RESULTS OF INVERSE DYNAMICS CALCULATIONS IN JAVELIN THROWING ARE STRONGLY INFLUENCED BY INDIVIDUAL BODY SEGMENT PROPERTIES

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The calculation of inverse dynamics (ID) solutions is widely used to examine potential injury risks and sources for performance enhancement. The results of these calculations are influenced, among others, by the chosen set of body segment inertia parameters (BSIP). While throwing movements are frequently analyzed via ID and there exists a broad variety of BSIP models, the influence of the BSIP sets on the outcome is not well examined. Therefore, the aim of this study was to clarify the influence of different BSIP sets on the modelling results in javelin throwing. For this purpose the kinematics of ten male javelin throwers were recorded. Six available models were used to estimate the BSIP values of the upper limp for each thrower. The chosen BSIP model had large influence on the derived BSIP parameters which showed variations between 8% and 120%. Also, the maximum net joint moment varied between 6% and 21%. Hence, our study suggests that for modelling joint kinetics in throwing movements the model should be chosen carefully.

KEYWORDS: inverse kinetics, upper extremities, modelling, high performance sport.

INTRODUCTION: Inverse dynamics (ID) is a widely used technique to analyze activities of daily living and sports. This also includes high speed movements like baseball pitching or javelin throwing. To calculate ID solutions kinematic data as well as body segment inertia parameters (BSIP) are needed. Both are a potential source of error. Errors, arising from the kinematic data can be controlled by using methods corresponding to the problem (Derrick et al., 2020). For the BSIP a broad variety of sets is available which includes in vivo models (e.g. De Leva, 1996), mathematical models (e.g. Hanavan, 1964) and models from cadaver studies (e.g. Dempster, 1955). While the influence of different BSIP sets is well known in gait (Rao, Amarantini, Berton, & Favier, 2006) the impact on the ID calculations on dynamical movements is not well examined. Although throwing movements are frequently analyzed via ID, to our knowledge there is no study showing the impact of numerous different BSIP sets on the outcome of ID calculations. Only Gasparutto (2018) and Sterner (2020) compared two different models each. They showed differences in the ID calculations between the chosen models, but the variation between a larger number of BSIP sets remains unclear. Therefore, the aim of the study was to examine the impact of six different BSIP sets on the ID calculations in throwing movements.

METHODS: Ten male javelin throwers (189.2 ± 7.2 cm; 92.4 ± 9.3 kg) of the German Athletics Federation took part in the study. Each of them was equipped with 18 reflective markers and 2 marker-cluster at the throwing arm and the upper body. Additionally, the javelin was prepared with 5 reflective markers. The throwing movement of each individual was recorded by 12 infrared-cameras capturing at 300 Hz and 2 video cameras recording at 150 Hz (Qualisys, Gothenburg, Sweden). Each participant performed at least three trials. The three trials with the highest release speed were analyzed further.
Marker trajectories were filtered with a 4thorder zero-lag Butterworth filter. The cut-off frequencies for each marker were determined by a residual analysis (Winter, 2009). A multi segment model consisting of javelin, hand, forearm and upper arm was built within Visual 3D (Germantown, USA) and fed with the kinematic data from the recordings. To calculate the differences in kinetic outcome 6 different BSIP sets were used. Three already published

models (Chandler (1975) [M_C]; De Leva (1996) [M_{DL}], Yeadon (1990) [M_Y]) and an individualized model which was subdivided by using three different density measures. The individualized model (IM) for each individual was calculated using a laser scanner (VITUS Smart XXL, Human Solutions GmbH, Kaiserslautern, Germany) which created a polygon mesh of the body's surface. After cutting each body segment out of the whole mesh, the moments of inertia (MoI) and the center of mass (CoM) of each segment were calculated using MeshLab (Cignoni et al., 2008). The three submodels were calculated multiplying the volume and MoI with the following density measurements: 1.) the density of ρ = 1 g/cm^3 ($IM_{\rho = 1}$); 2.) the density measurements from Chandler (1975) (IM_{CH}), 3.) Dempster's (1955) (IM_D), density measurements. Afterwards the maximum net joint moments for the following movements were calculated: shoulder internal rotation, shoulder horizontal flexion, shoulder abduction, elbow flexion, elbow varus and wrist palmar flexion. For the three analyzed trials the mean was calculated for each movement direction per participant. The differences between the calculated BSIP and maximum NJM were calculated via repeated measures ANOVA with Bonferroni corrected post-hoc comparisons and partial eta squared ($\eta^2{}_p$) as measure of effect size. The level of significance was set to $\alpha = 0.05$. Additionally the mean percentage of variation (MPV) was calculated for the different BSIP´s as well as for the different NJM as the range of values divided by the mean (Rao et al., 2006).

RESULTS: For the different BSIPs of all segments significant main model effects were found. The values for the BSIP varied from 8.1% up to 120% (see table 1).

Table 1: Statistical results between the BSIP sets for the different inertia parameters of the respective segments. CoM = center of mass; m_s = segment mass; I_{xx} = sagittal moment of inertia; I_{yy} = transverse moment of inertia; I_{zz} = longitudinal moment of inertia. The greek letters mark the results from the post-hoc comparisons, where: Ω = different from $IM_{\rho = 1}$, Φ = different from IM_{CH}; Ψ = different from IM_D; Γ = different from M_c; Θ = different from M_{DL}; Λ = different from M_Y. Please note, that for the CoM only four models ($IM_{\rho=1}$, M_c, M_{DL}, M_y) were compared due to equality between the individualized models.

		$IM_{\rho=1}$	IM_{CH}	IM_D	M_C	M_{DL}	M_Y	Statistical results
Hand	CoM	Θ			Θ	Ω,Γ		F = 7.72, p < .001, $\eta^2{}_p$ = 0.462, MPV = 8.1%
	m_s	Φ,Ψ,Γ,Θ	Ω,Ψ,Θ	Ω,Φ,Γ	Ω,Ψ,Θ	Ω,Φ,Γ		F = 13.65, p < .001, $\eta^2{}_p$ = 0.843, MPV = 23.6%
	I_{xx}	Φ,Ψ,Γ,Θ	Ω,Ψ,Γ,Θ	Ω,Φ,Γ,Θ	Ω,Φ,Ψ,Θ,Λ	Ω,Φ,Ψ,Γ	Γ	F = 41.95, p < .001, $\eta^2{}_p$ = 0.823, MPV = 76.2%
	I_{yy}	Φ,Ψ,Γ,Θ,Λ	Ω,Ψ,Γ,Θ,Λ	Ω,Φ,Γ,Θ	Ω,Φ,Ψ,Θ,Λ	Ω,Φ,Ψ,Γ	Ω,Φ,Ψ,Γ	F = 29.22, p <.001, $\eta^2{}_p$ = 0.765, MPV = 60.0%
	I_{zz}	Φ,Ψ,Γ,Θ	Ω,Ψ,Γ,Θ,Λ	Ω,Φ,Γ,Θ,Λ	Ω,Φ,Ψ,Θ	Ω,Φ,Ψ,Γ,Λ	Φ,Ψ,Θ	F = 114.43, p < .001, $\eta^2{}_p$ = 0.927, MPV = 120.1%
forearm	CoM	Γ,Θ			Ω,Θ,Λ	Ω,Γ	Γ	F = 49.97, p < .001, $\eta^2{}_p$ =0.847, MPV = 10.2%
	m_s	Φ,Ψ,Γ,Θ,Λ	Ω,Ψ,Γ,Λ	Ω,Φ,Γ,Λ	Ω,Φ,Ψ,Λ	Ω,Λ	Ω,Φ,Ψ,Γ,Θ	F = 61.59, p < .001, $\eta^2{}_p$' = 0.879, MPV = 31.0%
	I_{xx}	Φ,Ψ,Γ,Θ,Λ	Ω,Ψ,Θ,Λ	Ω,Φ,Λ	Ω,Λ	Ω,Φ,Λ	Ω,Φ,Ψ,Γ,Θ	F = 59.23, p < .001, $\eta^2{}_p$ = 0.872, MPV = 65.8%
	I_{yy}	Φ,Ψ,Γ,Θ,Λ	Ω,Ψ,Λ	Ω,Φ,Λ	Ω,Λ	Ω,Λ	Ω,Φ,Ψ,Γ,Θ	F = 60.82, p <.001, $\eta^2{}_p$ = 0.873, MPV = 65.9%
	I_{zz}	Φ,Ψ,Γ,Θ,Λ	Ω,Ψ,Θ,Λ	Ω,Φ,Θ,Λ	Ω,Θ,Λ	Ω,Φ,Ψ,Γ	Ω,Φ,Ψ,Γ	F = 26.96, p < .001, $\eta^2{}_p$ = 0.761, MPV = 37.18%
Upper arm	CoM	Γ ,Θ			Ω,Θ ,Λ	Ω,Γ,Λ	Γ,Θ	F = 66.04, p < .001, $\eta^2{}_p$ = 0.880, MPV = 27.4%
	m_s	Φ,Ψ,Γ,Λ	Ω,Ψ,Γ,Λ	Ω,Φ,Γ,Λ	Ω,Φ,Ψ,Λ	Λ	Ω,Φ,Ψ,Γ,Θ	F = 48.35, p < .001, $\eta^2{}_p$ = 0.598, MPV = 43.2%
	I_{xx}	Φ,Ψ,Θ,Λ	Ω,Ψ,Θ,Λ	Ω,Φ, Θ,Λ	Θ,Λ	Ω,Φ,Ψ,Γ,Λ	Ω,Φ,Ψ,Γ,Θ	F = 49.31, p < .001, $\eta^2{}_p$ = 0.846, MPV = 104.9%
	I_{yy}	Φ,Ψ,Θ,Λ	Ω,Ψ,Θ,Λ	Ω,Φ,Λ	Θ,Λ	Ω,Φ,Γ,Λ	Ω,Φ,Ψ,Γ,Θ	F = 46.79, p < .001, $\eta^2{}_p$ = 0.839, MPV = 109.1%
	I_{zz}	Φ,Ψ,Θ,Λ	Ω,Ψ,Θ,Λ	Ω,Φ,Θ,Λ	Θ,Λ	Ω,Φ,Γ	Ω,Φ,Ψ,Γ	F = 48.63, p < .001, $\eta^2{}_p$ = 0.844, MPV = 75.1%

For all NJM at the shoulder we found significant main model effects (internal rotation: $F = 66.16$; $p < .001$;$\eta^2_p = 0.880$; horizontal flexion: $F = 40.02$; $p < .001$; $\eta^2_p = 0.816$; abduction: $F = 56.03$; $p < .001$; $\eta^2_p = 0.862$). The MPV showed values from 10.3% for the internal rotation, 16.9% for the horizontal flexion up to 21.8% for the abduction.

Also for all analyzed NJM at the elbow joint a significant main model effect was found. The varus moment ($F = 41.45$; $p < .001$; $\eta^2_p=0.822$) showed variations from 8.8%, the flexion deviated up to 16.6 % ($F=13.51$; $p=.001$; $\eta^2_p=0.600$). The palmar flexion moment at the wrist showed a significant main model effect ($F=13.05$; $p<.001$; $\eta^2_p=0.592$) and a variation of MPV = 6.1%. For the values of the different NJM and the results of the post-hoc comparisons see figure 1

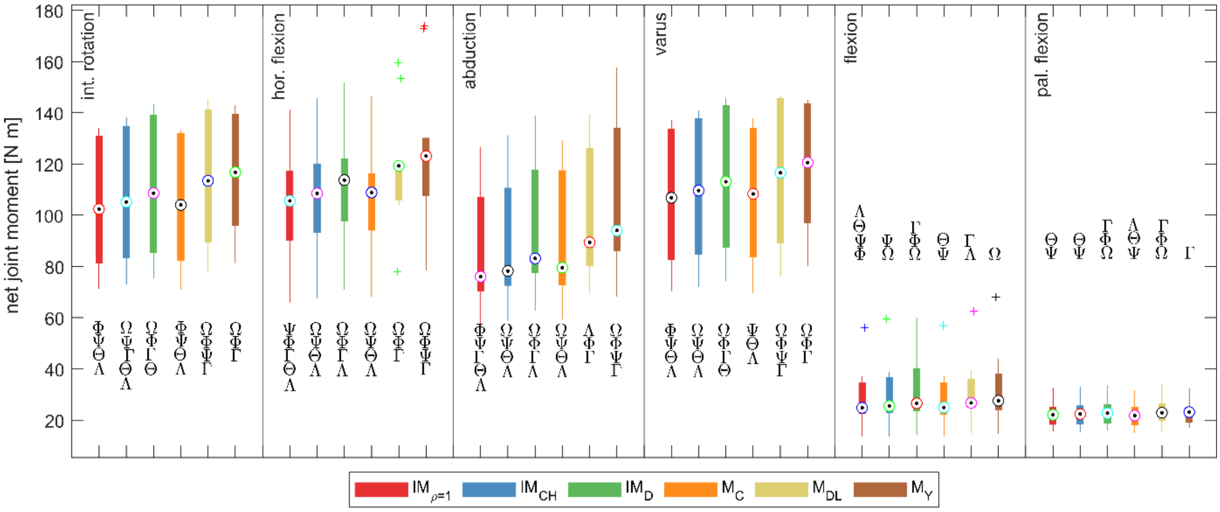

Figure 1: Boxplot of the modelled net joint moments of the different movements. The different colours represent the different BSIP models, see figure legend for assignment. The Greek letters above/ under each bar mark the results from the post-hoc comparisons, where: Ω = different from $IM_{\rho=1}$, Φ = different from IM_{CH}; Ψ = different from IM_D; Γ = different from M_c; Θ = different from M_{DL}; Λ = different from M_Y.

DISCUSSION: The aim of this study was to clarify, how strong the influence of different BSIP models is on the outcome of modelling net joint moments. For the BSIP the results show a large influence of the different BSIP sets on the parameters. In this context also could be observed a large difference between the different parameters. While the CoM locations and the m_s show smaller variations up to 43% the MoI of the different segments tend to fluctuate much more. Here variations of up to 120% could be observed. Compared to results from Rao et al. (2006) who showed differences up to 61% for the segments of the leg, the variation of the upper extremities tend to be more influenced by a change of the BSIP model. The difference in the variation between the extremities may be caused by the used BSIP models, Rao et al. (2006) used other BSIP sets. It is also conceivable that the larger differences depend on the dimensions of the different segments. While leg segments are bigger and heavier than arm segments, differences between the calculated BSIP from the diverse BSIP sets have larger influence on the variation of the upper extremities. Even when the differences are smaller in total.

For the calculated net joint moments, significant differences could be found for all investigated movement directions. This suggests that the peak value of the calculated NJM depends on the chosen BSIP model, just as Gasparutto et al. (2018) showed for a comparison between two different models. It is remarkable that the variations in the NJM calculations are not as big as would be expected due to the variations seen in the BSIP. With a maximum variation of 21% the variation is half as much as for the lowest BSIP. It may be possible that the larger differences in BSIP cancel each other out when it comes to the calculation of NJM. As m_s and CoM locations show much smaller variations than the MoI, it is also conceivable that the latter has smaller influence on the calculation of the NJM.

Furthermore, the variations of NJM seem to be dependent on the considered joint and the considered movement. While the differences between the various movements at the same joint show up to twice as much variation also the different joints seem to vary differently. The more distal joints seem to have less variation than the more proximal joints. This may be produced by the underlying calculating procedure, where the NJM were calculated from distal to proximal and therefore also the variances sum up. The differences between the movements at the same joint may be caused by the dependence from a certain BSIP. The NJM calculations of the movements maybe influenced in different scales from the various BSIP. But the dependency of the joints and movements from certain BSIP needs to be examined further to clarify if it is the case or not.

CONCLUSION: In conclusion, the choice of the BSIP model clearly influences the outcome of ID calculations. Therefore, the BSIP model used for ID calculations should be selected carefully to represent the underlying subjects in the best manner. Furthermore, the chosen BSIP model or the calculation methods must be reported to give the reader the option to evaluate whether a comparison of values between different studies is possible or the approaches differ too widely.

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