EFFECTIVE BODY POSITIONS FOR ROTATIONS ABOUT THE LONGITUDINAL AXIS – AN EXAMPLE IN FIGURE SKATING JUMPS

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For successful quadruple jumps (QJ) in figure skating an extremely high angular velocity during the flight and a safe and clean landing on one foot are necessary. The moment of inertia (MOI) of the skater is a key factor of the angular velocity in the air. It is important to achieve the smallest MOI as fast as possible and to maintain it as long as possible. In this study seven different flight positions in three different phases of the flight have been identified, namely two positions in the phase from take-off to the closed position, three closed positions in the air and two positions in preparation for landing. Thus a method has been developed to identify individually best flight positions in QJ. Two closed flight positions were found as positions with the smallest MOI, both with 17 % smaller MOI than the third closed flight position.

KEY WORDS: moment of inertia, biomechanical analysis, laser scan

INTRODUCTION: Male skaters striving for competition success have to perform quadruple jumps. QJ presented in the second half of the program obtain a base value factor of 1.1 compared to factor 1 in the first half. However, after 2:20 minutes in the competition program most skaters lack energy. Flight time of a jump in the second half in free skating competition programs is shorter than the flight time of the same jump in the first part of the program or in training (Sakurai, Ikegami, Akiya & Asano, 1999; Knoll, 2004). Those late quads need an extremely effective flight phase. Since strength conditions of the skater are limited one option is the reduction of the moment of inertia (MOI) with respect to the longitudinal axes. Effective flights are characterized by very small MOI values at the last contact on ice, during flight and before landing. Skaters very quickly reach the closed position and keep it as long as necessary (King, Smith, Higginson, Muncasy & Scheirman; 2003). Quads should be performed with a completed last rotation and a landing on the backward outside edge of one single blade. A fast increase of MOI by opening arms and legs just before ice contact is requested for a safe landing from a rotation velocity of 4.8 ± 0.1 rev/s (King et al., 2003). This kind of landing is achieved when the athlete rotates in a twisted shoulder-hip position with the shoulder axis twisted against the body rotation. We call this an against rotation position (ARP) as in Knoll (2004) and Knoll & Seidel (2015). In practice we observed different individual body positions of five elite skaters (Figure 1). We identified different closing positions (CP1, CP2) 0.12 s after take-off, three different closed flight positions after the second turn (FP1, FP2 and ARP) and two positions for landing (LP1 and LP2) at the first contact on ice.
Closing positions are characterized by parallel feet, one in front and one behind with bended knees. CP1 has a greater distance between the feet than position CP2. In CP2 elbows are closer to the trunk. The three closed positions in the air are characterized by tightly crossed skates. FP1 has elbows more outside than FP2 and ARP has a counter-rotation of the shoulder against the main rotation direction. The main difference between the landing positions LP1 and LP2 is the smaller hip angle in LP1 (Figure 1). The main purpose of this study was to identify body positions with smallest MOI in the three flight phases, to quantify their differences and to find out individually best solutions. The second purpose was to compare three different methods to compute MOI. The first approach used a laser scanner to determine the surface mesh. The other two approaches were video based: the individual model utilized 35 length data whereas Zatsiorsky's model used body height, body mass, and regression formulas only.

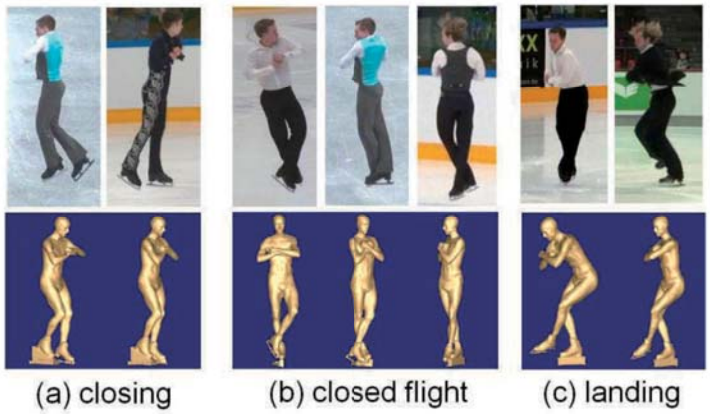

Figure 1: Positions in different phases of the flight, (a) two closing positions (CP), (b) two closed flight positions (FP) and the against rotation position (ARP), (c) two landing positions (LP).

METHOD: Three evaluation methods have been applied to determine the body inertia tensors of selected flight positions. In this study five male elite figure skaters S1-S5 (mass = 73.5 ± 10.6 kg, body height = 178 ± 8 cm, age = 23.4 ± 2.1 yrs) participated.
Seven static flight positions were recorded in two different ways, first with the laser scanner (Human Solutions GmbH, Kaiserslautern, Germany), then with two cameras. Two special blade holders were designed and built to keep the athlete stable during filming (Figure 2).

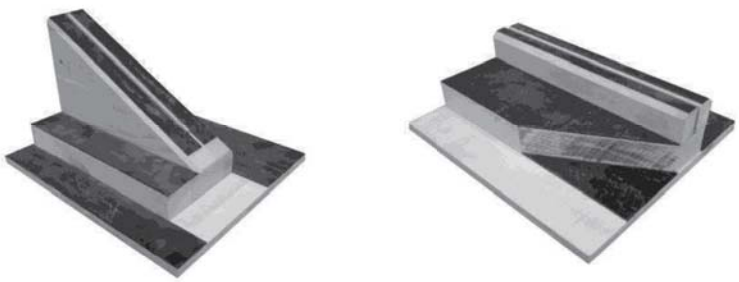

Figure 2: Blade holders, left: for closing positions, right: for closed flight and landing positions.

First approach (scan): The scanner software AnthroScan (Human Solutions, 2005) constructed a polygonal surface mesh, computed volume and center of mass and exported a mesh file. The inertia tensor of the mesh volume was computed by MeshLab (version 1.3.3, Visual Computing Lab, SourceForge).
Second and third approaches (kinematic): Two perpendicular cameras (Casio Exilim, 2816 x 2112 pixels) recorded seven positions. 24 body landmarks including toe tips, ankle, heel, knee, trochanter, ASIS, shoulder, ear, elbow and wrist were digitized using the 3D DLT method. The first kinematic approach is based on an individual body segment parameter (BSP) model: 35 anthropometric length data were utilized to construct an individual geometric BSP model of the athlete. The second kinematic approach employed Zatsiorsky's BSP model (Zatsiorsky & Seluyanov 1983). In both cases the inertia tensor was computed within the multi-body model dynamicus/alaska implemented in the software tool alaska 8.4.0 (dynamicus, 2009). The skates were not included into the MOI. Best solutions for closing, closed flight and landing positions as well as the major differences have been computed. Descriptive statistics were used to calculate MOI for closing, closed flight and landing positions.

RESULTS: To identify the smallest MOI for the flight positions, the scan method was carried out. Initially we compared the three closed flight positions FP1, FP2 and ARP. FP2 and ARP show almost the same MOI whereas FP1 is definitely larger (17 ± 8 % compared to FP2, see Figure 3). This is due to the wide elbows and the open knees in FP1.

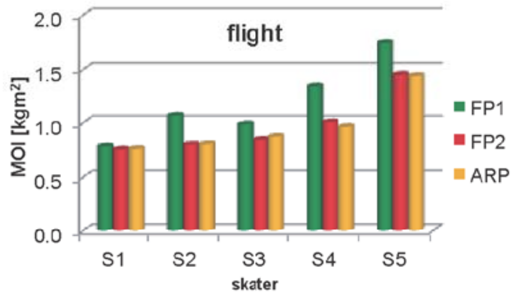

Figure 3: Moments of inertia of different closed flight positions FP1, FP2, ARP via scan.

As to the closing positions: Except for skater S1, CP2 has a smaller MOI than CP1 (5 ± 4 %, see Figure 4, left). This is caused by the different distances of the feet. The differences between landing positions LP1 and LP2 are more significant. Landing with a flexed hip (LP1) is much worse than in the more straight position (LP2). The mean difference here is 44 ± 10 %, skater S2 has maximum difference of 56 % (see Figure 4, right).

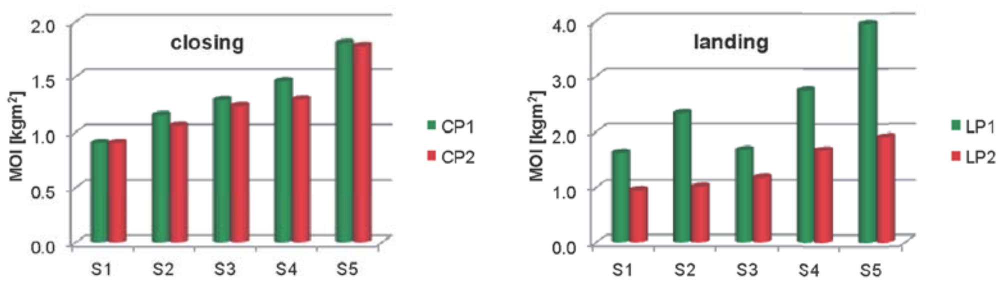

Figure 4: Moments of inertia of closing and landing positions via scan.

As to the second purpose, the comparison of computational methods. All three procedures to determine the skater's MOI with respect to the longitudinal axis (i. e. scan method, individual method and Zatsiorsky's method) result in quite comparable values. No systematic variation is apparent (see Figure 5).

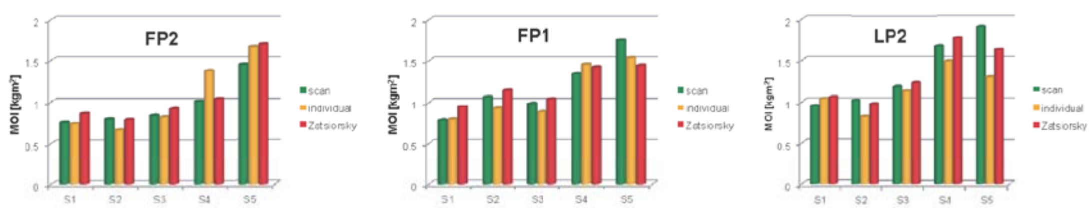

Figure 5: Three methods to compute the MOI for closed flight positions FP2, FP1 and LP2.

In most cases, the scan method and Zatsiorsky's method yield the closest results while the individual method assigns a smaller MOI. Note that for the two more athletic skaters S4 and S5, the absolute differences between the three methods are bigger than for the smaller skaters S1, S2 and S3. Further studies with more athletes are needed for a unequivocal result.

DISCUSSION: For sport practice we identified the closed flight positions FP2 and ARP, with arms tightly to the body and elbows in front, as preferable flight positions since they have the

smallest MOI. However, the ARP with a rotation of the shoulder against the rotation direction of the trunk allows a more stable landing than FP2. With ARP the skater is able to reduce the high angular velocity for a safe landing on one blade.
Flight position FP1 with closed feet, but open knees and elbows, is not recommended for QJ after 2:20 minutes in figure skating competition programs. Regarding the execution of closing movements we recommend closing position CP2 with minimum distance between the skates. The comparison of three different methods to compute the MOI on the basis of different body models showed no clear result. However, the laser scanner method is the quickest among the considered approaches and does not require time consuming digitization. We suggest replacing the individual model by the laser scan model.
Although the static situation in the scanner and during the filming is different from the flight position over ice, it was possible to reconstruct the seven types of flight positions individually, as the subjects for our study were all experienced skaters. This relation between the static and the dynamic situation will be part of a detailed future study.

CONCLUSION: The presented methods to compute skater's MOI have been proven useful for detecting individually best body positions in air for all three phases, i. e. closing, mid-air and landing. It was possible to quantify the advantage of rotation for the best flight position. Since MOI reduction requires an increase of rotation velocity, MOI reduction is an alternative to higher jump height and longer flight times.

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