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Pull and Dynamics

DIRECTION OF PULL AND DYNAMICS OF ARM ACTION IN HAMMER THROWING

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During the course of a hammer throw, a thrower winds the implement a couple or three times around the body while maintaining ground contact with both feet. Subsequently the athlete executes three or four turns where the whole body rotates with the hammer by alternating between double and single support. The speed at the time of release will dramatically affect the distance thrown with the angle of release also playing a role at that instance. It is imperative for the practitioner to understand the various factors that will positively affect the hammer velocity during the course of a throw.

FORCES ACTING ON THE HAMMER

Ignoring air resistance, two forces will act on the hammer during the course of a throw (figure 1). Those are: the weight of the hammer (W) and the wire pull (WP). These two forces can each be analyzed into a tangential (WT, WPT) and a perpendicular force (WPE, WPPE).The perpendicular forces will affect the direction of motion of the hammer, that is, the eventual curvature of the hammer path as well as the tilt of the plane of motion.Those two forces (WPE and WPPE) will not affect the velocity of the hammer.

The forces that will determine the velocity of the hammer are the tangential forces (WT and WPT). The tangential force of the weight will tend to increase the velocity of the hammer between the high point and the low point of its orbit. As the hammer ascends between the low and the high point, that force will tend to decrease the hammer velocity.The tangential force of the wire pull will depend on two factors: a) the size of the force exerted by the thrower on the wire itself and, b) the direction along which the wire is pulled in relation to the center of rotation of the hammer. If the thrower pulls ahead of the center of rotation, the velocity will tend to increase.If pulling behind, the velocity will tend to decrease. Therefore, the velocity of the hammer will fluctuate depending on whether the sum of the WT and the WPT points in the same or the opposite direction to the direction of the hammer.In comparing the two tangential forces, that of the wire pull is the one that is mostly responsible for the changes in hammer velocity. Dapena (1984) found that the maximum wire pull was about eight times greater than the maximum tangential force due to wire pull, which indicated that most of the force exerted by the athlete on the

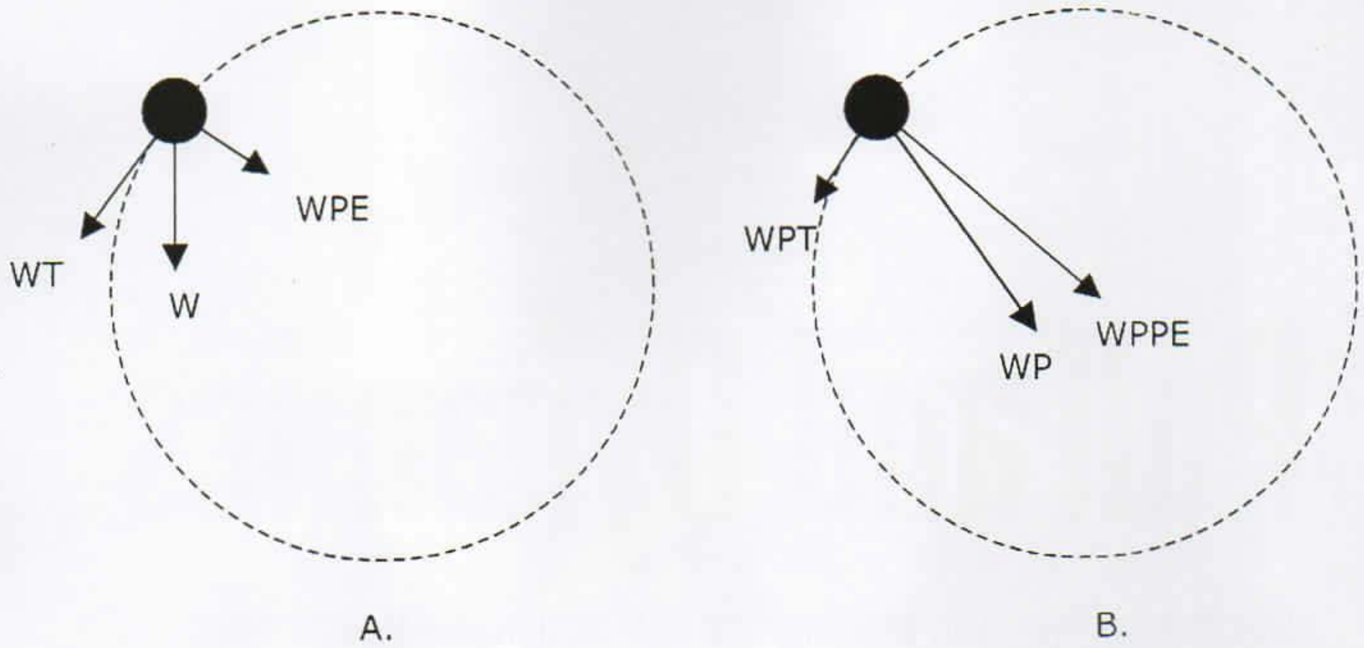

Figure 1. Forces acting on the hammer. A. Weight (W), tangential component of weight (WT), and perpendicular component of weight (WPE). B. Wire pull force (WP), tangential component of wire pull (WPT), and perpendicular component of wire pull (WPPE). The perpendicular components (WPE, WPPE) control the direction of motion of the hammer. The tangential components (WT, WPT) control the velocity of the hammer.

Figure 2. The triangle position and hypothetical optimum pull of the hammer.

wire is used to keep the hammer along its circular path leaving only a small percentage to be used for changing the velocity of the hammer.

THE IMPORTANCE OF THE DIRECTION OF THE PULL

Given the above information, the direction of the hammer pull becomes of paramount importance as one assesses the factors that would enhance the velocity of the hammer. Beginning with the findings of Kuznetsov in 1965, the theory of the lengthening of double support phase emerged. Although several years later others questioned some aspects of that theory (e.g., Dapena, 1989, Morriss & Bartlett, 1992, 1994), one "position" that eventually arose from the original double support theory is that of the maintenance of the arms in a generally straight fashion with the formation of a triangle throughout the execution of the throw after entering the first turn, which is what most competent throwers are doing nowadays (figure 2). However, top-level hammer throwers of the distant past used a technique that enabled them to more or less "drag" the hammer during the turns which, it was claimed later, caused a slowing down in the rotation of the body.One of the most obvious characteristics of that technique was a distinct flexion of the right elbow, particularly during single support (figure 5, red lines).

From a mechanical point of view, excessively "leading" the hammer in the entry to the first turn and throughout the execution of the throw, is indeed not desirable as compared to a straight arm position as shown in figure 2. This is because the old use of the technique with a bent right arm was the result of a misconception regarding the optimum direction of the pull. Figure 3, shows an outline of a hammer thrower, the shoulders and arms represented by a triangle.It shows the hammer and the circular path followed by the center of mass of the hammer, and the center of the curved path (dot in the middle). As one observes this figure, it is important to consider that the force exerted by the thrower on the hammer must always be aligned with the hammer wire, other-

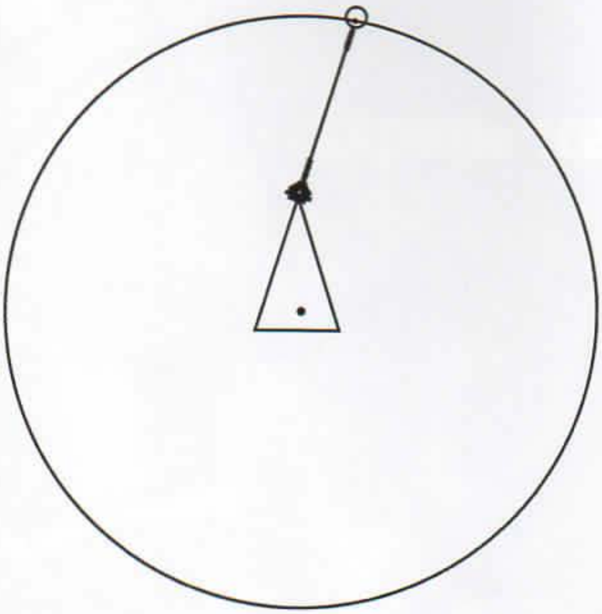

Figure 3. Straight-arm formation and rotation in hammer throwing. For practical purposes the left arm here is aligned with the hammer wire.

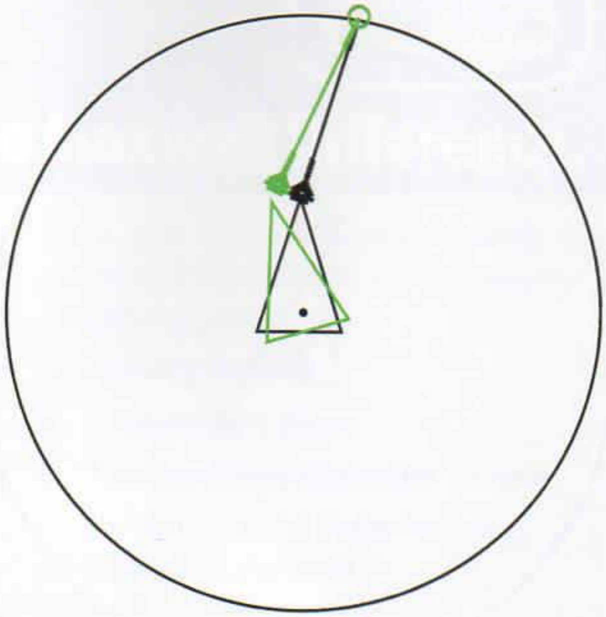

Figure 4. Pulling along the wire (green lines) where the latter points further ahead of the hammer's center of path

wise some applications from the laws of physics would be violated. A light, flexible wire (or a rope) can only be pulled along its length. If one tries to pull on a wire in a direction other than along its length, the wire will immediately point in another, new, direction of pull, so that one would still be able to pull along the wire. Although this can be proven using a mechanical explanation, it is also pretty self-obvious by experimenting with a string attached to an object laid on a table for example a book or a marble. In all this discussion, the hammer ball, hands and left shoulder will be kept aligned. As will be pointed out later, the body positions in figures 2 and 3 are quite close but do not exactly reflect what should be happening during actual throwing.

An observation of figure 3 shows that the hammer wire, and therefore the force made on the hammer, points ahead of the center of the hammer's circular path, and therefore the speed of the hammer will increase. Attempting to take advantage of this action, sometime around the 1950s or 1960s, some practitioners figured that, if the body could be made to face in a more counterclockwise direction relative to the hammer, this would be good, because the wire would be pointing farther ahead of the center of the circular path, and therefore there would be larger increases in hammer speed. This position is represented with the green lines in figure 4. The black lines show the same picture as in figure 3.

Such a direction for the hammer wire would indeed be advantageous since it would help in the generation of greater hammer speed. However, in this configuration it would not be possible to keep the hands in contact with the handle unless the wire were lengthened, which would be illegal, of course. So the basic idea was a good one, but it could not be implemented. The implication here is that, since a longer wire is not allowed, in case a thrower did maintain contact with the (legal) hammer and its handle, the radius of the hammer path would be reduced and so there would not be an overall advantage. It is impossible to pull farther ahead with both arms straight and at the same time keep the same radius merely by turning the body more counterclockwise, because the impossibility of lengthening the wire would only allow the thrower to do such a thing by simultaneously shortening the radius (Dapena, 2011). In figure 4, if one considers translating the entire green hammer farther down and toward the left, to allow the handle to be in contact with the hands (tip of the triangle) that would surely shorten the radius.

To shorten the radius less, one would need to bend the right elbow, as in the red image of figure 5. Therefore, searching for an alternative, practitioners figured that, by bending the right elbow and wrapping the left arm across the trunk in a clockwise direction, the thrower could stay facing more counterclockwise, but still remain in contact with the handle. Superficially, this would seem to solve the problem. But it did not. The wire force lost its desired more forward-pointing orientation relative to the center of the path. In other words, just because the thrower is now facing more toward the left, does not necessarily mean that the thrower is also pulling

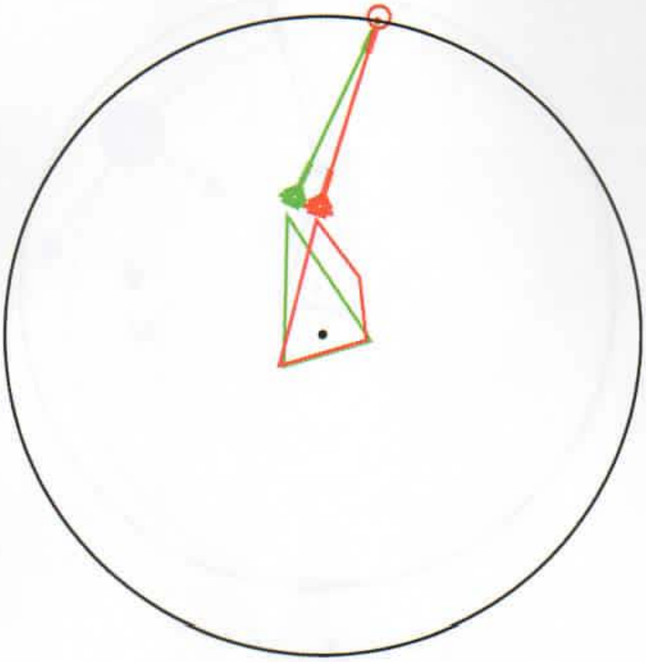

Figure 5. Bending of the right elbow (red lines), and wrapping of the left arm across the trunk, in a clockwise direction.

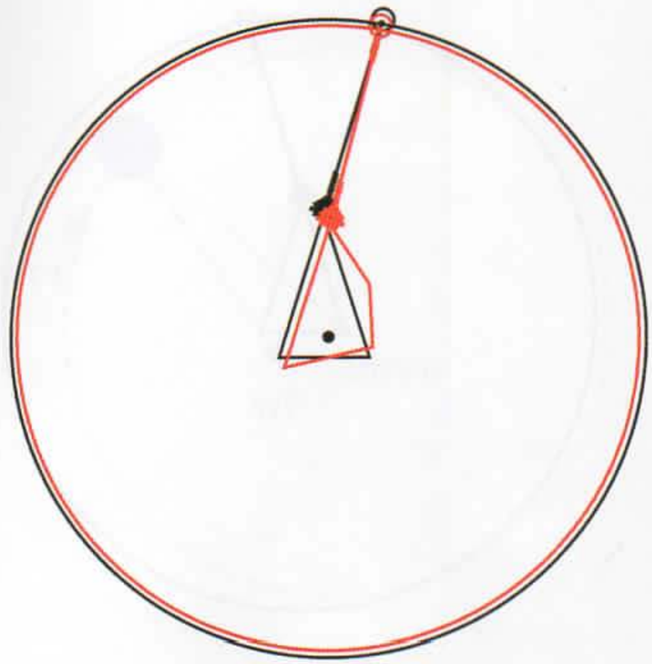

Figure 6. Comparison between a straight–arm and a bent right arm configuration in hammer throwing. The former provides for both a more advantageous pull of the hammer and a longer radius.

the hammer in a direction that is further ahead of the center of the path. In fact, by bending the right elbow, there will still be a slight shortening in the radius of the hammer path (figure 6).

The conclusion here is that, as one compares the straight arms position with the bent right arm position, the former allows for both a more optimum pulling of the hammer, that is, ahead of the hammer's center of path (even a slight advantage as shown in the picture), and also for a longer, albeit slightly, radius of the hammer path. Those two are the factors that explain the most regarding the differences between the two positions.

As hinted above, in real life, the direction of the wire pull will not point directly toward the left shoulder or the middle between the two shoulders, but toward a point somewhere between the left shoulder and the mid-point between the two shoulders (figure 7). This is so, because if the force points exactly between the two shoulders the force made on the hammer will be pointing less far ahead of the center of rotation of the hammer path, a less than optimum position. This, however, did not affect the present discussion, because the positions were kept the same for all the situations described above.

Some practitioners will claim that a disadvantage of turning, in the course of a hammer throw, by leading the hammer and with the right arm bent, may enable the thrower's body to rotate fast, but somehow the hammer itself will not rotate as fast as the body's rotation would indicate and, therefore this is the reason why hammer speed is compromised under those circumstances. It is not so.

First of all, if the body is made to rotate faster for whatever means, that does not mean that the hammer is going to have to rotate more slowly in absolute terms. It just means that the thrower will rotate faster, and thus that the hammer is going to rotate slower than before relative to the thrower. But so what? What counts is how fast the hammer rotates in absolute terms, not relative to the thrower.

It is true that, if the thrower were to rotate faster than the hammer and kept this up for a long enough period of time, there would be problems, because the thrower would not be able to twist his upper body clockwise enough to stay in contact with the hammer handle, and this, theoretically, could be a problem. However, if the thrower notices that his body is rotating farther and farther ahead of the hammer, he will surely slow down the hammer so that the thrower and the hammer have "ballpark" similar average speeds of rotation within each turn.

In summary, the practical implication is that pulling the hammer wire will not necessarily cause the hammer to increase its velocity. The crucial factor is the direction of the pull. If the thrower pulls behind the center of rotation it will cause a significant decrease in the hammer's velocity. The desirable effect is for the thrower to pull ahead of the center of rotation throughout the throw, although it seems that hammer throwers do pull both behind and ahead of the center of rotation, the former, for unknown reasons. Paradoxically, most of the force exerted by the athlete on the wire is used to keep the hammer along its circular path and only a small percentage is used for changing the velocity of the hammer. Therefore, optimum direction of hammer pull and maintenance of a wide radius path should be the two factors guiding the hammer thrower's actions

Figure 7. Actual optimum pull of the hammer. The hammer wire is aligned with a point somewhere between the left shoulder and the midline between the two shoulders.

for optimum performance.

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Some may think that when a mass spins around a fixed point, an additional force is generated which pushes that mass outwards, in the case of the hammer, keeping the wire stretched and away from the vertical. It is thought that this is the force that the hammer thrower has to counteract using her own weight. That force is often called the centrifugal force but it is, however, illusory as it does not exist. When a body is moving, it wants to stay moving in a straight line. For it to move in a circle, it must be acted on by a force acting inwards towards the center to keep its trajectory circular. This inward force does exist and it is called centripetal, and in this narrative it is called the wire pull (WP). The term centrifugal force has come about by the misconception that there is a force that acts in the opposite direction (reaction) to the centripetal force. The pull that the hammer thrower experiences is the force that has to act towards the center to keep the hammer head from flying off tangentially, until it is released. The so called "centrifugal" force is a virtual or fictitious force.

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