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PRELIMINARY BIOMECHANICAL STUDY OF TRIPLE LUTZ

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Preliminary biomechanical study of the Triple Lutz

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Literature review

In previous studies, biomechanical analyses of ice-skating jumps (as Axel and Toe-Loop), was performed using high-speed cameras. In a study by D.L. King and S. Smith (1994), entitled "A kinematic comparison of Single, Double, and Triple Axel", the single jump is compared with the double and the triple to individuate which parameters vary or remain constant among the three jumps, and the best technique to perform a triple Axel.

Another study by D.L King and S. Smith (2004), entitled "Characteristics of Triple and Quadruple Toe-Loops Performed during the Salt Lake City 2002 Winter Olympics" aimed to quantify the main characteristics of the triple and quadruple Toe-Loop and to compare them, in order to provide the coaches with information useful to teach the quadruple Toe-Loop to high-level athletes. A study concerning the analysis of the Triple Lutz in ice-skating was published by D.L. King in 2001: "Generation of vertical velocity in toe-pick figure skating jumps". In that research, the segmental contribution of the arms and the free leg to generate the vertical velocity in the Triple Lutz is determined, together with the use of the toe assisted for the same purpose.

Concerning roller skating, some studies on the Axel and the double and triple Toe-Loop (Giorgi C., Turchetti S.) are present in the Italian Hockey and Skating Federation website, (www.fihp.org/artistico/lista_dispense.php).

Furthermore, there exist some dissertations:

- Bernardi B. (1984), "Cinematographic analysis of the outside Axel in artistic roller skating;
- Dallari E. (1985), "Biomechanical analysis of artistic roller skating", with special reference to the analysis of the Flip;
- Cremonini L. (1988), "Biomechanics of the double Toe-Loop in artistic roller--skating";
- Morabito V. (2007), "Biomechanical analysis of the Toe-Loop in artistic roller skating";

- Cazzoli A. (2007), “Tridimensional Biomechanical Analysis of the Axel in artistic roller”.

However, in artistic roller skating, there are no quantitative biomechanical studies analysing the Lutz. Therefore, the aim of this research is to analyse the kinematic of the Triple Lutz in world-class athletes.

Subjects

Five subjects were analysed, including two senior world champions, a junior world champion, a bronze medallist at the junior world championship and a European champion. The mean (range) age, body mass and height were, respectively, 23 (18-26) years, 73 (71-81) kg, and 176 (160-184) cm. On average, the athletes practised artistic roller skating for 17 years (range: 14 20 years). Their mean experience with the Triple Lutz was of 6 years, ranging between 3 and 9 years. The athletes trained for 14 hours per week with 8 to 20 additional hours dedicated to the physical conditioning.

Vertical jumping tests were performed to assess the explosive strength of lower limbs. The mean (range) height in the squat jump and the countermovement jump were, respectively, 45.4 (42.2-51.2) cm and 51.1 (47.3-54.1) cm. Therefore, there was a 5.6 cm mean difference between the two jumps.

In the countermovement jump with free arms, a test resembling more than others the gesture of the Lutz, the height was 6.6 cm greater than in the countermovement jump with no arm swing, with a mean value of 57.7 cm (range: 51.8 - 65.2 cm).

Experimental apparatus

A motion analysis system constituted by ten synchronized cameras was used. The system allows a computerized reconstruction of the position of apposite markers placed on the athlete's body and on the skate. Therefore, accurate quantitative assessments can be performed. The BTS SMART-D Motion Capture System is an optoelectronic system allowing the study of the human movement through the measurement of indices such as position, speed and acceleration that describe the kinematic of body segments. The hardware component is constituted by a set of ten infrared cameras, a workstation for data acquisition and processing, and a kit of reflective markers. The markers, reflecting the light of infrared lamps, are plastic spheres of different dimension. They are covered with a reflective material and can be applied directly on the body or the skate with a double-sided tape or elastic bands.

The cameras have a maximum resolution of 0.48 Megapixel with an acquisition rate of 250 photogram's per second. The cameras were placed around the jump's trajectory, at various heights to film all the markers during the various phases of the jump from different points of view.

The software component of the system is constituted by the Smart Capture, through which the calibration and the data acquisition are performed. Furthermore, the Smart Tracker is the software allowing reconstructing the markers coordinates and analysing their trajectories. Finally, the data are analysed through the Smart Analyser, allowing to use opportune mathematical and geometric algorithms in order to compute all the derived measures as distances, axes, and angles, and allows visualizing the relative graphs.

The marker were placed on the skates (heel, first and fifth metatarsus), on the legs and the thighs, tetrads of markers were used in order to allow a better reconstruction of 3D articular centres with the CAST method. The pelvis, trunk and head were individuated by 4 markers for each segment. For the upper limbs, the markers were placed at the acromions, the elbows and the wrists.

The BTS Analyzer software allowed to obtain the linear spatial graphs (relative to given points) and the graphs of the relative speeds as a function of time.

Temporal analysis

For further analyses of the Triple Lutz, we decided to individuate typical points allowing to divide the movement into different phases. The first point is that of the toe assisted. The following phase corresponds to the lift of the gliding skate. Then, there are the take-off and the landing of the jump. In order to study the duration of each of the phases and determining eventual further subdivisions of the movement, the points corresponding to the following photograms were individuated:

- **Initial toe assisted point**: the first photogram in which the marker of the right skate tip displayed the lower height was individuated. Furthermore, the vertical speed was considered to estimate its zero-value.

- **End of the gliding point:** assessed by observing the marker corresponding to the inner tip of the left foot in the first photogram in which a displacement variation in the vertical direction is observed.

- **Take-off point**: the first instant in which the athlete is in the flight phase, defined by observing the right foot tip in the first photogram in which a displacement variation in the vertical is observed.

- **Maximum flight height point**: determined by considering the highest point the pelvis centre reaches during the flight phase.

- **Landing point**: corresponding to the first photogram in which the first wheel of the right skate shows a minimum and constant value.

The duration of each phase was computed as the difference between the time difference between the two extreme points of that phase. Therefore, the following variables were identified:

- **Gliding phase duration:** time between the left toe assisted point and the left skate take-off;
- **Contact phase duration:** time between the right toe assisted point and the right skate take-off;
- **Flight phase duration:** time between the take-off and the landing.

The data reported below are mean values of the five subjects or minimum and maximum individual values.

The duration of the gliding phase is about 2/3 of the entire contact phase (0.12 s vs. 0.18 s). Therefore, the duration of the pushing phase on one limb is only 0.06 s. The flight phase is definitely longer, with a mean value of 0.64 s (0.58-0.70 s).

In order to assess other events, it is necessary to analyse the motion of some particular points or of articular angles. Thus, it is possible to divide each of the phases described above in further subphases and compute linear or angular spatial measures for each of these subphases.
To analysis the motion of the whole body of the athlete, a point corresponding to the pelvis centre of mass, namely the centroid among the four iliac spines, has been computed. Then, it was possible to individuate:

- a minimum height value of the pelvis centre after the toe assisted;
- the height at the end of the gliding of the left skate;
- the height at the take-off of the right skate;
- the maximum height of the pelvis centre during the flight phase;
- the height value at the landing point;

Furthermore, the following durations were computed:

- time between the toe assisted and the point in which the height of the pelvis centre reaches its lowest value, equal to 0.04 s;
- duration of the rise, i.e. the time between the take-off and the maximum height reached during the flight phase, equal to 0.32 s;
- duration of the fall, i.e. the time between the maximum height reached during the flight phase and the landing, equal to 0.33 s.
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The small difference between the raise and the fall can be due to the different behaviour of the lower limbs at the take-off and the landing (they are extended at the take-off and slightly flexed at the landing). Furthermore, the horizontal distance travelled by the pelvis centre between the take-off and the landing was computed. Unfortunately, it was possible to assess that distance only in two athletes, and they show very different values (1.63 m vs. 2.59 m).

The mean loading of the pelvis just after the toe assisted is of 14 mm (range 2-38 mm). Then, the pelvis centre raises on average of 25.4 cm at the take-off (range: 19.5 – 34.8 cm). The mean height of the flight trajectory was of 50.5 cm (range: 42.2 – 57.8 cm).

Distances

Linear and angular distances were computed. The first are referred to the distances between the two skates when they are in contact with the ground, or even when they are lifted.

- **Distance between the left (gliding) heel, and the inner tip of the right foot**, in the two x (length) and z (depth) coordinates, measured at the toe assisted and the take-off.

The average distance between the two skates in the direction of the x-axis is 26.2 cm, whereas the transversal distance (z-axis) is longer, i.e. 29.4 cm.

- **Maximum distance between the left (gliding) heel and the inner tip of the right foot**, measured at the take-off.

Furthermore, the minimum distance value during the raise in the flight was considered.

The maximum absolute distance between the two aforementioned points is 53.8 cm. Conversely, it was 21.8 cm near the take-off, at the minimum observed at the beginning of the flight phase, being on average 0.21 s after the take-off. In the various athletes, this value oscillates between 0.10 and 0.28 s.

The absolute distances between the pelvis centre and the centre of the right foot in the toe assisted and take-off phase were also assessed. The absolute distance between the pelvis centre and the right foot centre at the toe assisted is 50.1 cm, whereas at the take-off it is 13.5 cm, i.e. definitely lower, with very wide oscillations between the minimum (2.6 cm) and the maximum (23.6 cm) value recorded in the five athletes.

Lower limbs angles

The lower limbs analysis was carried out considering the hip, knee, and ankle angles during the different phases of the movements, from the toe assisted to the flight. We consider first the values obtained from right limb goniograms.

The following **right hip** angular values were assessed:
-at the toe assisted: adduction and flexion values, and the respective maximum values reached in the instants after the toe assisted;
-at the take off: flexion and abduction values.

For the **right knee**, the following variables were assessed:
-before the toe assisted: maximum extension, only in some of the subjects;
-at the toe assisted: knee flexion, and the respective maximum values reached in the instants after the toe assisted;
-at the take-off: flexion angle.

For the **right ankle**, the following variables were assessed:
-at the toe assisted: flexion angle, and the respective maximum values reached in the instants after the toe assisted;
-at the take-off: flexion angle.

Concerning the hip, the neutral position (i.e. with 0° of flexo-extension and abdo-adduction) occurs when the thigh is perpendicular to the pelvis.
At the toe assisted, the hip is definitely flexed (36°), and almost in a neutral position on the frontal plane (2°). After the end of the gliding, similar flexion (37°) and abduction (15°) can be observed. At the take-off, the abduction is slightly reduced (13°), whereas the flexion is clearly decreased, assuming values close to the neutral point (5°).

The knee has been assessed before the toe assisted only in 3 subjects, and it is almost completely extended (close to the zero value). At the toe assisted, in all the subjects the knee shows a marked flexion (60°), with values oscillating from a minimum of 50° to a maximum of 67°. In the following phase, all the subjects tend to load the knee, i.e. the flexion increases (66°). Then, there is a pronounced extension action, leading the knee at 16° (range: 11°-19°) at the take-off point. Therefore, there is a 50° angular displacement between the maximum flexion and the maximum extension.
Concerning the ankle, the neutral position (i.e. that with 0° of flexo-extension) occurs when the shank is perpendicular to the ankle.
At the toe assisted, the ankle is in the neutral position (2°). Then, a loading occurs (23° of dorsiflexion) more markedly than in the knee. At the take-off, the ankle shows a plantar extension of 18°. Therefore, there is a 41° angular excursion between the maximum loading and the take-off.
In the analysis of loading values of knee and angle, it is possible to assess the time at which the maximum loading values occur. Then, it is possible to estimate the duration of the following two movements:

- **Knee loading time**: observing the goniogram, the loading duration (i.e. the time between the toe assisted and the maximum knee flexion) is assessed. The mean knee loading time is 0.027 s.
- **Ankle loading time:** observing the goniogram, the angle loading duration can be assessed, resulting in a mean value of 0.09 s.

The **left hip** angles were recorded:
-at the toe assisted: adduction and flexion values, and the maximum adduction and abduction values in the instants following the toe assisted;
-at the end of the gliding: maximum extension values;
-at the take-off: abduction and flexion values.

For the **left knee** angle, the following variables were assessed;
-at the toe assisted: flexion values;
-at the end of the gliding: maximum flexion values;
-at the take-off: flexion values.

For the **left ankle** angle, the following variables were assessed:
-at the toe assisted: flexion angle;
-at the end of the gliding: maximum flexion values;
-at the take-off: flexion angle.

The left hip movements in the latero-lateral direction (abuction – adduction) are very limited. At the toe assisted, the hip is in the neutral position. Then, there is a slight adduction followed by a moderate abduction before the take-off of the right skate. After the right leg take-off, the hip is slightly adducted. Concerning the flexion, at the toe-off, the left hip is more flexed than the right one (72°). Then, it is only moderately flexed (up to 22°), thus it remains still flexed. Afterward, the hip does not show clear extension movements in four out of the five subjects. Only one subject shows an evident flexion movement, leading the hip at 68° at the take-off point, whereas the other athletes show a 16° value.
The left knee and the ankle, at the toe assisted, are clearly flexed (knee: 62° and ankle: 24° of dorsiflexion). Then, the knee shows the maximum extension in correspondence with the take-off of the left skate (12°). In the same instant, the left ankle shows a moderate plantarflexion of 19°. At the take-off of the right foot, the left knee shows a slight flexion (24°), whereas the ankle shows a little flexion (21°).

Trunk variables

The trunk was assessed in different ways, considering points and axes referred each to the others, or to the external space.

Angle of **inclination of the trunk axis** (computed between the four markers of the trunk, placed on the C7 and T8 vertebrae, the sternum and the xiphoid process), **with respect to the vertical axis** at the ground at the toe assisted, end of the gliding, take-off, maximum flight height, and landing.

The subjects are inclined with the trunk always in the direction from which they come from. The inclination is more pronounced at the toe assisted (37°), and less marked in the following phases (end of the gliding: 32°, and take-off: 28°).

Pelvis axis with respect to the x-z plane: it corresponds to the axis defined by the posterior iliac spines, projected on the grounds at the toe assisted, end of the gliding and take-off. In this way, it is possible to compare the rotations in two moments of the toe assisted: beginning (toe assisted – end of the gliding) and end (end of the gliding – take off).

The same method was used to study the shoulders movement.

Shoulder axis with respect to the x-z plane: it corresponds to the axis defined by the two acromions projected on the ground in the toe assisted, end of the gliding, and take-off. The athletes show different strategies in the trunk torsion movements. One athlete shows limited movements in the two axes in the first phase and pronounced movements in the second phase. Two athletes move more in the first phase and less in the second, with both the axes. Finally, two athletes show hip movements of the same amplitude in the two phases, whereas the shoulders show wider movements in the first phase.

Velocities

The **angular velocities of the ground projections of the pelvis and the shoulders** were analysed at the toe assisted, end of the gliding, take-off and flight. All the athletes show a peak angular velocity of the hips that is more elevated (1134°/s) at the take-off compared to the other two points (515°/s at the toe assisted, 594°/s at the end of the gliding). Concerning the shoulders, three subjects show the highest peak at the take-off, whereas two subjects at the end of the gliding.

The **linear velocities of the pelvis centre** in the toe assisted, end of the gliding and take-off phases points were studied. Concerning the horizontal speed of the pelvis, a little reduction of it can already be observed at the toe assisted point. The peak velocity varies from 4.72 m/s (recorded before the toe assisted) to 4.18 m/s. Then, the velocity further reduces at the take-off of the gliding skate (2.71 m/s), and at the take-off of the jump it is 2.69 m/s. Therefore, the horizontal speed at the end of the gliding is almost equal to that at the take-off. The vertical velocities are negative at the toe assisted (-0.54 m/s). This confirms that the pelvis at the toe assisted is falling down. Then, the vertical velocities tend to increase from 2.2 at the end of the gliding, to 2.9 m/s at the take-off. In the biomechanics of jumps, to analyse the relationships between horizontal and vertical velocity, the resultant velocity angle is considered, given that if the horizontal velocity equals the vertical velocity at the take-off, the angle will be 45°. Angles higher than 45° indicate that the athletes use a vertical velocity that is higher than the horizontal one. The mean resultant velocity angle in the five athletes is 37° at the end of the gliding, and 47° at the take-off. This means that at the end of the gliding, the horizontal velocity is higher than the vertical velocity. Conversely, at the take-off, the two velocities are equivalent. It is important to note that, concerning the resulting velocity angle, the individual behaviour of the subjects is different: two subjects tend to make a more vertical jump with angles higher than 50°, whereas one subject shows an angle lower than 45°, thus exploiting more the horizontal than the vertical velocity.

Conclusions

In this section, the whole-body movement will be considered first, summarizing the pelvis centre kinematic. At the toe assisted, the pelvis centre shows a horizontal velocity that is slightly lower than that observable in the immediately previous phases. At the toe assisted, the pelvis decelerates in the horizontal direction and falls in the vertical direction of 1.4 cm for 0.04 s. The horizontal velocity decreases of almost one-half up to the take-off of the gliding skate, then it remains constant up to the jump take-off. The vertical velocity is already elevated at the left skate take-off (2.2 m/s), and it reaches higher values at the take-off of the jump (2.9 m/s). The five athletes adopt different strategies at the take-off: some of them use vertical velocities higher than the horizontal velocities, whereas other show and opposite behaviour. Anyway, the vertical velocity oscillates from a minimum of 2.62 m/s to a maximum of 3.13 m/s, warranting a big elevation, oscillating from 42.2 to 57.8 cm.

It is possible to explain what described about the pelvis motion by analysing the lower limbs kinematics. The toe assisted leg joints show a loading action just after the toe assisted, that is very little for the hip, moderate for the knee (6°), more pronounced for the ankle (21°). The loading time is the shortest for the knee (0.027 s) and the longest for the ankle (0.09 s). Considering the falling time of the pelvis (0.04 s), it can be concluded that the fall is related to the loading of all the three joints of the toe assisted leg. The action of vertical velocity reduction seems to depend mainly by the ankle. The pushing action of the right limb concerns all the joints. From the gliding skate take-off, the hip extends of 32°, the knee of 50°, and the ankle of 41°.

The hip and the knee show an eccentric work phase that is very limited concerning both the amplitude and the duration. Conversely, the ankle show a very pronounced loading phase, probably at the limits of the individual physiological capacities of dorsiflexion. In the final pushing phase, the ankle shows a plantar extension of 18°, far from the articular physiological limits.

Considerations on the gliding leg

The gliding leg, at the toe assisted, is in the neutral position on the frontal plane, whereas it is markedly flexed such as the knee and the ankle. Then, the three joints make an extension movement, continuing up to the end of the gliding phase. The latero-lateral movements (adduction – abduction) of the hips are less evident in the initial phase for the gliding.

Comparison between the Lutz heights and the vertical jumping tests performed without the skates

Comparing the heights of the jumps performed with the skates and those performed without the skates, the elevation values of the Lutz are closer to those recorded in the countermovement jump with no free arms. In fact, the mean height value is of 50.5 cm vs. 51.1 cm of the countermovement jump (range: 42.2-57.8 in the Lutz vs. 47.3 – 54.1 in the CMJ). This means that the athletes, that in the Lutz normally use the arms, reach lower heights compared to the tests performed without the skates. This leads to think that the contribution of the arms to the jump take-off is more useful in the rotation than in the elevation.

Rotations and angular velocities of the trunk

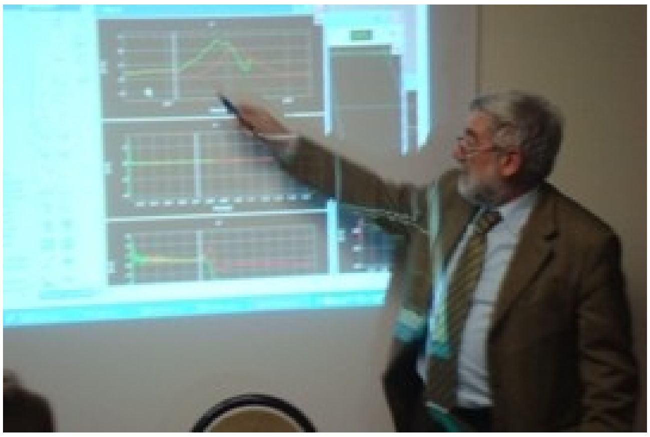
Concerning the trunk movements, the subjects show different strategies about the hip and shoulder movements in the toe assisted and take-off points. At least three different strategies can be individuated in the five athletes group examined.

Upper limbs movements

The upper limbs movements in the toe assisted and take-off phases are very different amongst the five examined subjects. Therefore, it is not possible to individuate a reference model that can provide useful for a general analysis. In the future, a qualitative analysis of the arms movements will be carried out to understand the different strategies adopted by the various athletes.

This document, strictly reserved to the participants to the STAGE FIHP/FIRS INTERNAZIONALE - ROCCARASO – 2010, is a preliminary study that will continue with the analysis of a wider number of jumps and will be completed by analysing other kinematic parameters. The study belongs to a research project involving the completion of experimental degree theses in Sport Sciences and scientific report that will be published later.

Prof. FRANCO MERNI



After graduating “cum laude” in Medicine and Surgery at the University of Bologna, thesis "Experimental applications of Biomechanics in functional anatomy” , he achieves in the following year the license to the practice of doctor, and since then he belongs to the Federation of Sports Medicine . From October 1, 2002 he is called as professor, by the Faculty of Sport Sciences in Bologna and since then he has taught ‘Theory and Methodology of Training’ and ‘Motor and Aptitude Evaluation in Sport’ in Bologna and since 2004 in Rimini.

From 1972 to 1988 he conducted research in the field of motor development with institutions and structures.

As director of the Laboratory of Biomechanics of ISEFof Bologna by the Institute of Anatomy ,he has developed equipment and software procedures for the analysis with film methods of: speed, jumping, throwing in athletics, speed skating, jumps of gymnastics and artistic skating, cross -country skiing alpine skiing techniques, volleyball and ballet. For this research in 1983 he won a scholarship from the Italian Olympic Committee.

He attended as speaker 30 experimental theses of the ISEF and Sports Medicine of the University of Bologna, which were honored by CONI as the best sport thesis at national level.

Since 1980 he has worked as a consultant and researcher with the Italian Olympic Committee and various sports federations, including: the School of Sport of CONI, Basketball, Cycling Federation and Athletics.