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The Horizontal Translation in Discus Throwing

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THE HORIZONTAL TRANSLATION IN
DISCUS THROWING

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On average, the forward linear momentum of the thrower-discus system contributes six percent of the horizontal speed of the discus at the moment of release, while the angular momentum around the vertical axis contributes the remaining 94 percent (Maheras, 2008). Therefore, the contribution of the forward linear momentum to the speed of the discus is quite small. However, it is not negligible and warrants attention particularly during the thrower's action in the back of the circle. More specifically, during the double-support phase in the back of the circle, the thrower makes horizontal so-called "pull-push" forces against the ground (figure 1) and the ground reaction to those forces generate most of the angular momentum around the vertical axis that the thrower will need for the throw. Similarly, forward horizontal linear momentum is generated in the early stages of the throw and it makes the system translate horizontally across the circle (figure 2). An analogy can be used here to explain the purpose of giving forward linear momentum to the thrower-discus system. That is, one can compare the discus thrower with a ship firing a cannon. If the ship, firing the cannon, is traveling forward as the cannon is fired, the forward speed of the ship is added to the forward speed of the projectile. This results in a larger total horizontal speed of the projectile as compared to a condition where the ship would be stationary when it fired the cannon. The forward motion of the thrower-discus system contributes to the speed of the discus at release and the thrower, indeed, needs to take advantage of this (admittedly limited) forward motion as much as possible contribution to the overall speed of the discus at release.

IDEAL VS. REAL HORIZONTAL TRANSLATION OF THE SYSTEM'S CENTER OF MASS

Ideally, it seems that during the double support phase in the back of the circle, the thrower should shift the system's center of mass to a position that is almost directly above the left foot, which is the time that the thrower starts generating the system's angular momentum around the vertical axis as she rotates counterclockwise. Following, after the thrower is facing towards the direction of the throw, she should thrust directly backward on the ground with the left foot. This way, the large and slightly off-center ground reaction force provides a large amount of linear momentum and additional angular momentum to the system. The thrower would then translate directly forward across the circle. During the double support delivery phase, the large horizontal linear momentum of the system will enable the thrower to obtain upward linear momentum at the expense of some loss of horizontal linear momentum. The upward linear momentum would further enable the thrower to generate vertical speed for the discus while the leftover horizontal speed would help in the generation of the horizontal speed of the discus (Maheras 2009).

In reality though most throwers do not move that way. Figure 3 shows a typical path of the center of mass at the instant that the discus reaches its most backwards point, at the take off of the right foot, at the take off of the left foot, at the landing of the right foot, at the landing of the left foot and, at release. During the double-support phase at the back of the circle, throwers tend to shift the position of the center of mass of the system in a diagonal fashion which, from the point of view of the thrower, expresses a shift toward the left and backwards (front of circle). The mental image that the thrower may have is that of displacing the center of mass to a position more or less directly above the left foot, before pushing off across the circle, but this does not usually occur (Hay & Yu, 1996a, 1996b). Although this is the case, Hay & Yu (1996b) addressed the fact that the closer the center of mass is to being in line with the left foot at take off in the back of the circle, the less the probability of the thrower having the left foot too far to the side (in the bucket) during the release effort. It is rather common then that, even with experienced throwers, the center of mass gets closer to the vertical of the left foot but does not reach it. Therefore, at the time that the left leg starts its main horizontal thrust against the ground, the center of mass is ahead and to the left of the position of the left foot (figure 4). Consequently, the thrust of the left foot against the ground is not directly backwards but in a rather oblique direction backwards and toward the right. The reaction force from the ground is forward and toward the left (figure 4). In turn this makes the system's center of mass travel in an oblique direction across the throwing circle, that is, forward and toward the left (figure 3).

OBLIQUE VS. DIRECT BACKWARD FORCES

Since this type of action deviates from what may be ideal, the question arises as to what may be the disadvantage of such a technique. Generally the oblique nature of the direction of the motion of the system's center of mass should not present any problems for the generation of the vertical speed of the discus. As long as the horizontal speed of the system is large, it should help the thrower obtain vertical linear momentum during the double-support phase at delivery, regardless of whether the horizontal translation is directly forward or more oblique.

On the other hand, there may be an issue for the generation of the horizontal speed of the discus. The more oblique the direction of the motion of the system's center of mass with respect →

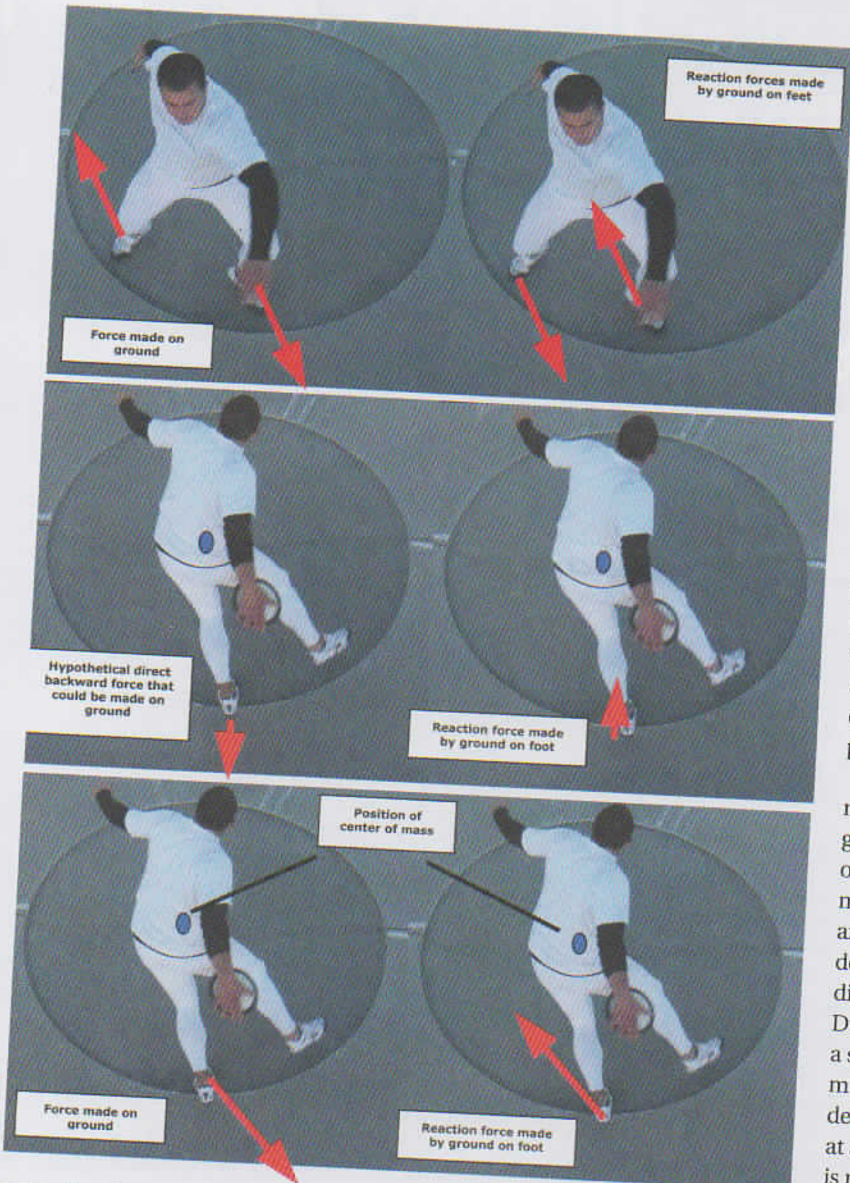

FIGURE 1. "Push-Pull" forces, made by feet on the ground, generating angular momentum during the initial double support in the back of the circle. FIGURE 2. Forward linear momentum in the early stages of the throw. FIGURE 3. Approximate path of the center of mass at the instant: the discus reaches its most backwards point (1), at the take off of the right foot (2), at the take off of the left foot (3), at the landing of the right foot (4), at the landing of the left foot (5) and, at release (6).

to the final horizontal direction of the motion of the discus after release, the smaller the contribution of the horizontal speed of the system to the horizontal speed of the discus at release. Considering the ship-cannon example described earlier, if the ship's cannon does not fire directly forward but at an angle with respect to the direction motion of the ship, the two speeds, the horizontal speed of the ship and the oblique horizontal speed of the projectile relative to the ship, do not exactly add up. Theoretically, this may pose a problem for the thrower.

Instead of pushing in an oblique fashion, a thrower may decide to push directly backward on the ground as shown in figure 5, in opposition of what is shown in figure 4. If the thrower chooses to do this when the system's center of mass is forward and to the left of the position of the left foot, as it happens in most throws, the force that the thrower will be able to exert on the ground would be much smaller than if the push were made in the standard oblique direction shown in figure 4. This may not present a problem regarding the rotation of the system. That is because the small ground reaction force as shown in the right of figure 5, points more off center with respect to the center of mass than the oblique ground reaction force shown in figure 4. For the generation of the angular momentum around the vertical axis this would tend to compensate for the size of the force. However, there may be a problem regarding the translation of the system. That is because the small size of the horizontal ground reaction force as shown in figure 5, would significantly reduce the horizontal speed of the system across the circle. This would tend to limit the contribution of the system's linear momentum to the horizontal speed of the discus at release. Also, a lower speed of horizontal translation would also make it more difficult for the system to obtain upward linear momentum during the delivery phase. A limited amount of upward linear momentum would result in a limited contribution to the vertical speed of the discus at release. All in all, this approach does not seem promising (Dapena & Anderst, 1996).

In good throwers (throwing between 58 and 60 meters), at the time the left foot loses contact with the ground in the back of the circle, the system's center of mass is traveling horizontally at approximately 2.4 m/s. The direction of the motion is oblique, forward and toward the left at an angle of approximately 23 degrees to the left. During the airborne phase the direction of motion and the speed remain constant. During the single support on the right foot, there is a small loss of horizontal speed in the order of 0.4 m/s. During the left foot landing at the start of the delivery phase the horizontal speed of the system is at approximately 2.0 m/s and its direction of motion is roughly similar to that in the back of the circle during left foot take off. During the delivery phase the horizontal speed decreases further by another 0.7 m/s. By the time the discus is released the system's center of mass has a horizontal speed of 1.3 m/s. The direction of motion is similar to that in the back of the circle when the left foot took off from the ground at approximately 22 degrees. This loss of horizontal speed of the system's center of mass during the delivery phase serves two purposes: a) it prevents the thrower from fouling and b) it allows the generation of upward linear momentum which is useful for the generation of the vertical speed of the discus.

DIVERGENCE ANGLE

In general then, the average horizontal direction of the motion of the system's center of mass is in a diagonal direction forward and toward the left. The horizontal direction of the motion of the discus after release varies but the average is four degrees and it points forward and to the right. The difference between the two angles indicates the divergence between the horizontal paths of the system and that of the discus. The size of the divergence angle determines how much of the horizontal speed that the system's center of mass had in the last quarter turn, effectively contributes to the horizontal speed of the discus. The larger the divergence angle, the greater the loss in the contribution of the horizontal speed of

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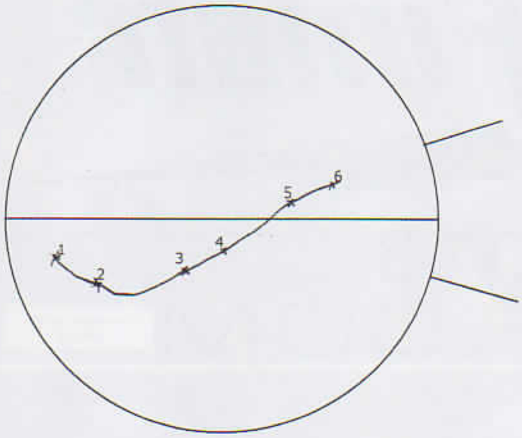

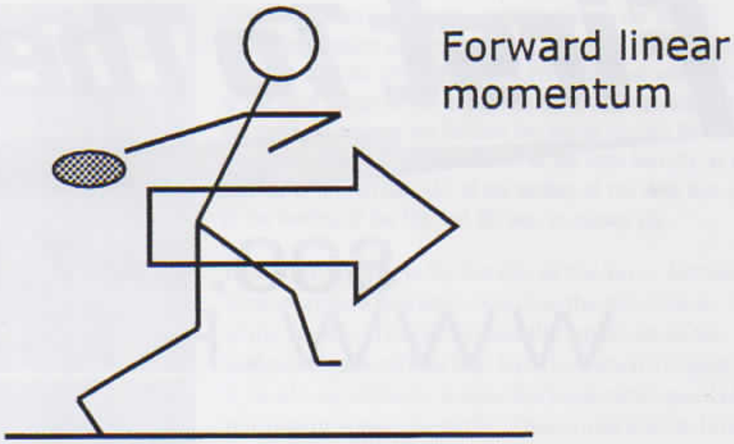

FIGURE 4. Generation of linear momentum during the first single support in the back of the circle. It is generated by an off center ground reaction force passing to the right of the center of mass of the thrower+discus system. This would probably be the preferred technique during the drive to the middle of the circle. FIGURE 5. Hypothetical direct backward force that could be made on the ground by the left foot during the first single support in the back of the circle. The assumption here is that the center of mass of the thrower is not directly over the left foot. The forces depicted here are small and the execution of such technique would probably not be good.

the system to the horizontal speed of the discus and, consequently the greater the loss in the distance thrown. According to Dapena & Anderst (1996) the losses increase at first gradually up to -20 degrees but at a higher rate after that value (the negative sign indicates that system's center of mass is moving on average toward the left with respect to the eventual horizontal direction of the motion of the discus at release). If the divergence angle is kept within reasonable levels the loss in distance is quite small. In an average 61.00-meter throw the contribution of the horizontal speed of the system to the horizontal speed of the discus at release is at approximately 1.2 m/s, only 0.1 smaller than the horizontal speed of the center of mass at release which is at 1.3 m/s. Given an average horizontal speed of the discus at release at 19.3 m/s, the 0.1 m/s loss due to the divergence of the paths of the center of mass and of the discus is about one half of one percent (0.1/19.3) of the total horizontal speed. In a hypothetical throw in vacuum this would reduce the distance of the throw by about 0.30 meters in a 60-meter throw. In a real-life throw, with the all the aerodynamic forces that act on the discus, the loss would be greater. The exact amount will depend on the wind and will result in a loss between 0.30 and 0.50 meters. On the other hand, when the divergence angle reaches –50 degrees, the loss of the horizontal speed due to the divergence is at an average of 0.46 m/s, and the loss in distance thrown is between 1.4 and 2.1 meters depending on the aerodynamic forces.

CONCLUSIONS, PRACTICAL APPLICATION

Experienced practitioners have always suggested that the discus thrower a) pivot/transition/balance well over the left foot during the turn in the back of the circle and b) attempt to move in a generally straight line across the circle. One of the reasons for this has to do with the proper generation of forward linear momentum and the horizontal velocity of the system's center of mass.

Ideally, the thrower should shift the center of mass to a position that is almost directly above the left foot, and then push directly backward on the ground to obtain a good drive directly forward across the circle. However, the exact execution of this movement is not practical. Coaches should avoid suggesting that the center of mass strictly pass over the left foot. Therefore, if the thrower fails to bring the center of mass close enough to the vertical of the left foot, as most throwers do, the thrower should make a strong horizontal drive across the circle in an oblique direction. In this case it would not be a good idea to attempt to push directly backward on the ground as shown in figure 5, because the forces generated in this instant are too small and not optimal for linear momentum generation. As long as the discus thrower drives across the circle at a moderate oblique angle toward the left and does not throw the discus too far to the right so that the divergence angle does not reach values beyond -20 degrees, there will not be a significant loss in the distance thrown. Coaches should always be aware of the direction the thrower is moving across the circle, particularly in relation to the direction of the released discus. That is because if the divergence angle reaches higher values, there can be significant losses in the thrower's performance. This implies that even in the case where the left foot lands in the "bucket," if the thrower is able to follow the left foot (move towards that direction) and throws towards that line, as experienced throwers do, then the thrower should be OK. Although in the majority of all discus throwers the center of mass never reaches vertical over the left foot, the closer the center of mass is to being in line with the left foot at take-off in the back of the circle, the lower the probability of the thrower having the left foot too far to the side (in the bucket) during the final release effort.

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