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SOME BIOMECHANICAL ASPECTS OF HAMMER THROWING

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A hammer throw consists of 2 or 3 "preliminary winds", in which both feet are kept in contact with the ground, followed by 3 or 4 "turns", in which the thrower rotates with the hammer. The speed of the hammer increases gradually in the winds and the turns, up to the instant of release at the end of the last turn.

The hammer ball moves in a relatively flat plane during the early part of the throw, but the plane tilts more in each successive turn, and reaches a slope of about 40° in the last turn. The final slope of the hammer plane is very important for the parabolic flight of the hammer: The key for a long throw is a large hammer speed at release, together with a good angle for the initial trajectory with respect to the horizontal plane.

Both feet are in contact with the ground during the preliminary winds, but there are single-support (SS) and double-support (DS) phases during the turns. Also, through pivoting on the heel and on the toe of the left foot, the combined thrower + hammer system slowly translates horizontally across the throwing circle during the turns.

The motion of the hammer with respect to the ground can be considered the sum of three separate motions: (1) a circular motion of the hammer around the athlete, (2) a gradual change in the tilt of the hammer plane, and (3) a horizontal translation of the whole system across the throwing circle. The sum of these three motions produces a fairly complex motion of the hammer ball relative to the ground.

Most researchers have tried to look at the total motion of the hammer ball relative to the ground, but the complexity of this motion makes it difficult to interpret how the throw works. In our laboratory, we prefer to look separately at the rotation of the ball, the change in the tilt of the hammer plane, and the horizontal translation of the thrower + hammer system, and then put this information together in the end to understand the total motion of the hammer ball. We have found that this approach facilitates very much the interpretation of the mechanisms involved in hammer throwing.

To keep the hammer ball in its circular path, the thrower has to exert on the hammer ball a centripetal force (a force pointing toward the center of the circular path followed by the ball). This force is exerted through the cable, and it can reach very large values (over

700 lb in the last turn of a world record throw). In reaction, the cable pulls on the hands of the thrower with an equal and opposite force. This reaction force pulls forward on the thrower.

One might expect the thrower to use large frictional forces between his feet and the ground to resist against being pulled forward, as in a tug-of-war, but the mechanisms involved in hammer throwing are very different from those involved in a tug-of-war. It is more accurate to think of the thrower and the hammer as a double-star system, with a small star and a large star rotating about their common center of mass (c.m.). As explained previously, the force made on the hammer ball through the cable serves to keep the ball in a circular path; in the same way, the reaction force exerted on the hands of the thrower does not make the thrower fall forward; it simply keeps the thrower in his own circular path. Therefore, contrary to what happens in a tug-of-war, the hammer thrower, in order to stay in place, does not have to push forward on the ground with his feet.

That is how the thrower keeps the hammer in its circular path. However, it is not enough to keep the hammer in a circular path: The thrower obviously needs also to increase the speed of the hammer.

Some people have followed a very simple logic to explain this. They assume that it is easier to produce a rotation about a vertical axis when both feet are in contact with the ground than when only one foot is in contact with the ground. And this seems to make sense (at least, superficially). Following this logic, it was concluded that the effective phase during each turn is the DS phase, because during that time it is possible to increase the speed of the hammer without making the body rotate in the opposite direction. According to this theory, the SS phase serves only for "recovery", that is, it serves only to prepare for the next DS phase.

Measurement of the speed of the hammer using three-dimensional film analysis techniques has shown that the speed of the hammer increases in each DS phase, and stays constant or decreases in each SS phase (Figs. 1a and 2a). This supports the theory presented above.

It was concluded that, to obtain optimum results, hammer throwers should maximize the time spent in DS during each turn, which also implied that they should minimize the time spent in SS.

The description of how this might be achieved will be facilitated by referring to azimuthal angles in the explanations. The azimuthal angle at any particular time is defined as a counterclockwise angle visible from an overhead view, and it describes the position of the hammer ball relative to the thrower. (The direction of the theoretical line that bisects the landing sector is the 180° azimuthal angle; the direction which the thrower faces during the preliminary winds coincides approximately with the 0° azimuthal angle; the direction of the left shoulder relative to the body during the preliminary winds coincides approximately with the 90° azimuthal angle.) During each DS phase, the hammer ball normally travels from an azimuthal angle of about 230/250° to one of about 40/60° (that is, about half the turn); the SS phase comprises the rest of the turn.

A method that has been proposed for minimizing the duration of the SS (and, therefore, for maximizing the duration of the DS) is to keep the right foot close to the body during the SS phase. This should speed up the rotation of the thrower during SS (following the same mechanism that figure skaters use to increase their speed of turning), which, in turn, should permit the thrower to rotate sooner into a position in which he can plant the right foot on the ground.

Another method that has been proposed for shortening the SS phase is early planting of the right foot. Normally, the feet should be expected to point roughly toward the 0° azimuthal angle during the DS phase, and film analysis shows that this is what some throwers do (allowing for about 45° of "toeing out" with each foot). But some time ago, a Soviet thrower invented a modified technique. In this technique, the right foot is planted on the ground when it is still pointing in the direction of the 270° azimuthal angle. The athlete then pivots on the ball of the foot to allow the hips to face the 0° azimuthal direction. This technique allows the thrower to plant the right foot earlier, and therefore it shortens the SS phase and lengthens the DS phase.

These two "tricks" (keeping the right leg close to the body, and landing with the right foot pointing toward the 270° azimuthal angle) are generally considered very helpful in hammer throwing technique because they contribute to produce a longer DS phase in each turn. However, their usefulness is based on the assumption that the very simple model proposed above is correct. And we are going to see now that this model is not accurate enough: It is too simplistic.

Since film analysis showed that hammer speed increases only during DS, this contributed to support the original theory. However, it did not necessarily prove it. Just because two things coincide in time does not necessarily imply that one causes the other: It could be a mere coincidence. In other words, it is possible that other factors might be the true causes for the fluctuations, and the increases in hammer speed may just happen to coincide with the DS phases.

One of these factors could be gravity. As the hammer ball moves in a tilted plane, it travels alternately uphill and downhill, and this would contribute to produce a fluctuation in hammer speed.

Another factor that could produce fluctuations in hammer speed is the horizontal translation of the thrower + hammer system across the throwing circle. To explain this mechanism, consider a large turntable that rotates counterclockwise about a vertical axis with constant angular velocity. Let us assume that the angular velocity is such that a small piece of paper glued near the edge of the turntable has a constant linear speed of 25 m/s. If we then push the turntable and make it translate horizontally across the floor at a constant speed of 1 m/s (imitating what happens in a hammer throw), the speed of the piece of paper will not be constant anymore: When the piece of paper reaches the 90° azimuthal angle, its speed will be (25 + 1 =) 26 m/s; when it reaches the 270° azimuthal angle, it will be (25 - 1 =) 24 m/s. Therefore, the speed of the piece of paper will fluctuate between 24 and 26 m/s in every turn, due to the combination of the rotation at constant angular velocity and the forward translation at constant linear velocity.

In a computer simulation at our laboratory, the cumulative effect on hammer speed by gravity and by the horizontal translation of the thrower + hammer system was subtracted from the total hammer speed. This produced graphs showing the pattern of hammer speed generated by all factors other than gravity and the horizontal translation of the system. The fluctuations almost disappeared in some of the throwers (Fig. 1b). This implied that in these throwers practically all of the fluctuation in hammer speed was due to the combination of gravity and the horizontal motion of the system, and not to being in SS or DS.

In other throwers, a clear-cut fluctuation in hammer speed remained even after subtracting out the effects of gravity and of the forward motion (Fig. 2b). Perhaps in these throwers the DS phase does have a true causal influence on the increase in hammer speed. But it is also possible that other causal factors may be involved in the hammer speed fluctuations (factors other than gravity and the forward motion), and thus it is not certain that the hammer speed fluctuations in these throwers are caused by the alternation of SS and DS.

If a long DS phase is not quite so important, why isn't it? What could be wrong with the theory? The major flaw may be that the theory only considered rotation about a vertical axis (that is, motion on a horizontal plane), when the rotation of the hammer actually takes place on an inclined plane. Therefore, yes, there is a component of rotation about the vertical axis: This is visible as a counterclockwise rotation when observed from an overhead position (Fig. 3c). But, since the hammer ball moves on a tilted plane, there is also a component of rotation about a horizontal axis. This second component of rotation is visible as a counterclockwise motion of the hammer in a horizontal view from the 0° azimuthal angle (Fig. 3a).

Given these considerations, it is clear that, in order to increase hammer speed, it is not sufficient to obtain from the ground a torque (or "moment of force") about a vertical axis; it is also necessary to obtain a torque about a horizontal axis. Furthermore, the results of research at our laboratory indicate that only a small part of the increase in hammer speed during the turns is associated with torque about the vertical axis; surprisingly, most of it is associated with torque about the horizontal axis.

Let us see now how the thrower obtains torque about the horizontal axis. During single-support, the torque is produced automatically, because the point of support (the left foot) is not directly beneath the athlete, and the vertical force made by the ground on the left foot exerts a torque about a horizontal axis passing through the c.m.

If a person who is standing with both feet on the ground suddenly removes the right foot from contact with the ground (without making any previous adjustments), there will be a tendency for the person to tilt toward the right, rotating about a frontal axis. However, that does not happen in the hammer throw. This is because the torque that the thrower receives from the ground is transmitted to the hammer. The net result is that the thrower does not fall down, even though his point of support is not directly under his own c.m., and, at the same time, the hammer speeds up.

The thrower can also obtain torque about the horizontal axis during the double-support phase. This can be achieved in two ways: (a) by pressing harder on the ground with the left foot than with the right foot; and/or (b) by making similar vertical forces on the ground with both feet, but keeping the c.m. of the thrower + hammer system closer to the right foot than to the left foot, instead of half-way between them.

In sum: It is an oversimplification to think of a hammer throw as a rotation about a purely vertical axis; it is a rotation about an inclined axis, with components of rotation about vertical and horizontal axes. While it is possible that the rotation about the vertical axis may be produced best during the DS phase, the rotation about the horizontal axis can be produced both during the DS and the SS phases. The main conclusion, from a practical standpoint, is that the SS phase of hammer throwing does not have to be simply a recovery phase, but a phase in which the thrower can actively increase the speed of the hammer. Therefore, the achievement of a long DS phase may not be as important as most practitioners think.

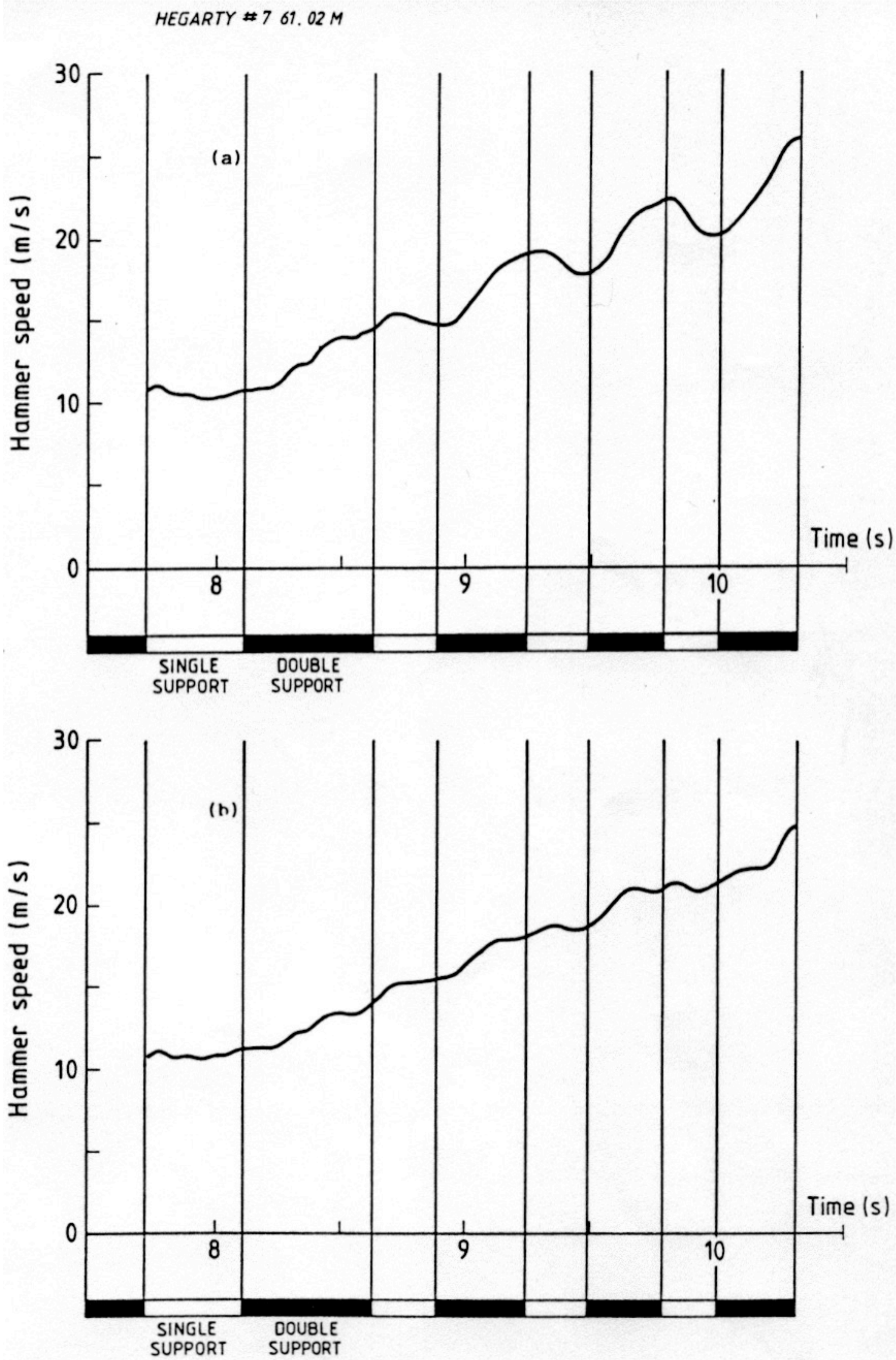

Figure 1. Speed of the hammer ball: (a) absolute speed; (b) speed after corrections for gravity and for the forward translation. In this thrower, the hammer speed fluctuations practically disappeared after the corrections.

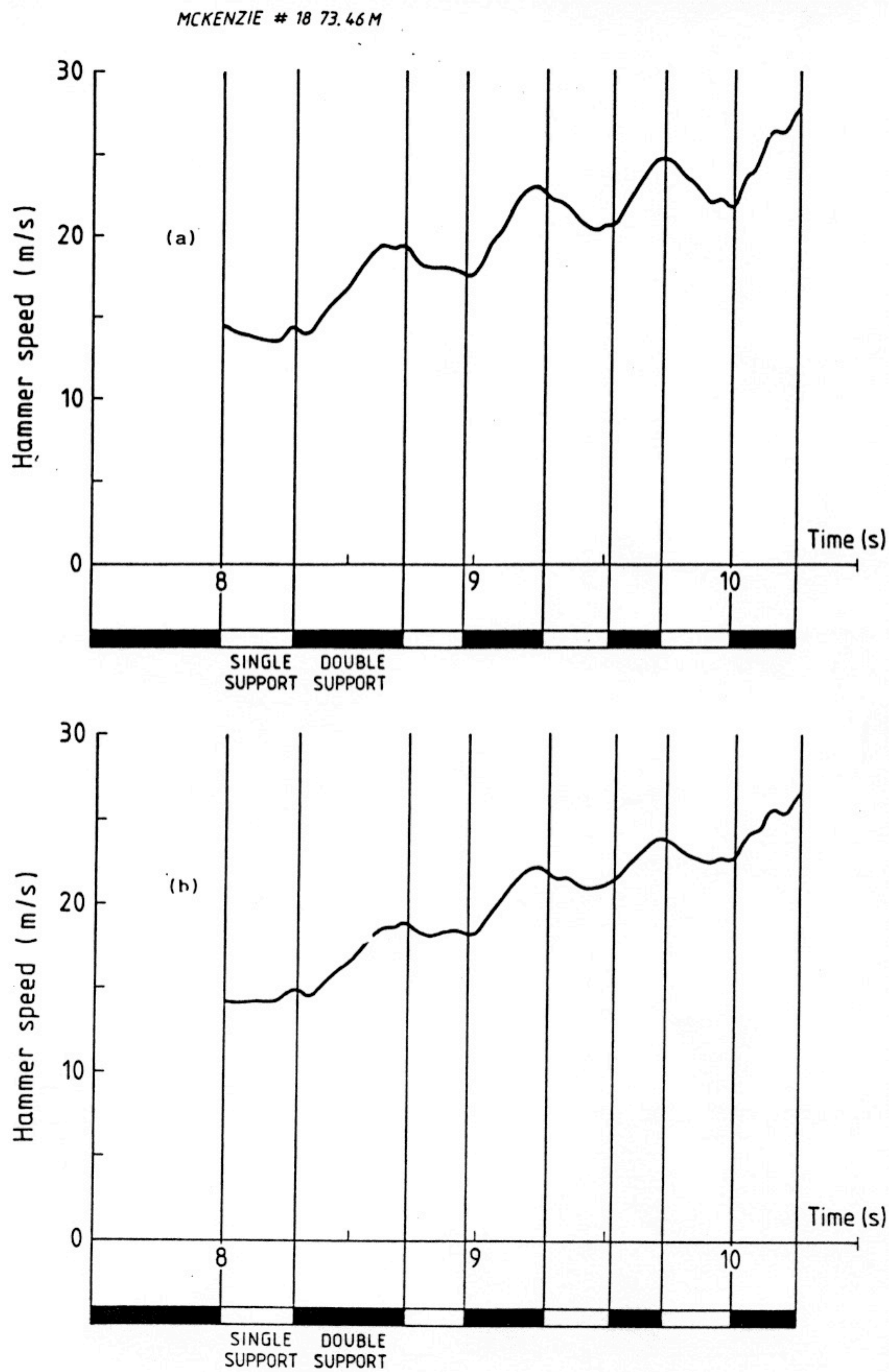

Figure 2. Speed of the hammer ball: (a) absolute speed; (b) speed after corrections for gravity and for the forward translation. In this thrower, marked fluctuations remained after the corrections.

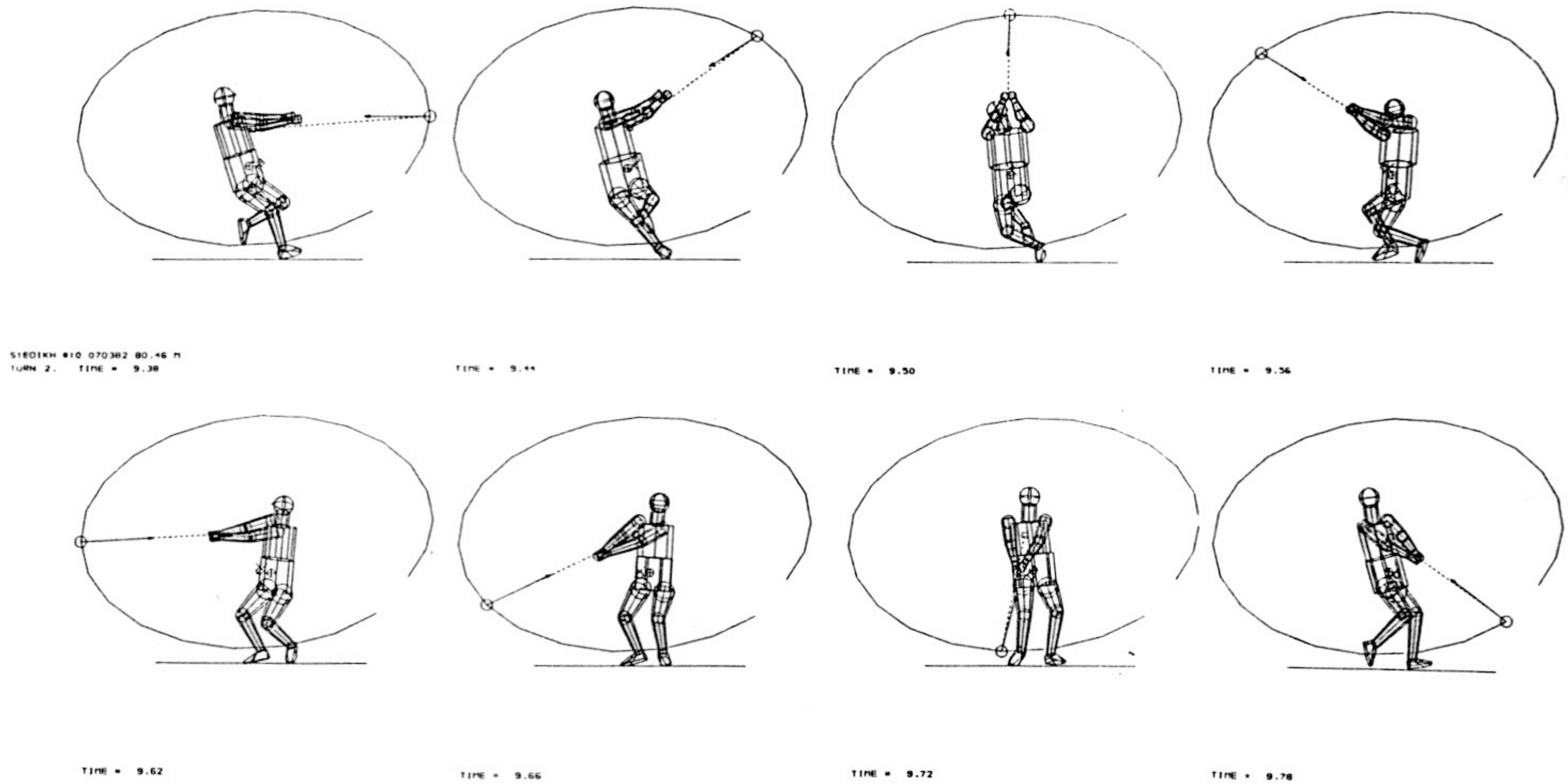

Fig. 3(a). Sequence of the second turn of a thrower viewed from the rear of the circle.

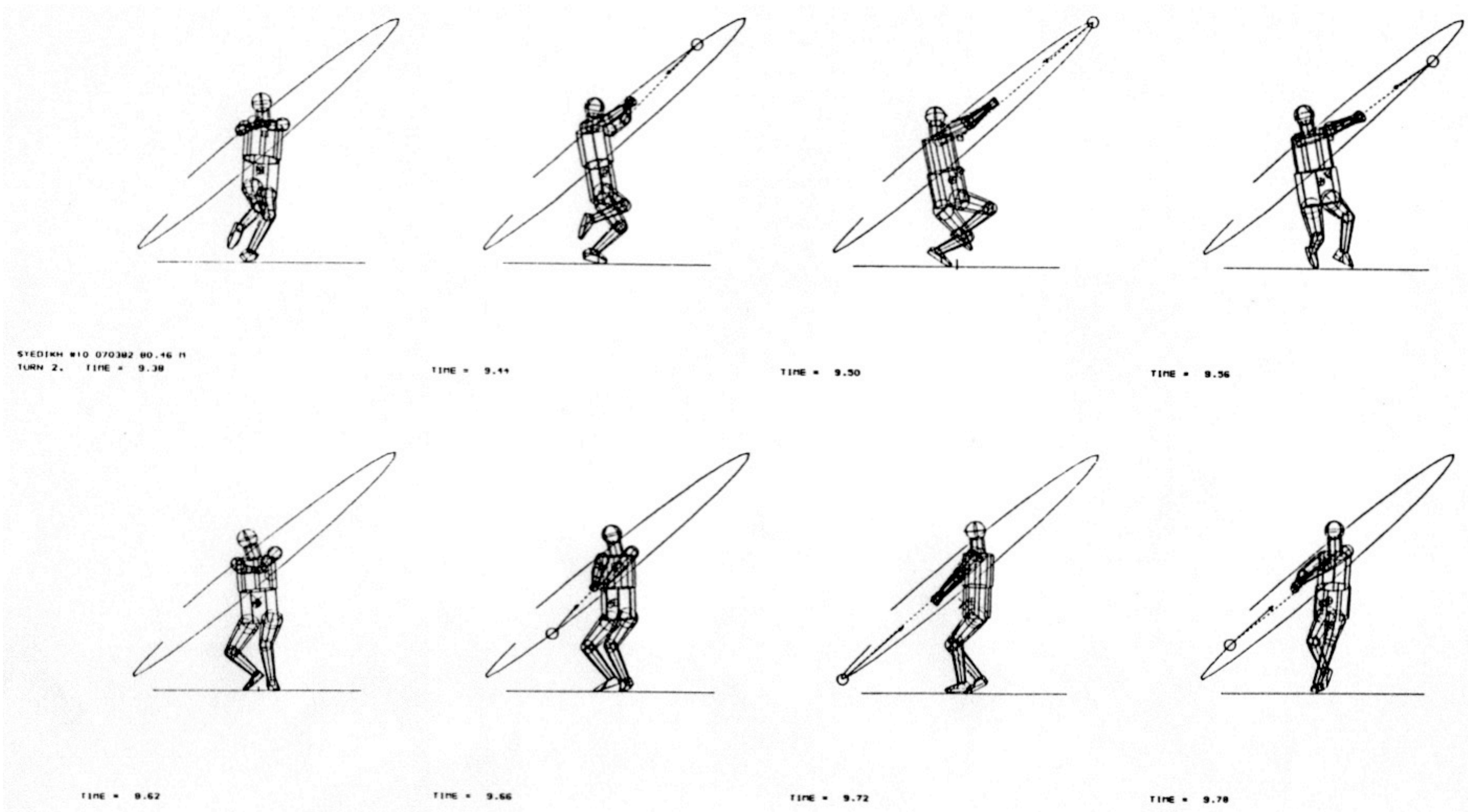

Fig. 3(b). Second turn viewed from the side of the circle

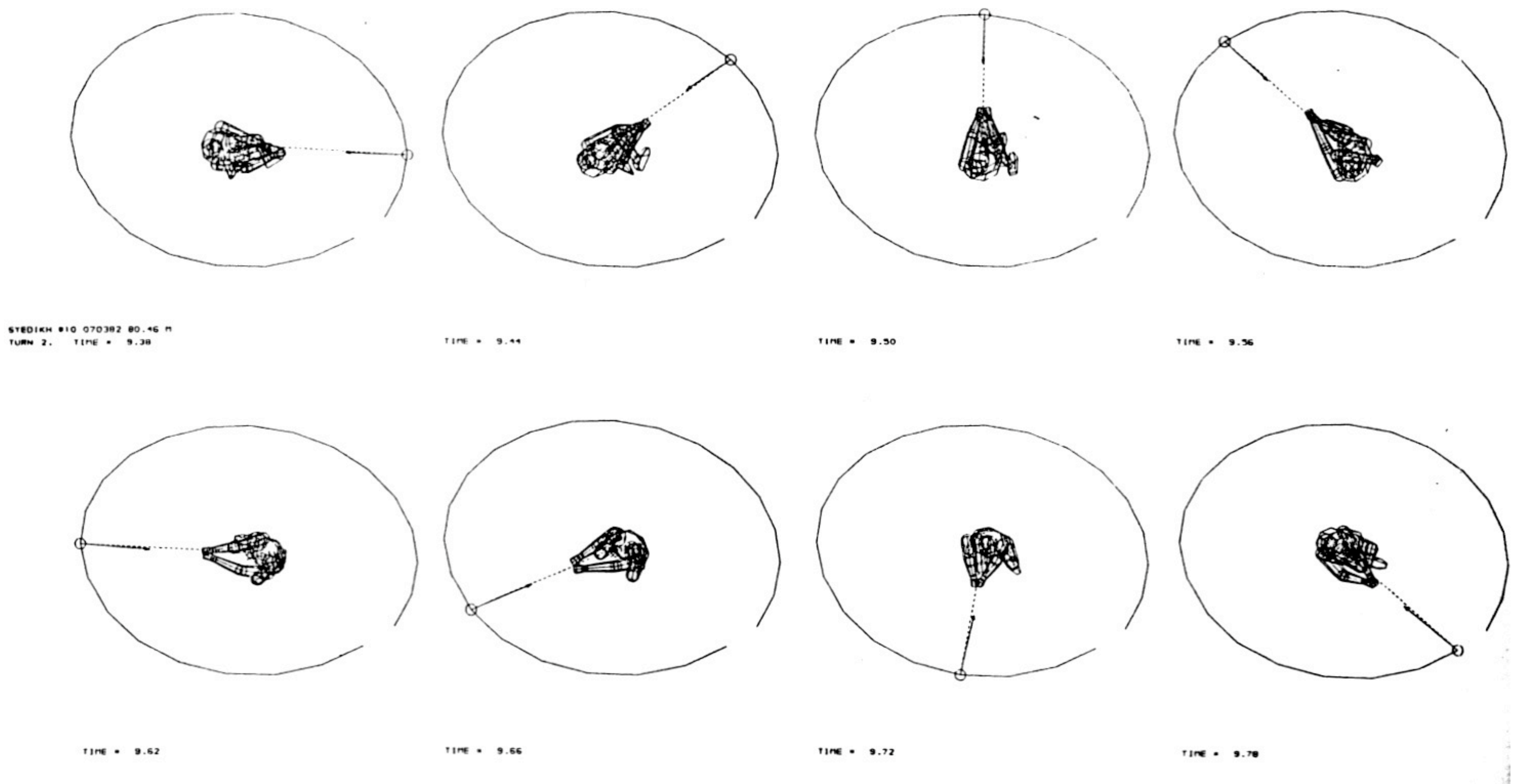

Fig. 3(c). Second turn viewed from overhead.

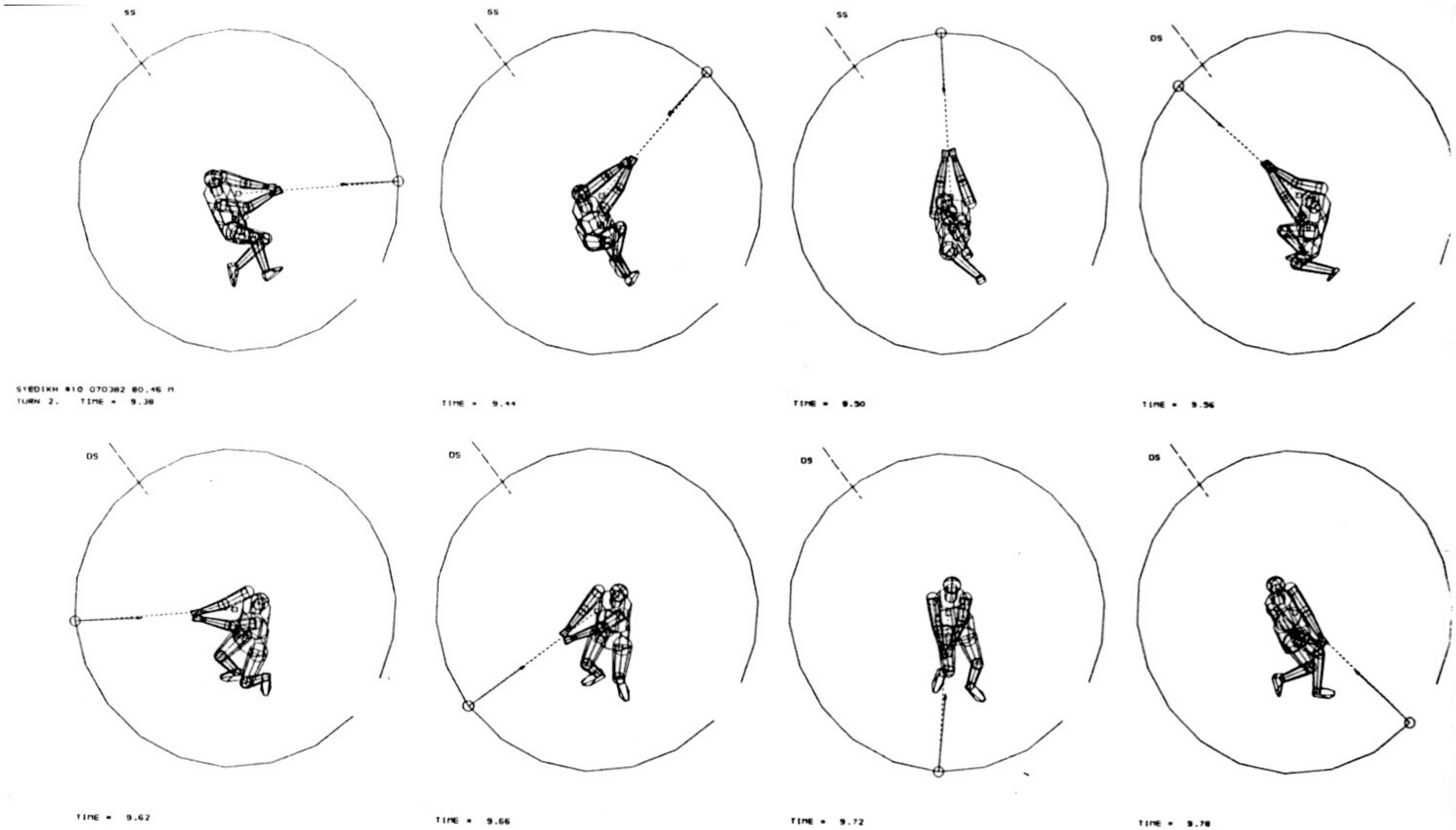

Fig. 3(d). Second Turn viewed along the perpendicular to the hammer-plane.