THE ROLE OF THE INTERNAL ROTATION OF THE UPPER ARM IN JAVELIN THROWING

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We performed a kinematic and inverse dynamic study with javelin throwers in order to assess the role of the internal rotation of the upper arm in javelin throwing and then compare the findings to baseball throwing. On the one hand, the results show an equal behaviour of the angular velocity, torque and power curves compared to baseball pitching. The evaluated peak values differ on the other hand. Hence, the different release velocities in baseball pitching and this study could serve as an explanation for the different values, which can vary enormously.

KEY WORDS: Javelin throw, inverse dynamics, kinematics, kinetics

INTRODUCTION: Throwing velocity is the most important factor for reaching high throwing distances in javelin throwing (Bartonietz, 2000; Morriss, Bartlett, & Navarro, 2001; Morriss & Bartlett, 1996). In order to achieve high throwing velocities, the transfer of mechanical energy through the kinetic chain plays an important role (Bartonietz, 2000). The internal and external rotation movement of the upper arm contributes greatly to the transfer of kinetic energy and the acceleration of the sports device (Roach & Lieberman, 2014; Roach, Venkadesan, Rainbow, & Lieberman, 2013).
For the different kinetic and kinematic parameters, different authors have reported a wide range of values for a broad range of subject types. Table 1 provides an overview of the different findings in the literature for the most commonly reported parameters. It is obvious that different authors produce different sets of results depending on the chosen methods and subjects. However, while the kinematics and dynamics of the internal and external rotation are well researched in baseball pitching, there are no studies about the torques and power acting at the shoulder joint in javelin throwing. Therefore, the aim of the study was to investigate the differences and similarities between baseball pitching and javelin throwing to receive a reference point for the chosen methods.

Table 1
Overview of the outcomes of different investigations in baseball throwing for often reported parameters by different subject types. The data represent mean values with standard deviations.

	Feltner et al. 1986	Fleisig et al. 1995	Fleisig et al. 1999	Roach et al. 2014
Subjects	College	Elite	Professional	College
Release speed [ms^{-1}]	33,5	38,3±0,7	37±2	27,7±3,8
Peak Torque [Nm]	90±20	67±11	68±15	206±42
Angular Velocity [°/s]	6100±1700	-	7240±1090	4290±1127
Peak Power [W]	-	-	-	11838±4170

METHODS: Eight healthy male throwers participated in the study. Each of them performed three throws out of their preferred approach into a net. Seventeen retro-reflective markers had been placed on the following bony landmarks: intermediate phalange of the middle finger, metacarpophalangel joint 2 and 5, lateral and medial side of the wrist, medial and lateral epicondyle of the elbow, acromion of throwing and non-throwing side, suprasternal notch, xiphoid process of the sternum, spinal process of the 7th cervical and 12th thoracic vertebra, right and left illium anterior superior and left and right illium posterior superior.

Additionally, a marker had been placed in front of the handgrip of the javelin. We used a system consisting of 12 infrared cameras (Oqus 7+, Qualisys AB, Göteborg, Sweden) and 2 video cameras (Oqus 210c) for data recording. Marker data was recorded at 250 Hz, video data at 50 Hz, using Qualisys Track Manager. Marker gaps up to 10 frames were filled by using polynomial interpolation. The touchdown of the support leg and the bracing leg was recorded manually The instant of javelin release was calculated as described by van den Tillaar & Ettema (2007).
After data recording, Visual3d Professional software package (C-Motion, Germantown, USA) made all further calculations. A four segment kinematic chain, consisting of torso, upper arm, forearm and hand, was constructed. Mass distribution data by Dempster (1955) were used. For simplification, the mass (805g) of the javelin was added to hand segment. The joint torque, power and angular velocity was calculated. The data was represented in the local coordinate system of the upper arm. In order to obtain the kinetic energy absorbed in the eccentric phase of muscle contraction and released in the concentric phase, the trapezoidal integral was computed over the power curve. The following parameters were examined: Initial velocity (IV) as velocity of the javelin at the instant of support leg touchdown and release velocity (RV) of the javelin as general parameters. For the internal rotation the following parameters were assessed: joint angular velocity at the instant of release (JAVR), maximum joint angular velocity (MJAV), peak torque (PT), peak Power (PP), eccentric work (EW) and concentric work (CW). Means (MW) and standard deviations (SD) were computed.

RESULTS: Table 2 shows the results of one athlete. The velocity at the beginning of the main phase (IV) was 5,37±0,21 ms^{-1}, RV reached 21,97±0,35 ms^{-1}. At the instant of release the internal rotation velocity reached 1376,74±567 °/s (see figure 1, left side), the MJAV, which occurred after release achieved 4484±220 °/s. PT (see figure 1, middle) gained 175,68±21,51 Nm at the instant of release. PP reached 3352,7±912 W at the instant of release. The work done in the eccentric phase (EW) gained -43,50±6,52J while the CW achieved 40,73±4,64 J.

Table 2
Overview of the examined parameters for the internal and external rotation and general parameters.

Parameter	MW±SD
IV [ms^{-1}]	5,37±0,21
RV [ms^{-1}]	21,97±0,35
JAVR [°/s]	1376,74±567
MJAV [°/s]	4484,53±220
PT [Nm]	175,86±21,51
PP [W]	3352,7±912
EW [J]	-43,50±6,52
CW [J]	40,73±4,64

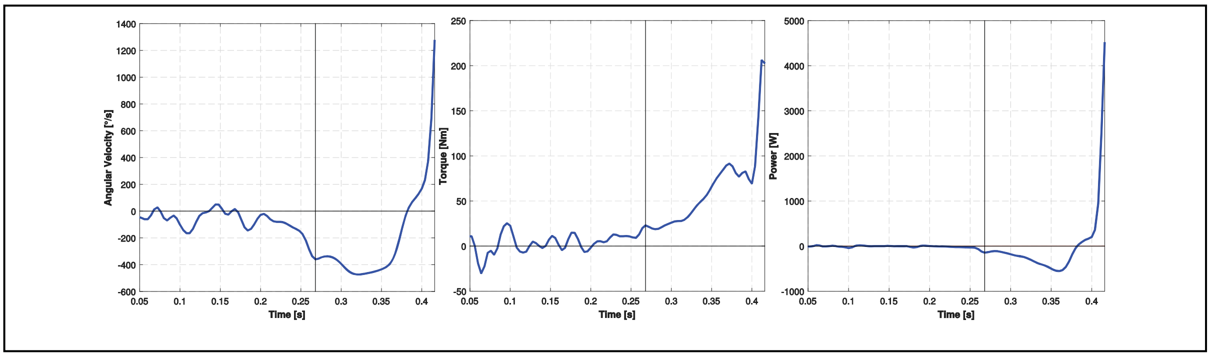

Figure 1: All graphs show the movement from the instant of support leg touchdown to the release of the javelin. The vertical line represents the touchdown of the bracing lag. In case of the angular velocity (left side) and torque (middle), positive values are related to the internal and negative values to the external rotation. In case of the power graph (right), negative values are related to eccentric contraction while positive values represent concentric contractions.

DISCUSSION: In comparison to the findings of Campos et al. (2004) and Lehmann (2010), who reported release velocities of up to 29 ms^{-1} for men, the values found in this study seem to be relatively low for the first thrower. The IV might serve as an explanation for this. While the IV is positively related to the throwing distance and therefore to release velocity, the IV should be higher in order to achieve greater release velocities (Murakami et al., 2006). The JAVR reported here seems to be in line with the findings of Morriss et al. (1997), which reported between 750 up to 2270 °/s for the internal rotation at the shoulder joint. In comparison to the findings in baseball pitching, this seems to be relatively low. Escamilla et al. (2001) reported up to 7087±1249 °/s for Olympic baseball pitchers. Other studies also report considerably higher values (Feltner & Dapena, 1986; Roach & Lieberman, 2014). Even the MJAV in this study did not reach these high values. A possible explanation for this could be that the RV of 21,97 ms^{-1} are comparatively low. The baseball studies reported values up to 39 ms^{-1} (Escamilla et al., 2001) respectively 33,5 ms^{-1} (Feltner & Dapena, 1986) and 27,7 ms^{-1} (Roach & Lieberman, 2014). When comparing the curve progression of the angular velocity to courses reported in other literature (Feltner & Dapena, 1986; Ishida, Murata, & Hirano, 2006; Roach & Lieberman, 2014), similar characteristics are shown (see figure 2, left). Different values for the reported peak torques can be found in the literature. While Feltner et al. (1986) reported 90±20 Nm for the internal rotation to be reached shortly before the instant of maximum external rotation, Roach et al. (2014) reported 206±42 Nm, which are similar to our findings. In contrast, the maximum torque was brought right before the release of the javelin. While the differences between Feltner et al. (1986) and Roach et al. (2014) could be explained by the methods used to examine the torques, our approach is similar to Roach et al. (2014). We examined torques near the values of Roach et al. (2014) which could be explained by the much heavier implement (javelin: 805g vs 144g Baseball). It could be stated that, while we have clearly smaller release and angular velocities, the heavier implement seems to influence the reached torques. We also found smaller values for the power examination than in baseball throwing. Roach et al. (2014) reported up to 11838±4170 W, while our findings reach 3352,7±912 W. Because the peak torques are equal, the angular velocity is the reason for these big differences. The pattern of the curve shows values similar to those of Roach et al. (2014) (see figure 2, right). The beginning of the eccentric phase with the touchdown of the bracing leg until the maximum external rotation leads to storage of up to -43,50±6,52 J of kinetic energy. An equal amount of energy is returned elastically in the following concentric contraction phase reaching 40,73±4,64 J. For the work done Roach et al. (2014) reported -201±70 J for the eccentric and 132±52 J for the eccentric phase. These values are different to our findings, but this could also be explained by the smaller values for the power respectively the angular velocity values.

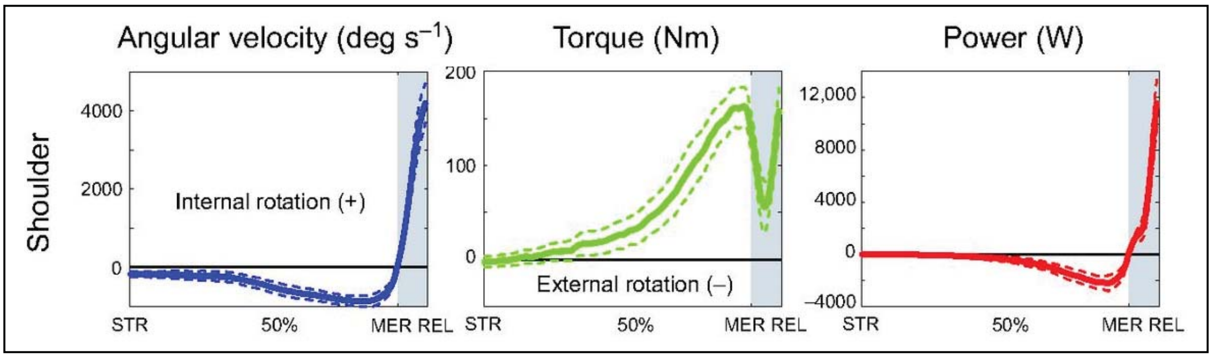

Figure 2: Time normalised mean values (bold line) of the angular velocity (left), torque (middle) and power (right) of the internal and external rotation at the shoulder joint. The dashed lines represent the 95% confidence interval. The curves show the throwing cycle from the instant of the front foot stride (STR) over the maximum external rotation (MER) to the release (REL) (modified, from Roach et al. 2014).

CONCLUSION: We were able to show that the curve progressions follow similar patterns compared to findings in baseball throwing. However, the reported peak values are different. The considerably lower release velocity respectively initial velocity could explain this. Thus, it could be assumed that the initial velocity and therefore the energy stored in the body is important for transferring kinetic energy through the kinetic chain to the javelin.

The results presented above only represent one athlete. The results of the remaining athletes have to be included into our further analysis.

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