Barefoot Running

Have sneakers changed the way we run?
Why Barefoot Running?

- Humans evolved to run long distances without the assistance of footwear
- An estimated 30% of runners experience some type of injury each year, often in the feet or lower legs
- Anecdotal evidence suggests that individuals who grow up running long distances without supportive footwear sustain fewer injuries
# Foot-Strike Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel Strike</td>
<td>Heel lands first, followed by rotation towards the forefoot</td>
<td><img src="image.png" alt="Heel Strike Illustration" /></td>
</tr>
<tr>
<td>Midfoot Strike</td>
<td>Entire foot lands simultaneously</td>
<td><img src="image.png" alt="Midfoot Strike Illustration" /></td>
</tr>
<tr>
<td>Forefoot Strike</td>
<td>Ball of the foot lands first, followed by the heel</td>
<td><img src="image.png" alt="Forefoot Strike Illustration" /></td>
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</tbody>
</table>
Kinematics of Running

- 1) Moment of Impact
- 2) Impact to Flat Foot
- 3) Flat Foot to Midstance
- 4) Midstance to Lift-off
Leg Muscles

Whole leg pulled back by contraction of this muscle

Leg bent by contraction of this muscle

Leg straightened by contraction of this muscle

Heel raised by contraction of this muscle

Toes raised by contraction of this muscle

Foot pushes against ground

Whole leg raised by contraction of this muscle

Peroneus anterior

Tibialis anterior

Gastrocnemius

Extensor digitorum longus

Soleus
Sneakers vs. Five Fingers
1) Moment of Impact

- Ankle is dorsiflexed
- Point of impact = rear of shoe
- Arch is not loaded

- Ankle is plantarflexed
- Point of impact = ball of foot
- Arch is loaded for support
2) Impact to Flat Foot

- Ankle position stays relatively constant
- Ankle dorsiflexes
- Arch stretches and begins to flatten
- Calf muscles and Achilles tendon stretch
3) Flat Foot to Midstance

- Ankle dorsiflexes
- Arch *begins* to flatten and stretch slightly

- Ankle dorsiflexes
- Arch *continues* to stretch and flatten
4) Midstance to Lift-Off

- Ankle plantarflexes
- Arch recoils
- Toes flex
Momentum

- Inelastic collision = momentum is not conserved
- Heel-strike: vertical momentum is mostly absorbed by the collision force
- Forefoot-strike: some vertical momentum is converted into angular momentum as the majority of the mass continues to rotate

- Linear momentum: \( p = mv \)
- Angular momentum: \( L = I\omega = I \times \frac{v}{r} \)
  - \( I = \) moment of inertia, \( \omega = \) angular momentum
Energy

- Energy is not conserved
- Lift-off velocities are all larger than just before landing - energy is supplied by the leg muscles
- Evidence suggests that tendons and ligaments can store some kinetic energy as potential energy
  - Forefoot-striking may utilize the arch and Achilles tendon for spring loading on landing
  - Heel-striking does not appear to stretch tendons until midstance
Force and Impulse

\[
\int_{0}^{T} F_2(t) = M_{\text{body}}(\Delta v_{\text{com}} + gT) = M_{\text{eff}}(-v_{\text{foot}} + gT)
\]

- \( M_{\text{eff}} = \) “effective mass” = portion of the body stopping abruptly on landing
  - Heel-strike = foot + lower leg = 6.8% body mass
  - Forefoot-strike = forefoot + some rearfoot + some leg = 1.7% body mass
- \( T = \) impact time
- \( v_{\text{foot}} = \) velocity of foot
- \( g = \) acceleration due to gravity = 9.81 m/s\(^2\)
**Heel-Strike**

- Impulse = \((0.068\times 64)[1.209+(9.81)(0.05)]\) = 7.40 N\(\times\)s
- Force = \(J/\Delta t\) = 7.40/0.05 = 147.92 N
Forefoot-Strike

- Impulse = \((0.017 \times 64) \times [0.964 + (9.81 \times 0.05)]\) = 1.58 N*s
- Force = \(J/\Delta t\) = 1.58/0.05 = 31.64 N
Impact Transient
## Putting it Together

<table>
<thead>
<tr>
<th></th>
<th>Heel-strike</th>
<th>Forefoot-strike</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effective mass</strong></td>
<td>Foot + lower leg = 6.8% total body mass</td>
<td>Forefoot + some rearfoot and leg = 1.7% total body mass</td>
</tr>
<tr>
<td><strong>Vertical Momentum</strong></td>
<td>Absorbed by collision</td>
<td>Converted into rotational momentum</td>
</tr>
<tr>
<td><strong>Spring-loading</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Impact force in 5 ms</strong></td>
<td>147.92 N</td>
<td>31.64 N</td>
</tr>
<tr>
<td><strong>Total force</strong></td>
<td>F=ma (same)</td>
<td>F=ma (same)</td>
</tr>
<tr>
<td><strong>Impact transient</strong></td>
<td>Present, reduced by cushioned sneakers</td>
<td>Absent!</td>
</tr>
</tbody>
</table>
Training

- Forefoot striking feels unnatural to most runners used to highly supportive footwear.

- Individuals who learn to run without footwear tend to naturally forefoot-strike.

- Training barefoot (or with “Five Fingers”) and wearing minimalist footwear with less support can encourage forefoot striking even in sneakers.
Conclusions

- Decreasing the effective mass on landing reduces the immediate force of impact (0.05 s)
- Supportive sneakers decrease the impact transient when heel-striking but not to the extent of a forefoot strike
- Loading of the arch tendons may store kinetic energy as potential energy for take-off during a forefoot strike
- Training barefoot can strengthen the muscles needed for running with a forefoot strike while wearing sneakers

Further questions
- How much potential energy is actually stored in the arch?
- How do impact forces correlate with injury?
- How much linear momentum is converted to angular momentum?
Sources