**OPTIMUM MOVEMENT CO-ORDINATION IN MULTI-REVOLUTION JUMPS IN FIGURE SKATING**

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**INTRODUCTION:** Triple axle and quadruple toe loops decide the winners in international competitions in men's figure skating. The essential problems are to find a stable in-flight figure-axis, to increase both vertical velocity and angular momentum at take-off and a safe landing with a rotational speed of about 1800 °/s and higher. The quadruple jumps are reaching out to the borders of human capacity and methods of training. To support technique training, a more sophisticated biomechanical investigation into jumps is required. To get a better effect in training for specific requirements, studies of the phase between take-off and landing are needed to define the necessary presuppositions.

**METHODS:** The complex of movements requires the use of different methods: computer simulation, simulation 3D-videotapes and, for monitoring jump power, measurements on the force platform and recording the electromyographical activities of several muscles - of essential muscles which are used in jumps during take-off and landing. For the registration of flight timing, data were obtained on 22 athletes during the finals in the Olympic Winter Games in Nagano (triple axle and quadruple toe loop). A PEAK5 Motion Measurement System was used to manually digitize the following phases: preparation, take-off, flight and landing of chosen jumps. To perform a 3D-analysis we created a 15-segment model of the whole human body including the skaters' boots. The model was used for the computer simulation of airborne movement to determine the relation between limb-motion and the movement of all three mean axes, and also the momentum of take-off and landing, angle about the axis behind the hip and blades during landing. The direction of the body axes and angular velocity of the whole body depend on the angular momentum and the direction and velocity of the limb-motion (Hildebrand 1996).

**RESULTS:** All the skaters analyzed successfully landed their triple axle or quadruple toe loop. And the investigations have shown that the minimum of flight time for a triple axle (Ax3) and quadruple toe loop (To4) is 0.68 s (compare Table 1).

**Table 1:** Flight time for triple axle and quadruple toe loop in the men's competition (Olympic Games 1998)

| Flight time [s] | | Technique value |
|---|---|---|
| min. time | 0.68 | ≥ 4 |
| min. time | 0.70 | ≥ 5 |
| max. time | 0.76 | ≥ 5 |

Legend: The scale of technique values ranges from 1 to 6.

*1. Preparation and take-off*

Due to the generation of the angular momentum during preparation and take-off, Table 2 presents parameters by Ax3 and To4 (mean values and standard deviation SD) of six skaters belonging to the international elite and performing with perfect technique. Miller and Albert (1996) investigated the double axle (Ax2) (Table 2) with eight male skaters. Our investigations have shown that all parameters at the last contact on ice with the preceding flight in the Ax3 (male skaters) are higher. But the relation between the Ax3 and To4 – is not different concerning flight time, angular momentum, horizontal velocity and maximum vertical acceleration.

**Table 2:** Take-off parameters (mean values and standard deviation SD)

| | Maximum values | | Parameters at the last contact with the ice preceding flight | | | |
|---|---|---|---|---|---|---|
| | max. L take-off [$kgm^2/s$] | max. vertical acceleration [$m/s^2$] | L take-off [$kgm^2/s$] | Vertical velocity [m/s] | horizontal velocity [m/s] | Driving height [m] |
| Ax3 means | 37.48 | 24.66 | 32.8 | 3.605 | 3.954 | 0.665 |
| Ax3 SD | 4.71 | 3.45 | 2.0 | 0.19 | 0.5 | 0.075 |
| To4 | 37.8/37.4 | 28.5/24 | 24.7/23.5 | 3.21/3.16 | 3.62/4.07 | 0.52/0.51 |
| Ax2 means | | - | 29.6 | 2.6 | 3.5 | - |

Legend: Ax2 values from Miller and Albert (1996)

The values for driving height and vertical velocity for To4 are lower than for Ax3. Both the Ax3 and the To4 really need 3.5 rotations.
The problems are to be seen in the vertical velocity and the achieved height of the center of gravity. During the take-off we found two technique variations. One variation is to increase the angular momentum to 2000 °/s or the skaters increase the vertical impulse so that it will be possible to reach a flight time of about 0.78 s.
2. *The relationship between angular momentum, direction of rotary axis and figure axis*.
Our investigations have shown that the possibilities to reach a higher rotational velocity are almost exhausted. The closed flight position, the minimum moment of inertia depends on individual physical requirements. Decisive for a successful quadruple jump is the relation between the direction of the angular momentum and the body’s longitudinal axis in a defined tolerance range. The direction of observation should be the flight direction. The resulting angular momentum will deviate to a greater or lesser extent from the plane of movement. As a rule, the axis of rotation and the body’s longitudinal axis are closer together, while their deviation from the direction of the angular momentum may indeed amount to more than 10° (Knoll & Hildebrand 1996).
In the triple axles and quadruple toe loops which we analyzed all possibilities for a close posture were used. The extended flight times are insufficient for a safe landing. So the time to reach the smallest moment of inertia has to be shorter than in the triple jumps, and the skater has to try to keep this moment of inertia as long as possible. But thus it becomes impossible to make corrections during flight - the take-off has to be perfect.
*3. Reducing rotational velocity prior to landing.*
Not only for the preparation of a safe landing, but also for being able to execute combinations of jumps it is important to reduce the rotational velocity of the lower part of the body before the actual landing. Additionally, in jump combinations it is

advantageous to transfer the highest possible angular momentum from the first jump to the second (or second to third). True top athletes display a reduction in rotational velocity already during the last half turn and a decreased angular momentum prior to contact with the ice. There are two classical possibilities to reduce angular velocity: to increase the moment of inertia around the figure axis and to transfer the lower part of the body's rotational energy to all the other body segments. In the first case the moment of inertia increases due to the opening of the body position, and angular velocity declines. A transfer of rotational energy occurs due to turning the arms, the trunk and the swinging leg forward in the turning direction. The more forcefully this turn is executed and the further the limbs are brought away from the body, the greater the effect will be. An active forward-turn of the arms being flexed 70° relative to the initial position produces a backward-turn of the trunk by 12°. When the arms are stretched, 30° may be achieved, so that at the moment of first contact on the ice the rotation of the landing leg may stop. Until then the angular momentum is again maintained to combine the jump with a following.

**Figure 1:** Two variations in landing techniques in the triple axle - triple toe loop combination (left side - skater V, right side - skater U)

In our investigations of two landing techniques in a triple axle - triple toe loop combination (Figure 1) we found that the high requirements on the flight result in an increased pre-rotation of the foot during landing. In addition to the vertical absorption of the body, the skater is faced with an extreme torsion of the knee joint. Skater U is landing after a complete last rotation and a pre-rotation of the landing foot of 44° in relation to the hip axis (see Table 3). Within the last 0.28 s of the jump the swinging leg passes the slightly flexed landing leg until a twisting of 80° is reached. After this action the landing leg is led right angled in a curve through the direction of the following triple toe loop and this strong torsion will be activated. V is not landing with a complete rotation, he lacks a ¼ turn when landing on the pivot of the blade. Within 0.34 s the twisting angle turns to zero. The maximum reduction of

**Table 3:** Landing parameters for the triple axle - triple toe loop combination

| Landing parameters | Skater U | Skater V |
|---|---|---|
| Last turn | Complete | without ¼ turn |
| Foot / hip axis | 44° | 20° |
| Decrease of acceleration | 19.5 m/s² | 20.7 m/s² |
| Maximum of power - during landing | 2.9 kW | 3.1 kW |
| Decrease of angular momentum | 50 % | 44 % |

vertical acceleration is reached after 0.04 s during further turn on the pivot. The maximum power amounts to 3.1 kW, but skater V has a 7 kg lower bodyweight compared with skater U. After a turn about 50° on the ice the opening is initiated by leading the swinging leg around the landing leg. The swinging leg of skater V is more extended compared with skater U, and he has a more pronounced knee flexion of the landing leg. So the angular momentum will be decreased by 50 % or 44 % - being sufficient for the following triple toe loop. The twisting angles are different too.

These two variations of landing have proved to be successful, and with both techniques the skater reached a high decrease in vertical impulse with the trunk and the arms and a lower reduction of the angular momentum.

*3. Development of requirements*

For better preparation we investigated vertical jumps with rotations on the force platform. We found a typical co-ordination of the muscle contraction and power-time courses. From these investigations we could draw conclusions for purposeful power workouts, identify exercises to overcome muscular deficiencies.

**CONCLUSIONS:** Jumps with more than three turns need an optimization of the vertical impulse and the angular momentum, and the individual possibilities in technique are lower. Our investigations have shown that the take-off technique for jumps with more than three turns rather tends to a longer flight time than to an increase of angular momentum. Therefore the skaters need more jump power. The take-off for quadruple jumps has to be perfect, the angular momentum must be at its maximum, because corrections during the flight are not possible, and moments of tilting are to be excluded.

Landing techniques have to be analyzed in detailed studies in order to find a technique with a lower injury risk in the knee joint. We need to immediately develop special preparation for the body.

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