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GENERATION AND TRANSFER OF ANGULAR MOMENTUM IN THE JAVELIN THROW

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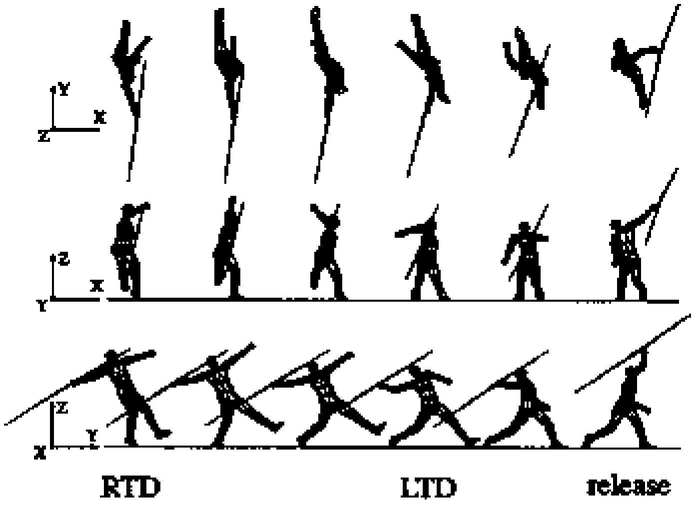
INTRODUCTION

At the instant of release in a right-handed javelin throw, the center of mass (c.m.) of the javelin is located in a high position to the right of the thrower, and it is traveling forward and upward at high speed. These conditions require rather large amounts of angular momentum in the javelin and throwing arm, as well as appropriate ratios among the three-dimensional components of the angular momentum. The angular impulses of the forces exerted by the ground on the athlete's feet during the throw generate angular momentum for the combined thrower-plus-javelin system. This angular momentum can be separated into two parts, associated respectively with the motions of the body-minus-throwing arm ("body-minus-arm") and of the throwing arm-plus-javelin ("arm-plus-javelin") subsystems. The purpose of this project was to study the changes in the system angular momentum in the course of the throw, and the transmission of angular momentum to the arm-plus-javelin.



METHODS

At the end of the run-up, a right-handed thrower makes a cross-over step, lands on the right foot (RTD), plants the left foot (LTD), and releases the javelin. The athlete is in single-support (SS) between RTD and LTD, and generally in double-support (DS) between LTD and release. A period including the SS and DS phases of eight of the finalists in the men's javelin throw competition at the 1995 USA Track and Field National Championships was filmed using standard three-dimensional (3D) film analysis procedures. Two throws were analyzed for each subject. Digitized data from the film images were used to calculate the coordinates of 21 body landmarks and three javelin landmarks. The 3D coordinates were expressed in an orthogonal reference frame in which the X axis pointed toward the right (normal to the runway), the Y axis pointed forward, and the Z axis pointed upward. The coordinate data were smoothed using quintic spline. Center of mass locations and the angular momentum values of the body segments and of the javelin were calculated following a method based on Dapena (1978). The location of the javelin c.m. was computed using information from Hubbard and Bergman (1989).

The SS and DS phases were each divided into two equal time periods. An inverse dynamics approach was used to calculate the average forces made by the ground on the system in each of the four periods. The 3D angular momentum values of the body-minus-arm, arm-plus-javelin and complete system, all relative to the whole-system c.m., were calculated for five instants: (1) RTD, (2) the mid-point of SS, (3) LTD, (4) the mid-point of DS, and (5) release.

RESULTS AND DISCUSSION

To facilitate this discussion, the terms "clockwise" (CW) and "counterclockwise" (CCW) will replace the signs of the X, Y and Z angular momentum components; the directions will correspond to views from the right, from behind and from overhead for the HX, HY and HZ angular momentum components, respectively.

At RTD the system had a CCW HX of 13 kg m2/s. Ground reaction forces in the YZ plane changed this to a CW value at LTD (35 kg m2/s), and to an even larger CW value at release (67 kg m2/s). During the first half of SS, the average ground reaction force exerted on the system pointed backward and upward (FY = -480 ± 200 N; FZ = 1230 ± 190 N). Since the right foot was almost directly below the c.m. during this period, the horizontal force was mainly responsible for the CW angular impulse (28 N m s) received by the system. During the second half of SS, the foot was clearly behind the c.m., and the ground reaction force was near vertical (FY =20 ± 200 N; FZ = 1010 ± 180 N). Therefore the CW angular impulse received by the system during this period (20 N m s) was produced mainly by the vertical force. During DS the system received large backward and upward ground reaction forces (FY = -1850 ± 320 N and FZ = 2200 ± 230 N during the 1st half of DS; FY = -1540 ± 480 N and FZ = 2400 ± 320 N during the 2nd half of DS). The resultant must have passed below the system c.m. to produce the CW angular impulses observed during both halves of the DS (14 N m s and 18 N m s, respectively) which increased the CW angular momentum of the system to its final value at release.

At RTD, the HY of the system had a CW value of 8 kg m2/s. During SS the average ground reaction forces in the XZ plane pointed upward and slightly toward the left (FX = -50 ± 140 N and FZ = 1230 ± 190 N during the 1st half of SS; FX = -110 ± 120 N and FZ = 1010 ± 180 N during the 2nd half of SS). The angular impulses were CCW (13 N m s and 17 N m s in the 1st and 2nd halves of SS, respectively), implying that the resultant force passed to the right of the system c.m. This must be attributed to the position of the support foot, which was located to the right of the c.m. The angular impulses changed the system HY to 23 kg m2/s CCW at LTD. The overall change in HY between LTD and release was small. The average ground reaction forces pointed upward and moderately toward the right during this period (FX = 380 ± 290 N and FZ = 2200 ± 230 N during the 1st half of DS; FX = 430 ± 280 N and FZ = 2400 ± 320 N during the 2nd half of DS). The left foot was planted clearly to the left of the c.m., and data from Deporte & Van Gheluwe (1988) has shown that most of the ground reaction force is exerted through the left foot during DS. This strongly suggests that the combination of the left foot position and the direction of the resultant force is what made the force pass near the system c.m., and led to the rather small changes in HY during DS.

The system HZ was very small during SS; at LTD, it had a CCW value of 3 kg m2/s. During DS the average ground reaction forces in the XY plane pointed backward and moderately toward the right (FX = 380 ± 290 N and FY = -1850 ± 320 N during the 1st half of DS; FX = 430 ± 280 N and FY = -1540 ± 480 N during the 2nd half of DS). The angular impulses were CCW (14 N m s and 6 N m s in the 1st and 2nd halves of DS, respectively), implying that the resultant force passed to the left of the system c.m. The angular impulses changed the system HZ to 23 kg m2/s CCW at release.

Having determined how the system obtains angular momentum, we will now examine how angular momentum was transmitted to the arm-plus-javelin in order to produce a large velocity of the javelin at release. At RTD, all the HX of the system was in the body-minus-arm, and most of the changes produced in HX during SS by the ground reaction forces also went into the body-minus arm; only a small CW amount of HX was transmitted to the arm-plus-javelin, in the 2nd half of SS. During DS the system received a large CW angular impulse, but the HX of the body-minus-arm did not change much; in essence, all the additional HX obtained from the ground during DS was transmitted through the body to the arm-plus-javelin.

At RTD, all the HY of the system was in the body-minus-arm, and during SS practically all of the CCW changes in HY produced by the ground reaction forces also went into the body-minus arm. Between LTD and release there was only a small overall change in the system HY, but during the 2nd half of DS there was a marked transfer of CCW HY from the body-minus-arm to the arm-plus javelin.

During most of the SS, the system HZ was close to zero. At LTD, the system had a small amount of CCW HZ, and essentially all of it was in the arm-plus javelin. During DS the ground reaction forces increased the CCW HZ of the system. Part of the HZ obtained during the first half of DS stayed in the body-minus-arm, and part was transmitted to the arm-plus-javelin; all the additional HZ obtained during the 2nd half of DS was transmitted through the body to the arm-plus-javelin.

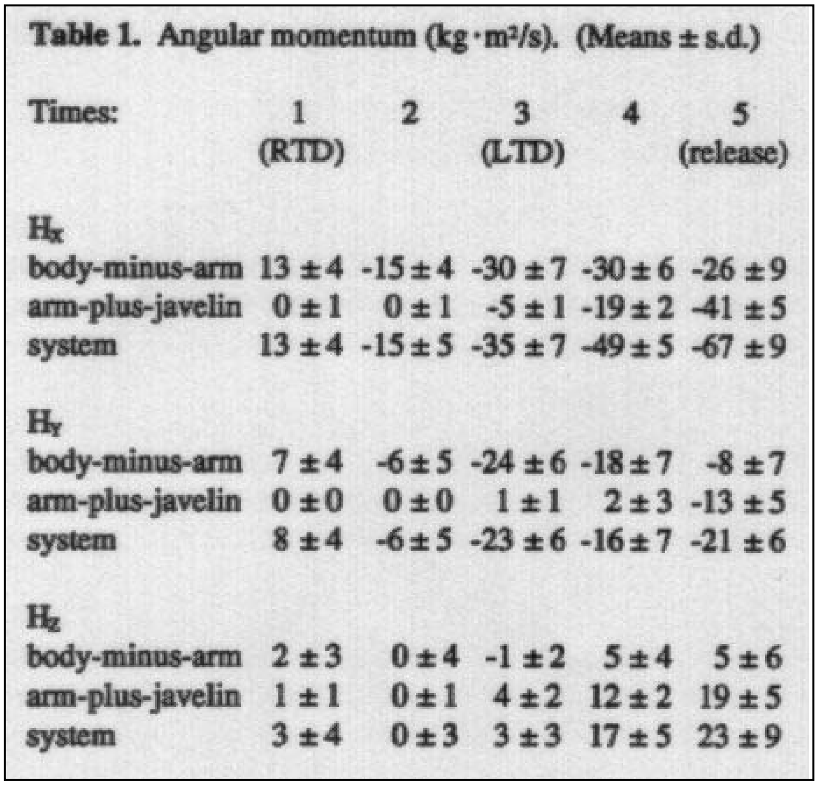


Table 1. Angular momentum ($kg \cdot m^2/s$). (Means ± s.d.)

Times:	1 (RTD)	2	3 (LTD)	4	5 (release)
H_X					
body-minus-arm	13 ±4	-15 ± 4	-30 ± 7	-30 ± 6	-26 ±9
arm-plus-javelin	0 ± 1	0 ± 1	-5 ± 1	-19 ± 2	-41 ±5
system	13 ±4	-15 ± 5	-35 ± 7	-49 ± 5	-67 ±9
H_Y					
body-minus-arm	7 ±4	-6 ± 5	-24 ± 6	-18 ± 7	-8 ±7
arm-plus-javelin	0 ±0	0 ±0	1 ± 1	2 ± 3	-13 ±5
system	8 ±4	-6 ± 5	-23 ± 6	-16 ± 7	-21 ±6
H_Z					
body-minus-arm	2 ±3	0 ± 4	-1 ±2	5 ± 4	5 ±6
arm-plus-javelin	1 ±1	0 ± 1	4 ±2	12 ± 2	19 ±5
system	3 ±4	0 ± 3	3 ±3	17 ± 5	23 ±9

CONCLUSIONS

The angular momentum of the throwing arm-plus-javelin at release is closely related to the velocity of the javelin, one of the most important factors affecting the result of the throw. The results of this project have improved our understanding of the mechanisms through which the ground reaction forces exerted on the feet of the thrower generate the angular momentum of the thrower-plus-javelin system. The results have also shown that the angular momentum of the system is produced during both single-support and double-support, while the transmission of angular momentum to the throwing arm-plus-javelin occurs almost exclusively during double-support.

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