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# Models and methods for analyzing interaction in springboard diving

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## 1. Introduction

The diving judgement is based on the technique and grace from the starting position to the entry into water. The degree of difficulty of the dive, which is multiplied by the judges' score, depends on the position of the diver in the air and the number of achieved somersaults and twists (FINA 2017). Previous studies figured out mechanical criteria of springboard diving performance, often focusing on how maximize dive height and/or number of rotations (Sinclair 2012, Cheng et al. 2008). A compromise between the diver's angular momentum leading to the rotations and his horizontal velocity required for clearing the board was highlighted (Cheng et al. 2008). It was also found that the interaction between the diver and the diving board was crucial at key moments as touchdown and take-off (Sinclair 2012). This interaction comes from a temporal synchronization between the diver's whole body and the diving board, which may be optimized to improve springboard diving performance (Sinclair 2012, Cheng et al. 2008).

The current study presents models and methods enabling to compute mechanical features involved in the performance. We hypothesize that observing these criteria may help to better understand how optimize synchronization between the diver and the diving board. A biomechanical model of the diver and motion capture data of the diver and the diving board were used to compute:

- The key moments (touchdown and take-off)
- The maximal altitude of the diver's centre of mass (CoM), which is related to dive height
- The diver's angular momentum, which is related to the number of rotations
- The maximal horizontal distance between the diver and the diving board free end after take-off (MHD), which must be managed while maximizing the angular momentum
- The efforts distribution under the participant's feet, which gives insight into the diver's balance and help to better understand his overall motor strategy

## 2. Methods

### 2.1 Motion capture data

Motion capture data were recorded using an optoelectronic system (12 cameras, 200 Hz, Qualisys).

A set of 45 markers was placed on a recreative diver (1.65 m; 66.7 kg) following ISB standards for a whole-body study. Markers were placed at 10 cm apart on a diving board side to have several markers in the contact surface between the participant's feet and the diving board. Another marker was placed on the other side.

This study was a preliminary one to test the method before applying it to more trials performed by elite divers. So, 4 dives were recorded: 2 with a running approach (RA dive) and 2 with a starting position at the diving board free end (SP dive).

### 2.2 Diver modelling and IF&M computation

An 18-segment model of the diver was used to compute the interaction forces and moments (IF&M). Firstly, joint coordinates were computed using an inverse kinematics method. They were filtered using a 4th-order Butterworth low-pass filter with no phase shift and a cut-off frequency of 10 Hz. The interaction forces and moments (IF&M) were then computed using these results and motion capture data of the diver and the diving board. Firstly, a contact detection step was performed considering 28 discrete contact points under the participant's feet. This process was suitable for interaction between a human subject and a moving and/or non-horizontal structure. Secondly, the forces were distributed among them using an optimization approach (Demestre et al. 2021).

### 2.3 Computed mechanical features

The time steps with no contact between the diver and the diving board were computed from the contact detection process of the IF&M computation method. The last time step with a contact between the diver and the diving board was considered as the take-off moment. The first time step after the last contact between the diver and the diving board before take-off was considered as the touchdown moment. These two key moments were plotted on the graph displaying the evolution of the other mechanical features according to time to give insights into the synchronization between the diver and the diving board (Figures 1 and 2).

The CoM positions were computed using the diver model and the method from (Kajita et al. 2015). The MHD were computed using the CoM positions and the motion capture data of the diving board (position of the diving board free end).

The angular momentum around the centre of mass of the diver's pelvis in the model was computed adding the contribution (angular velocity multiplied by the inertia tensor) from all the segments of the diver model (Kajita et al. 2015).

Each foot was regarded as two surfaces: the toes and the rest of the foot. For each foot, the contributions from the contact points under the toes and the other ones were split to know which part of the total force was applied on each part of the foot.

### 3. Results and discussion

The Table 1 presents the maximal altitude of the CoM and the MHD. The temporal evolutions of the angular momentum (Figure 1) and the vertical interaction force distribution (Figure 2) are presented only for one RA dive.

Dives	Max altitude CoM (m)	MHD (m)
RA dive 1	1.50	1.94
RA dive 2	1.51	1.81
SP dive 1	1.39	1.42
SP dive 2	1.36	1.46

Table 1 Maximal altitude of the CoM and MHD

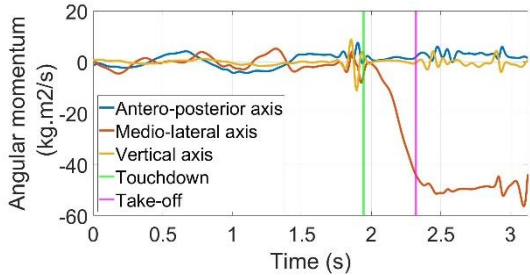


Figure 1 Temporal evolution of the angular momentum and key moments for a RA dive

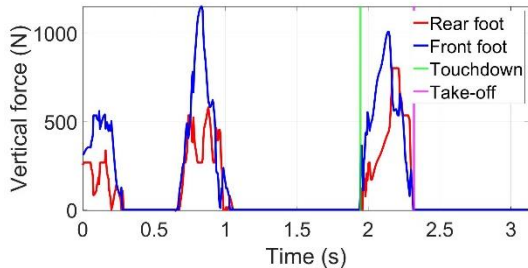


Figure 2 Temporal evolution of the vertical force under the left foot and key moments for a RA dive

As mentioned in the introduction, all these features are linked to springboard diving performance. Comparing all of them for different similar dives may help to better understand the performance discrepancy between them. The CoM is useful to compare dive height and thus may help to ranked objectively the studied dives. The angular momentum and the MHD give information about how the diver managed the compromise between those two features. It may show if the diver needs to reduce his horizontal velocity at take-off to increase his angular momentum and achieve more rotations. The distribution of the vertical force under the diver's feet give insight into his motor strategy. Observing the evolution of this distribution with respect to an evaluation of the studied dives by an expert may help to know more about the impact of the diver's balance on the performance. Considering the key moments at the same time may help to know how optimize the synchronization between the diver and the diving board.

All these features may be completed with other ones like joint coordinates, positions and velocities of specific points of the diver, and diving board motion. This method will be applied on trials performed by elite divers and evaluated by an expert. These data will be used to figure out how these criteria impact the springboard diving performance.

### 4. Conclusions

The models and methods presented in this study may be used to optimize synchronization between a diver and a diving board. They are based on motion capture data required to compute several mechanical features which are linked to springboard diving performance. This preliminary study enabled to compute the considered features but could not lead to concrete conclusions. These models and methods are intended to be used to analyze the performance of several elite divers performing several kinds of dives evaluated by an expert. It will help to better understand how the considered features impact the performance. The synchronization between the diver and the diving board may be optimized using those results.

Other features than those presented in this study may be computed from the used models and methods. Other discussions with divers and coaches are planned to determine more features to analyze.

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