COMPUTER SIMULATIONS OF BACK SOMERSAULTS IN PLATFORM DIVING

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The purpose of this study was to simulate the flight phase of a back 3½ somersault tuck (207 C) for a female elite diver. Starting with the analysis of a real performance initial conditions as angular momentum, takeoff velocity and trunk position were fixed. A multi-segmental angle-driven 3D model was used to study different knee and hip angle patterns. Hip and knee angle modifications were moderate variations of the real performance. Coming quickly into a more compact position and keeping this tight position until come-out produced an advantage up to 130° total rotation and 50°/s mean angular velocity. This advantage obtained in the first flight phases could be used to improve the come-out or to reduce strength requirements at takeoff.

KEY WORDS: flight phase, angle variation, 3d human model.

INTRODUCTION: Divers often perform multiple somersaults in a tuck position and then come out from the compact to an extended body position. Starting the come-out as early as possible and to complete the body extension soon is a good preparation for entry. In general there are two different ways to approach this objective. The first way is to maximize flight height or angular momentum, which was studied by Hamill, Ricard and Golden (1986). Later these release parameters were optimized by computer simulation. This was done in a series of works by Yeadon, Kong and King (2006), see also Cheng and Hubbard (2004). The second way to increase rotation is to change the patterns of joint angles without substantial increase of rotational energy or flight height (Kong, Yeadon & King, 2005). Since the angular velocity in air depends only on the moment of inertia about the somersault axis, a gain of rotation is the result of a more compact, earlier and more stable spinning position. This work is focused on the second approach. A computer simulation model was used to study the effect of changing knee and hip angles in the first flight phases. The model got more quickly into the compact spinning position and was able to keep this tight position until come-out. To exploit this gain of rotation two different come-out strategies were studies, the simultaneous and the successive one. The successive come-out is characterized by an extension in two steps first of the knee angle and then of the hip angle. If knee and hip joints are simultaneously opened we speak of a simultaneous come-out. Köthe (2005) studied the difference between successive and simultaneous come-out for the 307C dive from the springboard. In addition, predictions were made how the gain of rotation in the first two phases can contribute to a reduction of angular momentum at takeoff.

METHODS: The man-model dynamicus (dynamicus, 2009) was used to describe the diver. Dynamicus is a complex multi-body system consisting of head, spine, sternum, thorax, shoulder, arm, thigh, shank and foot. The spine splits into 24 flexible vertebras. Their huge number of degrees of freedom is restricted by a single vector which controls movement. An elite female diver (53 kg, 1.68 m) participated in this study. Subject-specific model parameters were required to customize the model to the diver. The dynamicus model was built of 31 anthropometric measures of the diver which were taken by a 3D laser scanner. Using these data segmental inertial parameters as mass centre locations and moments of inertia were calculated. One real performance of a back 3½ somersault tuck from the 10-m platform was recorded by two synchronized 50 Hz HD cameras Canon XH-A1. The camera axes were orthogonal to each other and formed a 45° angle to the plane of motion. Twenty two motion markers were digitized throughout the movement from both camera views. One body marker on the dynamicus model corresponded to one motion marker each. A weighted least square method was used to fit body markers to motion markers. In the first step time histories of the joint angles were calculated for the real performance. As usual five characteristic postures and four phases between successive postures are distinguished, see Table 1.

Table 1: Characteristic postures of a somersault dive in tuck position

posture	p1	p2	p3	p4	p5
description	takeoff last contact to platform	hands at knee minimal hip angle	start of come-out begin of extension	end of come-out knee extension completed	entry first contact to water

In what follows the real performance of a back 3½ somersault tuck (207C) is referred to as version v1. Input to the model consisted of angular momentum, takeoff velocity, trunk position to the platform and time histories of the joint angles of knee, hip, shoulder and elbow. Left and right joint angles are assumed to be equal. Output from the model were total angular velocity as well as the standard parameters for a non-twisted dive performance (Fricke, 1975) as flight height, phase duration, angular velocities in phases 2 and 3, height above water in all postures. In this study performance v1 was compared with three modifications v2 – v4 of hip and knee angle patterns. The aim was to complete the come-out as early as possible and at a certain height above water. Therefore, in modifications v2 – v4 the moments of inertia were reduced from 393 kgm^2 to 312 kgm^2 in posture 2 by assigning small hip and knee angles which are maintained until come-out, see Figure 1.

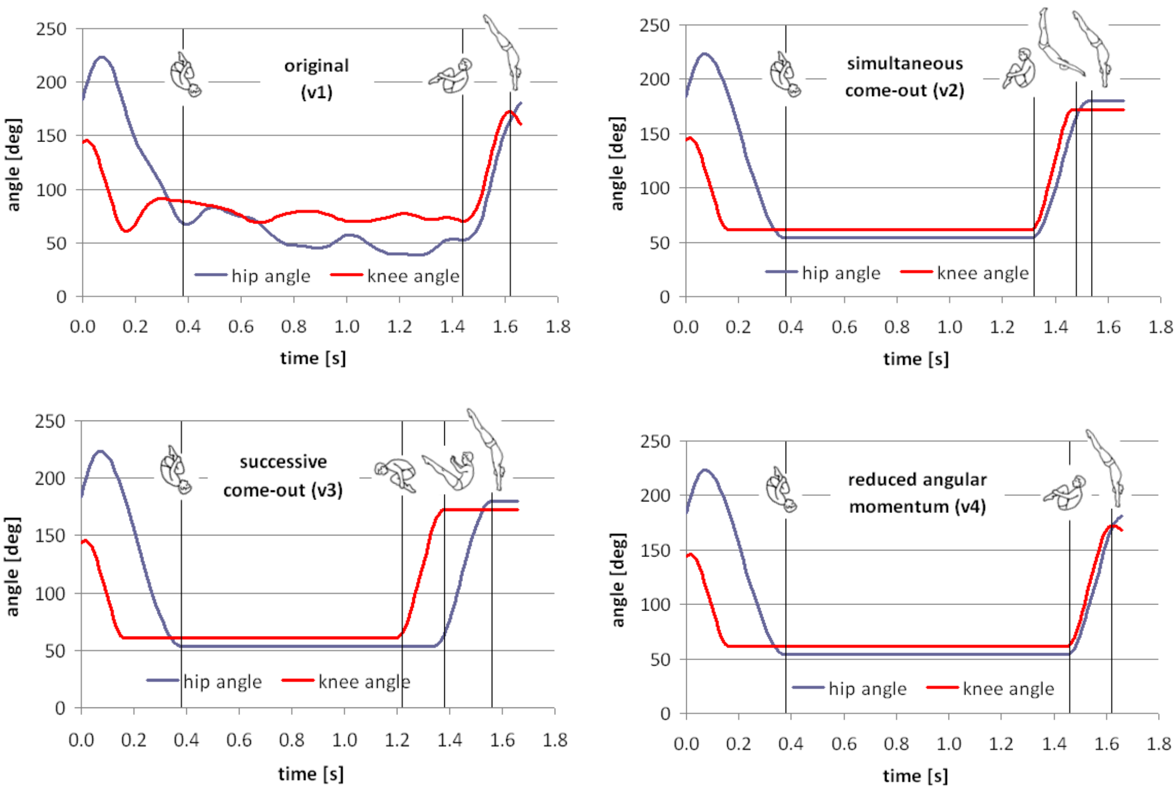

Figure 1: v1: Hip and knee angle patterns of the real performance. v2: simultaneous come-out. v3: successive come out. v4: reduced angular momentum L=43.1 Nms.

RESULTS: These modifications in hip and knee angles implied crucial consequences for phase times, angular velocities and heights above water, see Figure 3 and Table 2. In particular, phase 2 was much shorter for v2 and v3 than for v1. Different come-out strategies for v2 and v3 were simulated. Knee and hip extension started simultaneously in v2 while in v3 first knee extension started and when completed hip extension followed. The reduction of angular momentum in v4 yielded a smaller angular velocity compared to v2 and v3 which was compensated by late come-out and a short phase 4.

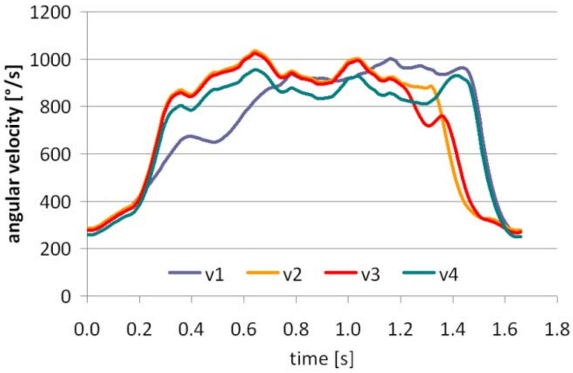

Figure 2: The angular velocities of v1 – v4.

The advantage in rotation is apparent in the mean angular velocities of phase 2 which was about 930°/s for v2 and v3 and 875°/s for v1. This advantage in the first two phases was re-used for a much earlier come-out. Indeed, in v2 and v3 the come-out started and ended quicker than in v1. In v2 and v3 the extended straight position was attained at an earlier stage and greater height above water.

Table 2
Comparison of real performance and variations

parameter		v1	v2	v3	v4
flight height [m]		0.20	0.20	0.20	0.20
angular momentum [Nms]		46.2	46.2	46.2	43.1
duration [s]	phase 1	0.38	0.38	0.38	0.38
	phase 2	1.06	0.96	0.84	1.08
	phase 3	0.18	0.14	0.16	0.16
	phase 4	0.02	0.16	0.26	0.02
angular velocity [°/s]	phase 2	875	927	933	871
moment of inertia [kgm^2]	posture 2	3.93	3.12	3.12	3.12
	posture 3	2.75	3.02	3.04	2.75
	posture 4	9.47	8.32	3.63	8.58
	posture 5	10.14	10.24	10.24	10.20
height above water [m]	posture 2	10.87	10.87	10.87	10.96
	posture 3	3.53	4.91	5.96	3.30
	posture 4	1.46	3.04	4.24	1.48

Figure 3 below visualizes total rotation and height above water for the four simulated dives. Come-out started very late both in v1 and v4. Knee extension was completed very early in cases v2 and v3.

DISCUSSION: The simulation results for the 207C dives v2 and v3 have shown that a substantial increase of rotation in phase 1 and 2 was possible by changing the knee and hip angle patterns according to Figure 2. Once the minimal hip and knee angles were attained the model is assumed to keep this tight position until come-out. Note that these modifications of knee and hip angles were very close to the real performance and respected the capabilities of the diver. This advantage in rotation speed and rotation angle was attained without any increase in linear or angular momentum at takeoff. The gain in the first two flight phases was used to improve the opening phase. Simultaneous and successive come-out strategies were studied. By successive come-out the diver was able to complete the extension to the straight position as early as possible. An unexcited and even entry was possible. Simulation v4 showed that a reduction of angular momentum up to 7% was possible without any loss in total rotation. This implied that the diver could successfully complete this dive even with lower strength capabilities.

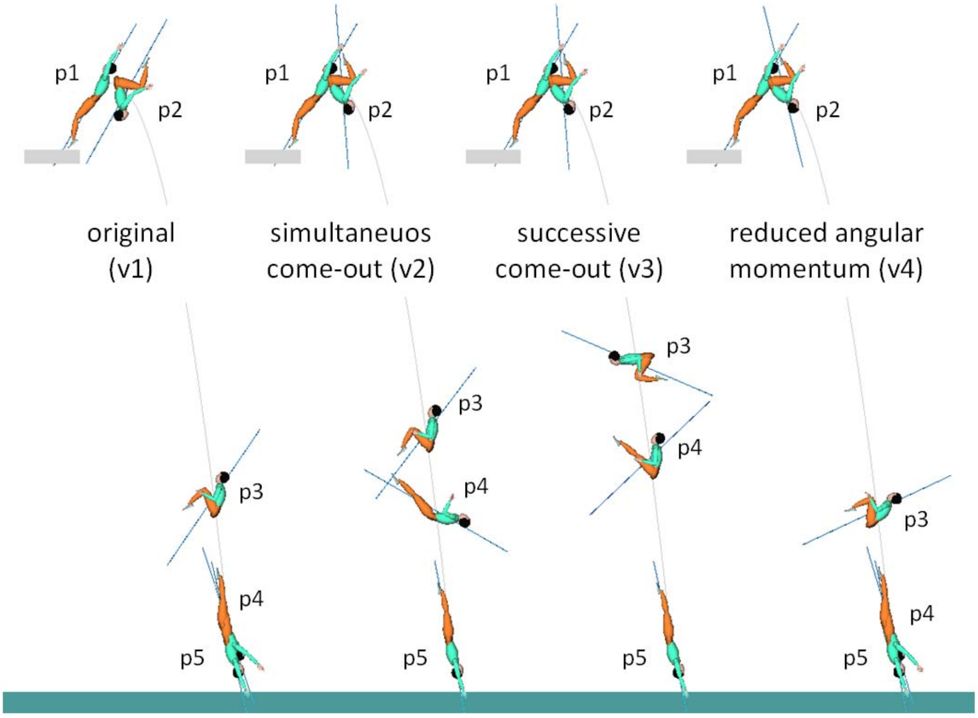

Figure 3: Comparison of the original dive v1 and the three modifications v2 – v4 with respect to the five characteristic postures. The mean inertia axis (blue line) characterizes the rotation angle. In v1 and v4 postures 4 and 5 almost coincide.

The possibility of reduction of initial angular momentum detected reserves of strength which can be useful when approaching and learning a difficult dive.

CONCLUSION: Hip and knee angle modifications of the 207C were studied to detect reserves of the real performance in phase 1 and 2. Coming soon into a stable compact tuck position is beneficial for an early come-out at a remarkable height. The applied method for analysing and modifying joint angles could be transferred to the three other groups of somersault dives without twists. The model is limited as the joint actuators are controlled by joint angle patterns only and not by muscle torque actuators. Future work will include modifications of arm movement and an extension to twisting dives.

REFERENCES:

Cheng, K. B & Hubbard, M. (2004). Optimal jumping strategies from compliant surfaces: A simple model of springboard standing jumps. *Human Movement Science, 23*, 35-48.

dynamicus (2009). *Reference Manual*. Chemnitz: Institut für Mechatronik.

Fricke, B. (1975). *Kinematische Parameter für die zweckmäßige Gestaltung der Flugphase bei Schraubensprüngen im Kunstspringen.* Dissertation, Leipzig: DHfK.

Hamill, J., Ricard, M. D. & Golden, D. M. (1986), Angular Momentum in Multiple Rotation Nontwisting Platform Dives, *International Journal of Sport Biomechanics, 2*, 78-87.

Kong, P. W., Yeadon, M. R. & King, M. A. (2005). Optimisation of takeoff technique for maximum forward rotation in springboard diving. In Q. Wang (Ed.), *Proceedings of the XXIII ISBS Symposium* (pp. 569-572). Beijing.

Köthe, T. (2005). Regulationspotenzial von Teilkörperbewegungen in der Flugphase bei Wassersprüngen. *Zeitschrift für Angewandte Trainingswissenschaft*, 12 (2), 41-58.

Yeadon M. R., Kong, P. W. & King, M. A. (2006). Parameter Determination for a Computer Simulation Model of a Diver and a Springboard, *Journal of Applied Biomechanics, 22*, 167-176.