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OPTIMAL STRATEGIES IN DIVING FOR DIVES OF THE REVERSE GROUP VIA EVOLUTIONARY ALGORITHMS

Axel Schüler[1], Thomas Köthe[1], Thomas Molka[2] and Falk Hildebrand[1]

Institute for Applied Training Science Leipzig, Germany[1]
Leipzig University of Applied Sciences, Germany[2]

The aim of this study was to optimize platform diving techniques of the reverse group using a computer simulation program along with an evolutionary algorithm. We used a planar four-segment model of a diver to study the aerial phase for the reverse 3½ somersault tuck. We fixed the initial angular momentum and five characteristic poses: takeoff, adoption of spinning position, leaving the spinning position, end of come-out, and entry. Starting with real performances of male elite divers executing 306C and 307C performances we found optimal performances for the 307C. The evolutionary algorithm ends up in several different optimal technique variants. The corresponding joint angle patterns are computed and compared. Decreasing knee and hip angles in spinning position by about 20° resulted in a gain of one complete rotation.

KEY WORDS: joint angles, computer simulation

INTRODUCTION: Biomechanical analysis of diving performances is the precondition for determining energetic requirements. Analyses of world-class divers have been carried out by Miller and Munroe (1985). They studied joint positions as well as linear and angular momentum of Greg Lougains' springboard takeoff. At takeoff a diver generates certain linear and angular momentum to perform somersaults and safely travel away from the platform. Sprigings and Miller (2004) studied optimal knee and hip extension to produce sufficient height and rotation for the reverse group. They used a 5-segment torque-driven 2D model to study the takeoff sequence in very detail. In a series of papers Kong, Yeadon and King (2005) presented an 8-segment planar model of a springboard and a diver. As a result optimal torque activation patterns for the takeoff were found. From our point of view the athlete's performance capabilities and technical skills concerning takeoff were known by video analysis. Therefore, in our model angular momentum and initial speed were assumed to be fixed and we were mainly interested in the flight phase. The instantaneous angular velocity during the flight only depends on the moment of inertia about the somersault axis. The timing of knee extension as well as positioning of the arms and the thighs relative to the trunk play a key role in the first and last flight phases. Thus the diver can control his spin rate. Köthe and Hildebrand (2005) determined a difference of 24° in the total rotation angle for a 307C dive from the board between one dive with arm rotation in phase 1 and one without arm rotation. The objective of our study was twofold. On the one hand we used an evolutionary algorithm to determine optimal joint angle pattern for a reverse three-and-one-half somersault tuck (307C). We were particularly interested in different come-out strategies. What is the best timing to stretch the body via knee and hip extension and arm movement? In addition, we asked for flexibility assumptions making a transition from 307C to 309C possible.

METHOD: Model: The diver was modelled two-dimensionally as a four-segment linked system consisting of shank, thigh, head/torso and arms. The five characteristic poses define the four phases between consecutive poses. We assumed constant angular velocity at knee, hip and shoulder joints in each phase. In this study we restricted ourselves to dives of the reverse group from the 10-m platform. Subject-specific model parameters were required to customize the model to the diver. An elite male diver (mass = 66 kg, height = 1.72 m) participated in this study. Six preparing dives of this diver, the reverse triple somersault tuck (306C), were recorded by a 50 Hz camera. Eight standard parameters (Fricke, 1975) have been computed: flight height, duration of the first flight phase, angular velocity in spinning position, duration of the third phase, rotation angle up to pose 4 and pose 5, height over water at pose 4, hip angle at pose 4. The same parameter set has been determined for n = 34 three and one-half somersault tucks (307C) of other male divers at international level. These real performance data have been used to fix some input data. Input to the model included the five characteristic time points and the matrix of joint angles at these moments, see Table 1 below. At pose 3 (start of come-out) the diver is leaving the compact spinning tuck position. By definition, in pose 4 (end of come-out) knee extension is completed, knees are unbent. Data on the height, the mass and the initial angular momentum were also input. Note that the trunk position and the total rotation angle at characteristic poses 2 to 5 were output of the model. Only the tilt angle of the body at takeoff was input.

Table 1
Pattern of joint angles at characteristic poses 1-5

pose		**time**	**angle [deg]**			
		[s]	**trunk to platform**	**knee**	**hip**	**shoulder**
1	takeoff	0	98	170	190	190
2	hands at knees	0.34		60	65	40
3	start of come-out	1.34		57	61	40
4	end of come-out	1.48		180	110	120
5	entry	1.71		180	190	190

Using the anthropometric model of de Leva (1996), the individualized segment parameters including mass, length, and radius of inertia have been determined. Conservation of angular momentum (L = 71.5 Nms) was used to compute total angular displacement and total angular velocity. Output of the model was the complete time history of the diver's positions given by joint angles as well as by planar Cartesian coordinates of head, shoulder, wrist, hip, knee and ankle at any 0.01 s from takeoff to entry.

Optimization: We performed parameter variation to find the optimal total rotation angle. We fixed angular momentum and the characteristic time points of the 5 poses (Table 1). We changed the 15 angles of the last 3 columns. Knee and hip angles were assumed to be not less than 40°, an anatomical constraint which can be different for other athletes. The knee angle was not allowed to exceed 180°. The systematic search for an optimal performance under these initial conditions was organised by an evolution strategy (Weicker & Weicker, 2003; Weicker, 2007). The fitness function given in fitness points (fp) included 10 penalty variables controlling unrealistic behavior like waving movements, multiple revolutions of arms and disparity of hip and knee angles in phase two. The most important part of the fitness function was however the total angular displacement (rotation angle at entry). For a three-and-one-half somersault (307C) this angle must be equal to $3.5 \cdot 360° - 15° = 1245°$. We subtracted a supplement of 15° since the diver is still rotating at the entry. An individual was formed by 21 parameters: time points of the poses; knee, hip and shoulder joint angles and the angle of tilt at takeoff. Mutation changed one or more of these angles randomly by $\alpha \leq 5°$. The magnitude of α depended on the fitness: the better the individual, the smaller was α. We used uniform crossover for recombination: the child individual inherits half of the parameters of the first parental individual and half of the second one. A population consisted of 20 individuals. By recombination we obtained 100 children which were all mutated. The fittest 20 children were selected to form the next generation. Individuals with lower fitness values were considered to be better. 1000 successive generations were sufficient to stabilize the fitness.

RESULTS: In our analysis we always refer to the four performances (a), (b), (c) and (d). The first three dives are shown in Figure 1. Dive (d) is a 309C with similar poses as dive (c). Their characteristic data are given in Figure 2 and Table 2. Dives (b), (c) and (d) were obtained by simulation and optimization. Dive (a) served only as initial individual. Moreover, (c) was also an initial individual for dive (d). We started the optimization procedure with the very bad dive (a). Instead of 3½ only 2¼ somersaults were performed. Knee and hip angles were too big; consequently angular velocity was too small to complete 3½ somersaults. Its fitness is 7350 fp. The evolutionary algorithm produced different quite good individuals (b) and (c), with fitness 172 fp and 60 fp, respectively. This is typical for applying an evolutionary algorithm to this model: A single individual can produce a lot of optimal individuals. We continued with dive (c) (307C) as an initial individual for a 4½ somersault tuck (309C). The fitness is high (3536 fp) because of the one missing somersault. Optimization resulted in dive (d) with fitness 428 fp where knee and hip angles are 40° and 49°, respectively, so the moment of inertia in the spinning phase is 3.42 kg m^2 compared with 4.48 kg m^2 for dive (c).

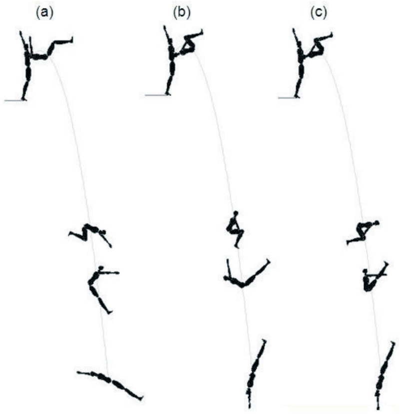

Figure 1: Five characteristic poses. (a): Initial simulation of a reverse "2¼ somersault". (b), (c): Simulation of two optimized reverse 3½ somersault tuck (307C).

The four performances differ only in the compactness of the body and therefore in their moments of inertia. The total rotation angles from takeoff to entry for dive (a) to (d) amount to 791°, 1250°, 1250° and 1606°, respectively. Dive (a) has an open spinning position and therefore a big moment of inertia. Dives (b) and (c) differ only in phases 3 and 4. In dive (d) 4½ somersaults can be performed because of the tight spinning position. We compare dives (b) and (c): In pose 2 (b) has 60° of hip angle of while (c) has 66°. This yields an advantage in total rotation of (b) over (c) in pose 3 of about 60° (Table 2). This shortcoming of (c) with respect to the rotation angle is compensated by an acute hip angle in phase 3 and small moment of inertia. We observed two different come-out strategies. Dive (b) is characterized by simultaneous hip and knee extension in phase 3 whereas in dive (c) the hip angle remains closed. This yields a higher angular velocity for (c) in phases 3 and 4. At touchdown the total rotation angle for both dives are the same. Dive (d) is a child individual of dive (c) under the evolutionary algorithm. The patterns of joint angles are quite similar; the main difference is the tighter spinning position of dive (d): Hip and knee angle of (c) are both 66° while for (d) 40° and 49°, respectively (Table 2). This results in an increase of angular velocity from 906°/s to 1266°/s. A complete additional rotation can be performed. In pose 4 knee angle should be 180°. This goal has been achieved by the evolutionary algorithm in case of (b) and (c). However for (d) we obtained a difference of 4° which effected a penalty of 21 fp in the fitness function. We observed striking differences for the hip angles. They are closed (40°) in case of dive (c) and (d) but open (110°) in (a) and (b). As a consequence the moments of inertia for (a) and (b) are more than twice as much as for (c) and (d).

Table 2
Comparison of the dives at pose 3 (start of come-out) and pose 4 (end of come-out)

	pose 3				pose 4			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
knee angle [deg]	57	57	66	40	180	180	180	176
hip angle [deg]	60	61	66	49	110	110	40	40
shoulder angle [deg]	145	40	40	30	120	120	85	34
moment of inertia [kgm^2]	6.33	4.20	4.57	3.43	9.96	9.96	4.80	4.39
total rotation angle [deg]	619	1061	1002	1322	718	1148	1088	1432

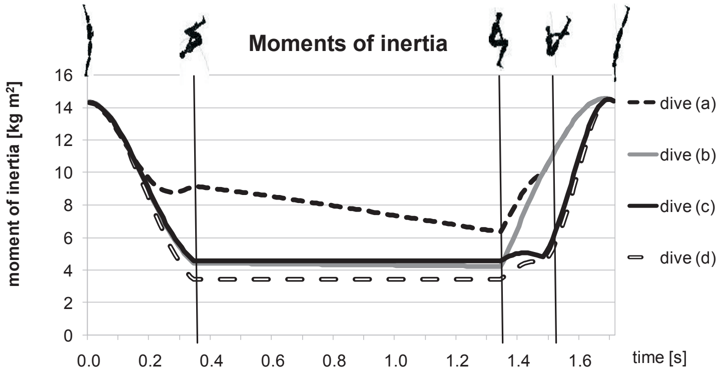

Figure 2: Moments of inertia for the above four dives.

DISCUSSION: The optimization results for the 307C dives (b) and (c) have shown that a substantial increase of rotation was possible by changing the activation pattern for knee, hip and shoulder angles. This was feasible without any increase in strength like higher angular momentum or higher initial vertical velocity. This is in agreement with the observations of Kong, Yeadon and King (2005) who studied optimal takeoff techniques in springboard diving. Note that optimal dives with minimal fitness are far from being unique. Further criteria are needed to distinguish several very good dives. The relatively simple four-segment model may be questioned. It should be extended to a pseudo 3D model with upper and lower arms. Another limitation of our model consisted in controlling the joint actuators only by angular velocities and not by muscle torque actuators. In future work relations between strength capabilities of the diver and amount of the joint angles should be included in our model.

CONCLUSION: This optimization procedure for 307C dive in conjunction with a precise analysis of the diver's anthropometry and strength capabilities was useful to create a personalized diving model. The diving model presented as set of parameters, as a sequence of key event pictures and as a video of the simulated dive can assist the athlete and the coach to transfer from a 306C dive to a more sophisticated 307C dive.

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