KINEMATIC ANALYSIS OF SOME BACKWARD ACROBATIC JUMPS

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The aim of our investigation was to determine kinematic parameters of some acrobatic jumps backward, related to the difficulty categories in the current men's FIG Code of points. Ten male gymnasts performed ten different acrobatic jumps backward during the European championship in 1996 in Koebenhaven (Denmark). The analyzed elements were stretched salto backward, stretched salto backward with 1/1 turn, stretched salto backward with 3/2 turn, stretched salto backward with 2/1 turn, double salto backward tucked, double salto backward tucked with 1/1 turn, double salto backward tucked with 2/1 turn, double salto backward stretched, double salto backward stretched with 1/1 turn and triple salto backward tucked. According to the results we can not define the difficulty categories, but the data are quite informative for further investigations, comparison with other similar types of sports and also for coaches for methodic purposes.

KEY WORDS: men, artistic gymnastics, acrobatic jumps backward, kinematic analysis

INTRODUCTION: In men's artistic gymnastics, a big effort to change the men's FIG Code of Points has been made in the last Olympic cycles in such manner that the difficulty of elements will be evaluated not only by expert knowledge but also by their bio-mechanic characteristics. By the present Code of Points, the acrobatic jumps backward are divided into the following difficulty groups, where B is an easy element and superE (sE) is the most difficult element.

Table 1 Analyzed Elements with Difficulty According to the Men's FIG Code of Points

Stretched salto backward	B
Stretched salto backward with 360 degrees (1/1) turn	B
Stretched salto backward with 540 degrees (3/2) turn	C
Stretched salto backward with 720 degrees (2/1) turn	C
Double salto backward tucked	C
Double salto backward tucked with 360 degrees (1/1) turn	D
Double salto backward tucked with 720 degrees (2/1) turn	E
Double salto backward stretched	D
Double salto backward stretched with 360 degrees (1/1) turn	E
Triple salto backward tucked	sE

METHODS: During the European championship in Koebenhaven (Denmark) in 1996 we recorded some of the elements listed above that were well executed. All elements were performed without major mistakes (fall).
We recorded the elements with several SVHS cameras, which covered the whole floor area. We analyzed 25 frames per second, with a CMAS 3D system and calculated the kinematic parameters according to the Sušanka (Karas, Sušanka, & Otahal (1987)) body model with 15 segments implemented in the CMAS. Each element was analyzed from the moment of 3 frames before touch-down prior to take-off up to first touch down at landing plus 3 frames.
For our presentation we chose the following variables which can best define the difficulty of elements: time of flight, maximum height (where 0 is at the level of body center of gravity just before take-off), amount of rotation around transversal axis up to the highest point, average angular velocity around transversal and longitudinal axes and the distance between take off and landing position. To calculate average angular velocity around the transversal axis we used the amount of trunk rotation.

RESULTS AND DISCUSSION:

Table 2 The Results of Chosen Variables

Element	Time of flight (second)	Maximum height* (meter)	Transversal rotation up to the highest point (°)	Average ω around transv. axis (°/s)	Distance of the flight (meter)	Average ω around long. axis (°/s)	
Stretched salto bwd.	0.84	0.70	135	357	2.67	0	B
Stretched salto bwd. With 1/1 turn	0.80	0.57	160	375	3.11	818	B
Stretched salto bwd. With 3/2 turn	0.76	0.69	145	447	3.23	710	C
Stretched salto bwd. With 2/1 turn	0.88	0.94	170	386	1.02	947	C
Double salto bwd. Tucked	1.00	1.07	310	665	3.30	0	C
Double salto bwd. Tucked with 1/1 turn	1.08	1.23	323	601	2.75	600	D
Double salto bwd. Tucked with 2/1 turn	1.04	1.14	253	596	2.00	750	E
Double salto bwd. Stretched	0.96	0.97	280	677	2.14	0	D
Double salto bwd. Stretched with 1/1 turn	1.08	1.00	300	583	2.72	450	E
Triple salto bwd. tucked	1.16	1.38	486	853	2.82	0	sE

* zero is at the body center of gravity just before take off

Results from our research are quite similar to the results of Brueggeman et a (1989) who analyzed the following elements: double salto backward stretched, double salto backward stretched with 1/1 turn and salto backward with 1/1 turn (from compulsory exercises), very interesting is their comparison of double salto backward stretched with 1/1 turn and salto backward with 1/1 turn performed by the same gymnast, where some data are almost equal.
Generally, the time of flight differentiates elements according to the difficulty of the element, more difficult elements require more flight time. Elements with a singular transversal rotation require less time (mostly around 0.80 s), than elements with double transversal rotation (slightly more than a second) and those also less time than elements with triple transversal rotation (significantly more than a second).
According to time of flight, there are also expected similar differences in maximum height of the flight. Austin (1976) reports that the height of body center of gravity during double salto tucked is between 211 to 258 cm, which is similar to the values in our measurements. More rotations - higher maximum height, triple salto backward has the highest results.
Average angular velocity around the transversal axis and transversal rotation up to the highest point show interesting values. As we calculated average angular velocity according to the position of the trunk, we noticed that nobody finished rotation at landing with trunk vertical and that angular velocity is lower than it should be, if we would calculate it from the position of the legs or virtual segment feet-body center of gravity, or virtual segment feet-shoulders. Almost all elements have more rotation in the second phase of flight after maximum height. The reason can be found in the different heights of the body center of gravity during the take off and landing. While the body is completely stretched with arms upward at the take off; at landing bent hips, arms and knees are normal. The difference can be up to 30 cm. More saltos - higher angular velocity is needed. The highest average angular

velocity is for the triple salto, where it reaches 853°/s, what is extreme angular velocity. Chinese circus acrobats on swing board while performing quintuple saltos backward also do not exceed an angular velocity of 900 °/s. Even in diving from a 1m spring board, the average angular velocity does not exceed 1000 °/s.
Distances between take-off and landing position are very different, without any common characteristics. Austin (1976) reports that double salto backward tucked has a distance between 427 to 676 cm, with the tendency that better gymnasts have a shorter distance and higher maximal height. Our results showed no similarity, as all distances are much shorter. The distance depends most on the proportion between velocity in x and y-axis during take off. The extreme low value was measured for the gymnast who performed salto backward with 2/1 turns, where the take-off was extremely vertically directed.
Average angular velocity around the longitudinal axis for elements with turns vary from 450 to 947 °/s. Again this angular velocity is very high and also comes close to 1000 °/s. As a rule more turns, higher average angular velocity is needed. Here is also one exception – salto backward with 1/1 turn, where all the turn has been finished almost in the inverted vertical position, which resulted in more than 800 °/s; with such a technique the gymnast shows a high degree of virtuosity with a quite simple element.

CONCLUSION: According to the results we can conclude:

- Elements were performed by different gymnasts, with different techniques of take-off, therefore are difficult to compare,
- Elements were performed successfully without major mistakes,
- According to the present Code of Points, the difficulty of elements is mostly related to the required and actual time of flight,
- Expert knowledge to determine difficulty is quite efficient in case of acrobatic jumps backward,
- Easier elements can also be performed with excellence and with high values of the measured variables (e.g. salto bwd. with 1/1 turn average angular velocity around longitudinal axis),
- Results are quite informative for further investigation and comparison with other similar types of sports,
- Results can be also used for training purposes e.g. control of movement after certain forced angular velocity.

REFERENCES:

Austin, J.M. (1976). Cinematographical analysis of the double backward somersault. The Modern Gymnast.
Brueggeman, G.P., Bernstein G., Braun P., Dietz M., Eckhard S., Knoll K., Krug J., Leuchte S., Neumann H., Oester S., Tippelt F., & Weber R. (1989). *The World Championship in Artistic Gymnastics Stuttgart 1989 (scientific report)*. FIG.
Smolevski, V.M., & Kyris, V.N. (1976). *Volnie upražnenija muščin* [Floor exercise routines for men]. Moskva: Fiskultura i sport.
Karas, V., Sušanka, P., & Otahal, S. (1987). *Zaklady biomechaniki telesnych cvičeni* [Biomechanics of sport exercises]. Praha: Univerzita Karlova.