CORRELATION BETWEEN SELECTED KINEMATIC PARAMETERS AND ANGULAR MOMENTUM IN BACKWARD SOMERSAULTS

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In this paper, on the base of correlation analysis applied on the biomechanical data extracted from the execution of seven different types of backward somersaults, functional relations among parameters responsible for defining the CG trajectory and angular momentum have been analyzed. The obtained results show that average angular momentum in the flight phase was greater with the greater horizontal and lower vertical velocity at take-off and lower value of the flight height.

KEY WORDS: gymnastics, somersaults, trajectory, angular momentum.

INTRODUCTION: Different types of backward somersaults dominate in floor exercises in male and female artistic gymnastics. The reason for that lies on the fact that backward somersaults provide greater flight height and greater angular momentum than can be achieved by performing forward or sideward somersaults. Thus, a relatively large number of authors have analyzed various characteristics of efficient execution of this gymnastic element (Payne and Barker 1976, Bruggemann 1981, Hong and Bruggemann 1992, Knoll 1992, Newton *et al.* 1992, McNitt-Gray *et al.* 1994.). However, in everyday gymnastics practice, the most interesting and not enough examined question is how to achieve the maximum height of the flight with sufficient rotation for successful execution of the specific somersault type. The goal of this study was to define the basic relations between selected biomechanical parameters of the CG trajectory and angular momentum of the gymnast in seven most typical, but significantly different types (according to the number of rotations and the position of the body) of backward somersaults.

METHODS: The subject of this study was a highly ranked, world-class gymnast. According to his basic anthropometric measures (height 164 cm, mass 57.5 kg), he can be considered as a typical morphologic type of the elite gymnasts. Acquisition of the videometric data was made by two video cameras operating 60 frames per second, during the training organized for the purpose of this research. Successful single executions of seven different types of backward somersault have been subjected to further analysis: tuck (TCK), pike (PKE), layout (LYO), layout with twist 360° (L36), double tuck (DTC), double layout (DLY) and double tuck with twist 360° (D36). All types of backward somersault are executed from the typical preparatory tumbling series: approach, round off, and back handspring. Acquisition and processing of the data are done according to standards of the APAS procedure (3D analysis, DLT, Cubic Spline), concerning specifically about the analyzed movements.

RESULTS AND DISCUSION: The parameters, which are defining the gymnast's CG trajectory, extracted from the data obtained from seven executions of typical backward somersaults, are shown in Table 1. Relations between basic values of angular momentum around the gymnast's transverse axis and kinematic parameters that determine the gymnast's CG trajectory, are shown in Table 2. The basic values of angular momentum (*L*) are considered as: angular momentum at touchdown (*Li*), angular momentum at take-off (*Lo*), and average angular momentum during the flight phase (*La*). As it can be seen from the Table 2, the initial value of angular momentum (at touch-down) is significantly related ($p > .05$) with CG height at touchdown (.82) and landing (- .88). Obviously, the values of *Li* will be higher with the higher position of the gymnast's CG at the end of backward handspring, e.g. in the moment of the first foot contact with the floor. Also, although not on the same significance level, the value of *Li* is relatively highly related with horizontal speed at touch-down. The angular momentum around transverse axis at take-off (*Lo*) is as well significantly related with a series of variables which define the CG trajectory. It is significantly positively related with the CG velocity at the touch- down (.86), with specific reference to it's horizontal component (.88). Afterwards, it is negatively related with velocity change during take-off (- .77) and take-off angle (- .80).

Table 1. Selected parameters of the CG trajectory.

Parameters	TCK	PKE	LYO	L36	DTC	DLY	D36
Vertical height of CG (cm)	225.6	221	226	222	224	196	216.6
Horizontal displacement of CG (cm)	240.7	222	252.4	235.8	255	258.2	238.4
Horizontal velocity at takeoff (cm/s)	285	277	300	284	296	328	293
Vertical velocity at takeoff (cm/s)	418	415	388	387	405	355	397
Velocity at takeoff (cm/s)	506	499	490	480	502	483	494
Take-off angle (°)	45	45.5	41.5	42.2	43.5	37	42
Angle at touch-down (°)	48	47	47	47	48	48	46
CG angle at takeoff (°)	73	69	75	78	77.5	78	74
Duration of the flight (s)	1.02	1.00	1.05	1.01	1.03	0.97	1.03
Duration of the flight relative to CG	0.97	0.95	0.98	0.97	0.97	0.86	0.95
Horizontal velocity at touchdown (cm/s)	326	332	346	333	335	372	346
Vertical velocity at touchdown (cm/s)	86	114	103	105	106	67	84
Velocity at touchdown (cm/s)	337	351	361	348	351	378	358
Change of the hor. velocity at takeoff (cm/s)	-41	-55	-46	-49	-39	-44	-53
Change of the ver. velocity at takeoff (cm/s)	332	301	285	282	299	288	313
Change velocity at takeoff (cm/s)	169	148	129	132	151	105	136
Average takeoff force (N)	1380	1196	1136	1023	1175	1087	1088
Duration of the takeoff (s)	116.7	116.7	116.7	116.7	116.7	116.7	116.7
Mass of the gymnast (kg)	57.5	57.5	57.5	57.5	57.5	57.5	57.5
CG height at touchdown (cm)	75	75	75.5	76	76.5	79	76.7
CG height at takeoff (cm)	102.4	103.2	101.1	101.8	103.8	101.3	102.1
CG height at landing (cm)	79.8	81.2	70.7	81.5	68.9	53.8	64.4

Also, *Li* is significantly positively related to horizontal (.83), and negatively with vertical (- .77) component of velocity at take-off. During the flight phase, which is very important from the competitive point of view – maximization of height, *Lo* is significantly negatively related with maximal height of CG trajectory (- .87). It proves the theory that the creation of a larger amount of angular momentum necessarily spents a certain amount of the flight height. The *Lo* will be greater with greater velocity at touch-down. Since it is primarily formed by its horizontal component, high value of this correlation coefficient was expected (.88). Furthermore, angular momentum at the end of take-off will be greater with the smaller change of velocity during take-off, as well as with the lower take-off angle. Consequently, the duration of the flight (relative to CG height) is significantly negatively related with *Lo*. In other words, the duration of the flight will be longer with the lower value of the angular momentum at the take-off, what is closely related with the previously described velocity components and take-off angles. The relationships between selected parameters of the CG trajectory and average angular momentum during the flight phase are interesting from the point of the everyday gymnastics praxis. Thus, *La* is significantly (.76) correlated with angular momentum at touch-down. This means that greater angular momentum around the transverse axis of the gymnast's body, generated through preparatory elements, will produce the greater amount of average angular momentum at the flight phase. Moreover, *La* will be greater with greater horizontal velocity at touch-down. Especially interesting is the high positive relationship with angle of CG at touch-down (.93). In other words *La* will be greater with a higher position of CG at touch-down (attack angle). It can be presumed that high positioning of CG disables effective development of ground reaction forces necessary for the efficient transfer from horizontal to vertical take-off impulse. Changes of the values of selected parameters are also significantly related to the average angular momentum registered through the flight phase. ΔL is highly negatively related with the velocity change during the take-off (- .82), as well as with the take-off angle.

Table 2. Correlation coefficients.

Variables	Li	Lo	ΔL
Vertical height of CG (cm)	-.64	-.87*	-.93*
Horizontal displacement of CG (cm)	.28	.20	.07
Horizontal velocity at takeoff (cm/s)	.68	.83*	.76*
Vertical velocity at takeoff (cm/s)	-.63	-.77*	-.84*
Velocity at takeoff (cm/s)	-.37	-.44	-.64
Horizontal velocity at touchdown (cm/s)	.74	.88*	.83*
Vertical velocity at touch-down (cm/s)	-.42	-.57	-.64
Velocity at touch-down (cm/s)	.71	.86*	.80*
Change of the hor. velocity at takeoff (cm/s)	.01	-.02	.04
Change of the ver. velocity at takeoff (cm/s)	-.32	-.36	-.38
Change velocity at takeoff (cm/s)	-.64	-.77*	-.82*
Take off angle (°)	-.61	-.80*	-.83*
Angle at touch-down (°)	-.23	.30	-.01
CG angle at takeoff (°)	.72	.41	.67
Duration of the flight (s)	-.16	-.74	-.64
Duration of the flight relative to CG	-.53	-.90*	-.86*
CG height at touchdown (cm)	.82*	.72	.93*
CG height at takeoff (cm)	-.21	-.56	-.48
CG height at landing (cm)	-.88*	-.69	-.78*

Correlation coefficients marked with (*) are significant on the level $p<.05$.

The smaller the degree of the velocity loss during take-off, and the lower the take-off angle, the greater the average angular momentum during the flight. As it was the case with *Li*, *La* is positively related with horizontal, and negatively with vertical take-off velocity, although, there was a stronger relationship with the vertical component (- .84). Average angular momentum at take-off will be greater with smaller vertical and greater horizontal CG velocity at take-off. Very interesting is the negative correlation coefficient of *La* with time of the flight (- .86) and with CG height at landing (- .78). It can be concluded that somersaults with greater average angular momentum in the flight phase are characterized with shorter time of the flight. Therefore, in an attempt to complete the expected rotation, this must be compensated with an extended flight phase, significantly under the CG height at take-off, which means a rather low CG position at landing.

CONCLUSION: The trajectory of the gymnast's CG, while performing the backward somersaults, is defined by CG take-off angle and velocity. Rotation of the gymnast, around the transverse axis, is determined by angular momentum, which is a product of moment of inertia and angular velocity. These parameters are common for all types of backward somersaults. At the same time, all of them can be considered as changeable and more or less dependent variables. This fact shows the existence of numerous different combinations of other biomechanical parameters that influence the formation of these values. In this study, on the base of correlation analysis applied on the biomechanical data extracted from the execution of seven different types of backward somersaults, functional relations among parameters responsible for defining the CG trajectory and angular momentum have been analyzed. The main results of the analysis point to the conclusion that average angular momentum in the flight phase will be greater with higher position of CG at touch-down, the greater horizontal and lower vertical velocity at touchdown and take off, smaller change of the velocity during the take-off, lower take-off angle, as well as with lower height of the flight. It can be also the concluded that the generation of angular momentum required by the completion of multiple rotations around transverse axis, necessarily expends a certain amount of the vertical component of the analyzed movements.

REFERENCES:

Bruggemann, G. P. (1987). Kinematics and kinetics of the backward somersault take-off from the floor. In H. Matsui and K Kobayashi (eds.), *Biomechanics VIII-B,* 793-800. Champaign, IL: Human Kinetics.

Hong, Y. and G. P. Bruggemann(1993). The Mechanism of Twisting Somersault and its Application on Gymnastics Practice. In G.P. Bruggemann and J. K. Ruhl (eds.), *Conference Proceedings of the First International Conference on Biomechanics in Gymnastics,* 357-366. Cologne: Bundesinstitut für Sportwissenschaft.

Knoll (1993). Zum biomechanischien Wirkungsmechanismus von Flugelementen aus borbereitenden Bewegungen und Ableitungen für die Technik von Rondat und Flick-Flack am Boden. In G.P. Bruggemann and J. K. Ruhl (eds.), *Conference Proceedings of the First International Conference on Biomechanics in Gymnastics,* 115-126. Cologne: Bundesinstitut für Sportwissenschaft.

McNitt-Gray at al. (1994). External Reaction Forces Experienced by Lower Extremities During the Take-off and Landing of Tumbling Skills. *Technique*, **10/11**, 9-12

Newton, J., Turner, R. i Greenwood M. (1993). Biomechanical Analysis of the Triple Back Somersault. In G.P. Bruggemann and J. K. Ruhl (eds.), *Conference Proceedings of the First International Conference on Biomechanics in Gymnastics,* 259-269. Cologne: Bundesinstitut für Sportwissenschaft.

Payne, A. H. and Barker, P. (1976). Comparison of the take-off Forces in the Flic-Flac and the Back Somersault in Gymnastics. In P. V. Komi (ed.), *Biomechanics V-B,* 314-321. Baltimore: University Park Press.