Interaction of leg stiffness and surface stiffness during human hopping

Jonathan Lam

09/25/21

1 Overview

by Ferris and Farley (1997)

- Humans act as a single linear "leg spring" when hopping on the ground
- We can model this as $k_{tot} = k_{leg} + k_{surf}$; the results found that the former remains relatively constant, i.e., we adjust our leg spring constant to the surface stiffness
- This can give us insights on locomotion mechanics for runners on uneven terrain
- "This model consists of a single linear 'leg spring' and a point-mass equivalent to the mass of the body"
- Leg spring stiffness is independent of forward speed during bouncing gaits
- It is adjusted for higher speeds by increasing the angle swept by the leg during the stance phase, reducing the vertical movements
- A stiffer leg spring allows humans to run with a higher stride frequency at the same forward speed
- This hypothesis is supported by single-impact studies, but those may be affected by other factors (e.g., injury prevention)
- Hopping in place as the experimental model: follows same basic mechanics and spring-mass model as forward running yet has simpler kinematics
- Much of the previous experimentation is on hard laboratory floors

2 Methods

- **Only five subjects????!!!!!** "healthy subjects ... between 19 and 26 yr of age"
  - See p-values later in document
- No shoes, hands on hips, digital metronome (within tolerance)
- Two separate experiments:
  - Adjustments to leg stiffness when humans hopped at a single frequency on surfaces with a range of stiffness
  - Adjustments to leg stiffness when humans increase hopping frequency
- On the stiff surface:
$$k_{leg} = \frac{F_{peak}}{\Delta L}$$
- On the stiff surface:
$$k_{tot} = \frac{F_{peak}}{\Delta y_{tot}}$$
where $\Delta y_{tot} = \Delta y_{surf} + \Delta L$
- ΔL and Δy_{tot} were calculated by integrating the vertical acceleration twice
- Inertial force (?) was small

3 Results

- On stiffer surfaces, larger leg spring displacement, and vice versa for more elastic surfaces
- Peak vertical ground reaction force decreased as surface stiffness decreased ($P < 0.0005$)
- Significant differences in leg spring stiffness among subjects ($P < 0.0005$)
- All subjects increased their leg stiffness as surface stiffness decreased ($P = 0.56$)

- The total stiffness was 17.89kN/m during hopping on the most stiff surface and 16.7kN/m during hopping on the least stiff surface ($P = 0.60$)
  - Is this a valid hypothesis?
- The constant total stiffness allowed the subjects to use the same ground-contact time regardless of the surface stiffness, ranging from 0.287s on the least stiff surface to 0.268s on the most stiff surface ($P = 0.17$)
- The leg spring surface was significantly greater on the compliant surface than on hte stiff surface at every hopping frequency ($P < 0.0001$)
- The total stiffness was the same at each hoppinng frequency on both surfaces ($P = 0.44$)

4 Conclusions

- The leg stiffness adjustments are not necessary to require a given hopping frequency
- Effect of surface stiffness on mammalian bouncing gaits is likely to vary with body size
- The increased stiffness of the leg spring on compliant elastic surfaces may lead to a lower energetic cost compared with hopping or running on hard surfaces
- "Althought it is clear that humans adjust their leg stiffness to accomodate changes in surface stiffness during hopping, the physiological mechanisms for this adjustment are not yet known"