD
- Mike Tuite, MD

**Sleep Medicine**
- John Dopp, PharmD

**Sports Medicine**
- Alison Brooks, MD, MPH
- Drew Watson, MD, MS
- John Wilson, MD, MS
The Kecia Lizbeth Erickson Physical Therapy Keynote was established in 2011 by family and friends in memory of Kecia, a long-standing member of Fairview - Institute for Athletic Medicine serving many facets such as Physical Therapist, Athletic Trainer, Clinical Director, Educational and Research Coordinator. Kecia brought an unsurpassed exuberance and mesmerizing charisma and charm to this profession. The Keynote lecture series now serves as a reminder and dedication to the educational foundation for clinical excellence Kecia advocated for and directed.
Thank You