Biomechanics of Explosive Sports Skills

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2019

document version
Publisher's PDF, also known as Version of record

In this thesis, we described mechanical analyses of athletes' movements in explosive sports offensive shooting and defensive jumping skills. The overall aim was to understand the nature and key determinants of performance of these movements, so that guidelines can be given to technical, and strength and conditioning coaches. To that aim, two theories of coordination of explosive movements and the biomechanical principles behind them were explored in the first chapter. Thereafter, the drag flick shot in field hockey and the goalkeeper's diving save in football were chosen for further analysis.

In the **second chapter**, we investigated the coordination pattern used to maximize stick head speed when performing the drag flick in field hockey. Full-body three-dimensional kinematics of the drag flick was measured in elite hockey players, in order to analyze upper body joint angular velocity and contributions to stick endpoint speed. We found that the athletes timed the onset and peak magnitudes of trunk and upper limbs joint rotations largely in accordance with a proximal-to-distal sequence. The drag flick started by laterally rotating the trunk segment, followed by sequential onsets of right shoulder flexion, right elbow extension and right wrist flexion. As for the left upper limb, left wrist radial deviation and shoulder internal rotation started after the onset of trunk lateral rotation towards the target, and they were followed by onset of left wrist extension. Subsequently, peak angular rotation magnitude was first reached in trunk lateral rotation, followed by left shoulder internal rotation and wrist radial deviation, while left wrist extension velocity peaked last. As for the right upper limb, right shoulder flexion reached peak velocity after trunk lateral rotation, and followed by right wrist flexion and elbow extension. The deviations from a perfect proximal-to-distal sequence were attributed to constraints set by bi-articular muscles, the closed-chain formed by the upper limbs, and a required straight ball trajectory. In addition, not all rotations were equally relevant for maximizing endpoint velocity; trunk rotations (lateral and axial), right wrist flexion and left wrist extension were found to be the main contributors to endpoint velocity at ball release.

From the **third chapter**, we started focusing on the mechanics of goalkeepers' diving save skill in football, by performing full body kinematics and lower limbs kinetics measurement of elite football goalkeepers. In the third chapter, we aimed to study the self-selected preparatory posture before the dive, the development of linear and angular momentum, and the legs' contribution to end-performance during high and low dives. Full-body three-dimensional kinematics were measured using a passive marker motion analysis system and ground reaction forces (GRF) were measured using two custom-made force plates. Balls were hanged with a magnet to a thin rope, 1 m in front of the goal line at two different heights (30 cm and 190 cm). During the preparatory posture, self-selected stance width was very consistent, with a relatively small standard deviation, compared to knee and hip flexion angles. We found little difference between dive heights in horizontal linear momentum, but the difference in vertical linear momentum was larger as high dives required more vertical displacement of the center of mass (COM) than low dives. Angular momentum in high and low dives were similar around contralateral push-off, but differences started to appear around ipsilateral push-off as angular momentum during low dives continued to rise, while it dropped gradually during high dives. Furthermore, the contralateral leg contribution to COM horizontal and vertical velocity was larger than the ipsilateral leg contribution during all diving save conditions. The contralateral push-off lasted longer than the ipsilateral one allowing for a further forces build up and contribution to COM velocity. The contralateral leg was also better positioned in the direction of the ball, while the orientation of the ipsilateral leg was more upright and therefore more suitable for vertical linear momentum.

In the **fourth chapter**, we aimed to look into lower extremity joint powers, moments and angular velocities in a more realistic experimental setup. The goalkeepers dived to save high and low balls, shot to both sides of the goal by a ball canon placed at the penalty spot. The shooting speed of the canon was calculated to make sure the goalkeepers have just enough time to react and dive as fast as possible to the correct side and height to save the ball. Similar to Chapter three, a passive marker motion analysis system and two custom-made force plates were used to measure three-dimensional kinematics and kinetics of the goalkeeper's dive. We found a proximal-to-distal sequence, with some minor deviations, in timings of peak joint powers in both lower limbs. The joints of the contralateral leg reached their peak first by starting with the hip power in the sagittal plane, followed by knee power and ankle power in the sagittal plane, and hip power in the frontal plane. The contralateral peaks were followed by a perfect proximal-to-distal sequence of ipsilateral joint peak powers, as ipsilateral hip power in the sagittal and frontal planes reached peak magnitudes first, followed by knee power in the sagittal plane and finally ankle power in the sagittal plane. Furthermore, hip extension and ankle plantar flexion moments in contralateral and ipsilateral legs were found to be the largest moments during push-off.

In the **fifth chapter**, we aimed to assess whether the performance of goalkeepers can be improved during the diving save. We independently altered knee angle and stance width at the starting position. In an experimental set-up similar to the one of the third chapter, three-dimensional kinematics and kinetics were measured in goalkeepers performing diving saves from: (1) their self-selected starting posture, (2) imposed knee flexion angles (45, 75 and 90 degrees), (3) imposed stance width (50, 75 and 100% of personal leg length). Stance width (SW) was left to the goalkeeper's choice when knee flexion angle (KA) was manipulated, and vice-versa. Remarkably, the self-selected starting posture was not the most optimal for end-performance. We found that starting the dive from a SW wider than the self-selected one, decreases the time required to save the ball and can therefore improve performance. The optimal SW between the ones tested, was equal to 75% of personal leg length (SW75). No positive effects of imposed KA on diving times were found.

In SW75, the COM had travelled more distance towards the target between contralateral and ipsilateral push-off, than in the self-selected preparatory posture, which we described as more explosive. Also, the goalkeeper performed a smaller countermovement when diving to high balls, and had a smaller vertical velocity when diving to low balls, than in the self-selected SW, which we described as more efficient.