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Original research papers

BIOMECHANICS OF THE AXEL PAULSEN FIGURE SKATING JUMP

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Abstract
Introduction. Figure skating is a sport discipline requiring a combination of artistic and athletic skills. The triple Axel Paulsen (Axel or A) jump is the most technically difficult jump of all figure skating jumps, which is why it is on the top of the International Skating Union (ISU) Judging System Code of Points (CoP). The purpose of this research was to explore the technical differences between the single Axel (1A), the double Axel (2A), and the triple Axel (3A) and to determine which parameters are the most important for performing the triple Axel successfully, using 3D kinematic analysis. ***Material and methods***. In the study, one Polish elite male junior skater was tested. Following the usual warm-up, the skater performed a series of jumps on the ice, which were recorded. Six jumps of each type were recorded (6 x 1A, 6 x 2A, and 6 x 3A). Three jumps which were the best technically were chosen for further analysis. The APAS 2000 system automatically calculated the centre of gravity of the skater (CG) and generated the kinematic data of each jump. ***Results***. The skater examined jumped higher when he was about to perform more rotations in the jump. The more rotations were to be made, the higher the jump was. Although the difference between the height of 2A and 3A was less than 10% and could not be considered significant, the height of 1A was significantly lower, by over 19%, that the height of the other two jumps. As also shown by previous research, the most substantial differences in the Axel jump technique were visible in the pre-take-off and take-off phases. ***Conclusions***. We observed substantial differences in the movement technique and kinematic parameters of the pre-take-off phase in the triple Axel performance compared to the performance of the other two Axels. It can be assumed that decreasing the ankle joint angle in the pre-take-off phase was most essential in achieving rotations in the Axel jump. This substantial change in ankle flexion caused greater stress on the blade before the take-off, which resulted in a reduction of vertical velocity and enabled an increase in the vertical take-off angle.

Key words: figure skating, Axel Paulsen, biomechanics, jump kinematics, 3D analysis

Introduction

Since 1908, figure skating has been an Olympic sport discipline. It is regarded as requiring a combination of both artistic and athletic skills [1]. In single figure skating, skaters perform specially choreographed programmes containing jumps, spins, steps, and spirals to music. They skate on the ice rink (30 x 60 m) wearing rigid leather boots with blades (about 4 mm in width). Nowadays, the best figure skaters perform triple and even quadruple jumps, which means that they rotate on their own vertical axis in the air 3 or more times. One of the jumps where a skater is required to perform more than 3 revolutions is the triple Axel Paulsen (3A).

The Axel Paulsen jump (Axel or A) is the most technically difficult jump of all figure skating jumps, which is why it is at the top of the International Skating Union (ISU) Judging System Code of Points (CoP). It can be divided into three phases: the entrance phase, which ends with the take-off; the flight phase, when the skater is rotating in the air; and the landing phase, which starts at the exact moment when the blade touches the ice and ends when skater is safely skating backwards on the full outside edge with one leg behind in the air. The entrance must be performed from the forward outside edge and landed on the backward outside edge on the opposite leg to the one used for the take-off. Nowadays, skaters perform the single Axel (1A), the double Axel (2A), and the triple Axel (3A). The jumping technique for 1A requires one and a half rotations in the air, the technique for 2A requires two and a half rotations, and that for 3A requires three and a half rotations.

Furthermore, since jumps are generally completed in less than 0.65 s [2], coaches have difficulty discerning and defining parameters that are important in enabling the skater to successfully land the most difficult revolutions. This is why researchers are constantly looking for the most effective and safest body movement model for jumpimg technique. Being the most difficult jump, the Axel jump has also been studied the most often by researchers. Although Aleshinsky [3, 4, 5], Mishin [6], and Laak [7] have authored significant publications on this subject, they have published most of their findings for coaching rather than scientific reasons. Aleshinsky ascertained that the better the skater, the greater the take-off velocities and jump lengths. Comparing double Axels to single Axels, he noticed that the skaters exhibited greater pre-flight rotation, took off in more closed positions, and attained greater rotational velocities in their double Axels. Alexey Mishin, who is considered to be one of the best figure skating coaches in the world, did extensive kinematic research into each jump in figure skating [6]. He based his research on video analysis and the shape left on the ice by the blades of the skates. Unfortunately, the specific results of that research have not been made available to the general public. Another figure skating coach and researcher, Trevor Laak [7], used kinenamic 3D analysis in order to create a list of characteristics that can be used as rules or guidelines for coaches. The researcher who made the biggest contribution to the research concerning the Axel jump was Canadian scientist King [2, 8]. The results of 3D kinematic analyses of single, double, and triple Axels indicate that skaters increase their number of turns by increasing their rotational velocity, not by increasing their time in the air. King's [2, 8] research led her to assume that achieving a high rotational velocity by generating angular momentum at take-off and minimising the moment of inertia about the spin axis was the key to completing 3A successfully. Based on this assumption, she suggested the best off-ice exercises helping skaters perform better in jumping, that is box jumps and medicine ball throws [8]. Despite the fact that King's research was very detailed, there are still many uncertainties around the topic of the best and safest technique of performing the triple Axel. Some parameters allowing for the proper analysis of body movement, like joint angles, were taken into consideration only in jump landing analysis during the testing of a new type of skating boots [9].

The primary purpose of this research was to study the technical differences between 1A, 2A, and 3A and to find out which parameters are of the greatest importance in the successful performance of 3A, using 3D kinematic analysis and comparing the parameters of 1A, 2A, and 3A.

Material and methods

The research involved one Polish elite male junior skater. He was the first one in Poland to have ever performed the triple Axel (3A), the quadruple Toe Loop (4T), or the quadruple Salchow (4S). He was 170 cm tall and had a body mass of 68 kg. In order to obtain kinematic data, two Canon LEGRIA HV40 (frame rate 50 Hz) cameras were positioned on the ice rink at an angle of approximately 90 degrees in relation to each other. The camera settings were carefully planned in order not to disturb the usual skating trajectory of the skater (Fig. 1). Both cameras recorded all the phases of each of the jumps (Fig. 2) in order to achieve a 3D effect. The video cameras were turned on to record the 1.5 x 1.5 x 2.0 m calibration frame box and were then removed from the ice rink. The cameras remained turned on for the duration of data collection.

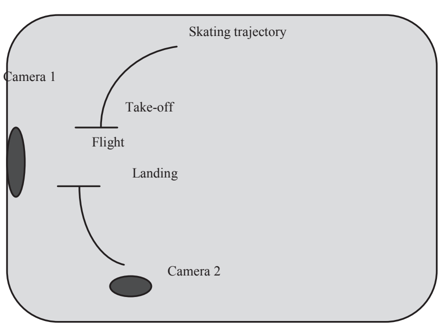


Figure 1. Camera set-up and movement trajectory of the skater during video recording

Following the usual warm-up, the skater performed a series of recorded jumps on the ice. Each jump was performed in complete physical and mental comfort. This allowed him to perform jumps of the best technical quality possible. Six jumps of each type were recorded (6 x 1A, 6 x 2A, and 6 x 3A). All of them were fully rotated and successfully landed. Nevertheless, three jumps which were the best technically were chosen for further analysis. The choice was made with help of top figure skating coaches.

Using the APAS 2000 Program, the recordings of each jump from each camera were manually digitised and synchronised. Seventeen check points were manually marked on each frame of the recordings. Based on the marked check points, the APAS 2000 program automatically generated a 12-segment 3D model of the figure skater's movement (stick figure) (Fig. 3).

Figure 2. Images from the original recording of one of the double Axels showing the characteristic moments of each jump phase (entrance – first two images from the left, moment of take-off – third image, rotational position during the flight phase – fourth image, and moment of landing and landing stabilised position – remaining two images)

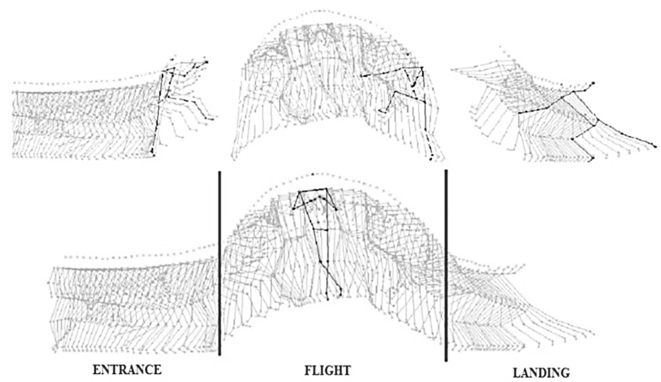


Figure 3. Stick figures showing the double Axel divided into jump phases created in the APAS 2000 program and used in the analysis

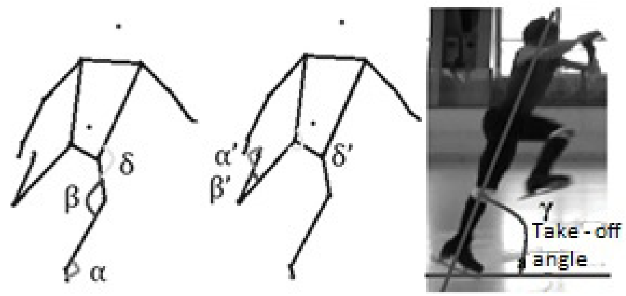
The APAS 2000 program also automatically calculated the centre of gravity of the skater (CG) and generated the kinematic data of each jump. The parameters taken into consideration in further analysis were: both leg joint angles (α, β, δ, α', β', and δ') and the take-off angle (γ, °) (Fig. 4), height of flight (h_{max}, m) (defined as the highest position of the skater's centre of gravity above the ice rink surface), and the horizontal (υ_{xz}, m/s) and vertical velocity (υ_y, m/s) of the CG.

The skater performed all the jumps entering on the left and landing on the right leg. That is why in the analysis, during the entrance phase (n), the left leg was the supporting leg, and the joint angles which were analysed were α, β, and δ (or α_n, β_n, and δ_n). During the landing phase (w), the right leg became the supporting one so angles α', β', and δ' were analysed.

Besides the joint angles, the take-off angle (γ) (Fig. 4) was analysed. The take-off angle can be defined as the angle between the ice rink surface and the vertical axis of the skater's body at the moment of take-off.

The most significant moments during the entrance phase (n) are the transition zone, called also the pre-take-off phase, and the take-off itself. The beginning of the transition zone was operationally defined as the start of the skater's upward motion signified by the beginning of the positive vertical velocity of the skater's centre of gravity (υ_y). The moment of take-off was determined based on the velocity of the centre of gravity (υ_{3Dsc}).

Directly before the take-off, υ_{3Dsc} achieves its maximum. Therefore, the moment of take-off was designated as the moment registered in the first recording frame after the skater reached the maximum υ_{3Dsc}. Once the data had been generated, the relative error was counted for each parameter of each jump attempt in order to check the repeatability of the performance of the jumps. The errors of all the parameters were lower than 10% taken as the upper limit of normal, which showed that there were no significant differences between the kinematic parameters of jumps with the same number of rotations in the air. In view of these results of the relative error calculations, only one jump of each type was taken into consideration in further analysis.



α – angle between foot and tibia of the left leg, β – angle between tibia and femur of the left leg, δ – angle between torso and thigh of the left leg, α' – angle between foot and tibia of the right leg, β' – angle between tibia and femur of the right leg, δ' – angle between torso and thigh of the right leg, γ (take-off angle) – angle between ice rink surface and the long axis of the skater's body.

Figure 4. Figures demonstrating the angles measured in the study

Results

The data obtained in the study were analysed in each specified phase of the jump. The first phase considered was the entrance.

As already mentioned, in the entrance phase, the beginning of the transition zone was operationally defined as the start of the skater's upward motion signified by the beginning of the positive vertical velocity of the skater's CG (v_y). It began an average of 0.24 s before the last contact with the ice (take-off) for 1A and 0.22 s before this moment for 2A and 3A. Although there were differences in the time of the pre-take-off phase between the single Axel and the multiple rotation Axels (2A and 3A), they cannot be considered significant.

The more rotations the skater was supposed to perform, the lower the vertical velocity he gained was. The skater achieved the highest horizontal velocity, of 5.42 m/s, entering the 1A; the $\upsilon_{xz\ max}$ for 2A was over 3% lower (5.23 m/s), and that for 3A was almost 11% lower (4.83 m/s). Nevertheless, the biggest difference between maximal and take-off velocity (υ_{xz} difference) was observed in 3A (Tab. 1). During the 3A entrance, the skater reduced his horizontal velocity from 4.83 m/s to 2.89 m/s at the moment of take-off (40% difference). For 2A, the reduction was 35%, and it was 26% for 1A.

Table 1. Maximal horizontal velocity value ($\upsilon_{xz\ max}$), velocity of the take-off ($\upsilon_{3Dsc\ take\text{-}off}$), and the percentage difference between these velocities in the 1A, 2A, and 3A

Type of jump	$v_{xz\ max}$ [m/s]	$v_{3Dsc\ take\text{-}off}$ [m/s]	Difference [%]
1A	5.42	4.02	26
2A	5.23	3.40	35
3A	4.83	2.89	40

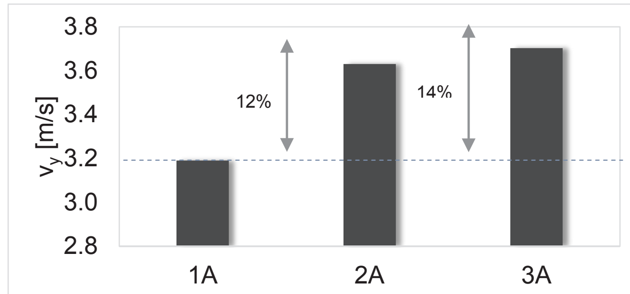


Figure 5. Vertical velocity of the take-off moment (υ_y, m/s) in 1A, 2A, and 3A

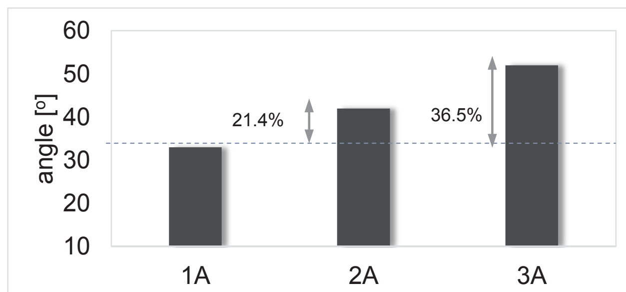


Figure 6. Take-off angle values (°) for 1A, 2A, and 3A

The skater gained the highest vertical velocity of the take-off performing 3A (3.7 m/s), and he had the lowest υ_y in 1A (3.19 m/s) (which means that there was a 14% difference). The observed differences between the υ_y values of 2A and 3A were very small. Moreover, the value of the take-off angle (Fig. 6) for 3A was the highest (52°), which means that the skater took off more vertically in the triple Axel than in the other Axels. The difference between the values of the take-off angle for 1A and 2A was over 21%, and it was over 36% for 1A and 3A, both of which were significant differences. These differences were also noticeable on the stick figures generated in the APAS program. The skater took off much more vertically in multiple rotation jumps (2A and 3A) (Fig. 7).

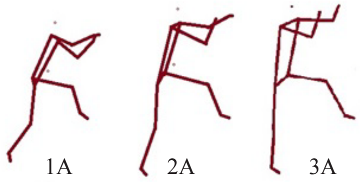


Figure 7. Stick figures of the skater in the take-off position entering 1A, 2A, and 3A generated in the APAS 2000 program

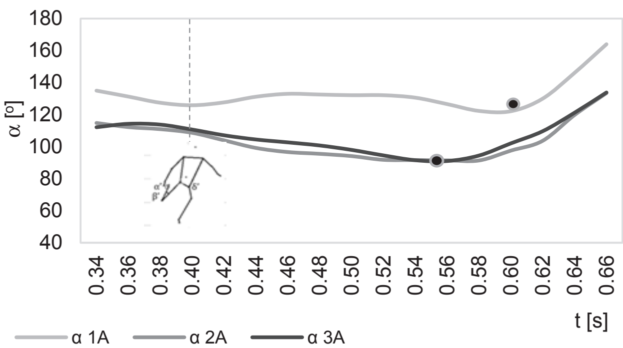


Figure 8. Changes in the ankle joint angle (α) value of the left (supporting) leg during the pre-take-off phase in 1A (light grey line), 2A (grey line), and 3A (dark grey line). Horizontal grey line shows the beginning of the pre take-off phase. Black dots show the lowest value of the angle during the pre-take-off phase

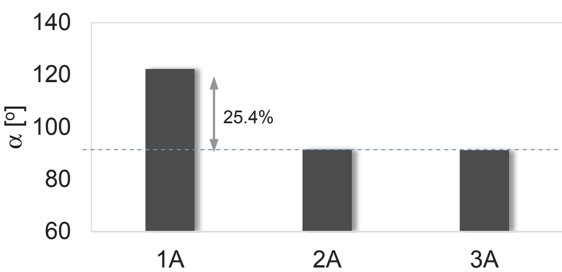


Figure 9. Lowest values of the ankle joint angle (α) during the pre-take-off phase in 1A, 2A, and 3A

The changes in the ankle joint angle in time during the entrance phase in 2A and 3A were very similar. During the whole phase, there were no significant differences between the values of the α angle in 2A and 3A (Fig. 8). On the other hand, the skater demonstrated significantly different joint flexion during entering 1A than in multiple rotation (2A and 3A) jumps. The values of the α angle were higher in 1A than 2A and 3A during the entire time of the entrance phase (Fig. 8). The lowest recorded value of this angle in 2A and 3A was exactly the same (91°), while in 1A, it was over 25% greater (122°) (Fig. 9).

As shown in the chart below (Fig. 10), there were no significant differences in the β angle values during the pre-take-off phases of 1A, 2A, and 3A. The curves illustrating the changes in the values were very similar. What is more, the differences observed in hip flexion values were also insignificant (Fig. 11). Both β and δ angle values were the lowest at the beginning of the pre-take-off phase and grew continuously during the whole phase (Fig. 10 and Fig. 11). The value growth increased rapidly just before the take-off. From the beginning of the pre-take-off phase (vertical grey line on Figure 11), hip angle increased by about 25° in the time of 0.16 s, whereas 0.06 s before the take-off, the values of δ changed from about 140° up to 160° (2A and 3A) or 170° (1A). The knee angle changed very similarly. During the first 0.18 s after the pre-take-off phase started, β values grew by 20°, while during the last 0.06 s before take-off, they increased by 35°.

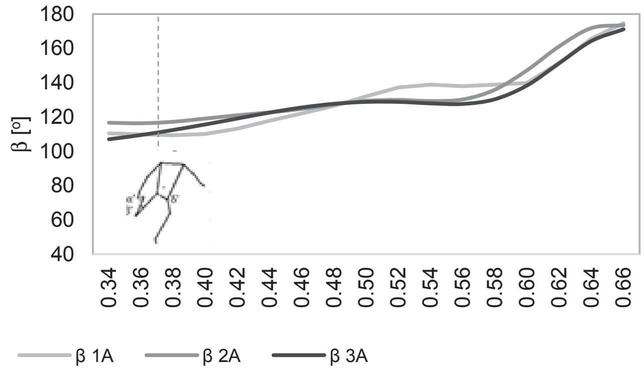


Figure 10. Changes in the knee angle (β) value of the left (supporting) leg during the entrance pre-take-off phase in 1A, 2A, and 3A. Horizontal grey line shows the beginning of the pre-take-off phase

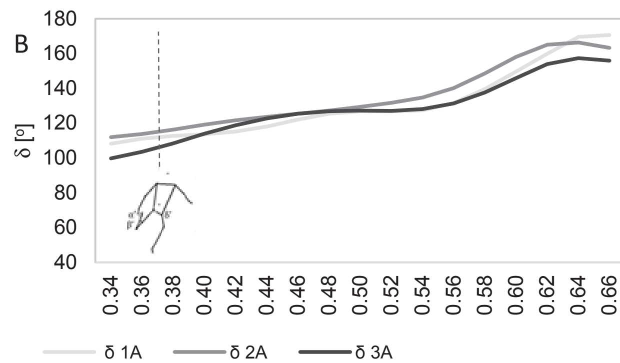


Figure 11. Changes in the hip angle (δ) value of the left (supporting) leg during the entrance pre-take-off phase in 1A, 2A, and 3A. Horizontal grey line shows the beginning of the pre-take-off phase

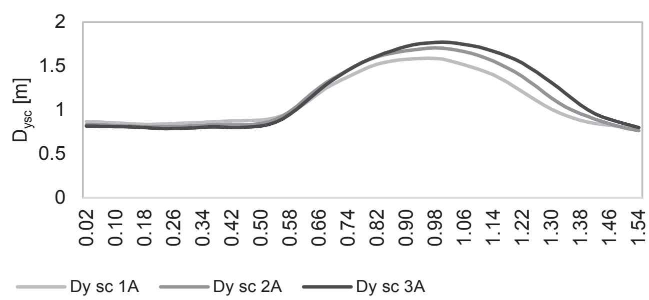


Figure 12. Centre of gravity vertical displacement ($D_{y\ sc}$) during 1A, 2A, and 3A

The parameters analysed in the flight phase were based on centre of gravity vertical displacement ($D_{y\ sc}$) (Fig. 12). As already mentioned, the moment of take-off was determined based on the velocity of the centre of gravity (υ_{3Dsc}) and knowing this, the moment of landing was verified on the $D_{y\ sc}$ chart. The centre of gravity of the skater was on the same height in the moment of take-off and at the moment when the skater's blade touched the

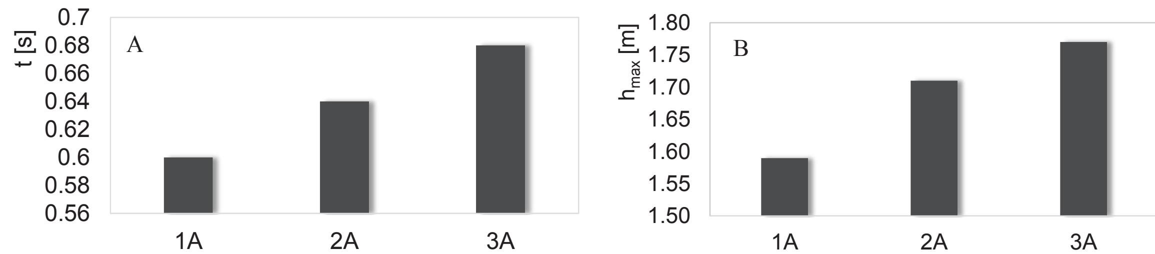


Figure 13. Time of the flight phase (A). Values of the maximal height of the centre of gravity placement for 1A, 2A, and 3A (B)

ice for the first time after the flight phase. The skater took off for 1A and 3A at 0.66 s and for 2A at 0.64 s counting from the beginning of the entrance phase. Although the time of the take-off for each jump was very similar, as shown on the chart above, the time of landing was different for each jump. That means that the flight phase of each jump was different. The more rotations were made, the longer the flight phase was. In 1A, the flight phase lasted 0.6 s; in 2A, it lasted 0.64 s; whereas in 3A, it was 0.68 s long (Fig. 13A). The biggest difference for the time of the flight phase was observed between 1A and 3A (12%).

What is more, the maximal height of the skater's centre of gravity was also different for each type of jump. The lowest h_{max} was observed in 1A (1.59 m), and the highest value of this parameter was found in 3A (1.77 m) (Fig. 14B). After subtracting the height of the skater's normal standing position from the centre of gravity (1.1 m), the height of the jump was counted. The height of 1A was 0.49 m, that of 2A was 0.61 m, and the height of 3A was 0.67 m. The difference between the two multiple rotation jumps (2A and 3A) and 1A amounted to over 19%.

During the landing phase, the ankle (α'), knee (β'), and hip (δ') angles of the supporting (right) leg were analysed. The values of the α' (Fig. 14), β' (Fig. 15), and δ' (Fig. 16) angles in each jump decreased just after the moment of landing and stabilised as the skater stabilised the landing position (the positions are shown in Figure 2). The time of achieving a stabilised position was different for each Axel jump. The time of that phase was 0.04 s in 1A, 0.08 s in 2A, and 0.1 s 3A. Thus in 1A, the stabilisation phase was the shortest; the differences in the values of the angle were minimal, and it decreased from 153° to around 140°. During this phase, in 2A, the α angle changed from 130° to 89°, and in the triple Axel, it changed from 145° to 95°. The α angle in the landing position was similar in 2A and 3A, but in 1A, the value of the angle was about 40° (about 30%) higher.

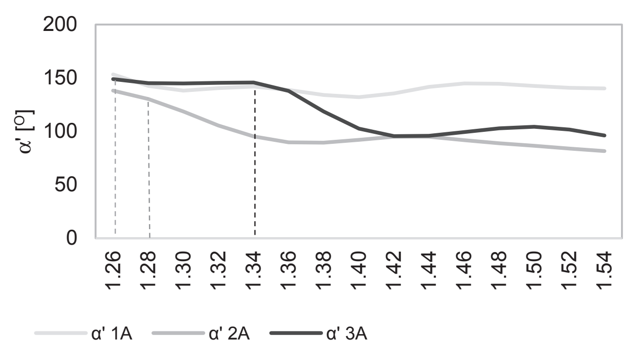


Figure 14. Changes in the ankle joint angle (α') value of the supporting leg during the landing phase in 1A, 2A, and 3A. Vertical lines show the moment of landing in each jump

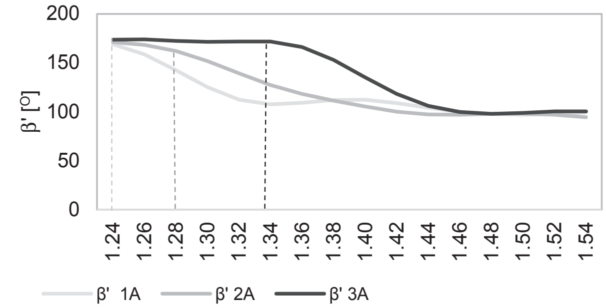


Figure 15. Changes in the knee joint angle (β') value of the supporting leg during the landing phase in 1A, 2A, and 3A. Vertical lines show the moment of landing in each jump

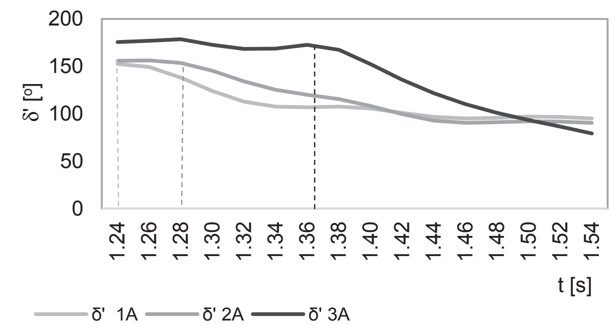


Figure 16. Changes in the knee joint angle (δ') value of the supporting leg during the landing phase in 1A, 2A, and 3A. Vertical lines show the moment of landing in each jump

The stabilisation of the knee flexion during the landing took longer in each jump than in the ankle joint. It took the skater 0.06 s in 1A and exactly 50% more in 2A and 3A. The differences in angle values were minimal between 2A and 3A, but the values for 1A were significantly different from those recorded for the two multiple rotation jumps. During the stabilisation, the β' angle decreased by 42° in 1A, by 62° in 2A, and by 66° 3A, which means there was a 30% difference between 1A and multiple rotation jumps. Nevertheless, the differences in the β' angles of the stabilised landing positions between the three types of the Axel jump were insignificant. The last angle analysed was the last one in which the skater achieved stabilisation during the landing phase. This moment was also considered as the moment of achieving a fully stabilised landing position. In 1A, this moment was observed after 0.08 s from the beginning of the landing; in 2A, this took the skater 0.16 s; and in 3A, this took them twice as long as in 2A and four times longer than in 1A (0.32 s). During the stabilisation of the landing, the hip angle in 3A changed by 113°, which was above 60% more than during

1A and more than 40% than in 2A. Moreover, the angle of the stabilised landing position in 3A was 50% lower than in 2A and 1A, which was a significant difference.

Discussion

As already mentioned, the primary purpose of this research was to study the technical differences between 1A, 2A, and 3A and to determine which parameters are the most important in performing the triple Axel successfully. Although some of the parameters considered in this study were analysed in previous research, some new parameters were examined as well. What is more, not all the data confirmed the results of previous studies.

King suggested that a figure skater must increase their time in the air and/or rotate faster in order to increase the number of revolutions completed in a jump [2, 8, 10]. While the current research confirmed King's hypothesis in that the skater spent more time in the air when he was performing jumps with more rotations, we reached the opposite conclusions concerning jump height. King's data showed that skaters jumped no higher in their triple Axels than in their double or single Axels and thus spent a similar amount of time in the air in each jump. The skater examined in this study, however, jumped higher when he was about to perform more rotations in the jump. The more rotations were to be made, the higher the jump was. Although the difference between the height of 2A and 3A was less than 10% and could not be considered significant, in the single Axel, the skater jumped significantly lower, by over 19%, than in the other two jumps. As was found in previous research, this study also showed that the most substantial differences for the Axel jump technique were visible in pre-take-off and take-off.

According to the data collected during the research, the skater slightly changed his pre-take-off technique in order to perform more rotations in the air in the Axel jump. Though the time of the pre-take-off phases were very similar in each jump, differences were observed in horizontal and vertical velocities and joint and take-off angles. The biggest difference between maximal horizontal and take-off velocity was observed in 3A. When entering 3A, the skater reduced his vertical velocity by 40%; in 2A, the reduction amounted to 35%; and in 1A, it was 26%. Reducing the horizontal velocity enabled the skater to achieve greater vertical velocity, which was significantly higher in 2A and 3A than in 1A. What is more, the figure skater's take-off angle was also greater in the double and triple Axels. The skater took off more vertically, the more rotations he was to make. Taking into consideration the joint angles of the supporting leg, the only significant difference was observed in ankle joint flexion. During the whole pre-take-off phase, the values of the α angle in 1A were nearly approximately 25% higher than in 2A and 3A. This means that the skater pushed the blade harder before multiple rotation jumps, which was visible in the ankle joint flexion and the vertical velocity reduction. Considering insignificant differences in the other joints analysed, it can be assumed that the skater pushed harder on the blade (decreasing the value of the ankle joint angle), not by leaning forward, which would have caused a more vertical rather than horizontal take-off, but by turning the blade perpendicularly to the skating direction; this also led to greater υ_{xz} reduction and increased the υ_y at the same time. This blade turning additionally caused pre-take-off rotation on the ice, which helped the skater perform multiple rotation jumps.

The analysis of the joint angles of the supporting leg in the landing phase showed some differences in the performance of this part of the Axel jump. Besides joint angle values, a significant parameter was the time of achieving a fully stabilised landing position. The more rotations were made by the skater, the longer it took him to achieve stabilisation. It took the longest for the skater to stabilise the hip flexion in all the jumps. It took him twice as long to stabilise in 2A and four times longer in 3A compared to 1A. This large differences was probably caused by the increasing impact forces in multiple rotation jumps, which was found by Lockwood in his research on landing forces in figure skating [11]. Landing forces can be decreased by using articulated boots, as demonstrated by Bruening and Richards [9]. Using this type of boots could improve work of the muscle-tendon complex during the amortisation of a jump. An appropriate stretch-shortening cycle decreases ground reaction forces [12] and injury risk during landing [9], although the exact kinematic mechanism of the movement technique of jumping is still unclear. For that reason, striving to achieve the optimal technique of jumping seems to be a crucial element of the training process, especially that in order to be competitive today, elite skaters should perform more than 50 jumps per day.

Conclusions

The research showed some differences in the movement technique and kinematic parameters of the pre-take-off phase that are important for performing the triple Axel. According to the data, the biggest differences were observed between multiple rotation Axels and the single one. It can be assumed that decreasing the ankle joint angle in the pre-take-off phase was the most essential for achieving more rotations in the Axel jump. This substantial change in ankle flexion caused greater stress on the blade before the take-off, which caused a reduction in vertical velocity and made the take-off angle more vertical. This caused the jump to become longer and higher, and, in the end, helped the skater to perform more rotations in the air. Differences in the landing phase were assumed to have been due to an increase of impact forces during landing.

Literature

1. Hines J.R. (2006). *Figure skating. A history*. Champaign, IL: University of Illinois Press.
2. King D.L., Arnold A.S., Smith S.L. (1994). A kinematic comparison of single, double and triple Axels. *Journal of Applied Biomechanics* 10, 51-60. DOI: 10.1123/jab.10.1.51.
3. Aleshinsky S.Y. (1986). What biomechanics can do for figure skating. Part two. *Skating* 63(10), 11-15. follow by Sharp C.M.P. (1999). A biomechanical analysis of the single toe loop and the single loop jump of novice figure skaters. file:///C:/Users/User/Downloads/31762104283245%20(1).pdf
4. Aleshinsky S.Y. (1987). A biomechanical report of USFSA/USOC/PSGA junior elite camp participants. *The Professional Skater*. 18(1), 24-28. follow by Sharp C.M.P. (1999). A biomechanical analysis of the single toe loop and the single loop jump of novice figure skaters. file:///C:/Users/User/Downloads/31762104283245%20(1).pdf
5. Aleshinsky S.Y. (1990). Biomechanics explores differences in Boitano's axels. *American Skating World* 21, 12-13.
6. Mishin A. (1981). *Figure skating jumps*. Moscow: Fitzkultura i Sport. [in Russian]
7. Laak T. (2008). *Jump manual*. Madison: Skating Jump Secrets and the TAL Group, LLC. Retrieved from https://pl.scribd.com/document/29509583/Figure-Skating-Jumping-Coaches-Jump-Manual.

8. King D.L. (2005). Performing triple and quadruple figure skating jumps: Implications for training. *Canadian Journal of Applied Physiology* 30(6), 743-753. DOI: 10.1139/h05-153.
9. Bruening D.A., Richards J.G. (2006). The effects of articulated figure skates on jump landing forces. *Journal of Applied Biomechanics* 22, 285-295. DOI: 10.1123/jab.22.4.285.
10. King D.L., Smith S.L., Brown M.R., Mccreary J.L., Munkasy B.A., Scheirman G.I. (2008). Comparison of split double and triple twists in pair figure skating. *Sport Biomechanics* 7(2), 222-237. DOI: 10.1080/14763140701841662.
11. Lockwood K.L., Gervais P.L., Mccreary D.R. (2006). Landing for success: A biomechanical and perceptual analysis of on-ice jumps in figure skating. *Sport Biomechanics* 5(2), 222-237. DOI: 10.1080/14763140608522876.
12. Sands W.A., Kimmel W.L., McNeal J.R., Murray S.R., Stone M.H. (2012). A comparison of pairs figure skaters in repeated jumps. *Journal of Sports Science and Medicine* 11, 102-108. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3737852.

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