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ORIGINAL ARTICLE

3D kinematic analysis of salto backward in acrobatic rock and roll: a case study

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim	The aim of the study was to determine and compare basic kinematic characteristics in the key phases of the acrobatic element Salto backward tucked.
Material and Methods	The research sample was created from two couples of the acrobatic rock and roll category Main class free style. The time, spatial, and time-spatial characteristics for both couples were determined based on a three-dimensional kinematic analysis. Measurements were carried out with Simi Motion 3D. The acrobatic element Salto backward tucked was chosen based on the fact that it is usually learned as the first overturn acrobatic element with the airborne phase.
Results	In the time duration of the acrobatic element, a very similar duration was observed for both couples (CZ couple: 3.59 s and SK couple 3.55 s). The maximal height of the center of gravity the partner from the Czech Republic reach 3.54 m and partner from the Slovak Republic 3.35 m. The biggest difference noticed was between the male partners 14.59° in knee angle in the staff phase. Among the female partners, a difference was noted in the angle between the torso and the vertical plane at the moment of the end of the vertical displacement, when SK female partner has twice as much deviation of the torso, by exactly 19.49°. In the staff phase, differences in acceleration were also observed, when the male partner (16.56 $m.s^{-2}$) and female partner (25.08 $m.s^{-2}$) from the Slovak Republic achieved higher maximum acceleration. In the airborne phase was the biggest difference between female partners in the culmination point, namely in the angle in the knee joint (35.98°) and the angle between the torso in the vertical plane at the moment of opening the somersault (25.52°).
Conclusions	The findings showed similarities and differences in various aspects of the performance, providing valuable insights into the kinematic structure of this acrobatic element in acrobatic rock and roll. Our study should contribute to the extension of knowledge of the kinematic structure of acrobatic element in acrobatic rock and roll.

Keywords: acrobatic rock and roll, kinematic characteristics, Salto backward tucked, Main class free style.

Introduction

Acrobatic rock'n'roll is acyclic, fast sport, which needs a high degree of coordination, strength, psychological resilience, and above all, synchronization of athletes [1, 2, 3]. Demonstration of technically demanding acrobatic elements and combinations requires a high level of coordination and an optimal difference in somatic indicators between the partners [4, 5, 6]. The optimal difference in body height is 16.7 ± 7.1 cm and in body weight 22.6 ± 1.9 kg [7]. Several researches [8, 9, 10] point to a trend in the development of acrobatic rock and roll, which is associated with increasing difficulty of the competition program and thus with increasing performance requirements for athletes. Unfortunately, it is still worthwhile for couples to choose more difficult acrobatic elements, even if they have a bad execution, because the number of points after a collision is still higher than when they choose less demanding acrobatics.

The acrobatic competition program is limited by correct timing. Synchronization between partners is trained by "Staff" take off, when the average number of repetitions ranges from 1178 to 1645 attempts per year. Technically less demanding acrobatic exercise forms such as somersaults backward tucked make a good starting point for their more demanding variants, e.g.: somersaults with multiple turns around the horizontal and vertical axes. The number of attempted Salto backwards ranges from 265 to 369 attempts per year [11, 12].

Take off from staff position is more often in especially for the backwards elements. Despite the fact that all couples perform the same element technique, almost every couple has small individual differences in the performance. The individual differences in the performance can be affected by biomechanical parameters [13]. The results of the calculations of mathematical models show that to achieve the best results it is necessary to increase the initial speed of rush out, the height of the center

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of gravity at the rush out, reduce the moment of inertia, which simplifies increasing the rotation speed of individual segments [14].

For performing any movement of an athlete, it is necessary to develop a dynamic effort determining the kinematics of the body [15]. In assessing the complexity of exercise elements, must be taken into account the degree of dynamic effort in performing movements, which is determined by the energy consumption to achieve the desired position [16, 17]. It is also necessary to take into account the static muscle tension in the process of performing exercise elements and the degree of dynamic effort to return to the final position [18]. There are three phases in performing all acrobatics elements from staff position: preparation phase, take-off phase and airborne phase, which is determined by previous two phases [11].

Materials and Methods

Participants

The acrobatic element was presented by the best Slovak (SK) couple (age: F 19 years, M 24 years; body height: F 159 cm, M 177 cm; body weight: F 47 kg, M 72 kg) and the best Czech (CZ) couple (age: F 26 years, M 29 years; body height: F 166 cm, M 190 cm; body weight: F 51 kg, M 89 kg) of the category Main class free style in that year. Measurements were done at the end of preparatory period of the season when couples trained 6 times a week.

Research Design

In our study we used ex post facto research. We compared two couples of Main class free style category. Acrobatic element salto backward tucked belong to obligatory group 2 (acrobatic element backward) with difficulty A and value 4 points [19, 20]. We processed the kinematic records using SIMI Motion 3D software (the German company Simi Reality motion Systems GmbH) and performed a 3D analysis of the acrobatic element somersault backwards (Figure 1). 12 important anthropometric points has been identified on the bodies of the dancers where markers were placed (Figure 2). 8-camera motion analysis system records the element with sampling frequency 100 Hz. The acrobatic element starts from two kicks and kick ball change and also ended with two kicks which is usually same as in competition program. Both couples performed the acrobatic element twice and then we chose a better performance. The measurement took place at the Faculty of Sports Studies of Masaryk University in Brno (Czech Republic).

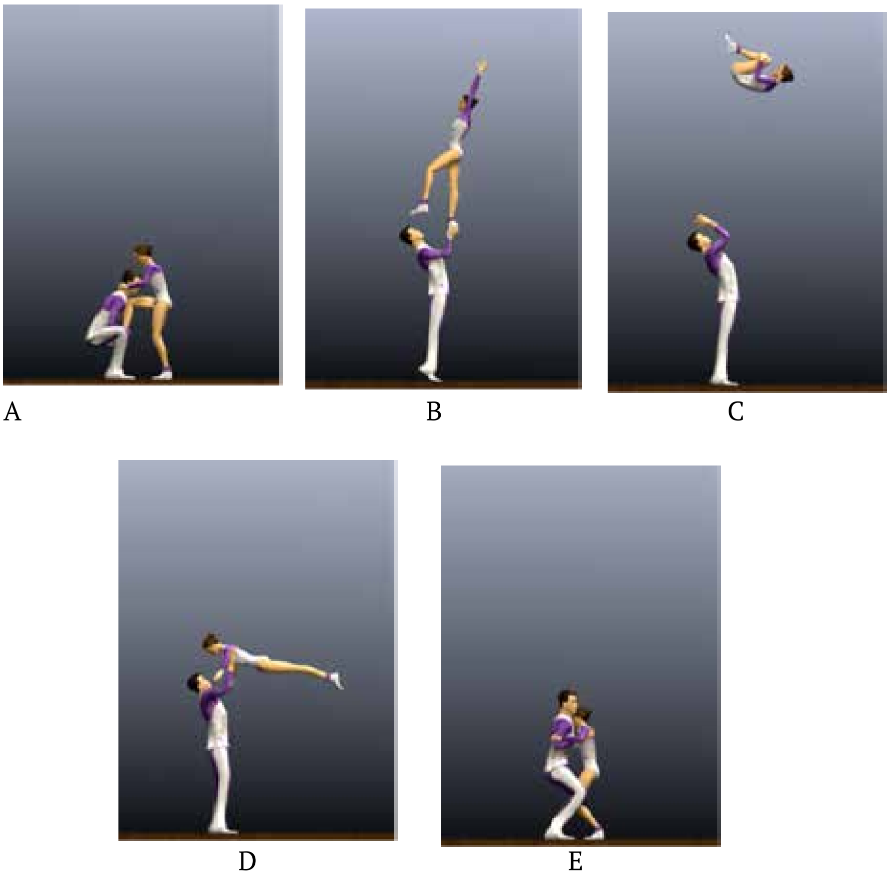


Figure 1. Salto backward tucked – preparation microphase (A), vertical displacement (B), ascending microphase and reaching the culmination point (C), descending microphase (D), contact and landing (E) [16]

Data for Analysis

Anthropometric data of the participants were used: body height, body mass. Twelve important anthropometric points on the participants' bodies were identified. A motion analysis system with 8 cameras (sampling rate of 100 Hz) was used. The acrobatic element was divided into 3 phases and 7 microphases. The duration of the element's execution was 3.59 seconds and 3.55 seconds.

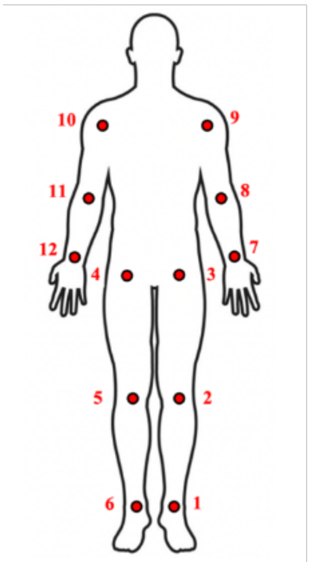
Results

Acrobatic element Salto backward tucked belongs to obligatory group 2 (acrobatic element backward) with difficulty A and value of 4 points [19, 20]. Both couples started the acrobatic element from a Staff position, which is the most often used in the backwards acrobatics. The Salto backward is one of the basic acrobatic element of Main class free style category and it is usually learned as the first acrobatic element with an airborne phase. It can be shown in the basic form in all rounds of the competition. The rules tell us that the difficulty of acrobatic element should increase during the competition with a peak in the final. To understand the kinematic characteristics of the chosen acrobatic element, we divided salto backward into 3 phases and 7 microphases (Figure 3).

Comparison of time characteristics

The time duration of the acrobatic element salto backwards was almost identical for both couples. The time duration of the element was 3.59 s for the CZ couple and 3.55 s for SK couple. The time was measured from the first movement after last kick to the landing female partner after the bounce, before start of dancing. The time duration of individual microphases is shown in Table 1.

The time characteristics of both rock and roll couples were very similar. We noticed the biggest differences in the staff phase, especially in the preparation phase. The second biggest difference was in the airborne phase, directly in the descending (0.06 s) and ascending microphase (0.02 s). This difference was caused by a longer path of movement, as the center of gravity of the Czech partner reached a greater height in the ascending microphase. The last difference was in the final phase, when in the microphase of contact with the landing was difference 0.05 s and in the bounde and dance



1. left ankle
2. left knee
3. left hip
4. right hip
5. right knee
6. right ankle
7. left wrist
8. left elbow
9. left shoulder
10. right shoulder
11. right elbow
12. right wrist

Figure 2. Anthropometric points

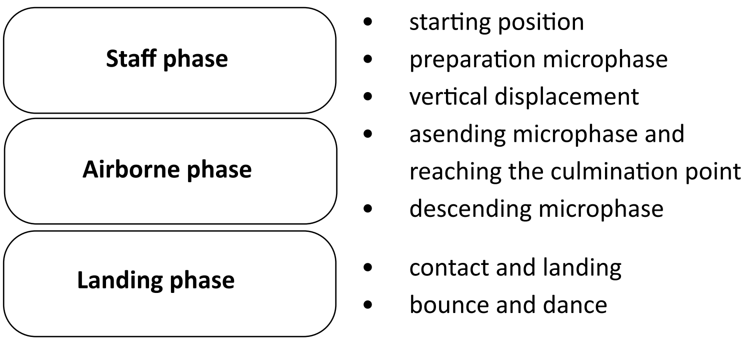


Figure 3. Phases and microphases of the acrobatic element [18]

micrphase was only a small difference (0.02 s).

Comparison of spatial characteristics

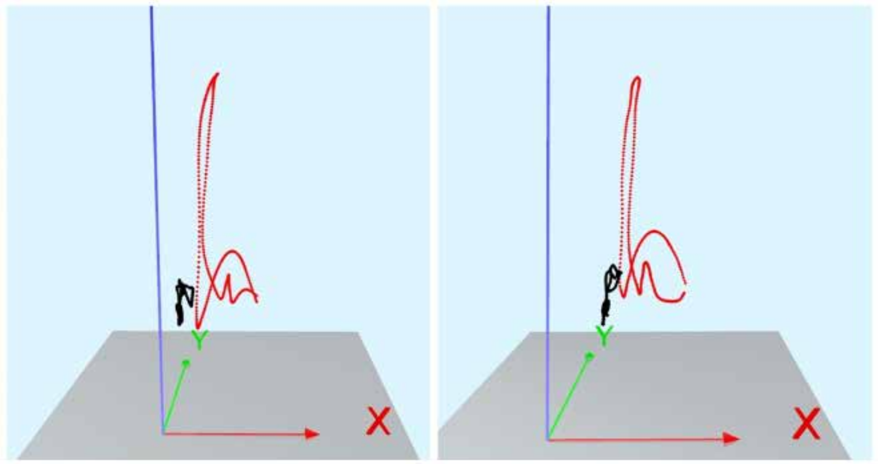
In spacial characteristics we focused on the trajectory and height of center of gravity in the individual phases of the acrobatic element and also on the various angles. Trajectory of center of gravity of the Czech and the Slovak couples were very similar. The ascending and descending paths are almost parallel for both couples (Figure 4). For better view at the differences between couples we focused also on heights of the female partner's center of gravity in the individual microphases of the acrobatic element (Table 2).

The biggest difference we found at the culmination point, which was 0.19 m. The second biggest difference was in the microphase of vertical displacement (0.17 m), when the partner from Slovakia prematurely deflected the trunk into rotation. The rest of the differences were caused by the somatic indicators of couples.

Table 1. Comparison of time duration in microphases [s]

Time duration of:	CZ	D	SK
staff phase	1.50	0.07	1.57
preparation microphase	0.88	0.07	0.95
vertical displacement	0.62	0.00	0.62
airborne phase	0.84	0.04	0.80
ascending microphase and reaching the culmination point	0.26	0.02	0.28
descending microphase	0.58	0.06	0.52
landing phase	1.25	0.07	1.18
contact with landing	0.37	0.05	0.32
bounce and dance	0.88	0.02	0.86

CZ- Czech couple, D- difference between couples SK- Slovak couple



A B

Figure 4. Trajectory of the center of gravity: Czech couple (A) and Slovak couple (B)

Table 2. Comparison of height of the center of gravity in microphases of female partner's [m]

Height of the center of gravity at the end of:	CZ	D	SK
starting position	1.09	0.13	0.96
preparation microphase	1.06	0.11	0.95
vertical displacement	3.13	0.17	2.96
ascending microphase and reaching the culmination point	3.54	0.19	3.35
descending microphase	2.23	0.07	2.16
contact with landing	0.76	0.10	0.86
bounce and dance	1.05	0.03	1.02

CZ- Czech couple, D- difference between couples SK- Slovak couple

Table 3. Comparison of other spatial characteristics

Staff phase		**CZ**	**D**	**SK**
F	angle in the partner's knee joint at the end of the preparation microphase	109.63° in 0.88 s	0.04°	109.56° in 0.95 s
M	angle in the partner's knee joint at the end of the preparation microphase	89.02° in 0.88 s	14.60°	74.42° in 0.95 s
F	angle between the partner's torso and the vertical plane at the time of termination	19.14° in 1.50 s	19.49°	38.63° in 1.57 s
M	maximal arch backward of the partner's torso during the vertical displacement	24.93° in 1.48s	2.17°	22.76° in 1.51 s
F	height of the swing ankle at the end of the staff phase	2.26 m in 1.50 s	0.14 m	2.40 m in 1.57 s
F	angle in the partner's knee joint at the end of the staff phase	147.05° in 1.50 s	19.03°	128.02° in 1.57 s
Airborne phase		**CZ**	**D**	**SK**
F	angle in the partner's knee joint at the culmination point	84.44° in 1.76 s	35.97°	120.41° in 1.85 s
F	angle between the partner's torso and the vertical plane at the moment of the salto opening	45.64° in 1.99 s	25.52°	20.12° in 1.92
F	angle between the partner's torso and the vertical plane at the end of airborne phase	48.67° in 2.34 s	2.62°	51.29° in 2.37 s
M	angle between the partner's torso and the vertical plane at the end of airborne phase	9.26° in 2.34 s	4.79°	14.05° in 2.37 s
F	angle in the partner's knee joint in the end of airborne phase	177.04° in 2.34 s	2.02°	175.02° in 3.37 s
Landing phase		**CZ**	**D**	**SK**
F	angle in the partner's knee joint at the end of landing microphase	80.54° in 2.71 s	30.26°	110.80° in 2.69 s

CZ- Czech couple, D- difference between couples SK- Slovak couple, F – female partner, M – male partner

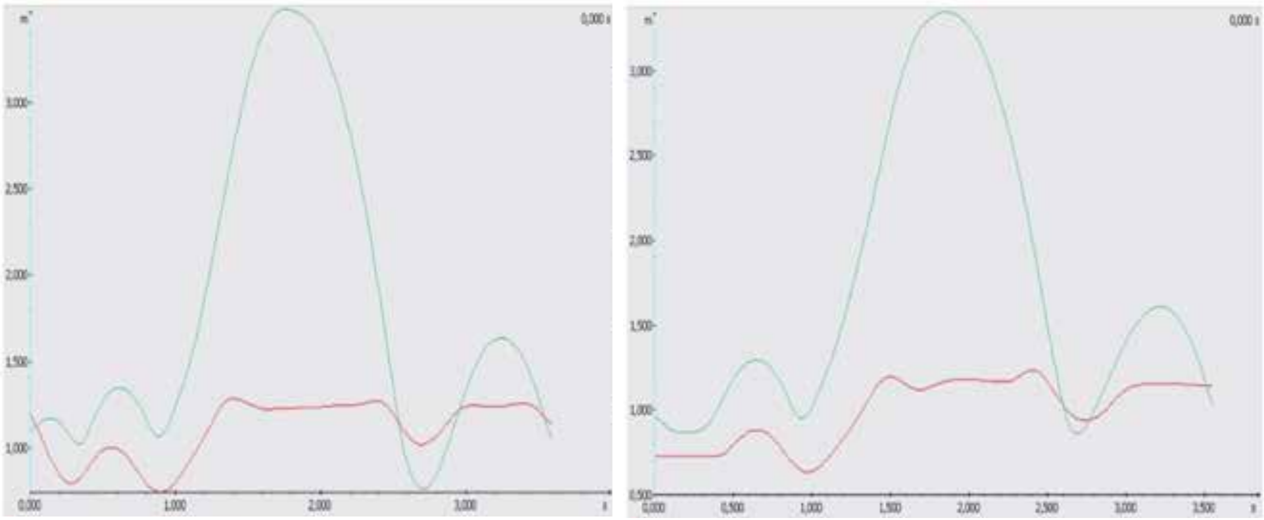
In this section, we aimed on every important characteristic which did not fit into the previous subsections. The comparison of the spatial characteristics is in Table 3.

In the starting phase, we noted the largest differences in the angle in the partner's knee joint from the compared values, when the difference was 14.60° and was caused by a different style of technique, since the partner from the Slovak Republic started the vertical displacement from a deeper squat than the partner from the Czech Republic. The biggest differences between the female partners, was in the angle between the torso and the vertical plane at the end of the vertical displacement (19.49°), when the female partner from Slovakia was twice as far away from the vertical axis. In the flight phase was the biggest difference between the partners was during the culmination point in the angle in the knee joint (35.97°) and in the angle between the trunk and the vertical plane at the moment of opening the somersault (25.52°). This difference was caused by the earlier opening of the somersault of the partner from SR, who did not complete the rotation. In the final phase, at the moment of finishing the landing, the difference in the angles in the knee joint of the partners was 30.26°.

Comparison of time-spatial characteristics

In the time-spatial characteristics, we focused on the acceleration and speed of the center of gravity of the dancers during the acrobatic element. The speed of the centers of gravity is shown in Figure 5.

In Table 4 are all the differences between the couples in time-spatial characteristics. The biggest difference was in the maximum acceleration in the starting phase for the male partner 1,74 $m.s^{-2}$ and for



A B

Figure 5. Speed of center of gravity of Czech (A) and Slovak (B) couple (green line- female partner, red line- male partner)

Table 4. Comparison of time- spatial characteristics

Partner's Center of Gravity Dynamics		CZ	D	SK
M	max. acceleration of the partner's center of gravity in the staff phase	14.81 m.s^{-2} in 0.31 s	1.74 m.s^{-2}	16.55 m.s^{-2} in 0.63 s
F	max. acceleration of the partner's center of gravity in the staff phase	23.68 m.s^{-2} in 0.37 s	1.39 m.s^{-2}	25.07 m.s^{-2} in 0.97 s
F	max. speed of the partner's center of gravity in the staff phase	4.54 m.s^{-1} in 1.32 s	0.22 m.s^{-1}	4.32 m.s^{-1} in 1.43 s
F	the speed of the partner's center of gravity at the end of the staff phase	3.35 m.s^{-1} in 1.50 s	0.23 m.s^{-1}	3.12 m.s^{-1} in 1.57 s
F	the speed of the partner's center of gravity at the end of the descending microphase	5.02 m.s^{-1} in 2.34 s	0.30 m.s^{-1}	4.72 m.s^{-1} in 2.37 s
F	max. speed of the partner's center of gravity in the landing phase	5,77 m.s^{-1} in 2,47 s	0,43 m.s^{-1}	5.34 m.s^{-1} in 2.45 s

CZ- Czech couple, D- difference between couples SK- Slovak couple, F – female partner, M – male partner

the female partner 1,39 m.s^{-2}. We noticed another difference in the final phase when the maximum speed of the center of gravity of the partner from the Czech Republic was greater by 0.43 m.s^{-1}. In other parameters, the differences were only minimal.

Discussion

This study aimed to investigate the kinematic parameters of acrobatic element salto backward tucked and compere characteristics of two rock and roll couples. Despite the absence of studies, we will compare the results also with acrobatic elements with a similar structure in acrobatic rock and roll.

Study which aimed on the same element as we, shown a few differences when we compare the highest values. In in height at the end vertical displacement (1. 2.70 m, 2. 2.62 m, 3. 2.94 m) was difference 19.20 cm and at the culmination point (1 3.05 m, 2. 3.10 m, 3. 3.32 m) 21.70 cm. Study shows that the airborne phase was 0.29 s longer than in our research (1. 1.14 s, 2. 0.96 s, 3. 1.01 s) [12].

In comparison of kinematic characteristics of 20 couples in MCFS category. They monitored 3 acrobatic elements from the staff and one of them was also salto backward with the maximum height of the partner's center of gravity 3.06 m [13]. Taking into account of our results, we observe that a CZ couple achieved a larger maximal height of the partner's center of gravity by 47.30 cm and the SK couple by 28.30 cm compared to the average maximal height of the center of gravity in their research. The length of the airborne phase in their study was 1.01 s and in our study for the CZ couple 0.84 s and SK couple 0.80 s so the difference is 17 s for CZ couple and 21 s for the SK couple.

The acrobatic element salto backward straight was observed on the same probands as in our study. Thanks to this, we can directly compare selected characteristics of a couple from the Czech Republic with a couple from the Slovak Republic. In terms of time characteristics, we noted a difference in the duration of the entire acrobatic element, when the difference of the CZ couple was 0.07 s and of the SK couple 0.02 s. Couples have similar durations of both somersaults, where the minimal difference indicates a longer duration of the straight salto. From the spatial characteristics, we can compare the height of the partner's center of gravity at the culmination point in the airborne phase. Here was the height almost same for the CZ couple (difference: 0.01 m), and for the SK couple (difference: 0.05 m), when SK couple, had the center of gravity higher during a straight somersault. We assume that this difference is caused by the error of the SK couple in the tucked somersault, when she stops the ascending phase with banding her knee. Since in the straight somersault partner must keep whole body extended for the entire time of the acrobatic element, she had no space for the same mistake. In the preparatory phase, we observed difference in the angle between the partner's torso and the vertical plane at the end of the vertical displacement. The Slovak partner is more deviated from the vertical plane in both acrobatic elements, in our work it was up to 38.63° and in a straight somersault 30°, so the difference was 8.63°. The Czech partner had a smaller angle, 19.14° in our work and 14° in the straight somersault, so the difference was 5.14°. From the time-spatial characteristics, we decided to compare the speed of the partner's center of gravity in the end of the preparation phase. The CZ couple reached a higher speed in the tucked salto (difference: 0.42 $m.s^{-1}$) and the SR couple reached a higher speed in a straight salto (difference: 0.33 $m.s^{-1}$) [22, 23].

From other elements with similar structure of motion is also double somersault backward. In this research was used 2D analysis to observe 15 couples (age: 17 – 25 years of female partners, 20 – 35 years of male partner). Maximal height of center of gravity shown minimal value 2.84 m a maximal value 3.66 m (median 3.30 m) which is close to our results (3.54 m and 3,35 m). In the angle between the partner's torso and the vertical plane at the end of the preparation phase was found minimal angle 14° and maximal 39° (median 30°) which is also similar to our values (24,93° a 22,76°). In the speed of center of gravity in ascending phase was the minimal speed 2.90 $m.s^{-1}$ and maximal 6.50 $m.s^{-1}$ (median 4.36 $m.s^{-1}$) our values was close to the median (4,54 $m.s^{-1}$ and 4,32 $m.s^{-1}$) [24].

Conclusions

Based on the results of the kinematic analysis, we can determine the errors of both couples. Within the rules, deductions are precisely defined for individual errors in the presentation of the acrobatic element. However, we have discovered errors that are not defined by collisions, but after their removal, the acrobatic element will be of higher quality. In this phase, we recognized the incorrect position of the rebounding lower limb of SK partner, which reduces the efficiency of the rebound. At the end of the preparatory phase, we also observe an incorrect position of the head in hyper extension Inadequate movements of the trunk, the upper limbs and swing of lower limbs during the vertical displacement have been performed as well by the same SK dancer. The large deviation of the partner's torso (38.63°) from the vertical plane together with the bending of the starting lower limb (128.02°) resulted in the disruption of the partner's forces and premature rotation. In the airborne phase, the biggest detected error was the bad position of the body of SK partner in somersault, where during the culmination point the partner had an angle in the knee joint of 35.97°. Such a value means a 25% deduction from the starting value of the acrobatic element. Additionally, in the culmination the SK partner made a mistake in timing - the opening of somersault has been performed very early, even before reaching the culmination. While watching CZ couple, in the landing phase, we found deficiencies in the partner's landing, namely in the height of the center of gravity (0.76 m) and in the angle in the knee joint (80.54°). This is since her partner does not help her enough when landing. For this reason, the entire landing and rebound of the CZ couple seems lengthy and lacks movement dynamics.

Recommendations

Based on the given analysis, we allow ourselves to make recommendations to eliminate the SK partner's mistake. In all these exercises, the partner tries to make a correct rebound. In addition, the perception of the position as well as the correction from the coach are important the most.

1. Individual exercises suggestions:
    - imitation of the staff phase using a bench or a box (different heights): starting from a standing position, staring from a step, staff from a standing position, staff from a step, repeated jumps with lower limbs exchange.
    - imitation of the staff phase using a bench or a box (the partner stands with her back to the wall): starting from a standing position, staring from a step, staff from a standing position, staff from a step, repeated jumps with lower limbs exchange.
2. Couple exercises suggestions:

- imitation of the staff phase - the partner sits on a bench or a box with his hands fixed in the stirrup: starting from a standing position, starting from a step, starting from a standing position with hold in extension, starting from a step with hold in extension.
- imitation of the staff phase - the partner sits on a bench or a box with his hands in the stirrup ready for a hint of the partner's lift: starting from a place, starting from a step, starting from kick.

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