ANGULAR MOMENTUM ANALYSIS OF MEN'S DISCUS THROWERS IN 1998 USA TRACK & FIELD CHAMPIONSHIPS

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Twenty-five discus throwers for USA Track & Field Championships 1998 were videotaped and analyzed using the three-dimensional (3D) DLT method. 3D coordinates of body segments and discus were then obtained. Angular momentum (H) of the thrower and discus was calculated using the link-segmental inverse dynamics approach. Positive H_Z for the thrower-plus-discus system was produced during the initial double-support and first single-support phases. Negative H_X for the system was a large increase, prior to, or in correspondence with the increase of the negative H_Y, during the latter half of the second single-support phase and the delivery phase. It seems reasonable to conclude that the increase of vertical speed of the discus (negative H_Y of the system) results from the interaction between the positive H_Z and the negative H_X of the system during the second single-support and delivery phases. This paper discusses the mechanism ("Gyro Model") for the discus throwing motion, based on the principle of the gyroscope.

KEY WORDS: discus, angular momentum, principle of gyroscope

INTRODUCTION: The discus throw (right-handed thrower) was divided into five phases (Dapena, 1993a): (1) initial double-support (DS1), (2) first single-support by the left foot (SS1), (3) non-support (NS1), (4) second single-support by the right foot (SS2), and (5) delivery phase (DV). The roles of these phases have not surely been clear (Dapena, 1993b). Recently, Dapena (1993a) completed a three-dimensional (3D) kinetic analysis of the angular momentum of the discus thrower. He found that the increase of the horizontal speed of the discus was closely linked with the angular momentum of the "system (thrower-plus-discus)" about the vertical axis, markedly increasing during the DS1 and the early part of the SS1. For this, he concluded that those phases were much more important phases for the discus. However he did not consider the influence of the angular momentum of the system about the right-left (X) axis (vertical to the direction of throw) on the velocity of the discus. It is not clear that his theory is applicable to other athletes.
The purpose of this study was to re-examine the Dapena's theory with a 3D angular momentum analysis for the USA top discus athletes, and also to propose a new mechanism ("Gyro Model") for the discus throwing motion.

METHODS: Filming procedures. Twenty-five, right-handed male discus competitors for the USA Track & Field Championships 1998 were filmed with two Panasonic 456 UP S-VHS video camcorders at 60 frames/s. The camcorders viewed the throwers from the rear and from the right (toward the direction of the throw) side. The best records of each thrower were selected for subsequent data processing. The mean distance of the analyzed throws was 57.76±4.72 m (range: 47.21 m-67.09 m).
Data Acquisition: Locations of 24 anatomical body landmarks (vertex, center of head, distal end of metacarpal III, wrist joint, elbow joint, shoulder joint, 12th rib, hip joint, knee joint, ankle joint, calcaneus, distal end of metatarsal I, distal phalange) and the center of the discus for each view were manually digitized by the Motion Analysis VTR System (*Frame-DIAS*, DKH Inc., Japan). 3D coordinates of the body landmarks were reconstructed by the 3D direct linear transformation (DLT) procedures (Abdel-Aziz, & Karara, 1971). They were expressed in a right-handed orthogonal, inertial reference frame: the Z-axis was vertical and pointed

upward, the Y-axis horizontal and at the direction of the throw, and the X-axis perpendicular to the other two (Dapena, 1993a). The 3D coordinates were then smoothed by a butterworth low-pass digital filter (a fourth-order zero-lag filter) at selected optimal cutoff frequencies (range: 3.6 Hz-9.6 Hz) for each coordinate using the residual analysis method (Winter, 1990).

Computation of angular momentum. A 15-segment model of 15 elements (hands, forearms, upper arms, thighs, legs, feet, head, upper torso, lower torso) was employed to determine the angular momentum of the thrower. The angular momentum (H) values of the thrower, the discus and the system were computed using algorithms reported in a previous study (Miyanishi, Sakurai, & Wakayama, 1997). All angular momentum (local term) components about three orthogonal axes passing through its center of mass (CM) of each segment were computed, except for those about the longitudinal axis of segment where the head, hands, forearms, upper arms and feet were assumed to be zero. The mean values of the inertial properties (mass, CM, moment of inertia) of the top Asian discus throwers (Miyanishi et al., 1997) were used for all body segments. Calculations were based on the method proposed by Ae, Tang, & Yokoi (1992).

RESULTS AND DISCUSSION: Time analysis. The time period (n =25) from the end of the backswing until the instant of the release was 1.41±0.14: DS1 for 0.59±0.10 s, SS1 for 0.37±0.04 s, NS1 for 0.09±0.03 s, SS2 for 0.20±0.04 s, and DV for 0.16±0.03 s. The time periods for the DS1, SS1 and NS2 were similar in those times reported in a previous study (Gregor, Whiting, & McCoy, 1985). However, the time periods for the SS2 and the DV were longer and shorter respectively than for previously reported studies (Gregor et al., 1985; Miyanishi et al., 1997).

Angular momentum. Figure 1 shows the typical predominant pattern in the angular momentum for the discus throwers. The positive H_Z of the system was produced mainly during the DS1 and the SS1. And also, the negative H_Y of the system increased during the latter part of the SS2 and the early part of the DV. These results correspond fairly closely to the data reported by Dapena (1993a). However the negative H_X of the system was markedly greater during the latter half of the SS2 and the DV. Also, the negative H_X of the system increase prior to, or in correspondence with the increase of negative H_Y.

Dapena (1993ab) did not consider the negative H_X of the system appeared during the latter half of the SS2 and the DV. Since the system has been generating a large positive H_Z at the instant of the right foot contact of the SS2 (See Figure 1), the principle of the gyroscope could be applied to the increase in the negative H_Y of the system (vertical speed of the discus) as following.

Model for discus ("Gyro Model"). Figure 2 shows a schematic diagram of the principle of the gyroscope for the discus throwing motion, using a wheel. The principle of the gyroscope indicates that, when the wheel is initially rotating about the Z-axis with a high-speed (Figure 2a), the negative angular rotation about the Y-axis (Figure 2c) is generated resulting from the force (torque about the center of mass of the wheel) which produces the negative angular rotation about the X-axis of the wheel as shown in Figure 2b.

Consequently, since the system has already gained a large positive H_Z in the early stage of the throwing motion as previously discussed, the increase in the negative H_Y of the system, which develops during the latter half of the SS2 and the early half of the DV, could be derived from the marked increase in the negative H_X of the system, resulting from the ground reaction force (white allow in Figure 2bc) by the right foot of the thrower in the SS2 and the DV. The mechanism for the discus throwing motion could be called the "Gyro Model".

Dapena (1993b) has suggested that the negative H_Y of the system in the SS2 and the early part of the DV was caused by the ground reaction force (GRF) by the right foot, passing somewhat to the right of the center of mass of the thrower ("off-center") in the view from the back of the circle (Figure 7 in his article). However this "off-center" in the view from the back of the circle may be smaller than that in the view from the lateral side (toward the X-axis) of the circle. This perhaps means that the amount of rotation about the Y-axis of the system generated by the right foot of the thrower is smaller than that of the rotation about the X-axis. Therefore, the reaction force in the view from the back of the circle might be not a main reason increasing the negative H_Y (vertical speed of the discus) of the system. Further investigation including the GRF measurement would be necessary.

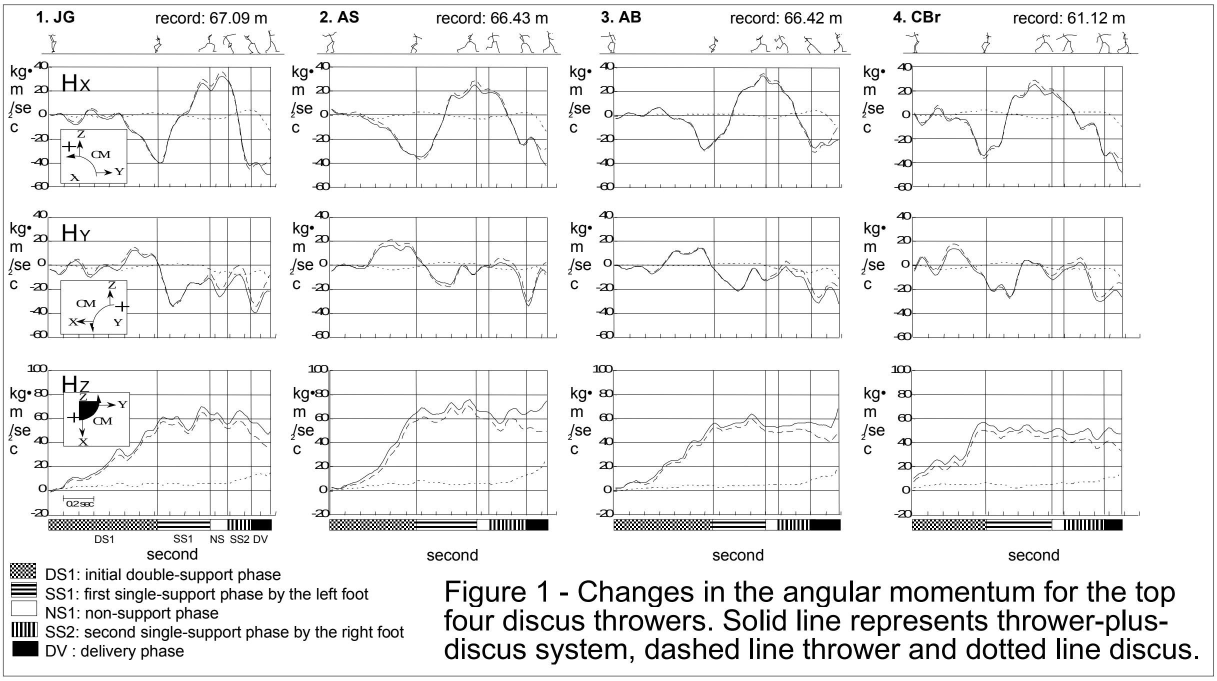

Figure 1 - Changes in the angular momentum for the top four discus throwers. Solid line represents thrower-plus-discus system, dashed line thrower and dotted line discus.

CONCLUSION: The most important conclusion of this study was that the SS2 and the DV are much more important phases as well as the DS1 and the SS1. According to the principle of the gyroscope, it is probable that the increase of negative angular momentum (H_Y) of the system (vertical speed of the discus) is generating resulting from the interaction between the positive momentum (H_Z) and the negative momentum (H_X) of the system during the SS2 and the DV.In a practical implication, it seems one of the most important factors that enhances the force made on ground by the right foot (right-handed thrower) in the SS2 and the DV in order to increase the negative angular momentum (H_Y) of the system in the final stage of the throwing motion (it is not explained by the Dapena's theory, but by the "Gyro Model"). The "Gyro Model" for the discus might be applied to the other athletes.

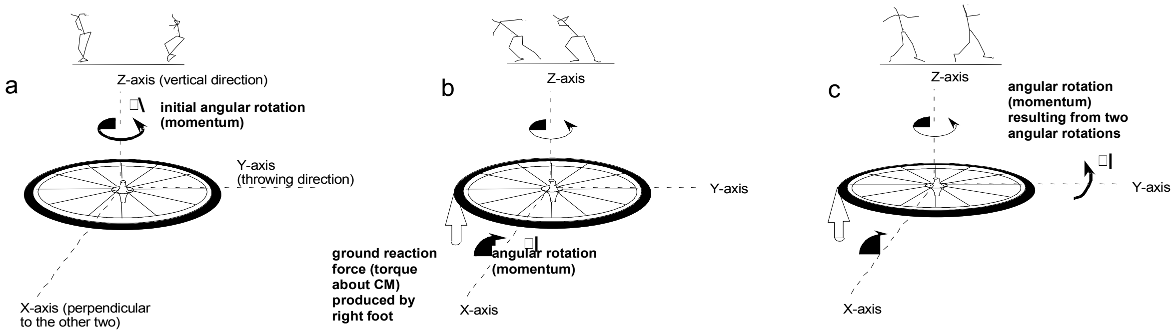

Figure 2 - Schematic diagram for the throwing mechanism ("Gyro Model") of the discus, based on the principle of the gyroscope. Above figures are the typical stick figures in the a)DS1 & SS1, b)SS2 & DV, and c)DV, in a view from lateral side of the circle. White allow in b and c diagrams indicates the expected ground reaction force vector by right foot.

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