Kinematics of Elliptical and Treadmill Exercise

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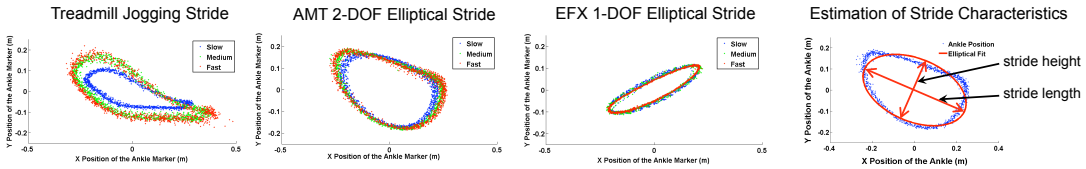
Abstract

This study compared the kinematics of two kinds of elliptical training to treadmill jogging at different paces. Colored markers were attached to anatomical landmarks and video analysis was performed during exercise on the three machines. Image processing techniques were employed in Matlab to identify the trajectories of an ankle, knee, and hip marker, which were used to calculate the knee flexion angle and to estimate stride characteristics. The one degree-of-freedom (1-DOF) elliptical exhibited stride characteristics and knee flexion angles that were smaller than jogging and did not vary with pace. The 2-DOF elliptical exhibited stride lengths more similar to jogging, but also larger stride heights and large prolonged knee flexion angles that did not vary with pace. This was attributed to a kinematic singularity in the mechanism design. Further studies should measure forces to determine if this results in increased loading of the knee joint.

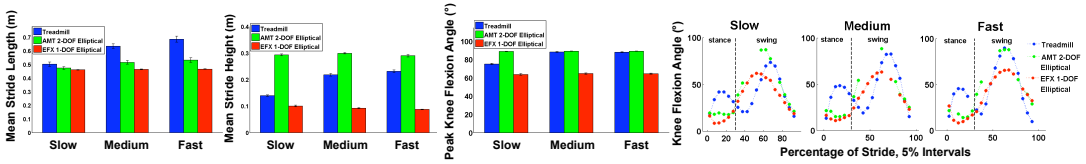
Introduction

- Elliptical training is a low-impact cardiovascular exercise.
- Most elliptical trainers have a 1-DOF mechanism that constrains the foot to a fixed elliptical path.
- The kinematic constraint at the foot in 1-DOF elliptical trainers may significantly alter the joint kinematics in undesirable ways.[1]
- A novel 2-DOF elliptical, the Adaptive Motion Trainer (AMT), uses a seven-bar mechanism to give more control over motion.
- Does this elliptical design offer a form of exercise that is kinematically similar to jogging without the disadvantage of high impact forces?
- This study compared stride characteristics and knee flexion angles over a range of speeds during use of the AMT 2-DOF elliptical trainer and a 1-DOF (Precor EFX) elliptical trainer, and compared this to treadmill jogging.

Stride Analysis



Comparison of Stride Characteristics and Knee Flexion Angle



Average stride length at different speeds, with 95% confidence intervals.

Average stride height at different speeds, with 95% confidence intervals.

Maximum knee flexion angle at different speeds, with 95% confidence intervals.

An ensemble average of the knee flexion angle. All strides were normalized by stride duration and compared over 5% intervals of the stride.

Results for EFX (1-DOF):

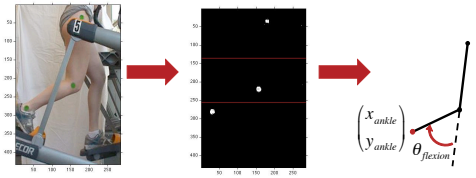
- no significant variation in any stride characteristics across speed ✔
- smaller stride length and height than jogging ✔
- smaller peak knee flexion angle than jogging and AMT ✔
- lower minimum knee flexion angle (extension during stance) ✖

Results for AMT (2-DOF):

- stride length increased slightly ✔
- reached plateau at smaller stride length than jogging ✖
- stride height larger than in jogging, independent of pace ✖
- large peak knee flexion angle, independent of pace ✖
- knee in flexion for greater duration of the stride, especially in swing ✖

✔ Result predicted by hypothesis ✖ Result not predicted by hypothesis

Video Analysis of Jogging and Elliptical Training

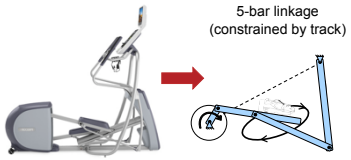


Video frames were imported to Matlab and converted to binary images by applying a color threshold to isolate the markers.

- Placed markers at anatomical landmarks
- Recorded video using the Sony HDR-SR8 on AMT, EFX, and treadmill at three speeds
- Processed images in Matlab to track ankle, knee, and hip marker trajectories
- Used angle between limb segments to calculate knee flexion angle and used ankle marker to analyze the stride

Comparison of Elliptical Trainer Designs

Precor EFX: 1-DOF Elliptical



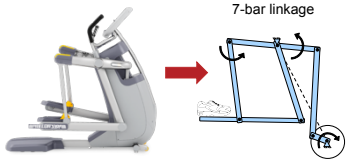
Hypothesis for EFX (1-DOF):

- stride characteristics will not vary with speed
- different stride and joint patterns from jogging

Hypothesis for AMT (2-DOF):

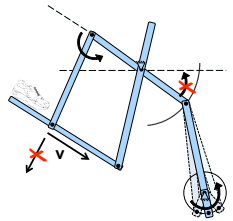
- stride characteristics will be more variable
- stride and joint patterns will resemble jogging

Precor AMT: 2-DOF Elliptical



Discussion and Conclusion

AMT 2-DOF Elliptical



Kinematic singularity during swing instantaneously reduces the elliptical mechanism to 1-DOF.

- Geometric constraints prevent long strides
- Singularity prevents natural downward swing
  - explains greater stride height
  - explains lack of stride height variability
  - explains high peak flexion angle at all speeds
- Forced knee flexion in AMT may increase knee joint stress, which can lead to injury
- An unpublished study found increased joint loading during swing for the AMT[2]
  - knee joint naturally unloaded during swing
  - knee joint loading during swing in AMT similar to lunges or stair climbing
- Further studies should measure joint forces and moments, as well as muscle contraction

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References

1. T.-W. Lu, H.-L. Chien, and H.-L. Chen, "Joint Loading in the Lower Extremities During Elliptical Exercise," *Med. Sci. Sports Exerc.*, 39(9): 1651-1658, 2007.
2. "Patellofemoral Joint Forces Between Two Non-Impact Cardio Machines," University of Wisconsin La Crosse in collaboration with Cybex Research Institute, accessed from http://www.cybexintl.com/, 2012 (unpublished).

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