INFLUENCE OF TRUNK MODEL DOF ON SHOULDER KINEMATICS IN JAVELIN THROWING - A CASE STUDY

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A case study was conducted to clarify the influence of different body-models and modelling approaches on shoulder joint kinematics. Therefore, a single subject performed a javelin throw. The recorded movement was analyzed using two different modeling approaches using two different body models each. Results from the two different body models are highly comparable, while comparability of model approach specific results depend on the movement direction. Source of the difference between movement directions may be the model specific location of center of rotation in the shoulder joint.

KEYWORDS: OpenSim, Visual 3D, inverse Kinematics

INTRODUCTION: Shoulder kinematics are an important measure for assessing performance and injury risk in the throwing movements (Escamilla et al., 2002). The influence of different body models and modeling techniques on kinematic results remains unclear. Studies using different modelling approaches have reported a variety of angular velocities at the shoulder for throwing movements (Table 1).
Often, the trunk is modeled as a single rigid object from the hips to the shoulder (e.g. Feltner, 1986; Moriss, 1997; Roach & Lieberman, 2014), however, Zatsiorsky (2002) suggested to model the thorax and abdomen as a two-segment kinematic-chain. Additionally, the approach to estimate shoulder kinematics varies between self-developed programs (Feltner, et al. 1986; Fleisig, 1995) and commercial software solutions (Escamilla et al., 2002; Roach et al., 2014). While the influence of different modeling approaches on kinematic variables is well known for gait analysis, it is unknown in throwing disciplines.
Therefore, the goal of the study was to investigate the influence of two different modelling approaches and body models on shoulder kinematics in javelin throwing.

Table 1: Overview of the findings off different investigations on throwing sports. Rotational angular velocity refers to internal rotation.

	Feltner et al. 1986	Fleisig et al. 1999	Roach et al. 2014	Moriss et al. 1997	Köhler et al. 2017
Sports	Baseball	Baseball	Baseball	Javelin	Javelin
Subjects	College	College	College	Professional	(youth) Elite
Release speed [ms^{-1}]	33,5	35±2	27,7±3,8	25,22±0,91	24,02±2,26
Rotational Angular Velocity [°/s]	6100±1700	7430±1270	4290±1127	1474±473	1597±403

METHODS: For the first modeling approach, an OpenSim model was developed for analyzing shoulder kinematics during a javelin throw. The model is based off the 3D, 23 degree of freedom (DoF) Gait Model with simple arms (Delp et al 2007) and the Dynamic Arm simulator model (Chadwick et al 2014). The dynamic arm simulator was slightly modified and consists of seven rigid bodies (thorax, right clavicle, scapula, humerus, ulna, radius and hand) with four degrees of freedom in the shoulder girdle (glenohumeral joint 3 DoF, sternoclavicular joint 1 DoF), shoulder, forearm, elbow and wrist joints. The muscles were deactivated for this

kinematic study. The upper body of the gait model was replaced with the dynamic arm model. Then, a simplified arm model with a simple ball and socket joint as the shoulder joint was added to represent the left (non-throwing) arm. Finally, a javelin was added to the model and connected with the right hand via a 6 DoF joint. The model was scaled to fit the anthropometric data of the subject and a set of fixed markers in prominent locations (lateral and medial knee, ankle, elbow, and wrist, as well as acromion, C7, sternum, and iliac crests) was used to scale the model. Other marker locations on the model were adjusted according to the static pose trial input data (total square error 3.8cm and root mean square error [RMSE] 2.6cm across all markers). The marker weights were defined to track the shoulder/arm region of the throwing arm with minimal deviation (high marker weights), while the left shoulder/arm region was allowed to deviate more due to the simplified shoulder/arm model. The overall movement was reproduced with a marker RMSE of <3.3cm.
The second model was built in the Visual 3D (V3D) Software Package (C-Motion, Germantown, USA) with the model consisting of a five-segment kinematic chain (trunk, thorax, upper arm, forearm, hand) where at every joint all degrees of freedom were allowed (6 DoF). The shoulder joint center was estimated using the approach for the hip joint as described by Schwartz et al. (2005) and applied to the shoulder by Roach et al. (2014). Additionally, a javelin was modelled as cylinder and attached to the hand. The model was fitted to the standing trail. No marker weights were defined for this model as there was no global optimization performed.
Both modeling approaches were used to evaluate shoulder kinematics for a javelin throw. First, inverse kinematics were calculated for both approaches using one rigid body for the trunk (StiffBack), secondly, the trunk segment in both approaches was divided into two rigid bodies with a 3 DoF (6 DoF for V3D) joint at the level of the processus xiphoideus (FlexBack).
The javelin throw of a single subject was captured by an infrared camera system consisting of 12 infrared and 2 video cameras (Qualisys AB, Gotenburg, Sweden) at measurement frequency of 250Hz. A modified Helen Hayes marker set was used (50 markers) to track the last two steps of the javelin throw.
Shoulder angular velocity was calculated in all models as the angular velocity of the upper arm relative to the thorax. The angular velocities were rotated via rotation matrices to the coordinate system for the shoulder reported by Feltner (1986). RMSE was computed between the two trunk models within each model approach (OpenSim/V3D) as well as between model approach and within the two trunk models. Data is reported from the touchdown of the right leg until the release of the javelin (REL). The minimum and maximum angular velocities were calculated until REL, while the maximum internal rotation angular velocity was calculated after release due to the associated injury risk (Escamilla & Andrews, 2009).

RESULTS: Calculated angular velocities of the different anatomical movement directions across the different approaches are shown in table two. Tables three and four provide the results of RMSE within/between the models/approaches, respectively. Time histories of angular velocities for each movement direction are shown in figure 1.

Table 2: Maximum angular velocity of the different anatomical movements. FLEX = hor. Flexion, EXT = hor. Extension, ADD = adduction, ABD = abduction, IR = internal rotation, ER = external rotation.

		Angular Velocity (°/s)						
		FLEX	EXT	ADD	ABD	IR		ER
						before REL	after REL	
V3D	FlexBack	266.40	731.85	456.11	287.81	809.67	4397.55	705.12
	StiffBack	274.46	811.57	328.13	352.24	1034.40	4528.89	786.12
OpenSim	FlexBack	188.96	1551.94	118.20	570.39	612.04	5176.30	513.96
	StiffBack	260.48	1671.81	160.64	492.44	433.74	6352.58	552.02

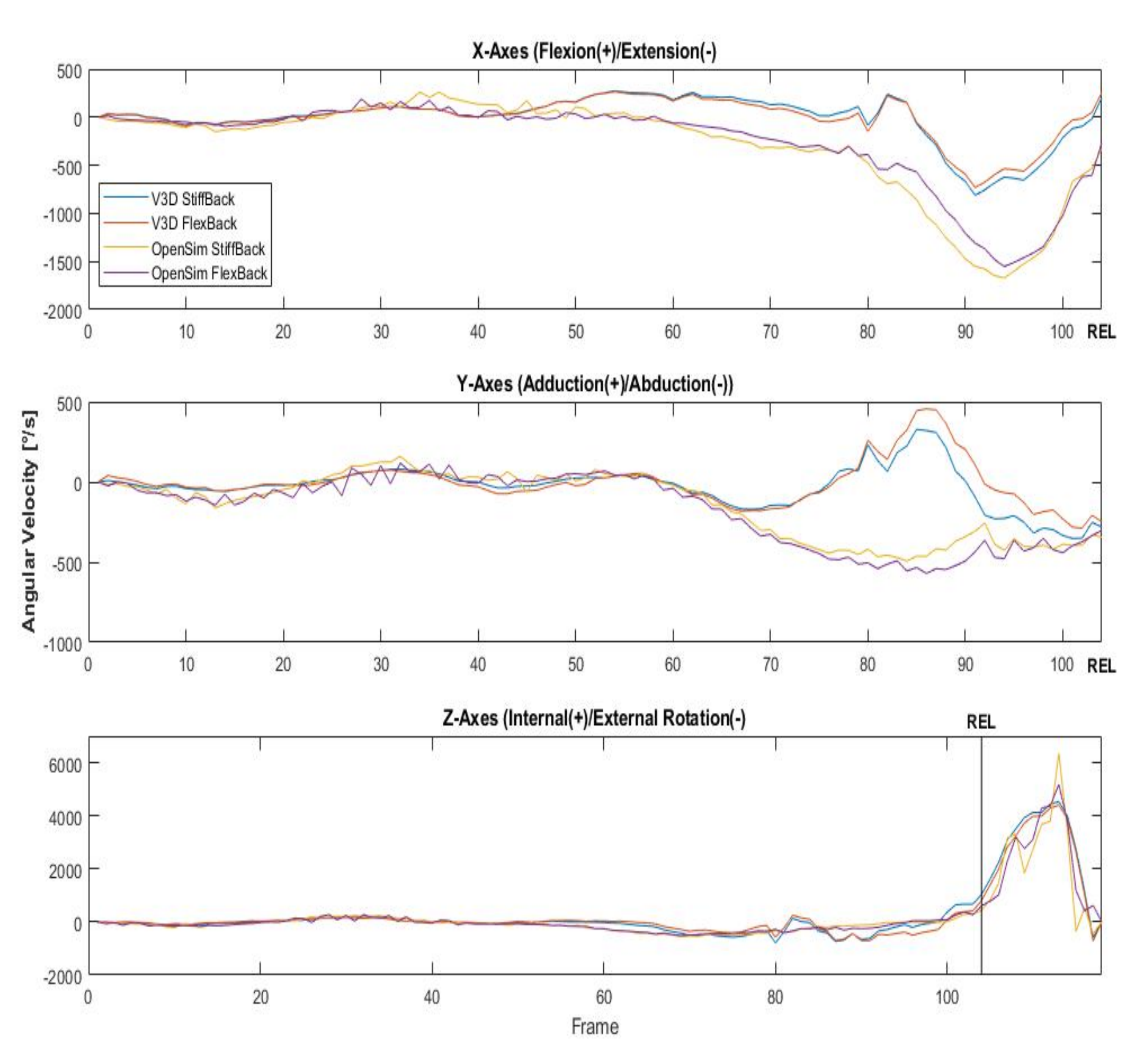

Figure 1: Time histories of angular velocities from touchdown of the right leg to the release of the javelin (REL). The internal/ external rotation additionally shows 10 frames after REL since the maximum internal rotation velocity occurs after REL.

Table 3: Comparison of two different body models within the different modeling approaches. RMSE-values are reported for each movement direction.

StiffBack vs. FlexBack (RMSE)			
	FLEX/EXT	ABD/ADD	IR/ER
V3D	40,46	64,34	121,50
OpenSim	107,64	54,19	67,54

Table 4: Comparison of two different modeling approaches within the different body models. RMSE-values are reported for the each movement direction

OpenSim vs. V3D (RMSE)			
	FLEX/EXT	ABD/ADD	IR/ER
StiffBack	441,58	245,55	201,62
FlexBack	392,19	322,92	213,57

DISCUSSION: The results of maximal internal rotation velocity for the OpenSim model is comparable with results presented by Feltner et al (1986) and Fleisig (1999) while the V3D model results are more aligned with values reported by Roach et al. (2014)(see Table 1 and 2). The IR/ER velocities show similar characteristics between the two trunk models as well as the two approaches leading to small RMSE between both approaches. However, the flexion/extension velocities show a shift between the two approaches which leads to compensatory adjustments in the ABD/ADD velocities between the respective model approaches. The source of the shift is likely to be due to a slightly different location of the center of rotation in the shoulder joint between the two approaches (OpenSim/V3D). The two trunk models further influence the location of the center of rotation, causing approach specific changes in all movement directions. Overall the influence of the modeling approach impacts movement direction dependent differences for flexion/extension and abduction/adduction much more than different trunk models within the same approach. These results highlight relatively consistent results for the internal/external rotation as well as limitations in comparing shoulder kinematics for the other movement directions between different modeling approaches. The biggest limitation of this study is it being a single case study. A follow up study will include multiple athletes and multiple repetitions.

CONCLUSION: The complexity of shoulder kinematics during throwing movements limits comparability of results even between relatively similar multi body system models. Slight changes of the shoulder center of rotation location in a model will influence kinematic results in all movement directions. Knowledge about the model and approach related impact on kinematic results for the shoulder joint will help practitioners to better compare and apply results from various studies on overhead throwing.

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