BIOMECHANICAL CONDITIONS FOR STABILIZING QUADRUPLE FIGURE SKATING JUMPS AS A PROCESS OF OPTIMIZATION

Karin Knoll[1] and Thomas Härtel[2]
[1]Institute for Applied Training Science, Leipzig, Germany
[2]Institute of Mechatronics, Chemnitz, Germany

Recent investigations of the stabilization of quadruple jumps in figure skating have shown that an efficiency oriented optimization of the jump technique is needed. In this process the biomechanical possibilities for a big angular momentum and a long flight time are important, but the losses during take-off and the efficiency of the usage of the produced angular momentum during the flight are crucial as well. The results of this optimization are necessary to create effective individual techniques for quadruple jumps.

KEY WORDS: techniques, biomechanical parameters, jumps

INTRODUCTION: In figure skating there are different ways from triple to quadruple jumps, but all of them are initially connected with an increase of the flight time. JOHNSON and KING postulated that the vertical velocity increases from the triple to quadruple. "This lead to higher jump heights and longer flight times, allowing the extra revolution" (2001, 2).

For a larger number of turns in the flight an increase of the angular velocity is also necessary. The two possibilities for quadruple jumps are reducing the time for reaching the maximum angular velocity or a rising the angular momentum. But investigations have shown that not all of the skaters use these possibilities (JOHNSON, M. & KING, D.L., 2001; KNOLL, Ka. & HILDEBRAND, F., 1998). The flight times corresponds with a high strength in jumping (MAUER, I., 1984) for a high vertical velocity.

Stabilization of the quadruple jumps is the most important problem for the result in the competition. To get a good stabilisation of the quads the skater needs a high number of repetitions in his training. If a quadruple jump needs a flight time corresponding to the individual maximal strength of the skater, he cannot repeat the jump as often as necessary. If he is able to realize the quad by using only 80% of his individual maximal jump power, many of repetitions of the jump are possible. To decrease the flight time he has to change the technique during the flight with the aim of reaching the maximum of the angular velocity faster and thereby keeping or even increasing his velocity as long as possible. The second way is to increase the angular momentum in the take-off and the angular velocity during the flight.

Our special goal is it to realize quadruple jumps with a flying time as small as possible.

METHODS: For investigations of figure skater motion is applied the multibody modeling and simulation system alaska, developed by the Institute of Mechatronics in Chemnitz (alaska 5.0). As an model of the human body will be used the 3D ergonomical human model DYNAMICUS. This human model consists of a template library of parts of the body including joints, anthropometric data, limit joints, damping properties etc.

The model of the figure skater enclosed 21 parts of the body with a Degree of Freedom 42 and the model of the skate additional.

By videometric analysis of the real motion with the system "Simmess" of the IAT (DRENK) are created the marker positions in the inertial reference frame. In a so-called "dynamic tracking"is used a visco-elastic coupling between the 3D-markers and body markers. The result is an reference motion of the inner joint angles of the human model and the time history of motion in the inertial reference frame.

The best possible initial conditions of flight phases will be determined by multicriterial optimization in view of minimal deviation between 3D-markers and body markers. In the total simulation will be used a dynamic control of joint angles to the reference motion. Only in the preliminary and landing phases is applied a dynamic control of the body in inertial reference frame additional. In the phase of flight is interacting no control of the 3D motion (dynamic control of underactuated systems) with resulting constant total momentum and total angular momentum.

A procedure for a three-dimensional presentation of angular momentum as vector is presented. When using this procedure reasons for errors can be determined and general orientations for sport technical models can be described. Another procedure offers the opportunity to quantify the partial contribution of individual parts of the body in producing angular momentum. To determine the efficient use of the produced angular momentum 3D computer simulation is applied.

In the study seven elite figure-skaters served as subjects – five of them perform the quadruple Toe Loop and three skaters the quadruple Salchow.

RESULTS: To increase the mean values of angular velocity in the take-off the angular momentum must be increased. HILDEBRAND (1997, p. 96) describes the angular momentum as follows:

$$L^S = \sum_i m_i r_{S_i} \times v_{S_i rel} + \sum_i \Theta_i^{S_i} \omega_i + \Theta^S \omega .$$

"The first and second term represent those parts of angular momentum that result from relative movements of the body segments or the apparatus. For spatial orientation the system of co-ordinates of principal inertial axes as well as the observer's system can serve." (HILDEBRAND, F., 1997, p. 96).

The investigations have shown that one way to perform jumps with more than three rotations is an increase in angular momentum with an increase of the moment of inertia and a constant angular velocity.

Analyses of the quadruple Toe-Loop and quadruple Salchow illustrate, that not only the increase in angular momentum is important but also the decrease of angular momentum from the maximum to the take-off. Figure 1 demonstrated that it is more important for a figure-skater to get an optimum of angular momentum and a minimum decrease of this parameter from the maximum to the take-off (Figure 1). Our investigation presents results from the elite skaters (column 1-4 for the Toe-Loop and column 1-3 for Salchow).

In the quadruple Toe-Loop we measured two typical arts for the sports technique. Skater 1 (S1) and Skater 2 (S2) with a mean angular momentum and only a minimal loss to the take off. The second technique is determined with an high maximum of angular momentum and an minimal loss of the angular momentum in the time from the Maximum to the last contact on the ice (Figure 1).

So we can describe two general ways to perform the quadruple Toe- Loop:

- A medium angular momentum with a minimum of decrease during the take-off
- Generation of a bigger angular momentum with a higher decrease of angular momentum during take-off.

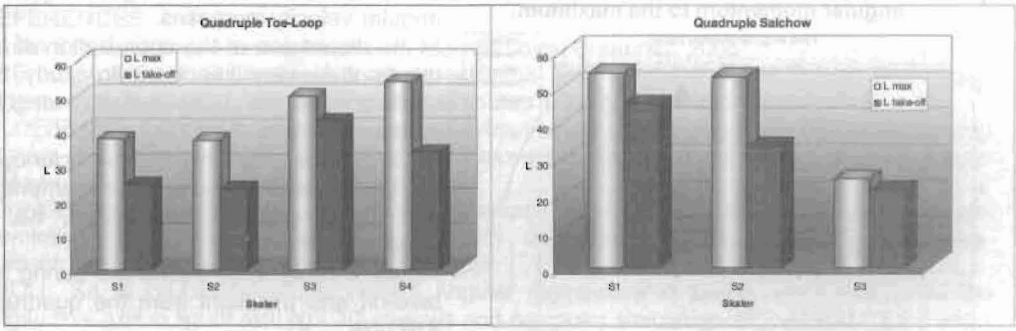

Figure 1 The maximum of the angular momentum and of the angular momentum in the take-off.

In the quadruple Salchow our investigations have shown that in the three measured jumps we have found three different ways to the quads. In one quadruple Salchow (S3) we have a very effective technique solution with a minimum of loss of the angular momentum from the maximum to the last contact on the ice. But the level is very low. His maximum of angular momentum is 24.7 kgm^2/s and the angular momentum in the last contact on ice is 21.5 kgm^2/s.

One other technique solution is shown in a higher level of the maximum of angular momentum. Skaters 1 (S1) and 2 (S2) have generated angular momentums of 54 kgm^2/s and 53 kgm^2/s, respectively. Skater 1 has in its last contact on ice an angular momentum of 45.5 kgm^2/s. This is different from that of Skater 2 who has 33.7 kgm^2/s. Skater 2 has developed a big angular momentum with a big loss till his last contact on ice (Figure 1).

We can describe different ways to perform the quadruple Salchow:

- Generation of a greater angular momentum with a small decrease of angular momentum during take-off;
- Generation of a greater angular momentum with a higher decrease of angular momentum during take-off;
- A small angular momentum with a minimum of decrease during the take-off.

For us it is also important to know the procedure of creating the angular momentum and its maximal value with respect to the movement of the skater.

In the Toe-Loop the maximum of angular momentum is reached in the toe-pick. After that peak value of angular momentum it decreases and is smaller in the take-off. In a quadruple Toe loop we measured for skater 1 a maximum angular momentum of 38 kgm/s^2 that decreased during take-off to 25 kgm/s^2.

In all jumps with take-off from the side of the blades the angular momentum will be increased, when the swinging movement is beginning and the rotational velocity of the trunk reaches its maximum (Figure 2). During this part of the jump the direction of angular momentum does not coincide with the curve of the take-off.

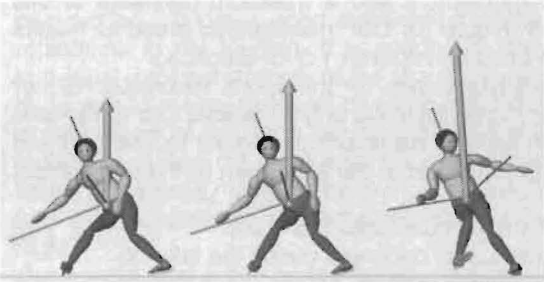

Figure 2 Generation of angular momentum in the quadruple Salchow by increasing the angular momentum to the maximum.

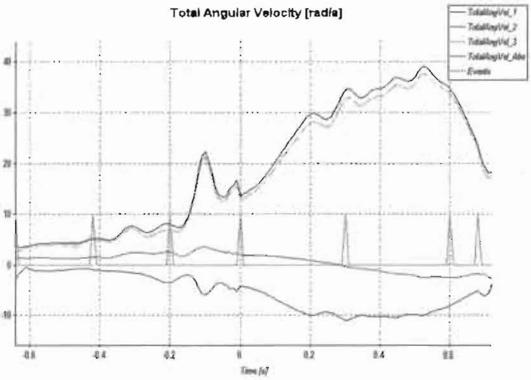

Figure 3 General angular velocity in the quadruple Salchow.

JOHNSON, M. & KING, D.L. (2001) measured quadruple jumps in figure skating. They have shown that the angular velocity of the quads is greater than for triple jumps. This result was also obtained by our measurements.

In Figure 3 the total angular velocity of the quadruple Salchow in the different events of the jump is represented. Time "0" is the last contact to the ice and the last event is the landing, the first contact on the ice.

From the closing process in the flight till the preparation for landing the general angular velocity increases.

In the discussion of the optimization of the quads it is very important to study the efficiency of the usage of the angular momentum in the flight (Figure 3).

An important criterion for the efficiency is the angle between the angular momentum and the longitudinal axis (Knoll, Ka. & Hildebrand, F., 1996).

Figure 4 represents this angle during the take-off and the flight from the quadruple Salchow.

The phase for the creation of the angular momentum is the take-off. In this part of the jump the angle between the angular momentum and the longitudinal axis is very great and decreases till the last contact on ice. In the jump measured by Figure 4 the angle is smaller than ten degrees. This is an effective result.

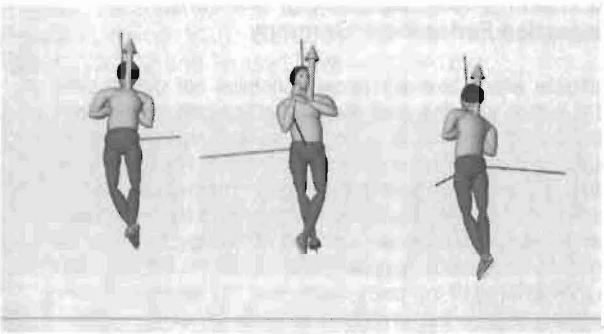

Figure 4 Angular momentum and the longitudinal axis in the quadruple Salchow.

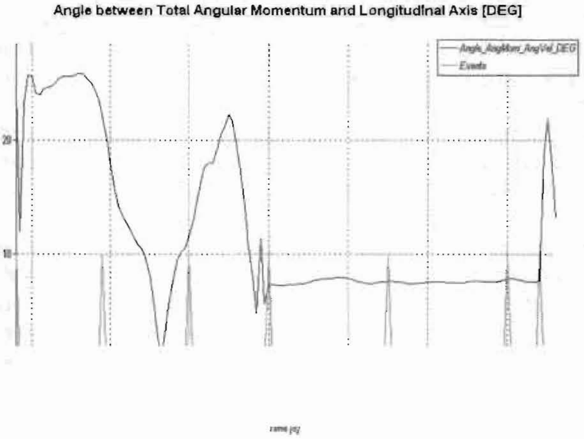

Figure 5: Angle between Angular momentum and the longitudinal axis in the quadruple Salchow

CONCLUSIONS: For the stabilization of quadruple jumps in figure skating an optimization of the jump technique is necessary.

In this process the vertical impulse, the angular momentum and the moment of inertia in the flight having to be optimized. The angle between the angular momentum and the longitudinal axis are important for the efficiency.

Our investigations have shown that there are different take-off techniques for the quadruple jumps. One way is to increase angular momentum by an increased moment of inertia and angular velocity during take-off. The second way is to generate a much longer flight time. In quadruple jumps we measured a minimal flight time of 0.64 s (Salchow). The longest flight time measured is accounted for 0.78 s (toe loop). Therefore the skaters need more jumping power, especially to perform a quick take-off. The take-off for quadruple jumps has to be perfect. Moreover, the angular momentum has to be at its maximum because corrections during the flight are impossible. A skater with a short flight time has to increase its mean value of the angular velocity during the flight.

REFERENCES:

Alaska 5.0; Reference Manual, Institute of Mechatronics, Chemnitz, 2005

DRENK, V. (1994). Bildmeßverfahren für schwenk- und neigbare sowie in der Brennweite variierbare Kameras. *Schriftenreihe zur Angewandten Trainingswissenschaft,* 1 (1), 130-142.

HILDEBRAND, F. (1997). *Eine biomechanische Analyse der Drehbewegungen des menschlichen Körpers (A biomechanical analysis of rotational movements of the human body).* Aachen: Meyer & Meyer.

JOHNSON, M. & KING, D.L. (2001). A Kinematic Analysis between triple an Quadruple Revolution figure skating jumps. Zugriff am 25. Januar 2005 unter http://www.asb-biomech.org/onlineabs/abstracts2001/pdf/063.pdf

KNOLL, Ka. & HILDEBRAND, F. (1996). Angular momentum in jumps with rotations on the longitudinal axis in figure skating - 3D-analysis and computer simulation. In J. ABRANTES (Hrsg.), *Proceedings of the XIV ISBS Symposium 1996* (S. 196-199). Lissabon: Edicoes FMH.

MAUER, I. (1984). Zavislost techniky skokov v krsokorculovani od urovne odrazovej vybusnosti (Die Abhängigkeit der Technik von Sprüngen im Eiskunstlauf vom Stand der Expbsivkraft des Absprunges). *Trener,* 28 (1), 5-6.