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The Complex Analysis of Movement in the Evaluation of the Backward Somersault Performance

Authors' Contribution:

A – Study Design
B – Data Collection
C – Statistical Analysis
D – Manuscript Preparation
E – Funds Collection

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Abstract

Complex methodology was applied to study a movement structure in the standing back tuck somersault (SBTS). We have checked the usefulness of the multi-modular measuring system (SMART-E, BTS, Company, Italy) consisting of six infrared cameras, and the wireless module Pocket EMG, for measuring muscle bioelectric activity and force plate (AMTI, USA). Software Smart Analyser was used to create a database allowing the chosen parameters to be compared. Using a comprehensive methodology in the studies of the back somersault, performed with the landing at the same place (salto – S), allows for the presentation of the external and internal structure of the movement of this exercise.

Keywords: EMG, force platform, infrared cameras, somersault

INTRODUCTION

One of the primary tasks of sports biomechanics is the quantitative analysis of movement technique to facilitate the learning of motor skills. Biomechanics is the primary sports science focusing on movement technique [2,3,11]. This is especially important in gymnastics where the performance techniques of the best gymnasts are becoming models for others to follow. A coach's ability to direct the technical and physical training for these specific skills is enhanced when thorough descriptions of the skills are available. In scientific research of a movement technique of motor skills, recording and/or measurement of different parameters (for example critical features; [1,2]) and a number of accessible biomechanical methods are utilised. Earlier, we applied a complex methodology of investigations to study the movement structures (*Figure 1*) in weight lifting [13] and the flat bench press [12]. The understanding of both the internal (muscle activation) and external (kinematics and kinetics) structure of the snatch and bench press of the barbell was acquired by simultaneous application of several devices (inter alia: force platform, electromyography, goniometers, cameras). In this study, the same purpose was established for the acrobatic tumbling exercise – the back somersault.

To 1972, performing a somersault on the balance beam seemed impossible. It was changed when the female teenager, Olga Korbut, a gymnast from the former Soviet Union, performed the tuck back somersault for the first time on the balance beam during the Olympic Games in Munich. Acrobatic tumbling exercises on the balance beam are movement structures which are decisive for performance. The development in balance beam gymnastics is characterized by a permanent increase in the degree of difficulty of the acrobatic tumbling elements and combinations.

Most of the complicated tumbling combinations are performed backwards. The advantageous anatomic conditions for the backward take-off are the reason why most tumbling combinations are performed backwards. The performance of the somersaulting skill is dependent on the linear and angular momentum at takeoff and the configuration changes used by the gymnast during flight. The two most important factors for a successful performance are the vertical velocity of the mass centre and the angular momentum about the mass centre at takeoff [4, 10]. The product of these two factors dictates how much somersault rotation can be achieved. To perform the somersaults on the balance beam, a large amount of kinetic energy has to be supplied. The conditions for the performance of tumbling exercises (acrobatic elements) are disadvantageous: width of the balance beam 10 cm, low elasticity, and the fact that it is necessary to perform a back somersault in place. Thus, is it possible to perform the standing tuck back somersault crosswise on the balance beam? Indeed, there are some biomechanical questions raised concerning performing a somersault in place. It is important to note, that to jump vertically, there should be no horizontal component of the ground reaction force (GRF). In fact, in order to induce the backward rotation of the body, the vertical push's centre of pressure (COP) should be in front of the body's centre of mass (COM) [6]. Is it even possible to exert a vertical push which is not directed through the COM without inducing a horizontal force?

To answer these questions, we will first completely check the usefulness of the multi-modular measuring system (SMART-E, BTS Company, Italy) in studying the structure of the standing tuck back somersault (STBS) performed in place. That was the main aim of this work. The second aim was to explore the differences in the internal and external structure of the STBS, according of the landing place.

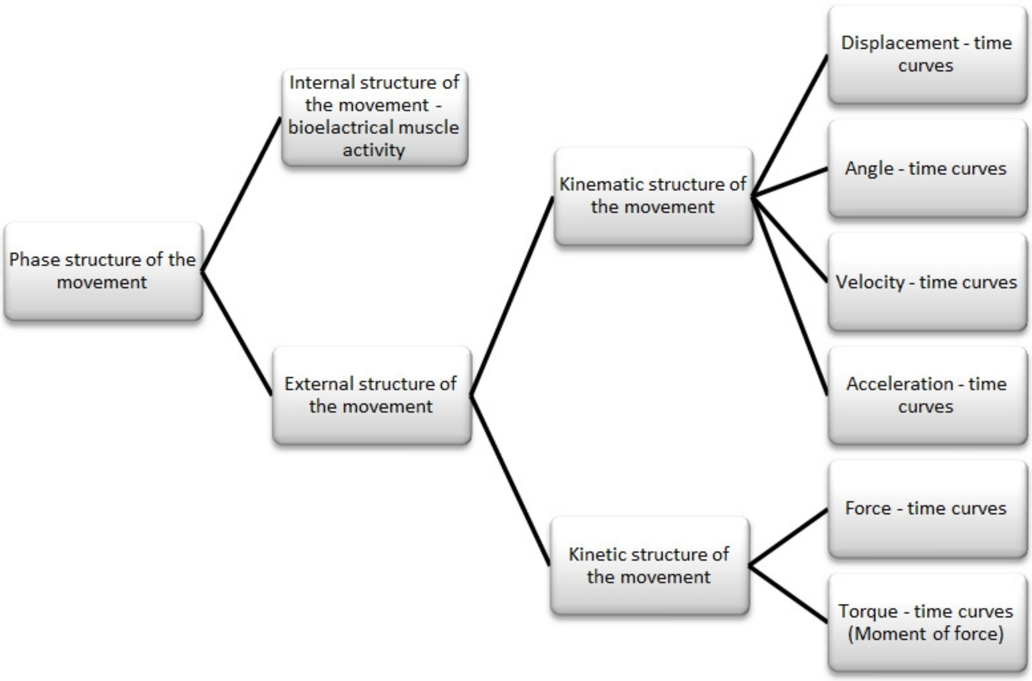

Figure 1. Phase structure of the movement.

MATERIAL AND METHODS

Subjects

Twelve healthy artistic gymnasts participated in this investigation. The participants were a convenient sample of highly competitive national standard female gymnasts who demonstrated proficiency in performing the skills required for the investigation. The gymnasts were informed about the nature of this study and prior to data collection they were required to sign a consent form according to human subject regulations. Parent or guardian consent was required for those younger than 18 years old. The research project was approved by the Ethics Committee for Scientific Research at the Jerzy Kukuczka Academy of Physical Education in Katowice. All subjects were tested under the same conditions in a laboratory setting. Each gymnast performed three randomised trials of four acrobatic skills: standing tuck back somersault, standing pike back somersault, back handspring, and vertical counter movement jump. In this study, the results of the standing tuck back somersault in place of one of the participants are included and reported on.

Instrumentation and data collection

Exercise. After a general warm-up, the subject performed a 10-minute stretching program. Afterwards, the gymnast were instructed on how to perform the standing tuck back somersault. The athlete started from an erect position and was required to take-off and land in the same place. During the testing session, the subject performed three training back somersaults and then three trials that were recorded. In the first trial, the female gymnast made the STBS with take-off and landing in place (salto - S_p). In the second trial, the gymnast landed 30 cm before (salto - S_{bf}) and in the third trial 16 cm behind (salto - S_{bh}) the starting line. The rest interval between single trials was 3 minutes.

Force platform. The gymnast was instructed to perform the back somersault from a standing position with take-off from the force platform (AMTI, USA). A vertical and horizontal (anterior-posterior) component of the ground reaction force was recorded. To calculate the vertical and horizontal force impulse (I_y; I_x), the COM velocity (v_y; v_x), and displacement (d_y; d_x), computer software was implemented (MATLAB).

Electromyography. Multichannel electromyography (EMG) may be used in studies of muscular coordination, enabling, in turn, certain evaluations of locomotor skills. Muscle activity was assessed using the BTS Pocket EMG (BTS Bioengineering, Italy). The electromyography signals were monitored using H124SG disposable surface electrodes. Two disposable surface electrodes were placed 2[cm] apart over the motor activation points of the *anterior tibialis* (AT), *medial gastrocnemius* (MG), *rectus femoris* (RF), *biceps femoris* (BF), *rectus abdominis* (RA), *gluteus maximus* (GM), *erector spinae* (ES), and *anterior deltoideus* (AD), in accordance with European Recommendations for Surface Electromyography – SENIAM, and further secured with athletic tape. All electrodes were placed on the right side of the subject. The surface electrodes were used to obtain the muscle activation characteristics of the gymnast during the counter movement, take-off, and flight (airborne, aerial) phases of each trial. Before electrode placement, the skin surface was vigorously scrubbed with an alcohol swab. All electrodes remained in place until the end of the all the trials. Cables from the electrodes to the transmitter were secured to the gymnast with athletic tape to minimize distraction to the gymnast and interference with the EMG signal. The transmitter was placed in a belt pack worn snugly about the gymnast's waist. The EMG signals were sampled at a 1 kHz rate. All active channels had the same measuring range and were fitted to the subject (typically +/- 5 mV). Analog signals were converted to digital with 16 bit sampling resolution and collected on the measuring unit. The signals were transmitted immediately after a single trial, to a computer via Wi-Fi Network. Following the data collection, the signals from each trial were stored on a hard drive and later analysed using the Smart Analyser software.

Measuring system SMART. Multidimensional movement was analysed with the measuring system Smart-E (BTS, Company, Italy) which consisted of six infrared cameras (120 Hz) synchronised with a force plate and Pocket EMG. Infrared camera recordings of the performances were collected to allow access to kinematic parameters of the take-off techniques of the somersaults that might explain the characteristics of muscle activation. Modeling in 3D space as well as calculations of parameters were performed with Smart Analyzer software (BTS, Italy). The set of passive markers permitting the calculation of some chosen parameters of the subject were applied. Technical accuracy of the system after the calibration process was 0.4[mm] – it was the accuracy of measurement, i.e. the distance between two markers in 3D.

Electromyography data reduction. The raw EMG signal was filtered (pass band Butterworth filter, 10-250 Hz). Next, the full-wave was rectified and smoothed using the root-mean-square (RMS) method with 100 ms mobile window.

RESULTS

Bearing in mind that biomechanics is concerned with the forces that act on a human body and the effects that these forces cause, the first place thing to be considered is the muscle action. Skeletal muscles are the primary actuator of the movement and are a real biological system designed to produce mechanical force and cause movement. *Figure 2* shows the muscle activation characteristics (so called internal structure of movement) of eight studied muscles. When considering muscle activity characteristics, a high amount of repeatability was found. In the take-off phase, there was an especially high amount of activity shown: *anterior deltoideus*, *medial gastrocnemius*, *biceps femoris*, *erector spinae*, and *anterior tibialis*. There was also an almost complete lack of activity of the rectus abdominis found.

According to Newton's third law of motion, there is reaction force, for example, of the ground, in response to muscular action. Vertical (R_y) and horizontal (*anterior-posterior* - R_x) ground reaction forces recorded by a force platform during the counter movement and the take-off phases for three different back somersaults (salto: S_p, S_{bf} and S_{bh}), are presented in Figure 2B–a, b. Vertical axis variables were slightly different during the impulse of the three take-offs (141.5 Ns; 145.6 Ns; 143.1 Ns, respectively, for S_{bf}, S_p and S_{bh}) (*Table 1*).

However, the horizontal impulse (*anterior-posterior* axis) was distinctly greater during the S_{bf} compared to the S_p and to the S_{bh} (32.0 Ns; -6.9 Ns; -9.1 Ns, respectively). Because the impulse of a force is equal to the change of momentum that is produced at the constant body mass of the gymnast. When the vertical impulse increases the COM vertical velocity and height of the flight will also increase (*Table 1*). However, as I have already mentioned, the performance of the somersaulting skill is dependent not only on the velocity (linear momentum) at take-off but also on the angular momentum. The angular momentum and components (moment of inertia and angular velocity) at the end of the take-off phase and average angular momentum during flight phase are presented in *Table 2*.

The whole curves of the vertical and horizontal COM displacement as a function of the timing of the back somersaults were shown in the *Figure 2B-c*, but the differences between the curves are slight. Though when observing the hip (*trochanter*) movement (*Figure 2B-d*), there were distinct noted differences. These differences can be seen even better when comparing the selected positions of the three analysed trials (*Figure 3*).

Table 1. Variables calculated based on ground reaction forces during the take-off for three different standing tuck back somersaults (salto): with take-off and landing in place (S_p), with landing 30[cm] before the place of the take-off (S_{bf}), and with landing 16[cm] behind of the take-off (S_{bh}).

Variable	Salto - S_{bf}	Salto - S_p	Salto - S_{bh}
Vertical impulse [Ns]	141.5	145.6	143.1
Horizontal impulse [Ns]	32.0	-6.9	-9.1
Vertical velocity [m/s]	2.38	2.52	2.41
Flight height [m]	0.29	0.32	0.30

- a minus sign indicates the opposite return

Table 2. Angular momentum and components, for three different standing tuck back somersaults (salto) obtained from infrared cameras: with take-off and landing in place (S_p), with landing 30[cm] before the place of the take-off (S_{bf}), and with landing 16[cm] behind of the take-off (S_{bh}).

Variable	Salto - S_{bf}	Salto - S_p	Salto - S_{bh}
Angular momentum at the end of the take-off phase [kgm^2/s]	57.9	63.4	60.9
Angular velocity at the end of the take-off phase [rad/s]	4.0	4.4	4.3
Moment of inertia at the end of the take-off phase [kgm^2]	14.5	14.4	14.2
Average angular momentum in the flight phase [kgm^2/s]	49.6	48.7	49.3

Comparative characteristics of vertical position and the centre displacement of the mass of the gymnast in the three back somersaults (salto S_p; salto S_{bf}; salto S_{bh}) are shown in *Table 3*.

The indication was that the results of the trials are very similar. The vertical differences of displacement were mostly 1-4 cm. However, some differences are important, for example, there was a difference between the vertical displacement of the COM of the gymnast's body from the beginning of the flight phase to the highest flight position (so-called critical feature). In this study, in the back somersault with the take-off and landing in place (S_p), the vertical displacement of the COM was 3[cm] higher than during the S_{bf} and the S_{bh}. Both the data from the force platform and the recording of the infrared cameras showed the same trend (*Table 1 and 3*).

Another image of the changes in kinematics can be seen in the time course of the hip, knee, angle of ankle, and shoulder joints (*Figure 2B-e, f, g, h*). Here, the differences between the curves were also very slight. The phase durations were also defined. The S_{bf} counter movement phase duration was shorter (0.925 s) than the S_p (1.017 s) and S_{bh} (1.024 s) somersault. The S_{bf} takeoff phase duration was shorter (0.316 s) than the S_p (0.325 s) and S_{bh} (0.343 s) somersault.

The S_p flight phase duration was longer (0.625 s) than the S_{bf} (0.617 s) and S_{bh} (0.617 s) somersault. Thus, the rhythm of the movement, defined as the ratio of the time duration of the successive phases, was varied.

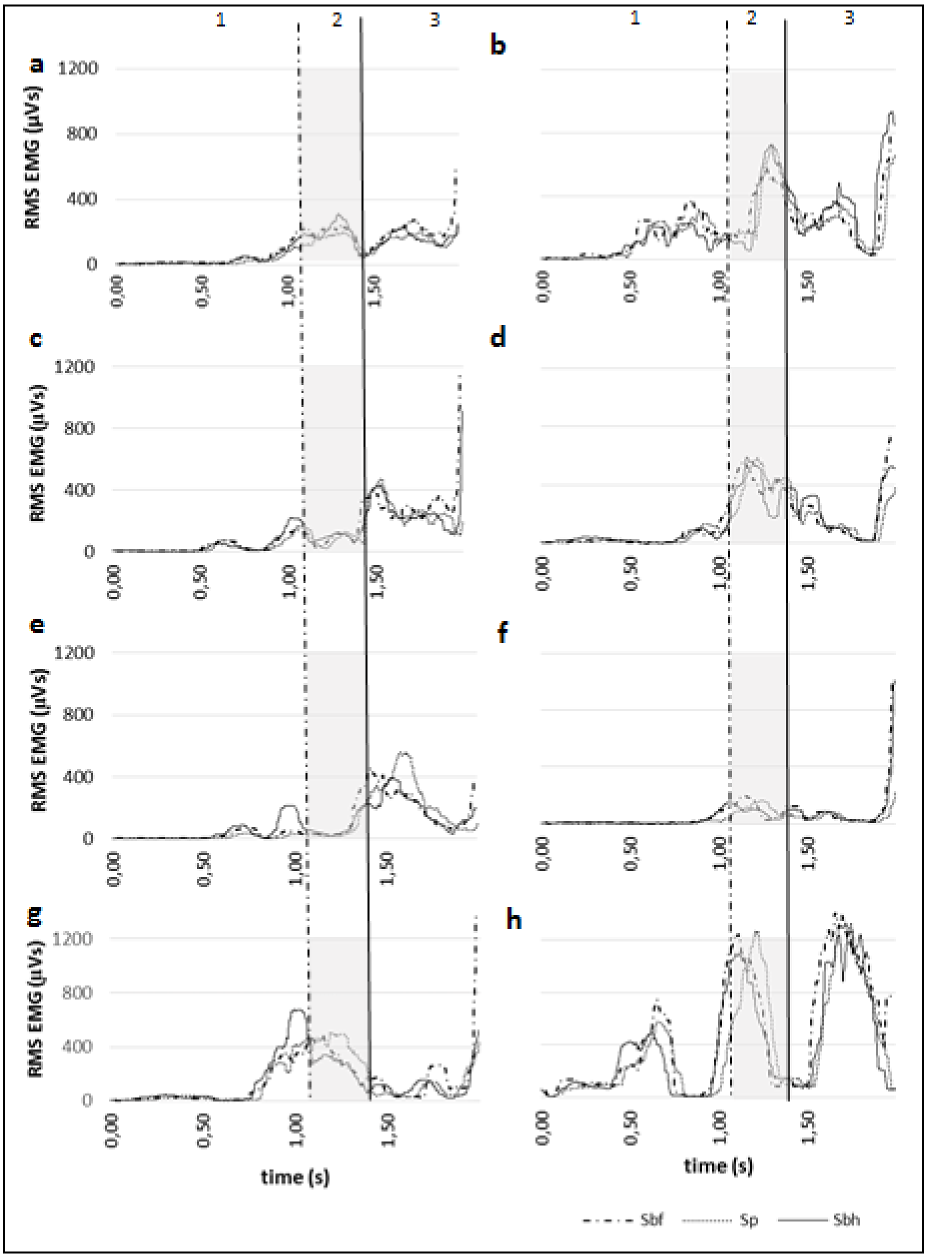

Figure 2. Structure of movement for the standing tuck back somersault with take-off and landing in place (S_p), with landing 30 cm before the place of the take-off (S_{bf}), and with landing 16[cm] behind the take-off (S_{bh}): A) Internal structure of movement – muscle activation characteristics: **a -** anterior tibialis, **b -** medial gastrocnemius, **c** - rectus femoris, **d** - biceps femoris, **e -** rectus abdominis, **f -** gluteus maximus, **g -** erector spinae, **h -** anterior deltoideus, **1** – counter movement phase, **2** – take-off phase (the shaded area), **3** – flight phase.

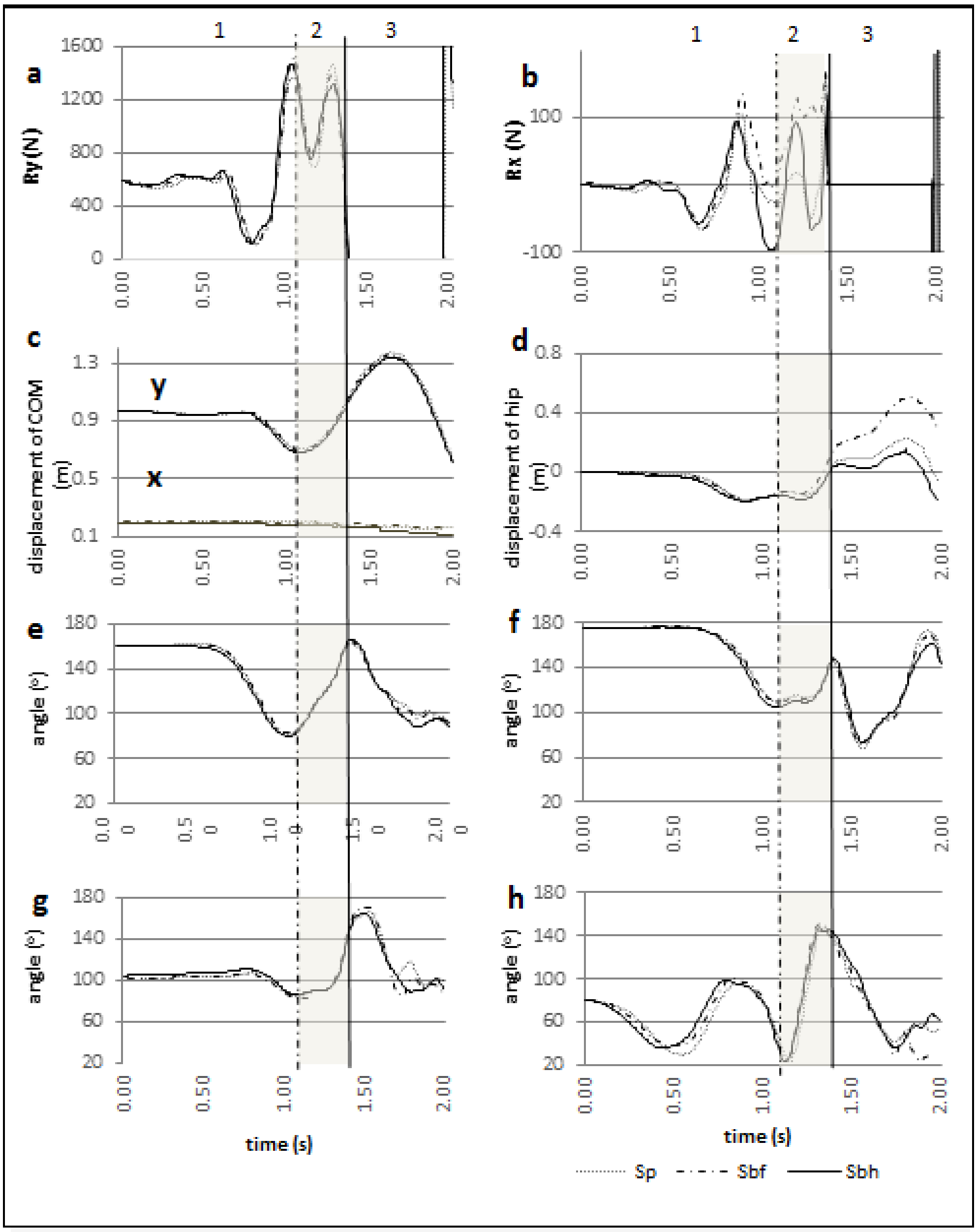

Figure 2 – continued,
B) External structure of movement: **a** – vertical and **b** - horizontal (*anterior-posterior*) ground reaction force, **c** - vertical and horizontal displacement of center of mass (COM), **d** - horizontal displacement of hip (*trochanter*), **e** - hip angle, **g** - knee angle, **h** - ankle angle, and **i** - shoulder angle, **1** – counter movement phase, **2** – take-off phase (the shaded area), **3** – flight phase.

Table 3. Vertical height and displacement of the center of mass (COM) of the gymnast's body for three different standing tuck back somersaults (salto): with the take-off and landing in place (S_p), with landing 30 cm before the place of the take-off (S_{bf}), and with landing 16 cm behind of the take-off (S_{bh}).

Position	COM height [m]			COM displacement [m]		
	Salto S_{bf}	Salto S_p	Salto S_{bh}	Salto S_{bf}	Salto S_p	Salto S_{bh}
Starting	0.97	0.97	0.97	0.27*	-0.26	-0.29
Squat in the end of the counter movement phase	0.70	0,71	0.68	0.41	0.39	0.41
Beginning of the flight (airborn) phase	1.11	1.10	1.09	0.25	0.28	0.25
The highest at flight	1.36	1,38	1.34	**	-0.73	-0.69
Beginning of the landing phase	**	0.65	0.65			

* a minus sign indicates the opposite return

** not available for technical reasons

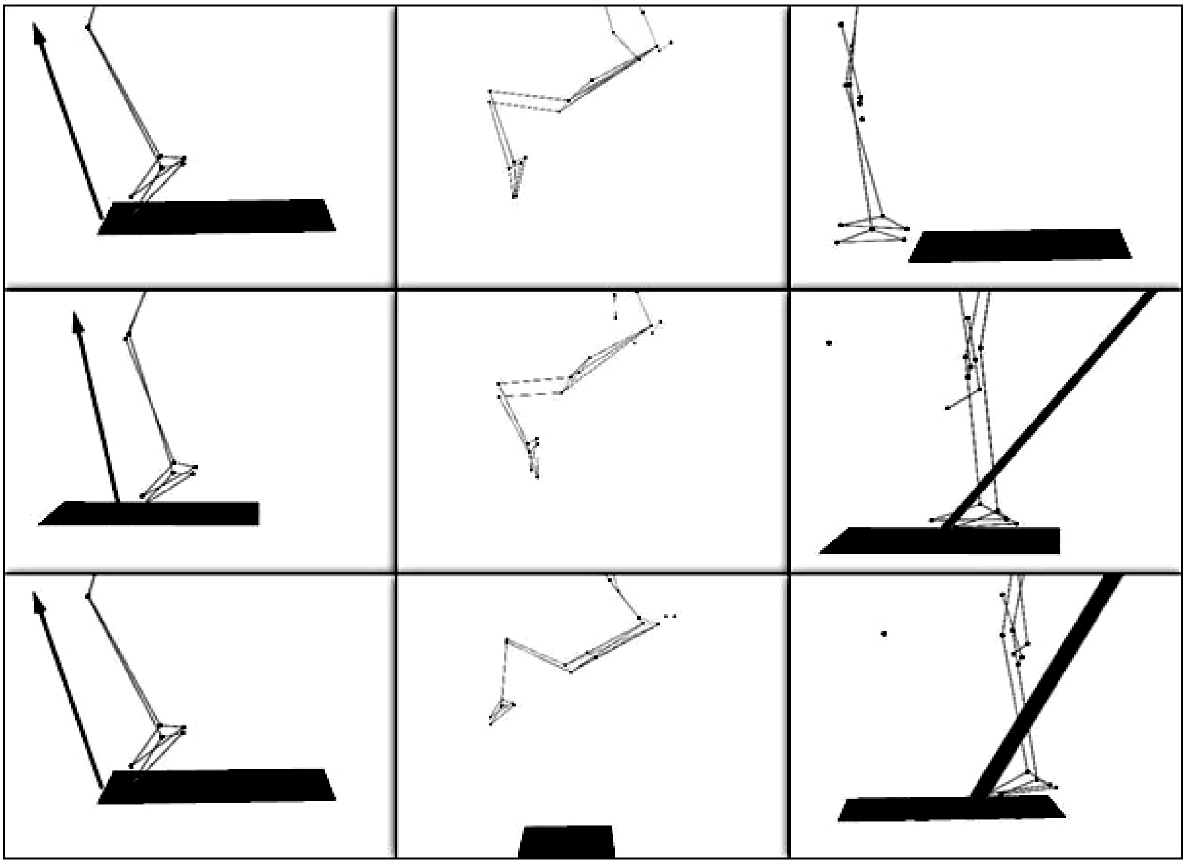

Figure 3. Standing tuck back somersault (salto): **a** - with the landing 30 cm before the place of the take-off (S_{bf}), **b** - with the take-off and landing in place (S_p), **c** - with the landing 16[cm] behind the take-off (S_{bh}), **1** – take-off position, **2** – flight position, **3** – touch-down position.

DISCUSSION

A back somersault has the characteristics of ballistic movement[1]. Many acyclic ballistic sport movements can be subdivided biomechanically into three phases: initial, main, and final. As far as the specific acyclic movements such as tumbling skills are concerned, the names of the phases are specific. In the back somersault from a standing position, the particular phases are as follows: counter movement, take-off, flight (airborn), and landing.

The counter movement is a special case of the initial phase, which aims to create optimal conditions for the implementation of the main phase. This is achieved by pre-stretching the muscles of the limbs (*gastrocnemius, quadriceps, gluteus maximus*) and trunk (*erector spinae pars lumborum*). This increase the elastic energy of the muscles, which in biomechanics is called the stretch-shortening cycle [5, 14, 18, 20]. Both the take-off and the flight are the main phases, since that is when the main task is performed. The main task is related with the body rotation around the free axis. The purpose of the take-off is to provide the projection velocity needed to lift the body and the angular momentum required to perform a rotary motion. The flight includes grouping (during the ascent of the body) and come out (during the descent). The effectiveness of this phase is determined by the skillful use of the conservation-of-angular-momentum principle [8].

The aim of the landing is to break_the momentum and the angular momentum of the body. Moreover, the purpose of this phase is to protect the joints of the lower limbs from damage and to restore the standing position. Although each phase of the movement is important, special attention must be given to the take-off phase when evaluating tumbling techniques. A perfect performance of the take-off phase influencing the following flight phase is crucial for a faultless performance of the whole tumbling skill. According Yeadon et al. *the technique used by the gymnast or tumbler during the take-off phase is clearly important for a successful performance. Gymnasts spend years learning the techniques required to perform a given tumbling movement* [21].

This study is focused on the variables that could affect the take-off phase by comparing three different standing tuck back somersaults: with take-off and landing in place (S_p), with landing 30 cm before the place of the take-off (S_{bf}), and with landing 16 cm behind the take-off place (S_{bh}).

Muscle activity generally had a high repeatability. In the take-off phase, almost no activity was found in the *gluteus maximus* muscle (*Figure 2A*). While the RMS EMG peak value of the *gastrocnemius* muscle in this phase was 710 µV. It was also shown that the end of the flight increased the muscle activation of almost all of the muscles, except for the *anterior deltoideus* muscle. This is called pre-activation. According to many researchers [1,7,19], the timing and extent of this activation is at least a partly pre-programmed, learned response. *Higher centers in the central nervous system appear to be able to plan for expected stretch loads* (feet hit the ground) *by increasing muscle stiffness to anticipated optimums* [15].

The kinetic analysis showed some differences between the test trials. In each of these three somersaults, the take-off phase was realized a little differently. The vertical impulse was the greatest during the S_p take-off, whereas the horizontal impulse was the smallest. However, the vertical impulse was the smallest during the S_{bf} take-off, whereas the horizontal impulse was the greatest. A large magnitude of the horizontal impulse is indeed a basic condition

1A ballistic movement is initiated by muscle activity in one muscle group, continued in a 'coasting' period with no muscle activation, and terminated by deceleration by the opposite muscle group or by passive tissue structures, such as ligaments [2] allowing backward rotation. Exactly it is the platform reaction force moment with respect to COM.

Our study shows, however, that the horizontal impulse can be both positive and negative, which translates into a touch-down place after the somersault. The smallest differences were between the take-off and touch-down position in the anterior-posterior direction for the horizontal impulses with low magnitude. According Miller et al. during the final weighting period (deceleration and take-off), the angular impulse produced by the horizontal component of platform reaction force retarded the development of the back somersaulting angular momentum [16].

The results from our research (*Table 1 and 2*) confirm the results of Hraski who stated that average angular momentum in the flight phase was greater with greater horizontal and lower vertical velocity at take-off and a lower value of the flight height [9]. Whereas the magnitudes of angular momentum obtained by Hwang et al. were two times larger than our results. However, in Hwang's study, seven elite male gymnasts performed the double back somersaults after a run-up (running start) [10].

The second performance condition of the somersaulting skill is projection velocity, which is dependent on the impulse. Therefore, the vertical velocity of COM was greatest in S_p in comparison to S_{bf} and S_{bh}. The magnitudes of the COM velocity obtained in our study are about two times smaller than the results obtained by Hraski [9]. In his research, all types of back somersaults were executed using the typical preparatory tumbling series: approach, round off, and back handspring, also the subject was a highly ranked, world-class male gymnast. Vertical speeds calculated from data obtained from both the force platform and the infrared cameras in our study, are comparable. More importantly, these data show the same trend of changes.

The result of the velocity value of COM is flight time. The time of the flight phase was largest in S_p compared to S_{bf} and S_{bh}. In our research, the flight duration was distinctly shorter than in Hraski's [9] study, but as I have already mentioned, he analysed all types of back somersaults from run-up.

The kinematic analysis showed great visual similarities between the angle-time histories to the hip, knee, ankle, and shoulder joint for S_p, S_{bf} and S_{bh}. The importance of kinetic and kinematic parameters analysed in this study, were also pointed out by many authors. However, the study mainly concerned complex or multi-turn acrobatic tumbling exercises [10,16,17].

In summary, as it was expected, the take-off that passes through the COM, allowed better amplitude of movement than the take-offs thrown of centre forward or backward. The S_p showed the highest level of vertical impulse, velocity, and displacement followed by S_{bh} and S_{bf}. This implies, that for better performance of the STBS, it is necessary that the force pass through the nearest point to the COM. As practical implications, we recommend that coaches carefully monitor the position of a gymnast's shoulders, and a backward inclination at the take-off during a STBS should be avoided.

Finally, although many variables influence success in the sport, including psychological and physiological factors, biomechanical considerations as reflected in correct or incorrect technique are crucial. This is especially true in irrational sports such as gymnastics. Gymnasts in particular, must develop the following technique attributes that apply to most acrobatic (tumbling) skills: the ability to gain height, the ability to rotate, increasing or decreasing rotation by altering body configuration.

To better understand the cause-and-effect relationships between the biomechanical factors, computer simulation is often used [21]. This is done through systematic manipulations of the key performance factors. The quality of the simulation outcomes depends on the accuracy of the input data and the complexity of the model used. This first factor depends inter alia on the class of the measuring devices. In our study, we used a modern comprehensive research methodology consisting of eight pairs of surface electrodes, six infrared cameras and a force platform, all of which synchronised each other (multi-modular measuring system SMART-E). This system allows the internal and external structure of somersaults to be explored. The often subtle differences between the mechanical parameters of motion can also be recorded and a technique assessment can be done.

References

1. Avela J., Santos P.W., Komi P.V.: Effects of differently induced stretch loads on neuromuscular control in drop jump exercise. European Journal of Applied Physiology, 1996, 72, 553-62.
2. Bartllet R.: Introduction to sports biomechanics, 2009 Routledge Taylor & Francis Group, London
3. Bober T.: Działanie mięśni w cyklu rozciągnięcie-skurcz a skuteczność techniki sportowej. Sport Wyczynowy, 1995, 1-2, 361-70.
4. Bruggemann G.P.: Biomechanics in gymnastic, [in:] van Gheluwe B., Atha J. (Eds.). Current research in sports biomechanics, Medicine and Sport Science, Basel, Karger, 1987, 142-76.
5. Cronin J.B., Mcnair P.J., Marshall R.N.: Magnitude and decay of stretch-induced enhancement of power output, European Journal of Applied Physiology, 2001, 84, 575-81.
6. De Jaeger D., Vandervetde L., Willems P.A.: Kinematics of standing back-somersaults, 2004, XXIXeme Congres de la Societe de Biomecanice, Creteil, 8-10 septembre, 91.
7. Gollhofer A., Kyröläinen H.: Neuromuscular control of the human leg extensor muscle in jump exercises under various stretch-load conditions. International Journal of Sports Medicine, 1991,12, 34-40.
8. Hochmuth G.: Biomechanik sportlicher Bewegungen. 1981, Sportverlag, Berlin (Ost).
9. Hraski Z.: Correlation between selected kinematic parameters and angular momentum in backward somersaults, 2002, ISBS Caceres, Extremadura, Spain, 167-70.
10. Hwang I., Seo G., Liu Z.C.: Takeoff mechanics of the double backward somersault. International Journal of Sport Biomechanics, 1990, 6, 177-86.
11. Knudson D.: Fundamentals of biomechanics, 2007,Springer, Chico.
12. Król H., Golas A., Sobota G.: Complex analysis of movement in evaluation of flat bench press performance, 2010, Acta of Bioengineering and Biomechanics, 12(2), 94-8.
13. Król H.: Kryteria doboru i oceny ćwiczeń doskonalących technikę sportową, 2003, AWF Katowice.
14. Król H., Mynarski W.: Effect of increased load on vertical jump mechanical characteristics in acrobats, Acta of Bioengineering and Biomechanics, 2010, 12(4), 33-7.
15. Mcneal J.R., Sands W.A., Shultz B.B.: Muscle activation characteristics of tumbling take-offs. Sports Biomechanics, 2007, 6(3), 375-90.
16. Miller D.I., Hennig E., Pizzimenti M.A., Jones I.C., Nelson R.C.: Kinetic and Kinematic Characteristics of 10-m Platform Performance of Elite Divers: I. Back Takeoffs, International Journal of Sport Biomechanics, 1989, 5, 60-88.
17. Miller D.I., Jones I.C., Pizzimenti M.A., Hennig E., Nelson R.C. Kinetic and Kinematic Characteristics of 10-m Platform Performance of Elite Divers: II. Reverse Takeoffs, International Journal of Sport Biomechanics, 1990, 6, 283-308.
18. Van Ingen Schenau G.J., Bobbert M.F., De Haan A.: Does elastic energy enhance work and efficiency in the stretch-shortening cycle? Journal of Applied Biomechanics, 1997, 13, 389-415.
19. Viitasalo J.T., Salo A., Lahtinen J.: Neuromuscular functioning of athletes and non-athletes in the drop jump. European Journal of Applied Physiology, 1998, 78, 432-440.
20. Wilson G.J., Elliott B.C., Wood G.A.: The effect on performance of imposing a delay during a stretch-shortening cycle movement, Medicine and Science in Sports and Exercise, 1991, 23, 364-70.
21. Yeadon M.R., Atha J., Hales F.D.: The simulation of aerial movement – IV. A computer simulation model, Journal of Biomechanics, 1990, 23, 85-89.

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