A COMPARISON OF TWO BODY SEGMENT PARAMETER MODELS VIA ANGULAR MOMENTUM AT TAKEOFF IN DIVING

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The angular momentum production during the takeoff phase in diving was computed in two ways: The first approach used the Hanavan model based on 15 landmarks. The second one was an image-based individual model. The remote angular momenta of the body segments were computed and compared. It turned out that both methods yield almost the same angular momenta of the total body. Depending on the body mass the arm segments amount to 52 ± 6 % to the total angular momentum for the individual model and 57 ± 9 % for the Hanavan model. The leg contribution was 33 ± 6 % and 33 ± 7 %, the head contribution was 19.1 ± 4 % and 14.2 ± 4 % for the individual model resp. for the Hanavan model.

KEY WORDS: Hanavan model, Simi Motion, alaska/dynamicus

INTRODUCTION: In figure skating, diving and gymnastics, fast rotations are important for successful performance. More and more complex movements of higher difficulties have been introduced for the last decades. The 4½ forward somersault tuck has been established in platform diving. To generate such rotations one needs to develop enough angular momentum and sufficient flight height in the support phase. This study was motivated by the question of the most effective armswing during the takeoff phase in a back somersault. How do straight or bent arms, fast or delayed arm movements contribute to rotation speed and flight height? To answer these questions one needs to compute accurate segmental angular momenta. This requires a precise estimate of body segment parameters (BSP) and accurate kinematic data. While the error in the kinematics can easily be estimated, the error coming from the BSP model is difficult to assess (Kwon, 1996). It is unclear how errors in BSP estimation influence biomechanical analysis. Rao, Amarantini, Berton, & Favier (2006) studied six different BSP models and reported up to 20 % differences in the hip joint moments during swing phase in gait analysis. Since regression formulas of most BSP models are based on population groups which are different from young athletes (Pearsal & Reid, 1994), we used individual personalized BSP. The objective of this study was to investigate the differences between the Hanavan model and the individual model with respect to angular momentum generation during the takeoff phase in diving. This work is focused on the sensitivity with respect to segment masses in particular of the upper limbs.

METHODS: The software Simi Motion 2D/3D (Simi Motion, Unterschleissheim, Germany) was utilized to digitize the motion. Our first approach used the geometric model of Hanavan (1964), and motion analysis was carried out in Simi Motion. The second approach used the same kinematic data but an individual BSP model obtained by a laser scanner. Motion analysis was performed within the multi-body model dynamicus implemented in the software tool alaska 8.4.0 (dynamicus, 2009). In this study three male divers participated (Table 1).

Table 1
Male subject data.

Subject	Height (cm)	Mass (kg)	Age (years)
A	151	41.4	12
B	158	48.0	12
C	177	61.8	19

They were instructed to perform 1½ back somersaults tuck into a foam block pit. Each subject carried out 13 trials with different arm movements: fast, slowly, and delayed. The takeoff phase, starting with the first upward movement of the arms while standing on toe tips, and ending with the last platform contact, was recorded by three synchronized 100 Hz cameras (Simi Motion). 15 landmarks were digitized and the Hanavan model was chosen for motion analysis. Similarly as in Sheets, Andriacchi, & Corazza (2010) the individual BSP model was obtained using a laser scanner (Human solutions, 2005). Eight anatomical landmarks (left and right acromion, anterior superior iliac crest, superior iliac crest, trochanter major) were tagged by markers. A polygonal surface mesh was constructed and 35 anthropometric length data were computed. Closed loops around neck, shoulder, elbow, wrist, thigh, knee and ankle were drawn on the mesh to separate segments (Figure 1, right). Each segment was treated individually. Geometric measures like volume, area, COM, inertia tensor and inertia axes were computed. Uniform density was assumed to determine the segment masses and 35 length data were used to build the dynamicus model (Figure 1, center). Motion analysis was performed within dynamicus/alaska. Output data were filtered by a 15 Hz low-pass Fourier filter. Rank correlation has been computed in SPSS (IBM SPSS statistics, version 21).

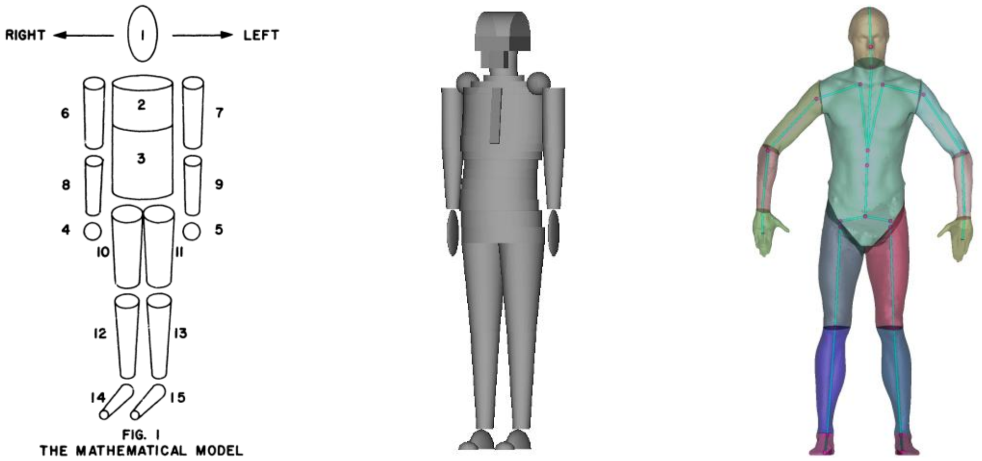

Figure 1: Left: Hanavan model of 15 segments (Hanavan, 1964). Center: dynamicus model of 44 segments. Right: laser scanner surface mesh with segmentation.

Both motion analysis tools, alaska/dynamicus and Simi Motion, were applied because none of them could compute both BSP models. It was impossible to detect differences in integration methods and equation solvers. Our main control parameter was the remote angular momentum rather than the total angular momentum since Simi Motion does not compute local terms.

RESULTS: Table 2 shows the remote angular momentum of the total body when leaving the platform. Each column corresponds to a single trial. The second, fourth, and sixth rows contain the values of the individual model (I) in descending order, the third, fifth and seventh rows are the corresponding values of the Hanavan model (H). Spearman's rank correlation coefficients are 0.626 (subject A), 0.742 (subject B) and 0.538 (subject C). For subject A the individual model yields throughout a larger angular momentum than the Hanavan model (except for trial 12). For Subjects B and C it is the other way around.

Table 2
Remote angular momentum ($kg \cdot m^2/s$) at takeoff, three divers A, B, C, all 13 trials.

trial	1	2	3	4	5	6	7	8	9	10	11	12	13	M ± SD
A (I)	19	18	18	18	18	17	17	16	16	16	16	14	13	17.0±1.5
A (H)	17	18	17	16	17	17	18	16	17	15	15	15	13	16.2±1.5
B (I)	25	25	24	23	22	22	21	21	20	20	20	19	18	21.5±2.4
B (H)	25	26	26	25	26	23	22	24	21	22	20	21	23	23.6±2.1
C (I)	36	32	31	30	29	28	28	27	27	26	26	25	25	28.4±3.1
C (H)	41	33	36	31	35	33	32	31	30	32	33	33	31	33.2±3.0

Table 3 presents the relative contribution of arms, legs, head and torso to the remote angular momentum of the total body. The individual model underestimates the arm contribution and overestimates the head contribution. This is true for 37 of the 39 trials of the three subjects. Subject C has a higher leg contribution in the individual model than in Hanavan's model. It is the other way around for subject B. For subject A there is no homogeneous behaviour. Note that the remote part of the torso is negative and of small absolute value.

Table 3
Remote angular momentum contributions (%) at takeoff (mean value ± SD, N = 13).

subject	arm		leg		head		torso	
	ind	Hanavan	ind	Hanavan	ind	Hanavan	ind	Hanavan
A (41.4 kg)	54±6	58±9	30±3	33±4	18±3	13±5	-6±2	-5±2
B (48.0 kg)	46±5	49±7	36±2	38±3	22±4	17±5	-5±1	-4±1
C (61.8 kg)	56±4	63±4	33±2	30±3	17±1	12±2	-6±2	-6±1

The standard deviation for arm, leg, and head segments are always smaller for the individual model than for the Hanavan model (Table 3). This indicates a higher reliability for the individual model. Note that the torso contribution to the remote angular momentum is negative. This changes when the local angular momentum is included (see Figure 2).

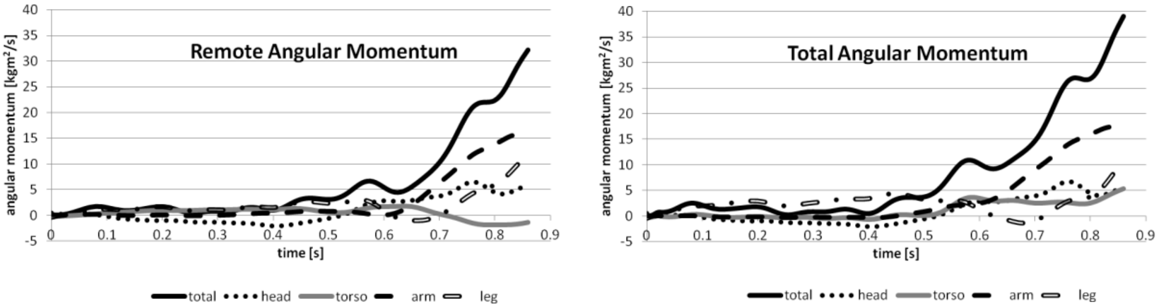

Figure 2: Segment contribution for remote and total angular momenta (individual model, subject C).

Figure 2 shows the time evolution of angular momentum during the 0.86 s of the takeoff phase. The difference between total and remote terms of 38.9 kg·m^2/s – 32.2 kg·m^2/s = 6.7 kg·m^2/s at the end of takeoff is due to the torso only (solid gray curve). Local angular momentum terms of head, arms, and legs are relatively small (less than 2 kg·m^2/s). This is in accordance with an observation of Miller and Munro (1985) that 80-90 % of the angular momentum at the end of takeoff are due to remote terms. Consequently, the use of the remote angular momentum rather than the total angular momentum is an acceptable alternative.

DISCUSSION: Both BSP models reflected angular momentum production during takeoff phase to a back somersault tuck in a similar way. This was established by the moderate (subject C) and strong (subjects A and B) rank correlation coefficients of the remote angular momentum. Subject A showed a higher value for the individual model than for the Hanavan model due to the higher relative arm mass of 5.2 % vs. 4.9 % in the Hanavan model. Subjects B and C had a smaller relative arm mass of 4.7 % and 4.3 % (vs 4.9 % in the Hanavan model) which caused a smaller remote angular momentum. It turned out that absolute and relative differences (total, arm, leg, head) are stable for all trials of one single subject.

The results for all 39 trials indicated that contribution of arms, legs and head to the angular momentum generation is about ½, ⅓ and ⅙, respectively. The remote part of the torso did not positively contribute to the angular momentum, its magnitude was negligible. This was caused by the very small distance of torso COM and total COM. Due to the small contribution of the torso, density differences between segments are of minor importance in this study.

However, the torso has about 50 % of the body mass and possesses a more considerable local angular momentum. For an accurate estimation of angular momentum and energy balances one has to compute the local angular momentum of the torso, too. This can be realized by the individual BSP model inside the alaska/dynamicus environment. The smaller standard deviation for the segment contribution (Table 3) indicated more stable results in case of the individual BSP model. This was due to the fact that the individual model is established by anthropometric measures of the athlet and it is fixed before motion analysis starts. On the other hand, the Hanavan model depends on the anatomical landmarks and changes during motion analysis from frame to frame.

The comparison of the individual and the Hanavan model was in conjunction with the comparison of the two different simulation systems. This shortcoming was unavoidable since the Hanavan model cannot be implemented into the dynamicus and the Simi Motion cannot be configured with the highly individualized BSP models we were interested in.

CONCLUSION: Two BSP models the Hanavan model and an individual model had been applied and compared via computation of remote angular momentum during back somersault takeoff. Segment contributions for arm, leg and head segments had been determined. The intermethod comparison indicated a moderate to strong rank correlation. It was concluded that both BSP models yield comparable results and both are appropriate to study armswing and leg coordination during takeoff in diving. A parallel study had used the above results to quantify the advantage of a fast, straight arm movement versus other movement patterns. This was useful for the coach to figure out the best individual solution. The individual model is preferable since only precise segment data yield exact biomechanical parameters. In an upcoming study the individual model will be improved via investigation of the airborne angular momenta for tuck, pike and straight positions at different rotation speeds. Moreover, the individual model will include moments of inertia of the segments and its relative COM positions.

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