KINEMATIC ANALYSIS OF TWO WAYS OF PERFORMING THE BACK HANDSPRING – A CASE STUDY

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Abstract

The aim of the study was to compare selected kinematic variables of the back handspring from a standing position (Bh) with a back handspring performed in the movement sequence: round off – back handspring – backward stretched somersault (R BhS). The study included 4 gymnasts (mean age: 19.5 years). The athletes performed 6 repetitions of Bh and RBhS. All gymnastic elements were recorded on film. The artistic gymnastics judges selected the best Bh and the back handspring in the sequence (RBhS) for each competitor, which were then subjected to kinematic analysis. Based on the phase division of the recorded gymnastic elements, the analysis of the temporal structure of movement, changes in displacements and velocity of the athletes' centre of gravity (CG), as well as changes in the position of their trunk in relation to the ground were analysed. In Bh and RBhS, the competitors' horizontal CG velocity component (v_x) *decreased from the beginning of the first flight phase until the end of the support phase on the lower limbs. In Bh, the median values (Me) of* v_x *decreased from 1.94m/s to 0.8m/s, and in RBhS, from 4.85m/s to 2.24m/s. In the case of the vertical component of velocity* (v_y)*, the highest values of Me for both back handsprings were recorded at the end of the support phase on the lower limbs (for Bh and RBhS: 3.27m/s and 4.79m/s, respectively). Both in Bh and RBhS, the value of CG velocity in the horizontal axis decreased from the beginning of the analysed movement until its completion.*

Keywords: *kinematics, artistic gymnastics, back handspring, technique.*

INTRODUCTION

In artistic gymnastics, there are different types of sports preparation for athletes. One of them is technical preparation, during which gymnasts learn and improve many gymnastic elements characterised by a diverse motor structure and degree of difficulty. The initial stage of this training comes down to the development of a wide technical and motor base that has a significant impact on the athletes' further sports development (Arkaev & Suchilin, 2004; Kochanowicz et al. 2015; Živčić Marković et al. 2015). A properly implemented sports training process should enable athletes to gradually learn increasingly more difficult elements and also planned movement sequences. In any situation, the priority of training gymnastic skills is to maintain a correct movement technique, which is also important with regard to injury prevention in sports (Bradshaw & Hume, 2012).

Therefore, the ability to introduce necessary modifications to the learned way of performing a task is as important as developing a repetitive movement technique. One of the basic gymnastic skills, performed initially as an independent element and later in different movement sequences, is the back handspring. Its learning begins when gymnasts already have several years of training experience. Most of them will perform it in various forms throughout their sports career. In its basic form, the back handspring begins and ends in a standing position. Another important skill in artistic gymnastics is mastering the handspring performed immediately after a round off. Ultimately, it is used by gymnasts as a transition skill preceding various acrobatic elements (Sands & McNeal, 2006; Potop, 2014), including those most difficult ones, such as the "Ljukin", or the "Ri Jong Song" (FIG, 2017). In addition, by mastering the back handspring, a gymnast can also learn the "Yurchenko" vault (Diener & Aedo-Muñoz, 2019). For female gymnasts, the back handspring is an element performed on a balance beam. It is also used in supplementary training carried out by athletes in other sports disciplines, such as rhythmic gymnastics or acrobatics (Huang & Hsu, 2009; Donovan & Spencer, 2019).

The aforementioned multiple use of the back handspring probably contributed to scientific research devoted to this element. Koh et al. (1992) analysed the forces of ground reaction on the upper limbs during the support phase of this element. Davidson et al. (2005) undertook research aimed at estimating the stiffness and damping properties of the wrist and shoulder in children by examining wrist impact on the outstretched hand in the back handspring and dive-roll. These authors demonstrated that the back handspring involved greater impact velocity and force compared to the dive-roll, indicative of an activity in which the body's full weight is decelerated by the hands. Grassi et al. (2005) analysed the short-term consistency of body trajectories during the performance of the back handspring.

When comparing the results achieved by male and female gymnasts, they found larger consistency between landmark trajectories in women than in men. Heinen et al. (2010) evaluated the effects of two manual guidance procedures on movement kinematics of a back handspring and a back tuck somersault following a round off on the floor. According to these authors, the sandwich-grip should be applied in the first instance if the coach's interest is to optimise the angular momentum of the somersault axis and the second flight phase in the back handspring. Mkaouer et al. (2013) compared kinetic and kinematic variables of the take-off between two acrobatic series leading to perform the backward stretched somersault (salto): round off, back handspring versus round off, tempo-salto. In these studies, it was shown that the combination of round off, tempo-salto to stretched salto allowed for greater horizontal displacement and momentum, while the combination of round off, back handspring to stretched salto allowed for better vertical displacement and velocity. Omorczyk et al. (2015) used reverse transfer to verify the usefulness of selected simple methods of recording and fast biomechanical analysis performed by judges of artistic gymnastics in assessing a gymnast's movement technique. Burton et al. (2017) presented the results of a study aimed at investigating the influence of hang position on the elbow and wrist joint coordination and variability during the performance of the back handspring in female gymnastics. Competitors performed this element with "inward", "parallel" and "outward" hand position. The authors concluded that lower variability within the parallel technique may be more suited to gymnastics performance, with the “inward” contributing more toward overuse injury reduction.

Other authors (Huang & Hsu, 2009; Penitente et al. 2011; Lovecchio et al. 2013) conducted biomechanical analyses of the back handspring, the results of which may also be helpful in the process of learning and improving this element by artistic gymnastics athletes, as well as in other sports.

So far, however, no comparison has been made between the technique of performing a back handspring from standing position with a back handspring serving as a transition element. Therefore, research was undertaken to compare selected kinematic variables of the back handspring from standing position (Bh) with the back handspring performed in the motor sequence: round off – back handspring – backward stretched somersault (RBhS).

METHODS

The study comprised 4 (n = 4), elite male gymnasts at the mean age of 19.5 ± 3.0 years, body height: 172.5 ± 2.5 cm, body mass: 65.8 ± 3.6 kg, and training experience: 14.3 ± 2.5 years. The inclusion criteria were: master class in artistic gymnastics; participation in the Polish Championships in Artistic Gymnastics; training for at least 10 years; no injuries to the musculoskeletal system, and the ability to safely perform a back handspring and the round off – back handspring – backward stretched somersault (confirmed by a coach).

The subjects participated in the research voluntarily. The study was approved by the Bioethics Committee at the Regional Medical Chamber in Krakow, Poland (Approval Ref. No. 42/KBL/OIL/2017).

Before initiating the tests, the competitors performed a general and acrobatic warm-up (series of forward rolls, backward rolls; handstand; cartwheel; round off; front handspring; forward and backward tucked somersaults). All exercises, both performed during the warm-up and the subject of research proper, were executed on the spring floor of the AWF Krakow gymnasium.

After the warm-up, the proper part of the research began. All tested men were asked to perform 6 back handspring repetitions as well as possible, followed by the same number of movement sequences including round off – back handspring – backward stretched somersault. The athletes performed their exercises in a fixed order, one after another. As a result, the duration of the interval between consecutive exercises performed by the same person was similar. A 5-minute resting interval was introduced between the Bh and RBhS. Bh was performed by all gymnasts from the same starting position: stance with the arms elevated, while the take-off was preceded by an arm swing. After Bh, the athletes performed a rebound and landed in standing position. RBhS began with the gymnasts performing a run-up, with no interference in its length, number of steps or speed. All 6 Bh and RBhS attempts were filmed with a digital camera (Sony DSC RX100 M4) at 120 Hz. The recording device was placed next to the spring floor, on a levelled, stable tripod, so that the optical axis of the lens was perpendicular to the direction of the subject's movement. In the described manner, 12 videos were recorded for each competitor.

Before beginning the recording, on the left side of the body (from the camera side), markers made of white, flexible adhesive tape were fixed to the subjects’ skin, in the places corresponding to the rotation axis of the joints: shoulder, elbow, radiocarpal, hip, knee and shin-ankle. This was carried out on all athletes by the same person with appropriate anatomical knowledge.

Exercises recorded on the film were evaluated by a judge to select the best performance of Bh and RBhS for each competitor. This evaluation was made independently by 3 judges licensed by the Polish Gymnastics Association. The films selected by the judges (2 for each athlete) formed the basis for the subsequent kinematic analysis carried out with the use of the Skill Spector v.1.3.2 computer program, implementing a 10-point mathematical model of the body, created by the developers of this software. Thanks to this, on the basis of changes in the position of the centre of the previously marked main joints of the limbs (upper and lower), as well as the chin, forehead (glabella point) and the ends of the distal phalanges of the big toe and middle finger, the values of a number of kinematic indicators of movement were determined. Based on the phase division of the registered gymnastic elements (Bh and RBhS), an analysis was performed looking at the temporal structure of movement, changes in displacements and velocities of the gymnasts' centre of gravity (CG) and changes in the position of their trunk in relation to the ground.

Both analysed gymnastic elements were divided into phases. This was carried out by identifying the beginning and the end of the flight and support phases. As a consequence, nodal division points were determined:

A - beginning of analysis, initiation of the first flight phase,

B - completion of the first flight phase,

C - beginning of the second flight phase,

D - completion of the second flight phase,

E - end of analysis, end of the support phase on the lower limbs.

The proposed points were the basis for distinguishing the following successive phases of movement:

A-B - first flight phase ($\mathbf{F_I}$),

B-C - support on upper limbs ($\mathbf{S_{UI}}$),

C-D - second flight phase ($\mathbf{F_{II}}$),

D-E - support on lower limbs ($\mathbf{S_{LI}}$).

Based on the applied mathematical model, the following kinematic variables were determined:

$\mathbf{t_t}$ - total time [s],

$\mathbf{t_{FI}}$ - time of first flight phase [s],

$\mathbf{t_{SUI}}$ - support time on upper limbs [s],

$\mathbf{t_{FII}}$ - time of second flight phase [s],

$\mathbf{t_{SLI}}$ - support time on lower limbs [s],

$\mathbf{v_A}$ - resultant, initial CG velocity of gymnast at time of A [m/s],

$\mathbf{v_{Ax}}$ - gymnast's horizontal CG velocity at the beginning of movement (A) [m/s],

$\mathbf{v_{Ay}}$ - gymnast's CG vertical velocity at the beginning of movement (A) [m/s],

$\mathbf{v_B, v_{Bx}, v_{By}}$ - resultant, horizontal and vertical velocity CG at time of B [m/s],

$\mathbf{v_C, v_{Cx}, v_{Cy}}$ - resultant, horizontal and vertical velocity of CG at time of C [m/s],

$\mathbf{v_D, v_{Dx}, v_{Dy}}$ - resultant, horizontal and vertical velocity CG at time of D [m/s],

$\mathbf{v_E, v_{Ex}, v_{Ey}}$ - gymnast's final CG velocity (resultant, horizontal and vertical) (E) [m/s],

$\mathbf{h_{ACG}}$ - height of the CG position at initial period (A) [m],

$\mathbf{h_{BCG}, h_{CCG}, h_{DCG}}$ - altitude of CG at times B, C and D [m],

$\mathbf{h_{ECG}}$ - final height of CG position (E) [m],

$\mathbf{L_{FI}}$ - displacement in the first flight phase (horizontal distance between the location where the feet are removed from the ground and where the hands are placed; A-B) [m],

$\mathbf{L_{FII}}$ - displacement in the second flight phase (horizontal distance between the location where the hands are lifted off the ground and where the feet are placed; C-D) [m].

It should be noted that the vertical component of the CG velocity vector in the athletes (v_y) during their performance of the Bh and RBhS could change its turn. Therefore, the values of this variable marked with the sign "-" (minus) mean a turn towards the spring floor.

It is also worth noting that the linear displacements in the flight phase (L_{FI}, L_{FII}) comprise the value of the shortest horizontal distance between the take-off and the landing site.

The analysis of the collected footage also helped to distinguish the characteristics of changes in the angular position of the athletes' trunk in relation to the ground during the performance of both gymnastic elements: Bh and RBhS. The arms of that angle were two intersecting rays. The first was marked by the section connecting the athlete's shoulder and hip joints (trunk), and the second - the ground (spring floor). In this paper, it was decided to present only the instantaneous values of such an angle in relation to the boundaries of the distinguished phases.

Therefore, at the nodal points: A, B, C, D and E, the following variables were defined: **α_A, α_B, α_C, α_D, α_E**. The method of determining the angles and their vertices is presented in Fig. 1. This also enables the identification of the adopted phase division.

It was decided to reduce the statistical analysis of the results to determine the median (Me) as well as the minimum (min) and the maximum (max) values for all variables.

RESULTS

In Fig. 2, the total time to perform both analysed back handsprings is presented. As it can be seen, in the case of RBhS, the duration was shorter. The median values noted for Bh and RBhS differed by more than 0.2s.

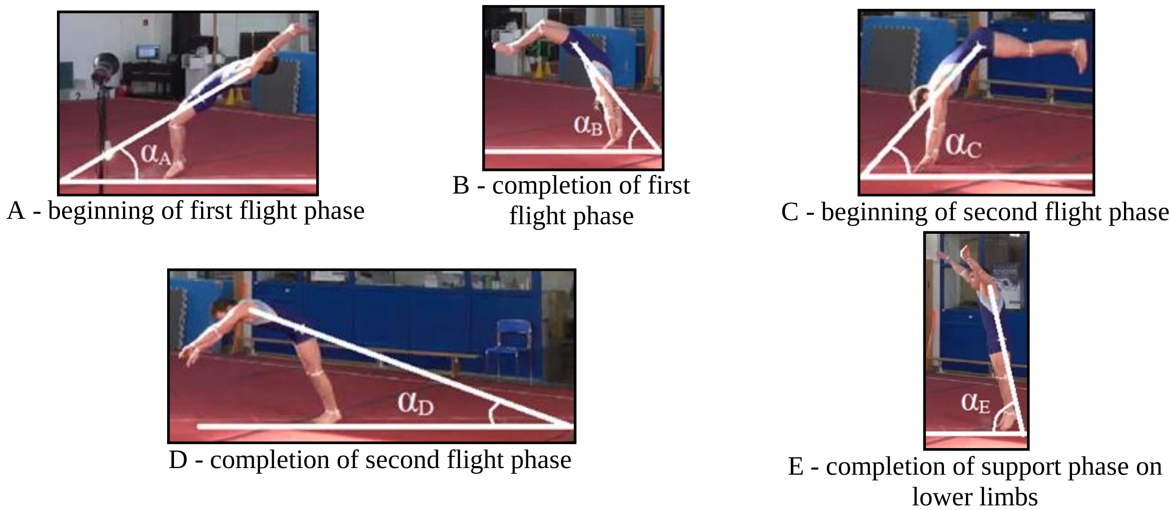

Figure 1. Method of determining instantaneous value of the trunk angle at nodal points separating individual phases of movement.

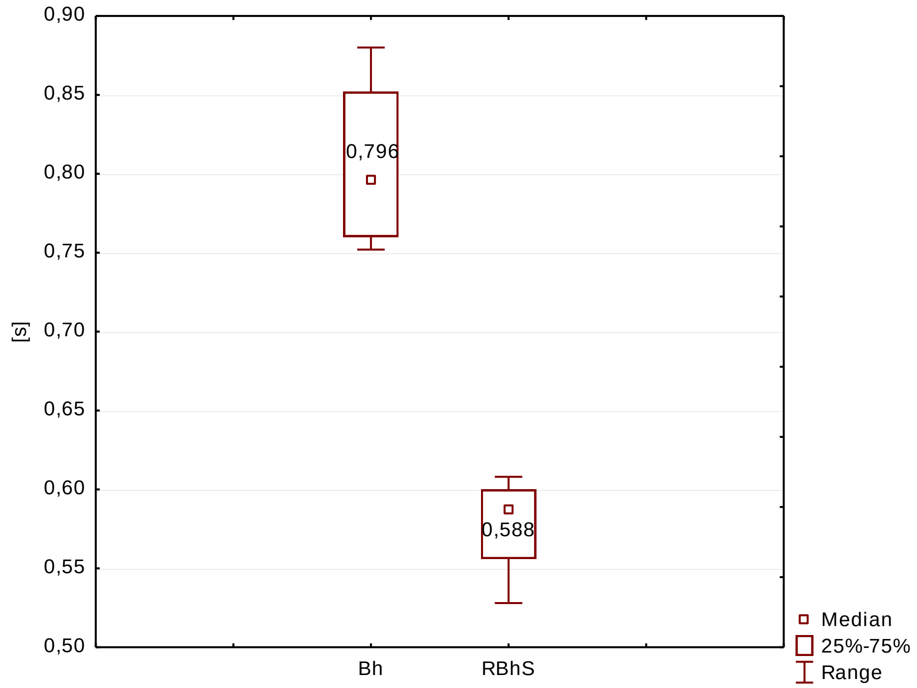

Figure 2. Total time (t_t) to perform a back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS); [s].

Table 1

Duration of successive phases of back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS) (t_{FI} - first phase of flight; t_{SUI} - support on the upper limbs; t_{FII} - second phase of flight; t_{SLI} - support on lower limbs).

Gymnastic element	t_{FI}		t_{SUI}		t_{FII}		t_{SLI}	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[s]		[s]		[s]		[s]	
Bh	0.21	(0.15 – 0.23)	0.27	(0.22 – 0.30)	0.18	(0.17 – 0.24)	0.15	(0.13 – 0.17)
RBhS	0.16	(0.14 – 0.17)	0.17	(0.15 – 0.18)	0.11	(0.10 – 0.13)	0.14	(0.13 – 0.14)

Table 2

Competitors' instantaneous CG velocity (x - horizontal, y - vertical and resultant) at the nodal points of the back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS) (A, B - beginning and end of the first flight phase; C, D - beginning and end of the second flight phase, E - completion of the lower limb support phase).

Gymnastic element	A		B		C		D		E	
	v_{Ax}		v_{Bx}		v_{Cx}		v_{Dx}		v_{Ex}	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[m/s]		[m/s]		[m/s]		[m/s]		[m/s]	
Bh	1.94	(1.57 – 2.04)	1.67	(1.20 – 1.85)	1.62	(1.31 – 2.28)	1.53	(1.16 – 1.75)	0.80	(0.36 – 2.01)
RBhS	4.85	(4.48 – 5.82)	4.43	(4.07 – 4.61)	4.32	(3.81 – 4.98)	4.29	(3.70 – 5.40)	2.24	(1.94 – 2.82)
	v_{Ay}		v_{By}		v_{Cy}		v_{Dy}		v_{Ey}	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[m/s]		[m/s]		[m/s]		[m/s]		[m/s]	
Bh	0.68	(0.49 – 1.53)	-0.62	(-0.74 – 0.38)	0.11	(-0.08 – 0.38)	-1.73	(-1.55 – -1.88)	3.27	(2.65 – 3.66)
RBhS	0.78	(0.23 – 1.47)	-0.36	(-0.46 – -0.19)	-0.48	(-0.63 – -0.28)	-1.41	(-1.12 – -1.98)	4.79	(3.10 – 5.09)
	v_A		v_B		v_C		v_D		v_E	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[m/s]		[m/s]		[m/s]		[m/s]		[m/s]	
Bh	2.06	(1.64 – 2.55)	1.73	(1.41 – 1.98)	1.62	(1.36 – 2.29)	2.27	(2.21 – 2.40)	3.57	(2.69 – 3.82)
RBhS	4.90	(4.51 – 6.00)	4.44	(4.09 – 4.62)	4.34	(3.86 – 4.99)	4.61	(3.87 – 5.60)	5.36	(3.90 – 5.51)

Table 3

Height of gymnasts' centre of gravity (h_{CG}) at the boundaries of movement phases during the back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS); adopted symbols - as in Tab. 2.

Gymnastic element	A		B		C		D		E	
	h_{ACG}		h_{BCG}		h_{CCG}		h_{DCG}		h_{ECG}	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[m]		[m]		[m]		[m]		[m]	
Bh	0.86	(0.79 – 0.91)	0.91	(0.85 – 0.98)	0.98	(0.97 – 1.01)	0.82	(0.81 – 0.82)	1.03	(1.00 – 1.07)
RBhS	0.91	(0.87 – 0.94)	0.95	(0.92 – 0.99)	0.92	(0.88 – 0.92)	0.80	(0.75 – 0.82)	1.09	(1.06 – 1.13)

Table 4

Displacement in the first (L_{FI}) and second (L_{FII}) flight phase during back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS).

Gymnastic element	L_{FI}		L_{FII}	
	Me	(min-max)	Me	(min-max)
	[m]		[m]	
Bh	1.06	(0.83 – 1.19)	0.90	(0.64 – 1.11)
RBhS	1.40	(1.10 – 1.61)	1.49	(1.35 – 1.74)

Table 5
Values of angle between trunk and ground (α_A, α_B, α_C, α_D, α_E) during back handspring from standing position (Bh) and back handspring in the movement sequence (RBhS) recorded at the boundaries of the movement phases; adopted symbols - as in Tab. 2.

Gymnastic element	A		B		C		D		E	
	α_A		α_B		α_C		α_D		α_E	
	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)	Me	(min-max)
	[deg]		[deg]		[deg]		[deg]		[deg]	
Bh	28	(21 – 30)	63	(58 – 89)	64	(48 – 86)	21	(15 – 23)	53	(47 – 56)
RBhS	34	(28 – 36)	65	(63 – 75)	50	(44 – 51)	18	(16 – 28)	81	(78 – 98)

Data from Tab. 1 indicate that not only was the overall time to perform the back handspring in the RBhS movement sequence shorter than that of Bh but also that all corresponding phases of the compared gymnastic elements were shorter for the back handspring after the round off. Our analysis of Me value shows that the greatest differentiation was related to the support on the upper limbs (t_{SUl}), and the smallest to the support on the lower limbs (t_{SLl}). In the first case, the difference was 0.1s, and in the second, 0.01s. The described differences for the first and the second flight phases ranged from 0.05s to 0.07s.

In Tab. 2, the characteristics of changes in the instantaneous CG velocity of the competitors at the nodal points Bh and RBhS are presented. These changes were described both in relation to all components of the velocity vector (horizontal and vertical) and the resultant vector.

In Bh and RBhS, the horizontal component (v_x) decreased in value from the beginning of the first flight phase (A) up to the end of the support phase on the lower limbs (E). For Bh, median v_x values decreased from 1.94m/s to 0.8m/s, while for RBhS, this value fell from 4.85m/s to 2.24m/s. As expected, the values of this variable were always higher in RBhS. A slightly different characteristic was found for the vertical component of velocity (v_y). The obtained results indicate that it changed not only the value but also its return. Basically, with one exception (beginning of the second flight phase, C), the sense of the vertical component at the boundaries of the movement phases was identical for both Bh and RBhS. In the case of the absolute values of the discussed variable (v_y), it turned out that both for Bh and RBhS, they were the highest at the end of the support phase on the lower limbs (E): 3.27m/s and 4.79m/s, respectively. Data from Tab. 2 additionally show that v_y values exceeding 1m/s were also recorded at the end of the second flight phase (D). This indicates that the highest values of the vertical component of CG velocity were recorded in the final part of the analysed gymnastic elements (from the end of the second flight phase). In turn, the lowest values of this velocity component (v_y) were recorded from the end of the first flight phase to the beginning of the second one (B and C), i.e., the middle part of the analysed elements (Bh and RBhS). The presented results demonstrate that the vertical CG velocity recorded at the beginning of the first flight phase (A) was 0.1m/s higher during the round off – back handspring – backward stretched somersault.

The resultant CG velocity of the athletes (v), recorded in the corresponding so-called nodal points of the back handspring, was always higher in RBhS than in Bh. The differences in the median values of this variable ranged from 1.8m/s (end of movement, E) to about 2.8m/s (beginning of movement, A). Data presented in Tab. 2 indicate that in the case of Bh and RBhS, the nature of changes in the resultant velocity was similar. At the beginning of the first flight phase (A), it was slightly higher than the values recorded chronologically later (the end of the first flight phase and the beginning of the second one, B and C). Finally, from the end of the second flight phase (D), the resultant velocity of the athletes increased, reaching its maximum value at the end of the support phase on the lower limbs (E).

In Tab. 3, information is provided on the athletes' height of centre of gravity (h_{CG}) at the boundary between the various phases of movement when performing back handsprings. Medians of this variable noted for Bh and RBhS varied from 2cm to 6cm. It can be noticed that the gymnasts performing RBhS in the initial and final phases (their limits - respectively: A, B and E) assumed a position in which the centre of gravity was higher than in the case of Bh. An opposite observation can be made in relation to the nodal points marking the beginning and end of the second flight phase (C and D) - in this case, higher h_{CG} values were noted for Bh.

In Tab. 4, the displacement of gymnasts was characterised in each of the two flight phases during the back handspring. As mentioned, this distance was marked by a horizontal line between the take-off and the landing site. The reported values indicate that the RBhS technique is different from Bh. For both indicators (L_{FI} and L_{FII}), the median values were higher for RBhS. Their absolute differences were 0.34m (L_{FI}) and 0.59m (L_{FII}). It is also worth adding that in the case of Bh, displacement in the second flight phase was smaller than in the first phase by 0.16m. On the other hand, in RBhS, the displacement in the second flight phase was greater by 0.09m than in the first one.

In accordance with the developed methodology, the values of the angle between the trunk and the ground were determined during the performance of Bh and RBhS. The effects of this part of the video recorded material analysis are presented in Tab. 5. The main differences concern the positioning of the gymnast's body at the beginning of the second flight phase (α_C) and at the end of the support phase on the lower limbs (α_E). The accumulated values show that when the second flight phase (α_C) began, higher values of the angle in question (by 14°) were recorded for Bh. At the end of the support phase on the lower limbs, the median values of α_E were higher for RBhS by 28°. The value of 81° recorded in this case indicates assuming a more straightened body in this position while performing RBhS. The angular values characterising the position of the trunk in relation to the ground at the beginning and end of the first flight phase (α_A, α_B) and at the end of the second flight phase (α_D) were similar in both types of back handsprings (Bh and RBhS).

DISCUSSION

The obtained results showed differences between two techniques of performing the back handspring: one began from a standing position (Bh) while the other was performed in the motor sequence: round off – back handspring – backward stretched somersault (RBhS). Data was also obtained on the method of performing the back handspring following the round off, which allowed the gymnasts to safely perform the backward stretched somersault, along with a flawless landing on the lower limbs referred to as the "stick landing" (Marinsek & Cuk, 2010).

As predicted, the RBhS demonstrated shorter durations of all movement phases (t_{FI}, t_{SUl}, t_{FII}, t_{SLl}) which also resulted in a shorter total time (t_t). The greatest differences in duration of the individual Bh and RBhS phases were noted for support on the upper limbs (t_{SUl}), while the smallest for support on the lower limbs (t_{SLl}). The horizontal component of the velocity for all athletes had direct impact on shorter execution times of all phases and the total time of movement in RBhS, which assumed higher values in the back handspring preceded by a run up and round off. The greatest differences between Bh and RBhS were noted at the beginning of the first flight phase (v_{Ax}). It was observed that in both variants of the back handspring, the value of CG velocity in the horizontal axis decreases from the beginning of the analysed movement until its completion (v_{Ax} – v_{Ex}). Penitente et al. (2011), analysing the back handspring performed after a round off by female artistic gymnasts at various levels of advancement, also noted the highest value for the horizontal CG velocity component during the take-off performed with the lower limbs (point A of this study). At the same time, however, they indicated a slightly higher value of this velocity in the examined competitors during the push-off performed with the arms preceding the second flight phase (point C in this work) compared to the beginning of the support phase on the upper limbs (point B in this paper).

The smallest differences between the values of the horizontal velocity component for Bh and RBhS were obtained at the end of the support phase on the lower limbs (v_{Ex}). At the same time, at the end of this phase, the greatest differences were observed between values of the vertical component of athletes' CG velocity (v_{Ey}) recorded for both back handsprings. Clearly smaller differences of this variable can be noted: at the beginning (v_{Ay}) and the end of the first flight phase (v_{By}), as well as and at the end of the second flight phase (v_{Dy}). In turn, at the beginning of the second flight phase, different returns regarding the vector of the vertical velocity component (v_{Cy}) were observed. This return was positive for Bh and negative for RBhS. This indicates that in Bh, at the beginning of this phase of flight, the competitors' CG moves up, and in RBhS, it goes down. Penitente et al. (2011) also observed different turns of the CG velocity vector in the vertical axis. However, the explanation for the various velocity turns in the vertical axis at this nodal point requires additional experiments. Nonetheless, it may be assumed that the negative return of this vector in RBhS results from higher rotational velocity in the flexion movement of the lower limbs in the hip joints. It is possible that this could also result in a smaller value of the angle between the trunk and the ground (α_C) in this version of the back handspring.

It is worth noting that the values of the velocity components obtained by the authors of this study at the end of the support phase on the lower limbs in RBhS (v_{Ex} and v_{Ey}, respectively: 2.24m/s and 4.79m/s) guaranteed the athletes performance of the planned backward stretched somersault. However, the volatility of the values regarding these indicators may be significant, as evidenced by the data presented in Tab. 2 and the collected literature. Compared to the present study, in their analyses, Mkaouer et al. (2013) noted a much higher value of horizontal velocity (3.743m/s) and a slightly lower value of vertical velocity (4.500m/s). These differences may result from technical differences in the execution of the described movement. They may also be related to the fact that the athletes tested by Mkaouer et al. (2013) performed gymnastic elements on an acrobatic track which could have different (better) elastic properties.

In both analysed gymnastic elements (Bh and RBhS), the general nature of changes in the resultant velocity and its vertical component were quite similar. Taking into account their absolute values (excluding the sense of v_y), it can be seen that they increase from the beginning of the movement to its completion. Additionally, they adopt their local minimal values between the first and the second flight phase. The described similarity may result from the necessity to perform the back handspring in such a way that moving the body upwards above the spring floor does not excessively restrict movement along the floor. Therefore, until the completion of the second Bh and RBhS flight phases, the value of the horizontal velocity of the athletes was greater than the vertical velocity. And it is this component (v_x) that more clearly influenced the resultant velocity. The situation changed at the end of the support phase on the lower limbs. At this point, the vertical velocity of competitors (v_y) reached its maximum and was significantly higher than the horizontal velocity.

Although the horizontal velocity of the athletes performing Bh and RBhS decreased from the beginning of the movement until its end, its value was sufficient for the effective movement of the gymnast. Until the completion of the support phase on the lower limbs, it had a major impact on the quality of technical performance of the back handspring, further enabling the performance of the round off – back handspring – backward stretched somersault.

Characteristics of changes in the height of athletes' CG position (h_{ACG} – h_{ECG}) during the back handspring from standing position and the back handspring in the movement sequence, were similar.

The total range of vertical CG oscillations, however, was greater in RBhS. Comparing the two methods of performing the back handspring, it can be seen that the gymnasts obtained a higher CG position at the beginning (h_{CCG}) and also at the end of the second flight phase (h_{DCG}) in Bh. At the remaining nodal points (h_{ACG}, h_{BCG} and h_{ECG}), CG was higher in RBhS.

As it is known, in each of the two phases of flight during the back handspring, the horizontal displacement of the athletes is related to the height of the CG position and its horizontal velocity (v_x). The results of the authors' research indicate that the back handspring that fulfilled the transition skill (RBhS) was characterised by a longer second (L_{FII}) and shorter first flight phase (L_{FI}). In this handspring, greater displacements were also noticed in flight phases (L_{FI} and L_{FII}) than in Bh. In turn, Bh was performed by athletes with a longer first (L_{FI}) and shorter second (L_{FII}) flight phase. Opposite proportions to the results recorded for Bh were obtained by Lovecchio et al. (2013), who also performed a kinematic analysis of the back handspring from a standing position (the study including male and female gymnasts). In the opinion of these authors, the reasons for the shorter first flight phase can be seen in the use of greater spine hyperextension during this phase of movement.

As already mentioned, the height of the CG position for both back handsprings was similar. At the same time, the values for the horizontal component of the velocity of movement in RBhS were higher than those recorded in Bh (even by 2.9 m/s). The results also show that at the beginning of the second flight phase, the velocity was lower (by 10 and 16%, respectively: RBhS and Bh) than that recorded at the beginning of the first flight phase. The combination of these facts can be the basis for the claim that the velocity value for the flight distance is the key, provided that the optimal CG altitude is maintained.

In both types of back handsprings, at the beginning and the end of the first flight phase and at the end of the second flight phase (α_A, α_B, α_D, respectively), the values of the angles between the trunk and the ground were similar. The angle α_C determined for the beginning of the second flight phase indicates that in RBhS, the trunk of the gymnasts was more inclined toward the floor than in Bh. The greatest differences were observed at the end of the support phase on the lower limbs (α_E), which was certainly related to various motor tasks performed immediately after Bh and RBhS. Smaller values of this angle were observed in Bh. It is worth noting that the take-off angle (α_E), which allowed the gymnasts to do the backward stretched somersault (81°), was similar to the results obtained by other authors (Mkaouer et al. 2013).

In gymnastics training, it is possible to interfere with the technique of back handspring initiated from a stance. This interference is implemented for the performance of this element in an acrobatic sequence (after a round-off). It is effective to make use of the assistance of an experienced coach who can support and guide the gymnast during the movement. Performing the back handspring on equipment with greater elasticity (e.g., standard trampoline or tumble track) may also be helpful. The obtained results show that the exercises carried out independently or with coach's assistance should enable athletes to gradually become used to the increased speed of movement (the shorter time of all phases of the back handspring) as well as longer first and second flight phases. Our analysis of the angular position of the trunk in relation to the ground led us to note that it is necessary to reduce the value of this angle at the beginning of the second flight phase. On the other hand, for the performance of the backward stretched somersault, the trunk must be positioned closer to the vertical axis during the final part of the support phase ending on the lower limbs. The obtained results also indicate other differences between the two methods of performing the back handspring. However, due to the small number of participants, the possibility of formulating unambiguous conclusions requires further research with a larger sample size.

CONCLUSIONS

The conducted research indicated the differences between the selected kinematic variables of the back handspring from standing position and this movement throughout the transition. In the process of technical training, it should be noted that the back handspring performed in the movement sequence ending in a backward stretched somersault requires a higher resultant velocity of the gymnast than in the case of a back handspring started from a standing position and ending in a rebound and then landing. Obviously, decreasing the horizontal velocity component in both ways of performing the back handspring in the subsequent stages of movement should be considered. However, in RBhS, its value should be greater than in Bh.

In advanced artistic gymnasts, the beginning of the second flight phase in Bh is characterised by a positive return of the vertical velocity vector CG (v_{Cy}). However, in RBhS, the sense of this vector may change. Therefore, in the handspring performed in the movement sequence (round off – back handspring – backward stretched somersault), there is no scientific justification for the competitors to try to achieve a positive return in vertical velocity during this phase.

In RBhS, the greater horizontal velocity component contributed to the reduction in the duration of all specified phases of the back handspring, and thus, to obtain a shorter time of the total movement.

The differences between the height of the gymnasts' CG positioning (h_{CG}) in Bh and RBhS seem to be insignificant. The authors' own observations showed that in RBhS, the competitors' CG was slightly higher at the beginning (h_{ACG}) and at the end of the first flight phase (h_{BCG}), as well as at the end of the support phase on the lower limbs (h_{ECG}). However, it was lower at the beginning (h_{CCG}) and at the end of the second flight phase (h_{DCG}).

When comparing the two methods of performing the back handspring, it should be stated that RBhS requires longer both flight phases (L_{FI} and L_{FII}). Nevertheless, on the basis of the obtained results, it seems important to reverse the proportion of flight phases - in RBhS, the second flight phase (L_{FII}) should be longer than the first one (L_{FI}).

In both types of the handspring, the position of the trunk in relation to the ground is similar at the beginning and the end of the first flight phase, and also at the end of the second flight phase (successively α_A, α_B, α_D). In RBhS, at the beginning of the second flight phase, the trunk should be at a lower angle in relation to the ground (α_C), and lower at the end of the support phase on the lower limbs (α_E).

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