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Biomechanical analysis of the final push of an elite springboard diver

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1. Introduction

Springboard diving is a sport which is evaluated by judges. The performance is based on the technique and grace from the starting position to the entry into water (FINA 2017). The interaction between the diver and the springboard, depending on the temporal synchronization between them, may be optimized to improve this performance (Sinclair 2012).

This **pilot** study focuses on the synchronization between the final push of the diver before take-off and the maximal deflection of the springboard during forward dives. The technical sport manager and the literature (Miller et Munro 1985) agree that this push should be synchronized with the maximal deflection of the springboard. But they also observed that this push was usually performed while the springboard was still deflecting. **The current abstract presents a study of the synchronization between this push and the maximal deflection of the springboard for dives with different difficulty levels.**

This push was studied according to knee joint coordinates and torques. The synchronization between the knee kinematics and dynamics and the maximal deflection of the springboard was then addressed. A biomechanical model of the diver and motion capture data of the diver and the springboard were used to compute the required mechanical features.

2. Methods

2.1 Motion capture data

Motion capture data were recorded using an optoelectronic system (18 cameras, 200 Hz, Qualisys). A set of 36 reflective markers was placed on an elite diver (1.80 m; 79 kg) following ISB standards for a whole-body study. A set of 51 markers was placed on diving board sides (50 on a side and 1 on the other side) and spaced 10 cm apart. The diver performed 9 forward dives (3 101C, 3 105C and 3 107C). These types of dives differ in the amount of half somersaults achieved, which corresponds to the last number of the code. These dives were evaluated by another elite diver watching them: **the 3 repeats of each type of dive were ranked against each other.**

2.2 Diver modelling and IF&M computation

A three-dimensional 18-segment model of the diver was used to compute the interaction forces and moments (IF&M) between the diver and the springboard. 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 IF&M were then computed using these results and motion capture data of the diver and the springboard. Firstly, a contact detection step was performed considering 28 discrete contact points under the diver'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. 2022). An inverse dynamics step was then carried out using the Matlab toolbox CusToM to compute joint torques (Muller et al. 2019).

2.3 Data analysis

To study the diver's final push on the springboard, the knee kinematics and dynamics were considered. The temporal evolution of joint coordinates and torques of the two knees were computed from touchdown (start of the last contact phase before take-off) to take-off. The two knees were observed separately to verify the hypothesis of a movement in the sagittal plane admitted in the literature.

The touchdown and take-off moments were identified using the contact detection results of the IF&M computation method. The maximal deflection moment was identified using motion capture data of the springboard free end. The flexion-extension angles of the knees were obtained from inverse kinematics results. Maximal extension corresponded to an angle of 0° and maximal flexion to an angle of -180°. The flexion-extension torques of the knees were obtained from the inverse dynamics results. The torque was positive during extension and negative during flexion. The duration between maximal torque and deflection (DT) was computed as the difference between the maximal deflection moment and the maximal torque moment. A negative duration corresponded to a maximal torque happening after maximal deflection. A similar duration was also computed regarding the maximal knee flexion (DF).

3. Results and discussion

3.1 Knee flexion-extension angle

Right and left knees have a similar kinematic behaviour (Figure 1). Therefore, the hypothesis of a planar movement seems suitable for studying knee kinematics during a forward dive.

Diver's knees were in flexion at touchdown. Then, the diver started an extension which then remained nearly constant before the maximal

deflection of the springboard. Finally, the diver was increasing extension until the take-off.

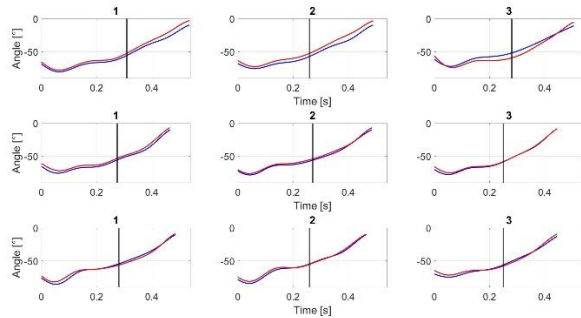


Figure 1 Evolution of the flexion-extension angles of the right (blue) and left (red) knees for 101C (up), 105C (middle) and 107C (bottom) dives. For each line, each graph corresponds to a repeat. The vertical line corresponds to the maximal deflection moment

No tendency was observed regarding DF according to difficulty and quality of the studied dives. This observation may come from a similar DF for all the dives, which shows that the diver was repeatable considering his knee kinematics.

3.2 Knee flexion-extension torque

Regarding knee dynamics, the hypothesis of a planar movement seems not suitable (Figure 2). This asymmetry may also come from lateral dominance, anatomical asymmetry, posture, fatigue, traumas (Loffing et al. 2017) or an imbalance during the dive.

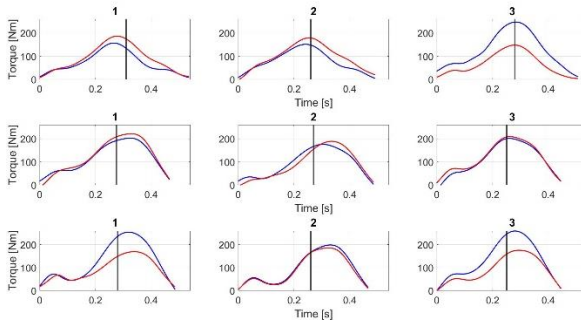


Figure 2 Evolution of the flexion-extension torques of the right (blue) and left (red) knees for 101C (up), 105C (middle) and 107C (bottom) dives. For each line, each graph corresponds to a repeat. The vertical line corresponds to the maximal deflection moment

Torques were always positive even if flexion was observed at touchdown. This observation shows that the diver provides a resistive torque at touchdown to limit flexion increase due to contact with the springboard. During the constant extension phase observed in Figure 1, torques also remain constant, or even decrease. Maximal torques were then reached close to the maximal deflection. These maximal

torques could be reached before (for 101C 1 and 2) or after the maximal deflection (for all the other dives). Considering all the dives with a maximal torque after the maximal deflection, this duration increased as the dive difficulty increased. This phenomenon may come from a higher maximal torque for more difficult dives, which requires more time to be reached. No tendency was observed regarding DT according to dive quality.

4. Conclusions

This study enabled to study knee kinematics and dynamics from touchdown to take-off during forward dives. It was found that the hypothesis of a planar movement was suitable for studying knee kinematics but not dynamics.

No performance criteria were identified regarding the synchronization between knee behaviour and maximal springboard deflection. It was observed that the maximal knee torque increase with the difficulty of the dive.

A study involving more divers performing more dives could enable to validate the observed tendencies. Other type of dives may also be studied following the presented method.

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