Evaluation of Start Techniques in Sports Swimming by Dynamics Simulation (P18)

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Topics: Biomechanics, Modelling, Performance Sports, Virtual Reality & Computer application in Sports.

Abstract: Winning and losing times in swimming competitions sometimes differ by only a few hundredths of a second. Marginal improvements in executing the start phases may give a significant advantage. Two basic techniques are performed: grab and track start including significant parameters like reaction time, take-off velocity, flying width etc. Modern methods of modelling and simulation of human motion supply new knowledge on efficiency in execution of the start process. The model of a swimmer describes the essential anthropometrical and kinematical properties. The motion is simulated based on video capturing including the free flight phase. The differences of the techniques, advantages of high level execution and the influence of the anthropometric data are shown in a comparison of animations of the motion and the parameter based evaluation as well as time histories of joint angles.

Keywords: Biomechanics, Simulation, Modelling, Swimming, Start.

1- Introduction

The performance development in sports swimming shows tendencies of decreasing competition time and lags between the athletes. Slight differences are strongly influenced by start and turning techniques (Küchler 1994). This non-cyclic and springiness oriented phases of motion are crucial factors for lost and won races. An increasing role is assigned to the configuration of the start motion of the athlete (Küchler and Graumnitz, 2006, Vilas-Boas *et al.* 2000, Breed and McElroy, 2000, Krüger *et al.* 2003). Disadvantages of the swing start are described more then 30 years ago (Lowell 1979, Roffer 1972).

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Figure 1 - Start techniques.

The currently favoured start techniques differ in the initial position. In case of the grab start the motion is characterized by a symmetric motion of legs. The track start is distinguished by a forward or backward shifted body mass and asymmetric initial position of the legs (see figure 1).

2- Modelling

Based on the multibody simulation tool alaska, an integrated development environment for modelling of mechanical systems (alaska 2007), a specific modelling interface for the analysis of start techniques in sports swimming has been developed. The functionality of alaska is applied in biomechanics in sports, rehabilitation, ergonomics, as well as mechanical and automotive engineering and robotics.

The three-dimensional biomechanical human model DYNAMICUS (2007) has been used for this investigations. It consists of a highly granular template library of parts of the body including joints, anthropometrical data set, joint limits, damping properties etc. These elements are used to set up the model and to simulate the motion. The hierarchical structure of the model includes the components head and cervical, trunk, left and right arm with hand, left and right leg as well as left and right foot. Every component consists of rigid bodies connected by joints. The coupling between the components is realized by joints in a selectable granularity (Härtel and Hermsdorf, 2006).

The anthropometric data are computed either with respect to total mass, length and gender based on regression formula or with a body segment measurement method for length, width and circumference. All necessary model parameters like length and inertia properties of the segments are used to define an individual anthropometric data set of swimmers and to define a database of swimmer properties.

The swimmer model contains 21 body segments with a maximal total degree of freedom of 57. The environment is parameterized to adapt the different calibration conditions and compare different executions in the same reference frame. It is embedded in a special simulation environment for application in sports swimming. The user can apply predefined models for grab or track start technique, choosing a 2D- or 3D- motion and only has to specify the anthropometrical data set. All essential parameters for the simulation of the motion can be defined in a simple way using the input dialogs. Modelling is supported by a visualisation of components in different kind of characteristics in an arbitrary combination (see figure 2).

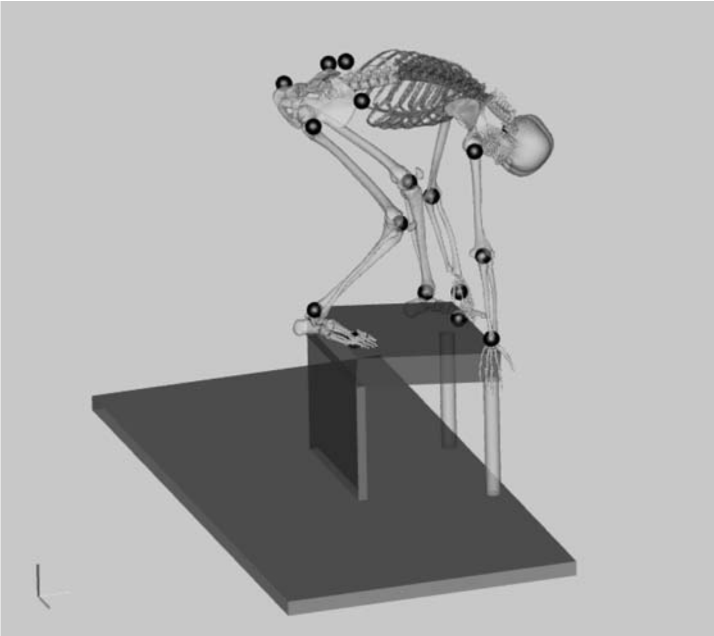

Figure 2 - Human body model with body markers.

3- Pre-processing

The real motion of the swimmer is captured by digital cameras and analysed from the beginning with the start signal to the touch of the hands on the water surface. Special marker points on joints or specific points of the body surface are labelled. For the planar analysis in case of grab start 10 motion marker points and in case of track start 13 marker point are used (see figure 3), while up to 19 marker points for a 3D-motion can be analyzed. Using the measure and analyse program "Mess2DDV" of the IAT, the time history of the marker positions with respect to the inertial reference frame are computed (Drenk and Hildebrand, 2002). For a calibration of the motion area special markers of the environment are utilized.

In a following process the motion markers and body fixed markers are joined. For every motion marker a weight parameter exists and joint limits bound the range of motion in every joint. In this process of inverse kinematics the minimum of the distance between all motion and body markers will be computed in an optimization process. As a result of this pre-processing the reference motion of the inner joint angles of the human model and the time history of motion in the inertial reference frame of the body pelvis can be extracted.

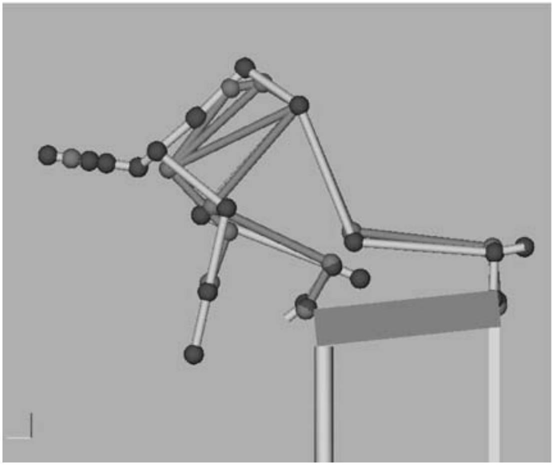

Figure 3 - Motion and body markers.

Additional knowledge for the analyses of start techniques is generated by the reaction forces at the blocks (Kibele *et al.* 2007). Therefore, in addition to video based analyses a dynamometric block (see figure 4) was applied. With usual dimensions and a forward tilted surface of 5°, the block, developed at the IAT, is able to measure vertical and horizontal forces separately for each leg and total vertical forces of the hands (Knoll and Wagner, 2006, see figure 4). The measured forces are represented as vector arrows in the simulation environment and serve as comparison to the computed ground reaction forces.

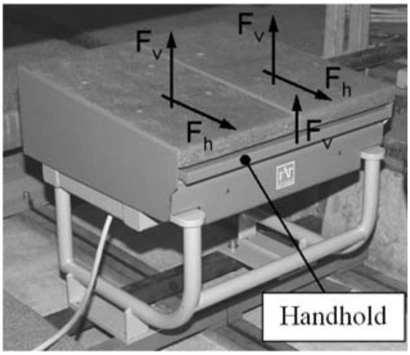

Figure 4 - Starting block dynamometer.

4- Simulation Process and Results

For the predefined time of take-off the best possible initial conditions of flight phases are determined by multicriterial optimization with regard to minimal deviation between motion markers and body markers. The simulation of the entire process is based on a dynamic control which guides the actual motion to the reference motion of joint angles.

During the whole simulation, except the flight phase, the pelvis is dynamically controlled in the inertial reference frame by a so-called Lyapunov-stable control law for underactuated systems (Härtel *et al.* 2006).

For the evaluation of time parameters the block time (from the start signal to the take-off) and the flight time (from take-off to initial water contact) is used. Basic simulation results of every body segment are position, angular velocity, linear and angular momentum etc. Motion specific results are system parameters like the velocity and angle of take-off, jump width and the position of the center of mass. Other results are the time history of linear and angular momentum, angular velocity and all joint angles, which are very useful for motion analyses. The time history of the results is given by curves or text files.

Figure 5 shows the graphs of knee and hip angles of two track starters. There are two reasons for swimmer S1, represented by the solid curve, to achieve a shorter block time versus swimmer S2 (dotted line) with the same reaction time (time between start signal and first movement of the swimmer): First, swimmer S1 starts flexing the knee joint of his front leg immediately and secondly, a faster stretching of the back leg knee joint. Furthermore, the greater amplitudes in the knee and hip of swimmer S1 provide a higher take-off velocity.

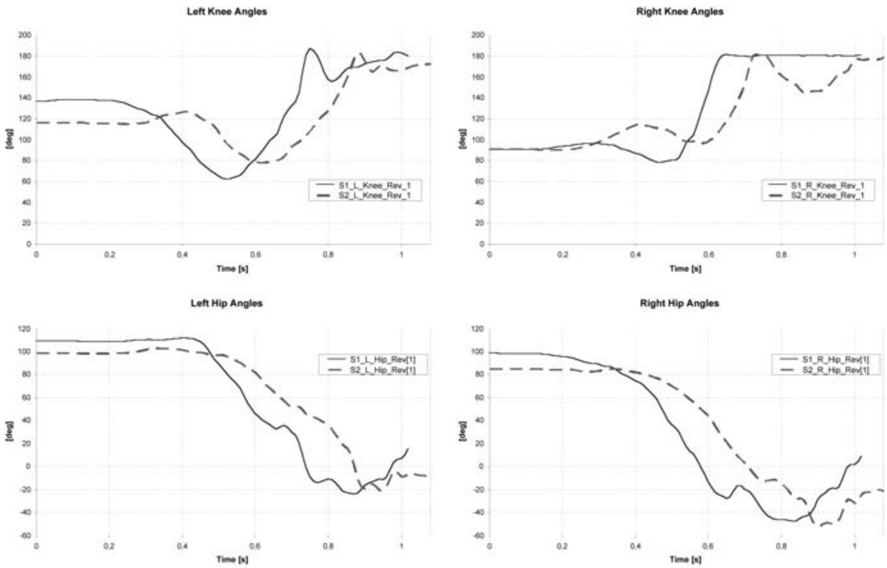

Figure 5 - Hip and knee joint angles of track start variants (solid line conforms to a high level execution)

Further graphical topics are the representation of the environment, different kinds of visualisation of the swimmer, several views with fixed or moving camera and visualisation of mechanical parameters like total angular velocity and angular momentum. The trajectory of body points or the total center of mass can be represented in a spatial track in the animation. It is possible to shown additionally the projection point on the water surface of the hand and of the center of mass. The motion of several swimmers can be compared using a special animation viewer in order to explain the different techniques of the swimmers and the execution quality of top level swimmers.

Figure 6 is representing the comparison of male swimmers in the initial position and the time point of the first water contact. Each two swimmers use the grab start, track start with a forward or a backward shifted body mass. The point of first water contact differs up to 0,85 m. Angle and velocity of the take-off differ significantly. In this comparison a swimmer with a track start and a backward shifted body mass reached the best start parameters and flight width.

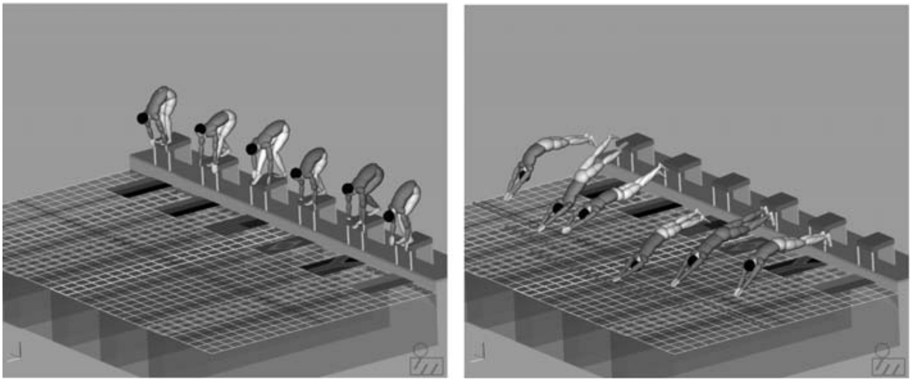

Figure 6 - Comparison of national and top level start techniques.

To analyse the influence of take-off parameters or segment motion a method to manipulate the movement in the flight phase is implemented. The velocity and angular velocity of the body pelvis, the total linear momentum or total angular momentum may be given explicitly by value as initial conditions of this phase. Furthermore, it is possible to change the motion of selected body segments, e.g. the leg or the arm.

5- Conclusion

The application-specific simulation environment enables the user to carry out an efficient analysis of different start techniques without specific modelling and simulation knowledge. Many results of the simulation allow a comprehensive analysis of the start execution. The tool offers several options for manipulating the conditions in the start phase in sports swimming. So the user can easily analyse the different interrelations of biomechanical parameters during the start phase. Variations of initial parameters of the take-off generate new knowledge for the understanding of dominating factors. Animations can be used in cooperation with the swimmer to explain cause-effect-connections in the execution.

Analyses show, that both techniques lead to top start performances (Graumnitz *et al.* 2007). The asymmetric track start requires higher movement coordination. On the other hand for the horizontal acceleration and shorter block times the initial position, based on the placed back leg, is more beneficial. Furthermore the effort of the back leg can be used to produce a larger vertical impulse and advanced angular momentum. Even so there cannot be a recommendation for one or the other technique unless taking individual physical conditions of the swimmer into account.

This project is supported by the Bundesinstitut für Sportwissenschaft (BISp), Bonn, Germany.

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