Biomechanical characteristics of hammer throwing technique

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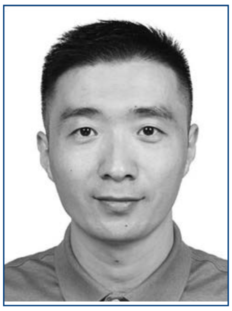

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Abstract

Objective of the study. To study the biomechanical characteristics of hammer throwing technique.

Methods and structure of the study. To determine the biomechanical characteristics of the hammer throwing technique, 3 attempts were made by all participants of the experiment with mandatory shooting by high-speed video cameras KASIO with a frequency of 120 frames per minute. The sample size of athletes of CG and EG was 10 observations for each investigated kinematic parameter. A total of 75 hammer throw attempts were recorded and 675 kinematic parameters were processed. We used APAS (Ariel Performance Analysis System) 3D video motion analysis system for video analysis and processing.

Results and conclusions. Comparing the relevant technical parameters with outstanding athletes in the world, it can be seen that the acceleration rhythm of Chinese hammer throwers in each lap fluctuates greatly during the rotation process, the center of gravity moves slowly and the acceleration time is especially inaccurate. At the same time, this is due to factors such as insufficient forward body inclination, right leg extension, little movement of the right foot on the ground, and slow landing speed. The rhythm of body rotation and the rhythm of hammertoe rotation were clearly raised, and it was pointed out that during single-supported rotation, the athlete increased the speed of the hammertoe end by increasing the angular velocity, while during the double-supported period, the speed of the hammertoe end was maintained by increasing the radius, thus achieving control of the equipment.

Keywords: *biomechanics, movement parameters, hammer throwing, movement technique, athletes.*

Introduction. An analysis of world record changes in the men's hammer throw shows a steady increase in performance from when the discipline was first introduced as an Olympic event in 1900 until the mid-1980s. In the late 1980s, Bartoniec [1] indicated that it was certain that the 90m mark would be surpassed in the men's sport. Although the years passed, the 1986 world record of 86.74m set by Yuri Sedykh still stands. Reasons for this lack of progress have been suggested to be that the current training models used by many coaches involve introducing strength training at a much younger age, which has led to less emphasis on skill acquisition [4].

In order for there to be further progress in sport, it is believed that coaches need to adopt a more critical, scientific approach to help with more accurate technical adjustments [3]. In addition, clearer guidelines need to be developed to optimize technique, without which hammer throwing can only be improved through trial and error [4].

Hammer throwing is a complex sport in which the laws of mechanics play an important role. Therefore, athletes and coaches must have a clear understanding of the laws underlying the sport to ensure technique improvement [5]. This chapter provides an overview of the biomechanical aspects of hammer throwing, firstly looking at the motion of the hammer projectile after release and then examining the kinematics and kinetics of the hammer, the thrower and the hammer thrower system.

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Results of the study and discussion. After the hammer is released, it performs a projectile motion on which two types of forces act on it: gravity and aerodynamic forces [2]. The gravity force acts vertically downward and its magnitude remains constant throughout the projectile motion, while the aerodynamic forces will vary depending on a number of factors. There are two aerodynamic forces acting on the hammer after release: drag force and lift force [2]. The magnitude and direction of the drag force (air resistance) will vary depending on environmental factors such as wind direction; however, in the absence of wind, this vector acts in the opposite direction to the hammer's linear velocity vector (opposite to the direction of throw). The lift force acting on the hammer is due to the Magnus effect and is considered negligible compared to other forces present [2].

The aerodynamics of an object is a measure of the maximum possible acceleration from aerodynamic forces during flight [3]. For a hammer, the aerodynamics is reported to be 0.74 m/s2, indicating that the assumption of zero drag is incorrect when estimating the range or throwing distance when throwing a hammer [3]. Hence, ignoring air resistance in range calculations will lead to an overestimation of the throwing distance [3].

Several studies have evaluated the effect of aerodynamic forces on hammer throwing distance. De Mestre [3] and Hubbard [4] derived two different analytical solutions to determine the effect of air resistance on range. Hubbard [4] reported that the inclusion of air resistance in the calculation resulted in an approximate 6% decrease in the range of a 7.26 kg hammer throw, while De Mestre's [3] analytical solution resulted in a range that was approximately 2% less. Neither of the results of these two models were compared with real throwing data.

If aerodynamic forces are ignored, aerodynamics is zero, which in turn causes the trajectory of the hammer to become parabolic [3]. Furthermore, the only force to be considered under these conditions is gravity; hence, the hammer experiences constant acceleration. For any projectile, the motion can be decomposed into horizontal and vertical components. Analysis of the equation describing horizontal displacement or range shows that the kinematic parameters at ejection that affect range in hammer throwing are the linear velocity of the hammer, the angle that the linear velocity vector forms with the horizontal, and the height at which the hammer is released above the ground [6].

Increasing the velocity and/or height of the throw will increase the throwing range. However, in order for the range to be as long as possible, throwers must ensure that all three throwing parameters are optimized. If an optimal value for each parameter exists, it can be determined by differentiating the equation for each parameter and setting the derivative equal to zero. Differentiating this equation by the ejection velocity and ejection height shows that there are no optimal values for these variables. This indicates that the linear velocity and height at ejection should be as large as possible [6]. This is not the case for ejection angle, which for a given velocity and altitude may have an optimal value that maximizes range [5].

If the projectile is fired from ground level, the range will be maximized if the angle of release is 45° [2]. However, if the projectile is released from a height that is higher than the landing height, as in the case of hammer throwing, the optimal release angle will always be less than 45°. Differentiating the equation with respect to the release angle and equating the derivative to zero, we obtain the following:

Using throwing velocities and throwing heights corresponding to hammer throwing shows that there is a small variation in the optimal throwing angle. The optimal angles fall in a narrow range between 44.15° and 44.56°. This is also evident when the optimal throwing angles are determined using the following simplified equation for range,

However, female throwers tend to have a flatter projectile ejection than males, which is likely due to an unfavorable relationship between projectile length and height.

Research suggests that throwers should ensure that the throwing height is as high as possible. However, the maximum throwing height achievable for a thrower is limited by anatomical constraints [1]. If the throwing height is too high, it can compromise the thrower's ability to apply accelerating force to the hammer, which in turn can lead to a decrease in throwing velocity. In hammer throwing, the ideal throwing height is approximately shoulder height and to capitalize on this fact, hammer throwers should be tall. Less experienced throwers tend to release the hammer at a lower height [5].

Once the thrower has developed a technique that allows him or her to consistently achieve optimal throwing height and angle, it follows that the range can only be increased by increasing the throwing velocity, so it is imperative that the throwing velocity be as high as possible.

Two other kinematic parameters that must be considered when considering velocity development in hammer throwing are the radius of rotation and the angular velocity of the hammer. For a simplified model of a point mass (m) making a circular motion, the linear velocity (v) at any instant of time is equal to (v=r), where r is the radius of rotation (the distance between the point mass and the axis of rotation) and is the angular velocity of the point mass. This relationship implies that an increase in both the radius of rotation and angular velocity will result in an increase in the linear velocity of the rotating point mass. This confirms previous work that suggested that throwers should provide the largest possible radius of rotation, as this leads to an increase in hammer velocity [5]. A larger radius of rotation also results in a greater distance over which the hammer can be accelerated, but changing the radius of rotation will change the inertial drag of the hammer. For a point mass rotating at a distance r from the center of rotation, the magnitude of inertial drag/moment of inertia (I) at any instant of time is, I=mrr. From the equation, it is clear that increasing the radius of rotation will increase the inertial drag. An increase in inertial drag will in turn lead to a decrease in angular acceleration ( ) and hence angular velocity (assuming that the external torque ( ) applied to the mass remains constant). This is due to the following relationship,(= /I). Therefore, to maximize the linear velocity, the thrower needs to achieve an optimal relationship between angular velocity and radius of rotation that also minimizes the inertial drag of the hammer.

Having a larger radius in the initial parts of the throw has important consequences. For a given linear velocity, a larger radius allows the hammer-thrower system to rotate at a lower angular velocity. A lower rotational velocity allows the muscles involved to contract more slowly, allowing those muscles to exert greater forces. This is due to the force to velocity ratio for skeletal muscles. In turn, greater muscle force results in greater torque and an increase in the overall angular momentum of the system. Thus, the use of a larger radius in the early stages of the throw contributes to an increase in the angular momentum of the system [4].

As the throw progresses, the tendency to reduce the rotational radius leads to a decrease in the moment of inertia and an increase in angular acceleration. Thus, radius reduction, especially in the last part of the final turn, can be utilized by throwers to facilitate an increase in hammer velocity before release [3].

At any instant, the tether weight and force can be decomposed into three components: normal, radial, and tangential to the instantaneous circle of rotation [2, 6]. The normal components of the tether weight and force are equal and opposite and have no effect on the linear velocity of the hammer. The sum of the radial components determines the radial acceleration of the hammer head, which in turn determines the radius of curvature [6]. The only components that directly affect the instantaneous linear velocity of the hammer are the tangential components of the tether weight and force [4].

Researchers Isele R [4]., Nixdorf E. studied the hammer throw technique among the top eight men at the 2009 World Athletics Championships. They recorded hammer throw technique parameters using cameras and analyzed them using three-dimensional kinematic measurement techniques to obtain data and produce results. Parameters analyzed include:

- General parameters: hammer throwing velocity, hammer throwing angle, and hammer throwing height.
- Velocity parameters: the starting velocity of the first lap of the hammer and the value of velocity change in each lap.
- Time parameters: Single rest time, double rest time, sum of single and double rests.
- Path parameters: Length of the path traveled by the hammer in each lap, total path. The path corresponding to the single and double support stages of each lap.
- Angle parameters: azimuth angle, torsion angle.

It is concluded that achieving the maximum possible throwing distance in hammer throwing is primarily the result of creating the maximum possible throwing velocity and achieving the optimal throwing angle. The throwing height has little effect on the throwing distance. The fourth factor affecting the flight of any object is air resistance, which cannot be affected by the thrower. In hammer throwing, the angle of release is achieved by practicing and gradually increasing the inclination of the initially flat trajectory of the hammer to a biomechanically optimal angle. Ballistically, the optimal release angle is 44˚. However, this value is rarely achieved in hammer throwing, as a slightly more gentle release angle provides more favorable conditions for the leg, trunk, and arm muscles. In the current analysis, the average release angle for men was 41.3˚. Our various analyses in recent years have shown similar results, with men achieving an average of 41.0˚ for throws over 77 meters.

Athletes need achievable guidelines for individual movement patterns to achieve a positive orientation in technical training. To meet this need, athletic trainers should consider the following basic technical requirements: 1. Shorten the duration of the single support phase by: a) leaning back in the first half of the double support phase, b) utilizing the back of the support, part of the double support phase. Perform a quick half rotation, c) turn the free leg close to the support leg, d) place the free leg behind the right side of the support leg. 2. Overcoming horizontal movement. Use the fourth lap to increase the dynamic parameters of the athlete and the hammer system,

At present, it is still difficult to obtain reliable kinematic and kinetic data in field/real competition conditions, resulting in a lack of real-time biomechanical feedback studies in sport domains.

Four factors can be considered influential, causal and interacting during hammer throwing and taken into account as a decisive factor affecting the thrower's technique:

a) The angle of the hammer at each turn.

b) The distance between the turn radius and the momentum at double support, estimated from the azimuthal angles of the hammer when the right foot comes off and resumes contact with the ground in each turn.

c) The behavior of hammer velocity, both horizontal and vertical, during the throw.

d) The angular momentum of the hammer through the vertical and horizontal axes.

In general, it can be said that, observing the data obtained by higher level throwers, the theory that the hammer can only accelerate during the double prop period, without the possibility of actively influencing its velocity during the single prop period, is only confirmed when the rotation around the vertical axis (horizontal velocity) is taken into account. In this sense, the angular momentum of the hammer generated through the vertical axis is in all cases greater during the double support phase than during the single support phase, which means that athletes develop more force during the double support phase and that the best throwers are those who reduce their angular momentum less during the single support phase.

Conclusion. Thus, comparing the relevant technical parameters with the outstanding athletes of the world, it can be seen that the acceleration rhythm of Chinese hammer throwers in each lap fluctuates greatly in the process of rotation, the center of gravity moves slowly and the acceleration time is especially inaccurate. At the same time, this is due to factors such as insufficient forward body inclination, right leg extension, little movement of the right foot on the ground, and slow landing speed. The issue of the rhythm of body rotation and the rhythm of hammertoe rotation was clearly raised, and it was pointed out that during single-supported rotation, the athlete increased the speed of the hammertoe end by increasing the angular velocity, and during the double-supported period, the speed of the hammertoe end was maintained by increasing the radius, thus achieving control of the equipment.

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