Hammer throw: $v = \omega \times r$

FizziQ activity · High school · 40 min

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Tracking a hammer throw video frame by frame in FizziQ's kinematics module on smartphone or tablet, students measure release speed and test $v = \omega \times r$.

Learning objectives

- Analyze a hammer throw video using kinematic tracking to determine the release speed
- Compare the measured ejection speed with the theoretical value calculated from angular velocity and rotation radius
- Understand the relationship between circular motion parameters and the resulting linear velocity
- Investigate the optimal release angle for maximum throwing distance
- Apply the concepts of centripetal acceleration, tangential velocity, and projectile motion to a real athletic performance

Instruments and sensors

Video (kinematics) analysis module

Materials

- Smartphone or tablet with the FizziQ application
- Hammer throw video available in the FizziQ Cinematic Video Library
- FizziQ experiment notebook
- Note: the protocol remains adaptable to any comparable video analysis tool.

Protocol

1. Open FizziQ and navigate to the Kinematics module. Load the hammer throw video from the FizziQ video library.
2. Identify a reference scale in the video. The throwing circle diameter (2.135 m) or the athlete's height can be used.
3. Set the scale and coordinate origin in FizziQ. Place the origin at the center of the throwing circle.
4. Track the position of the hammer head frame by frame during the last revolution before release and during the initial projectile phase after release.
5. During the circular phase, collect at least 10-15 points around the final turn to accurately determine the rotation speed.
6. Continue tracking the hammer for 5-10 frames after release to determine the initial projectile trajectory.
7. From the circular phase data, calculate the angular velocity ω by measuring the angle swept per unit time.
8. Calculate the rotation radius r (distance from the athlete's axis of rotation to the hammer head, typically 1.8-2.2 m including arm length).
9. Compute the theoretical tangential velocity: $v = \omega \times r$.
10. From the post-release tracking data, determine the actual ejection speed by measuring the distance traveled per unit time in the first few frames.
11. Compare the theoretical and measured ejection speeds. They should be approximately equal.
12. Estimate the release angle from the trajectory direction at the moment of release and calculate the theoretical throwing distance using the projectile equation: $D = v^2 \times \sin(2\theta) / g$.

Expected results

For a competitive hammer throw, the angular velocity during the final turn is typically 2.5-3.5 revolutions per second (15-22 rad/s), and the effective rotation radius is about 2.0 m, yielding theoretical tangential velocities of 25-30 m/s. The measured ejection speed from the kinematic analysis should agree with this value within 10-15%. The optimal release angle is about 42-44 degrees (slightly less than the theoretical 45° due to the release height being above ground level). The predicted throw distance from the projectile equation should be roughly consistent with the actual distance, though discrepancies arise from air resistance and the difference between the release height and ground level. Pointing errors in the video analysis typically limit the velocity accuracy to ±10%.

Questions

- Why is the ejection speed equal to the tangential velocity of the hammer at the moment of release?
- How does the athlete increase the rotation speed from the first turn to the last?
- Why is the optimal release angle slightly less than 45 degrees?
- What limits the maximum rotation speed the athlete can achieve? What role does the centripetal force play?
- How does the length of the cable affect the throw distance for the same rotation speed?
- Why is conservation of angular momentum important during the spinning phase?

Going further

- Compare the hammer throw with the discus or shot put, analyzing the different biomechanical strategies
- Calculate the centripetal force the athlete must exert on the cable during the final rotation ($F = m\omega^2 r$)
- Analyze how the rotation speed builds up progressively over the three or four turns
- Investigate the effect of release angle by calculating the theoretical distance for angles from 30° to 60°
- Compare the kinematics of elite and novice hammer throwers to identify the key performance factors